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

2013 Final Crab SAFE

Compiled by

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

With Contributions by

K. Bush, W. Donaldson, M. Dorn, G. Eckert, H. Fitch, R.J. Foy,
W. Gaeuman , B. Garber-Yonts, J. Gasper, T. Hamazaki, D. Pengilly, A.E. Punt,
L. Rugolo, M.S.M. Siddeek, W. Stockhausen, D. Stram, B. J. Turnock, and J. Zheng

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605 W. 4th Avenue, #306
Anchorage, AK 99501

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for the King and Tanner Crab Fisheries
Fisheries of the Bering Sea and Aleutian Islands Regions

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BSAI Crab SAFE ***Introduction***

2013 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands

Introduction

The annual stock assessment and fishery evaluation (SAFE) report is a requirement of the North Pacific Fishery Management Council's *Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (FMP)*, and a federal requirement [50 CFR Section 602.12(e)]. The SAFE report summarizes the current biological and economic status of fisheries, total allowable catch (TAC) or Guideline Harvest Level (GHL), and analytical information used for management decisions. Additional information on Bering Sea/Aleutian Islands (BSAI) king and Tanner crab is available on the 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 District and St Matthew Island), 2 golden (or brown) king crab, *Lithodes aequispinus,* stocks (Aleutian Island and Pribilof Islands), EBS Tanner crab *Chionoecetes bairdi*, and EBS snow crab *Chionoecetes opilio*. All other BSAI crab stocks are exclusively managed by the State of Alaska.

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF&G and the National Marine Fisheries Service (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 new ACL requirements in 2011, the Crab Plan Team reviews three assessments in May to provide recommendations on OFL, ABC and stock status specifications for review by the Council's Science and Statistical Committee (SSC) in 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 Crab Plan Team met from September 17-20, 2013 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 2013 Crab SAFE report contains all recommendations for all 10 stocks including those whose OFL and ABC were determined in June 2013. This SAFE report will be presented to the Council 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 (Chair), Karla Bush (Vice-Chair), Wayne Donaldson, Heather Fitch, Brian Garber-Yonts, Jason Gasper, Ginny Eckert, 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 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.

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.

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

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 acceptable biological catch (ABC) levels are annually formulated. The annual catch limit (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 overfishing level (OFL) equals 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.

NMFS will determine whether a stock is in an overfished condition by comparing annual biomass estimates to the established MSST, defined as ½ B_{MSY}. 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 Council 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 Council, Scientific and Statistical Committee, and Crab Plan Team will review (1) the stock assessment documents, (2) the OFLs and ABCs, and total allowable catches or guideline harvest levels, (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 the FMP Chapter 4. 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 maximum sustainable yield (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 State 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 State 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 Crab Plan Team process to the Council's Scientific and Statistical Committee. The Council's Scientific and Statistical Committee 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 Scientific and Statistical Committee 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 Scientific and Statistical Committee 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 Crab Plan Team annually reviews stock assessment documents, the most recent abundance estimates, the proposed OFLs and ABCs, and complies the Stock Assessment and Fishery Evaluation Report. The Crab Plan Team then makes recommendations to the Scientific and Statistical Committee on the OFLs, ABCs, and any other issues related to the crab stocks.

Third, the Scientific and Statistical Committee annually reviews the Stock Assessment and Fishery Evaluation Report, including the stock assessment documents, recommendations from the Crab Plan Team, and the methods to address scientific uncertainty.

In reviewing the Stock Assessment and Fishery Evaluation Report, the Crab Plan Team and the Scientific and Statistical Committee 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 State has accounted for and will account for on an annual basis in TAC setting.

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

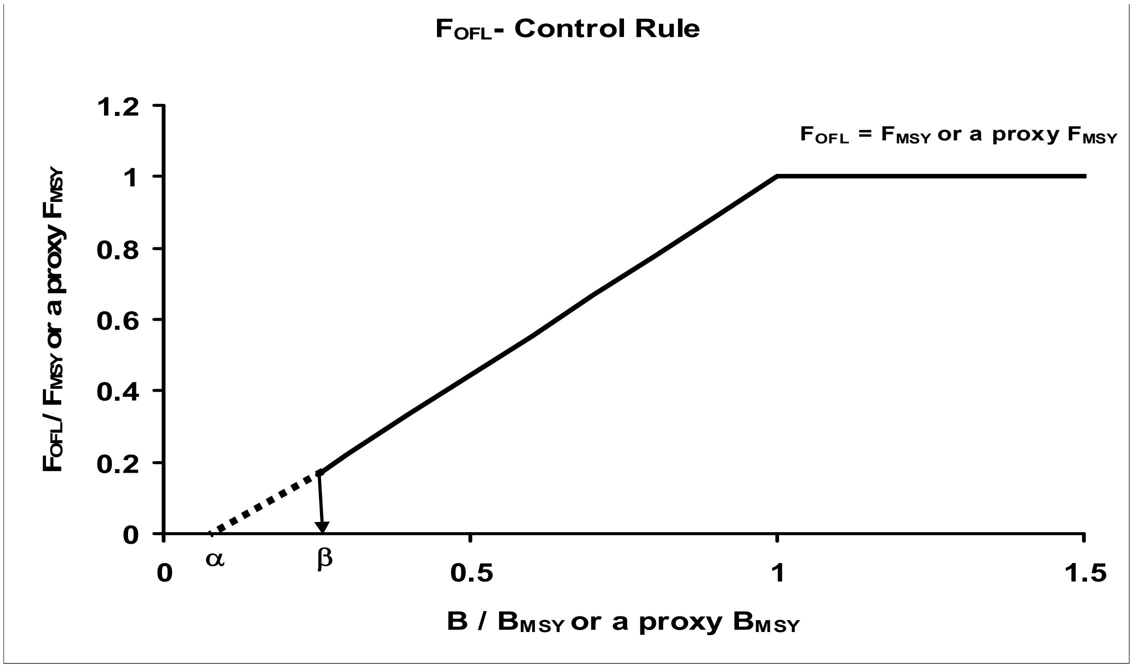

Table 1 **Five-Tier System for setting overfishing limits (OFLs) and Acceptable Biological Catches (ABCs) for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.**

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:
  - o 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
  - o 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
  - o 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
  - o β — a parameter with restriction that $0 \leq \beta < 1$.
  - o 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 $\beta\cdot B_{MSY} < B \leq B_{MSY}$.
  - o Larger values of α result in a smaller value of F_{OFL} when B decreases to $\beta\cdot B_{MSY}$.
  - o 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 2013/2014 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 Island blue king crab, Pribilof Island red king crab and Norton Sound red king crab) and three stocks in Tier 5 (AI golden king crab, Pribilof Island 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 2013/14. Stock status in relation to status determination criteria are evaluated in this report (Table 5).

The team has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2014 assessment. The general comments are listed below while the comments related to individual assessments are contained within the summary of plan team deliberations and recommendations contained in the stock specific summary section. Additional details regarding recommendations are contained in the Crab Plan Team Report (September 2013 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 team recommends supporting the recruitment and survey average workgroup recommendations for crab assessments as well as groundfish
5. 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 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.

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

- lbs to t [/2.204624]
- t to lbs [x 0.453592]

Economic SAFE overview

The economic status chapter is delayed pending completion of 2012 EDR data processing, and will be forwarded to Council with the Groundfish Economic SAFE report for December. A summary of economic indicators is included as a brief appendix to the SAFE report; key points are as follows:

2012 Production and Y/Y Change 2011-2012

- total volume of ex-vessel landings: 104 million pounds, +48%
- finished production volume: 67 million, +39%
- total gross ex-vessel revenues: $253 million, -2%
- total first wholesale revenues: $392 million, +8%
- All directed catch allocations > 98% exploited, including SMB

2012 Prices: returned to 2010 levels

- AIG Ex-Vessel: $3.51 WS: $8.37
- BBR Ex-Vessel: $7.27 WS: $15.09
- BSS Ex-Vessel: $1.89 WS: $4.72
- SMB Ex-Vessel: $3.77 WS: $12.45

2013 Wholesale Price Forecasts: return to 2011 levels

- Median, 90%CI
- AIG $10.24 ±1.07
- BSS $5.48 ±0.3
- BBR $18.38 ±2.48

Crew and processors employment and income indicators: limited information available pending completion of EDR data analysis and resolution of confidentiality limitations

Stock Status Summaries

1 Eastern Bering Sea Snow crab

Fishery information relative to OFL setting

The total catch in the 2012/13 fishery was estimated at 32,400 t (including model estimated bycatch) and the retained catch in the directed fishery was 30,100 t. This is below the 2012/13 OFL of 67,800 t. Snow crab bycatch occurs in the directed fishery and to a lesser extent in the groundfish trawl fisheries. The estimate of discard mortality rate for bycatch in the directed fishery was updated to 30% from 50% during 2013 based on data collected from the fishery and experimental results. The estimates of trawl bycatch in recent years are less than 1% of the total snow crab catch. Estimates of stock status have been above $B_{35\%}$(currently estimated to be 154,170 t) since 2010/11.

Data and assessment methodology

The stock assessment is based on a size- and sex-structured model in which crabs are categorized into immature, mature, new and old shell. The growth transition matrix is based on a linear growth function with the transition probability based on a gamma distribution where the variance term for the growth increment is pre-specified. 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, and size frequency data for male retained catch in the directed fishery, and male and female bycatch in the directed fishery and trawl fishery. The model is also fitted to the 2009 and 2010 BSFRF study area biomass estimates and size frequency data. Unlike the model on which the 2012 assessment was based, the model on which the 2013 assessment is based fitted new data on growth increments and did not impose a prior on the parameters of the growth curve. The 2013 model assumed that the discard mortality in the directed fishery was 30% rather than 50%. The 2013 model also used updated bycatch data for the 2009/10 – 2011/12 trawl fishery and 2013 survey and 2012/13 fishery data.

The assessment author presented three variants of the base model. These variants explored the impacts of assuming a discard mortality rate of 50% and not making use of the new growth data. The estimates of biomass were relatively insensitive to these changes, but the estimate of $F_{35\%}$ and hence the OFL for the 2013/14 fishery were sensitive to the assumed discard mortality rate. For example, scenario 2, which was the same as the base model except it assumed that the discard mortality rate was 50%, led to an OFL which was 9,000 t lower than that from the base model. All of the models considered led to estimates of survey catchability (Q) (~ 0.55) which were lower than the estimate from the 2012 base model.

Stock biomass and recruitment trends

Observed survey mature male biomass decreased from 167,400 t in 2011 to 120,800 t in 2012 and to 96,100 t in 2013. Observed survey mature female biomass also decreased in the last three surveys: from 280,000 t in 2011 to 220,600 t in 2012 and to 195,100 t in 2013. The 2013 model, however, estimates that mature male biomass increased between 2012 and 2013, almost returning to the 2011 level. While the model-predicted survey mature male biomass for 2012 (127,900 t) is close to the observed value, the model-predicted mature male biomass for 2013 (142,300 t) is 1.5 times higher than the observed value. Fits by the 2013 model to the size frequency data from recent surveys, particularly from the 2013 survey, are poor; fitted size frequencies are lower than observed for females and higher than observed for males. The model is apparently “carrying forward” a relatively high abundance of small (~50 mm CW) males observed in the 2010 survey into the mature and harvested sizes in 2013 at higher than observed abundances.

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 team recommends that the proxy for B_{MSY} ($B_{35\%}$) be the mature male biomass at mating based on average recruitment over 1979 to present (154,170 t), and hence the minimum stock size threshold (MSST) is 77,100 t. The CPT recommends that the ABC be less than maximum permissible ABC, and concurs with the authors' recommendation to use a default 10% buffer for setting the ABC.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	66.6	127.7[A]	21.8	21.8	23.9	33.1	
2010/11	73.7	196.6[A]	24.6	24.7	26.7	44.4	
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		157.6[B]				78.1	70.3

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
2009/10	146.8	281.5 [A]	48.1	48.1	52.7	73.0	
2010/11	162.5	433.4 [A]	54.2	54.5	58.9	97.9	
2011/12	170.4	364.2 [A]	88.8	89.3	98.5	162.0	145.8
2012/13	169.9	374.9 [A]	66.3	66.3	71.4	149.5	134.5
2013/14		347.4[B]				172.1	154.9

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.

Additional Plan Team recommendations

The CPT identified several additional model runs for the May 2014 CPT. These runs further explore the use of growth increment data in the assessment

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, initially prosecuted mostly by foreign fleets but shifting 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 size (≥ 135.1mm (6.5-in) carapace length), sex (male only), and season (no fishing during mating/molting periods).

The current State harvest strategy allows a maximum harvest rate of 15% of mature males, but also incorporates a maximum harvest rate of 50% of legal males, a threshold of 14.5 million lb (6.6 thousand t) of effective spawning biomass (ESB), to prosecute a fishery. The TAC increased from 15.5 million lb (34.2 thousand t) for the 2006/07 season to 20.4 million lb (45.0 thousand t) for the 2007/08 and 2008/09 seasons, and then declined through the next two seasons to 14.9 million lb (32.8 thousand t) for 2010/2011. 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. Estimated fishing mortality ranged from 0.3 to 0.4 yr^{-1} following implementation of crab rationalization. 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 each season since then; total retained catch in 2012/13 was 8.59 million lb (3.90 thousand t).

Data and assessment methodology

The stock assessment model is based on a sex- and size-structured population dynamics model incorporating data from the NMFS eastern Bering Sea trawl survey, the Bering Sea Fisheries Research Foundation (BSFRF) trawl survey, commercial catch, and at-sea observer data program. 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 2013 survey and mature male biomass was projected to 15 February 2014. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date) from the directed fishery, which targets males ≥ 135mm (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. Catch and bycatch data were updated with data from the 2012/13 crab fishery year.

Six alternative models were evaluated in the 2013, including a base model based on the accepted model from the 2012 assessment. The author presented results from all six alternatives and discussed his reasons for preferring two of them, Models 1 and 4 as identified in the SAFE chapter. After discussion, the CPT selected Model 4 as its recommended model to proceed with status determination and OFL setting. Unlike the base model (2012 assessment model), this model begins in 1975 and consequently does not incorporate data from the NMFS trawl survey prior to 1975 that both the author and the CPT found to be problematic due to changes in survey timing, coverage and gear prior to 1975. It also differs from the base model in computing effective sample sizes more simply, it combines new shell and old shell males in the likelihood rather than separating them, it estimates molting probabilities for two time periods rather than three, and it incorporates sex/length compositions and survey biomass from the BSFRF trawl surveys into the likelihood rather than mature male abundances. It is similar to the base model in that it uses a constant natural mortality of M = 0.18yr^{-1}, but with additional natural mortality for males and females during 1980−1984 and for females during the "split period" 1976−1979 and 1985−1993, it estimates initial proportions-at-size, and (with respect to the "Bristol Bay retow data") it uses only the standard survey data for males and uses the re-tow data for females.

Stock biomass and recruitment trends

Model estimates of total survey biomass increased from 254.5 thousand t in 1975 to 301.9 thousand t in 1978, fell to 37.3 thousand t in 1985, generally increased to 91.5 thousand t in 2007, and subsequently declined to 74.2 thousand t in 2013. 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 declining trend. Recruitment has been poor (less than the mean from 1984-2013) 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 or 2013 surveys.

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

The CPT supports the use of Model 4 for the 2013 assessment for stock status determination.

Bristol Bay red king crab is a Tier 3 stock. The proxy of B_{MSY} ($B_{35\%}$) for a Tier 3 stock is based on mature male biomass at mating (MMB) and is computed as the average recruitment over some time period multiplied by the mature male biomass-per-recruit corresponding to $F_{35\%}$ less the mature male catch under an $F_{35\%}$ harvest strategy. 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 58.2 million lb (26.4 thousand t). MMB for 2012/13 is estimated at 55.0 million lb (25.0 thousand t), slightly less than $B_{35\%}$. Consequently, the Tier level for the BBRKC stock is 3b.

The team recommends that the OFL for 2013/14 be set according to Model 4, for which the calculated OFL is 15.58 million lb (7.07 thousand t). The team recommends that the ABC for 2013/14 be set below the maximum permissible ABC. The team recommends that a 10% buffer from the OFL be used to set the ABC at 14.02 million lb (6.36 thousand t).

The stock is estimated to have been above MSST in 2012/13, hence the stock was not overfished in 2012/13. The total catch in 2012/13 was less than the OFL, so overfishing did not occur in 2012/13. The stock at 2013/14 time of mating is projected to be 55.0 million lb (24.95 thousand t), which is above the MSST and 95% of the B_{MSY} calculated from the 2013 assessment. Hence the stock is not projected to be in overfished condition in 2013/14.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	31.3	89.0 ^{A}	16.00	16.03	18.32	22.56	
2010/11	30.0	72.0 ^{A}	14.84	14.91	17.00	23.52	
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		55.0 ^{B}				15.58	14.02

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 (thousand t) for Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	14.22	40.37[A]	7.26	7.27	8.31	10.23	
2010/11	13.63	32.64[A]	6.73	6.76	7.71	10.66	
2011/12	13.77	30.88[A]	3.55	3.61[C]	4.09	8.80	7.92
2012/13	13.19	29.05[A]	3.56	3.62[C]	3.90	7.96	7.17
2013/14		24.95[B]				7.07	6.36

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.
C- Catch > TAC represents cost recovery catch in that year

Additional Plan Team comments

The CPT noted that Model 4, the model the CPT selected as its preferred model for status determination and OFL setting, was the result of a previous CPT request to the author to incorporate length compositions and abundance data from the BSFRF trawl surveys into the assessment model. As part of that request, the CPT intended that the model would also fix catchability for the BSFRF trawl surveys to 1 and estimate catchability for the NMFS trawl surveys. Model 4, however, fixes catchability for both surveys. The CPT thus requests that the author evaluate an alternative model, using Model 4 as the new base model, which estimates catchability for the NMFS trawl surveys and present the results of this evaluation to the CPT at its May 2014 meeting.

The CPT also noted that the results from Model 7, a diagnostic model in which natural mortality was allowed to vary in an autoregressive manner, appeared to provide support for the use of higher natural mortality rates in the late 1970's-early 1980's in the CPT's recommended model. These results also suggested that natural mortality may have been high in a more recent time period (mid-to-late 2000's), as well. The CPT requests that the author explore the use of an additional "recent" period of higher natural mortality, using Model 4 as the base model.

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, in the directed Tanner crab fishery (principally as non-retained females and sublegal males), and in other crab fisheries (notably, eastern Bering Sea snow crab and to a lesser extent in the fishery for 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 two directed fisheries, one east and one west of 166˚ W longitude. NMFS declared this stock overfished in 1999 and the Council developed a rebuilding plan. 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. In 2007, NMFS determined the stock was rebuilt because spawning biomass was above the proxy for B_{MSY} for two consecutive years. The mature male biomass was, however, 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 again in 2010/11 and 2011/12 crab fishery years, and remained closed in the 2012/13 crab fishery year. NMFS determined the stock was not overfished in 2012 based on a new assessment model with a revised estimate of B_{MSY}.

Data and assessment methodology

A stock assessment model is used for EBS Tanner crab. The SSC accepted the model for use in harvest specifications in 2012 and classified it as a Tier 3 stock. The model is structured by size, sex, shell condition, and maturity state. It uses available information on the magnitude and size-composition of the landings and discards by the directed fishery, and bycatch in the Bristol Bay red king crab, EBS snow crab, and groundfish fisheries. It also uses index and size-composition data from the NMFS trawl survey. The model includes prior distributions on parameters related to natural mortality and catchability, and includes penalties on changes in recruitment and in the proportion maturing. The current model is unchanged from the model that was used last year, except for the correction of several minor coding errors. New input data include the 2013 NMFS bottom trawl survey results (abundance and size composition), and discard (biomass, size composition) from the 2012/13 snow crab fishery, Bristol Bay red king crab fishery, and the EBS groundfish fishery.

Stock biomass and recruitment trends

The MMB peaked in the mid-1970s and early 1990s; MMB at the time of mating was highest early in the modeled period (February 1972; 352.5 thousand t), with secondary peaks in February 1989 (70.6 thousand t) and February 2009 (71.6 thousand t). MMB has subsequently declined. The MMB in February 2013 is estimated to be 59.4 thousand t compared to 59.3 thousand t in February 2012. Recruitment is estimated to have peaked before 1974, the first year for which survey data are included in the assessment. Subsequent peaks in recruitment occurred during 1985 through1987 and 2009 through 2010.

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 the mean recruitment corresponding to B_{MSY}($\bar{R}_{MSY}$),which should reflect mean recruitment under prevailing environmental conditions. Last year, the CPT recommended that $\bar{R}_{MSY}$ be set to the mean recruitment from 1990 onwards based on an analysis of the relationship between log(R/MMB) and MMB that identified a change in this relationship in 1985 (1990 year of recruitment to the model). The SSC subsequently recommended that the years from 1982 onwards be used, corresponding to a change in 1977. This recommendation was based on various considerations, including the reliability of the earlier recruitment estimates, and the identification of the late 1970s as a period of rapid ecological change in the EBS.

An appendix to the Tanner crab assessment includes a more extensive change point analysis of the relationship between log(R/MMB) and MMB (note that this analysis is equivalent to fitting a Ricker stock-recruit relationship). Two candidate periods for a change in the relationship of log(R/MMB) and MMB were identified, 1974-75 and 1983-1987. The 1974-75 change point models indicate that primary difference between the two periods is a decrease in overall productivity at all stock sizes (i.e., a change in the intercept parameter), whereas the 1983-1987 models indicate an increase in density dependent mortality (i.e., a change in the slope parameter). The CPT considered the 1974-75 change point models to be more consistent with what is generally understood as a change in stock productivity. An increase in density-dependent mortality was considered less plausible by the CPT, though the assessment author suggested a scenario in which reductions in habitat available for settlement due to changes in the cold pool could lead to greater competition at the early life history stages of Tanner crab. A change point in 1974 implies use of recruitments from 1979 onwards to estimate $\overline{R}_{MSY}$. However, this is reasonably close to the SSC recommendation to use recruitments from 1982 onwards, and the CPT found no compelling reason to deviate from the SSC's recommendation.

Based on the estimated biomass at 15 February 2014, the stock is at Tier 3 level a. The F_{MSY} proxy ($F_{35\%}$) is 0.73 yr^{-1} (note an increase from 0.61 last year), and the 2013/14 is F_{OFL}=0.73 yr^{-1} under the Tier 3 OFL Control Rule, which results in a total male and female catch of 25.35 thousand t.

Last year, the team recommended that the ABC be adjusted over three year period due to the major change in stock status, and concern about the stability of assessment model and the uncertainty of the OFL estimate. The NMFS bottom trawl survey showed a modest increase in both female and male mature biomass in 2013. Therefore the team considered it appropriate to make the next incremental adjustment to the ABC. The calculation of the ABC is as follows:
2011/12 OFL = 2.75 thousand t
2013/14 OFL = 25.35 thousand t
2013/14 ABC = (2/3) X (25.35 thousand t– 2.75 thousand t) + 2.75 thousand t = 17.82 thousand t.

The CPT remains concerned about the uncertainty of the assessment and the estimates of stock status and will consider making a final adjustment to ABC next year.

Historical status and catch specifications (million lb) for eastern Bering Sea Tanner crab

Year	MSST	Biomass (MMB)	TAC (east + west)	Retained Catch	Total Catch	OFL	ABC
2009/10	92.37[c/]	62.70[c/A]	1.34[a/]	1.32	3.62	5.00	
2010/11	91.87[c/]	58.93[c/B]	0.00	0.00	1.92	3.20	
2011/12	25.13[C]	129.17[C]	0.00	0.00	2.73	6.06	5.47
2012/13	36.97[D]	130.84[D]	0.00	0.00	1.57	41.93[C]	18.01[C]
2013/14		117.07[b/D]				55.89[D]	39.29[D]

(b) Historical status and catch specifications (thousand t) for eastern Bering Sea Tanner crab

Year	MSST	Biomass (MMB)	TAC (east + west)	Retained Catch	Total Catch	OFL	ABC
2009/10	41.90[1/]	28.44[c/A]	0.61[a/]	0.60	1.64	2.27	
2010/11	41.67[2/]	26.73[c/A]	0.00	0.00	0.87	1.45	
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		53.1[B]				25.35	17.82

1/ Projected 2012/13 MMB at time of mating after extraction of the estimated total catch OFL.
2/ Based on mature male biomass at the time of mating inferred from the NMFS survey under the assumption Q=1
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.

EBS Tanner crab MMB was above B_{MSY} at the time of mating in mid-February 2013. Overfishing did not occur during the 2012/13 fishing year because total catch removals (0.71 thousand t) did not exceed the total catch OFL (19.02 thousand t).

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

The Pribilof Islands red king crab fisherybegan in 1973 as bycatch during the blue king crab fishery. The directed red king crab fishery opened with a specified GHL for the first time in September 1993. Beginning in 1995, combined Pribilof Islands red and blue king crab GHLs were established. Declines in crab abundance of both king crab stocks from 1996 to 1998 resulted in poor fishery performance during those seasons with annual harvest levels below the GHLs. The Pribilof red king crab fishery was closed from 1999 through 2011/12 due to uncertainty in estimated red king crab survey abundance and concerns for incidental catch and mortality of Pribilof blue king crab which was an overfished and severely depressed stock. Prior to the closure, the 1998/99 harvest was 246.9 t (0.544 million lb). The non-retained catches, with application of bycatch mortality rates, from pot and groundfish bycatch estimates of red king crab ranged from 2.8 t (0.001 million lb) to 192.1 t (0.424 million lb) during 1991/92 to 2011/12.

Data and assessment methodology

There is no stock assessment model for Pribilof Island red king crab. The 2013 assessment is based on trends in male mature biomass (MMB) at the time of mating inferred from NMFS bottom trawl survey from 1975-2013 and commercial catch and observer data from 1973/74 to 2012/13. The revised time-series of historical NMFS trawl survey abundance estimates were used in this assessment. The 2012/13 non-retained catch from all non-directed pot and groundfish fisheries were included in the SAFE report, incorporating a new data set for observed groundfish fisheries which aggregates data on crab catch by species to the level of the respective stock area; prior to 2009, bycatch data are aggregated over all crab species by federal reporting area. An F_{OFL} for 2012/13 was determined using a mean MMB at the time of mating, the default γ value of 1.0 and an M of 0.18yr^{-1}. As recommended by the CPT (September 2011) and SSC (October 2011), the annual index of MMB for this stock was derived as the 3-yr running average centered on the current year MMB and weighted by the inverse variance. The $B_{\mathrm{MSY\ proxy}}$ was calculated using the unweighted observed survey MMBs from 1991-2013.

Stock biomass and recruitment trends

The stock exhibited widely varying mature male and female abundances during 1975-2013. The average MMB estimated for 2013 was 4,679 t (10.32 million lb). Retained catches have not occurred since the 1998/99 season. Non-directed discard losses in the pot fisheries decreased in recent years, and there are no discard losses in the current year. Mature stock biomass declined in 2008/09 and 2009/10 followed by increases in MMB in 2010/11 through 2012/13. The estimated biomass of pre-recruit size crab remained relatively constant over the past decade although pre-recruit sized crab may not be well sampled by the NMFS survey. Bycatch losses resulting from the fixed gear groundfish fleet using the new dataset decreased from 2011/12 to 2012/13, while losses resulting from discards in the groundfish trawl fleet increased from 4,470 t (9.85 million lb) to 12,980 t (28.62 million lb) between 2011/12 to 2012/13. In 2013, estimates of legal male biomass and mature male biomass increased substantially relative to 2012, whereas mature female biomass decreased substantially from 663 t to 169 t.

In 2012/2013, using the new database estimation, 16.46 t of male and female red king crab were caught in fixed gear (0.24 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 (Table 5). Unlike previous years no bycatch was observed in Alaska plaice fisheries in

2011/2012 or 2012/2013.

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

Based on available data, the author recommended classification for this stock is Tier 4 for stock status level determination. For 2012/13 the $B_{\text{MSY proxy}}$ = 5,164 t of MMB_{mating} derived as the mean of 1991/92 to 2012/13. MMB varied considerably during these periods likely leading to varying estimates of B_{MSY}. Male mature biomass at the time of mating for 2012/13 was estimated at 4,679 t. The $B/B_{\text{MSY Proxy}}$ =0.91 and F_{OFL}=0.16. $B/B_{\text{MSY Proxy}}$ is < 1, therefore the stock status level is *b*. For the 2013/2014 fishery, the OFL was estimated at 903 t of crab. The projected exploitation rates based on full retained catches up to the OFL is 0.17 for both LMB and $MMB_{fishery}$

. The CPT concurred with the author's recommendation to set the ABC below the maximum permissible, given the relative amount of information available for Pribilof Island red king crab. For 2013/14 using the recommended $B_{MSYprox}$, the multiplier equivalent to a P* of 0.49 was 0.84. The maxABC was thus estimated to be 759 t. Incorporating additional uncertainty by applying a σ_b of 0.40 resulted in a multiplier of 0.80 and a recommended ABC of 718 t (1.58 million lb).

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	4.22	4.80[A]	0	0	0.006	0.50	
2010/11	4.97	6.07[A]	0	0	0.009	0.77	
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		10.32[B]				1.99	1.58

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	1,914	2,175[A]	0	0	2.7	227	
2010/11	2,255	2,754[A]	0	0	4.2	349	
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		4,679[B]				903	718

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 2012/2013 and is hence not overfished. Overfishing did not occur during the 2012/2013 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 due to declining stock abundance and has remained closed through the 2012/13 season. The stock was declared overfished in 2002.

A revised rebuilding plan has been submitted for review by the Secretary of Commerce in 2013 as NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. This rebuilding plan closes the Pribilof Island Habitat Conservation Zone to Pacific cod pot fishing, which comprises the highest historical rates of bycatch of this stock. This area is already closed to groundfish trawl fishing.

Data and assessment methodology

NMFS conducts an annual trawl survey that is used to produce area-swept abundance estimates. The CPT has discussed the history of the fishery and the rapid decline in abundance. It is clear that the stock has collapsed, although the annual area-swept abundance estimates are imprecise.

The 2013/14 survey biomass time series uses the area definition established in 2012/13 that includes an additional 20 nm strip east of the Pribilof District. MMB was estimated using a three-year running average centered on the current year weighted by the inverse variance of the area-swept estimate. Groundfish bycatch was recalculated for 2009/10 – 2012/13 using State of Alaska statistical areas. The new time series in the newly defined Pribilof stock area resulted in significantly different estimates of blue king crab bycatch biomass in 2009/2010-2012/2013. In 2012/2013, using the new estimation method, 0.82 t of male and female blue king crab were caught in fixed gear (0.16 t) and trawl (0.67 t) gear groundfish fisheries. The targeted species in these fisheries were Pacific cod (19%), yellowfin sole (78%), and flathead sole (3%) fisheries. The catch was in non-pelagic trawls (81%) and longline (19%) fisheries. There was no bycatch attributed to pot fisheries. The discrepancy between the old and new methods highlights the problems attributing non –observed vessels from outside the stock boundaries. The analyses in this document use only the new method for 2009/2010 through 2012/2013 catch data.

Stock biomass and recruitment trends

The estimated mature-male biomass increased to 579 t in 2012/13 from 365 t in 2011/12. The 2013/14 MMB at mating is projected to be 278 t, which is 7% of the proxy for B_{MSY}. The Pribilof blue king crab stock biomass continues to be low. From recent surveys there is 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 3,988 t (8.70 million pounds).

Because the projected 2013/14 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 2013/14 is 1.16 t (0.003 million lb). The CPT concurred with the author's recommendation to set ABC less than the maximum permissible by employing a 10% buffer consistent with a Tier 5 average catch calculation, as was used in 2012/13. The ABC was estimated at 1.04 t (0.002 million lb.). The CPT did not see justification to change ABC from status quo.

Historical status and catch specifications (t.) of Pribilof blue king crab in recent years.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	2,105[A]	401[A]	closed	0	0.5	1.81	
2010/11	2,105[B]	286[A]	closed	0	0.18	1.81	
2011/12	2,247[C]	365[A]	closed	0	0.36	1.16	1.04
2012/13	1,994 [D]	579[A]	closed	0	0.61	1.16	1.04
2013/14		278 [B]				1.16	1.04

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 (million lb.) of Pribilof blue king crab in recent years.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	4.64[A]	0.88[A]	closed	0	0.001	0.004	
2010/11	4.64[B]	0.63[A]	closed	0	0.0004	0.004	
2011/12	4.95[C]	0.80[A]	closed	0	0.0008	0.003	0.002
2012/13	4.39[D]	1.28[A]	closed	0	0.0013	0.003	0.002
2013/14		0.61[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 2012/13 (0.61 t, 0.0013 million lb) was less than the 2012/13 OFL (1.16 t, 0.003 million lb) so overfishing did not occur during 2012/13. The 2013/14 projected MMB estimate of 278 t (0.61 million lb) is below the proxy for MSST (MMB/B_{MSY} = 0.07) so the stock continues to be in an overfished condition and failed to rebuild within the maximum required rebuilding time.

Additional Plan Team comments

None.

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 1.88 million lb. represented 80% of 2.36 million lb. TAC. In 2012/13, by contrast, harvesters landed 99% 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. 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; (2) annual trawl survey data from 1978 to 2013; (3) triennial pot survey data from 1995 to 2010; (4) bycatch data in the groundfish trawl and groundfish fixed-gear fisheries from 1991 to 2013; and (5) ADF&G crab-observer composition data for the years 1990/91–1998/99, 2009/10–2012/13. Trawl survey data are from summer trawl survey for stations within the St. Matthew Section. Trawl survey data provided estimates of density (number/nm^2) at each station for males in the three size categories. The pot survey data originate from the ADF&G triennial pot surveys that occurred during July and August in 1995, 1998, 2001, 2004, 2007, and 2010. 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 five 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

The 2013 assessment estimates that the stock is currently below the proxy for B_{MSY} even though previous assessments estimated that the stock was above B_{MSY}. The MMB has fluctuated substantially over three periods, increasing during 1978 to 1981 of the first period from 7.6 million lb. to 17.6 million lb., followed by a steady decrease to 2.9 million lb. in 1985. The second period had a steady increase from 1986 to 13.3 million lb. in 1997 followed by a rapid decline to 2.8 million lb. in 1999. The third period starting in 2000 had a steady increase in all size classes and peaked at 15.80 million lb. in 2011/2012 before declining to 6.64 million pounds in 2012/2013. The low 2013 survey estimate of stock biomass along with declining trends in model recruitment raises concern that the stock maybe approaching and overfished condition.

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

The CPT agrees with the author recommended base model, which results in a Tier 4b specification. The recommended model follows past CPT and SSC guidance. The model uses the full assessment period (1978/79-2012/13) to define the proxy for B_{MSY} in terms of average estimated MMB_{mating} with gamma (γ)=1 and an instantaneous natural mortality = 0.18^{-1} year. The MMB estimated for 2012/13 under the recommended model is 6.76 million lb (3,060 t) and the F_{MSY} proxy is taken equal to the assumed instantaneous natural mortality rate (0.18^{-1} year), resulting in a mature male biomass OFL = 1.24 million lb (1.02 t). The maxABC based on a P* = 0.49 is 1.23 million lb. However, the CPT had strong concerns about the declining trends of abundance in recent years and historical "boom and bust" patterns in the trawl survey indices.. The team noted a downward trend in most-recent biomass estimates in the retrospective assessment analysis, giving rise to concerns that the 2013 MMB may be over-estimated. Due to this retrospective patterns, the estimate of F was greater than the estimated F_{MSY} in each of these years. These concerns highlighted the large amount of uncertainty and the need to be precautionary in setting the ABC. The CPT therefore recommended a 20% buffer (1.24 *0.80) for an ABC of 0.99 million lb. (453 t).

Historical status and catch specifications (millions lb.) of St. Matthew blue king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL*	ABC
2009/10	3.4	12.76[A]	1.17	0.46	0.53	1.72	
2010/11	3.4	14.77[A]	1.60	1.26	1.41	2.29	
2011/12	3.4	11.09[A]	2.54	1.88	2.10	3.31	3.40
2012/13	4.0	6.29[A]	1.63	1.62	1.81	2.24	2.02
2013/14		6.64[B]				1.24	0.99

Historical status and catch specifications (kt) of St. Matthew blue king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL*	ABC
2009/10	1.5	5.79[A]	0.53	0.21	0.24	0.78	
2010/11	1.5	6.70[A]	0.73	0.57	0.64	1.04	
2011/12	1.5	5.03[A]	1.15	0.85	0.95	1.70	1.50
2012/13	1.8	2.85[A]	0.74	0.73	0.82	1.02	0.92
2013/14		3.01[B]				0.56	0.45

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 male catch for 2012/13 (1.8 million lb.) was less than the 2012/13 OFL (2.24 million lb.) so overfishing did not occur during 2012/13. Likewise, the 2012/13 MMB (6.29 million lb.) is above the MSST (4.0 million lb.) so the stock is not in an overfished condition.

Additional Plan Team recommendations

The author presented preliminary models (Tbase and TC) incorporating alternative stage-transition matrix motivated by the work by Otto and Cummiskey (1990). The CPT recommended further development of this transition matrix using pertinent biological information such as molting and growth. A biologically defensible transition matrix would improve model structure and may also improve trawl selectivity estimates.

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 lbs retained catch. Retained catches since 1982 have been below 0.5 million lbs, averaging 275,000 lbs, including several low years in the 1990s. Retained catches in the past four years have been about 400,000 lbs.

Data and assessment methodology

Four types of surveys have been conducted during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot, but none of these surveys have been conducted every year. The 1976-1991 NMFS trawl survey data were revised during the last year and were included in the May 2013 assessment. A length-based model of male crab abundance was developed that combines multiple sources of data, and estimates abundance, recruitment, and selectivity and catchability of the commercial pot gear. The model has been updated using data from the 2012/13 winter pot survey, the 2012 summer commercial fishery, the 2012 summer trawl survey, the finalized catches for the 2011/12 winter commercial and subsistence fisheries, and the most up-to-date 2012/13 winter commercial and subsistence catches. The model assumes M=0.18yr^{-1} for all length classes. The assessment author revised the model based on the recommendations from the January 2013 crab model workshop and the May 2013 CPT meeting recommendations. This assessment was reviewed in September 2013 due to the change in the assessment timing from July-June to October-September so that harvest specifications can be set in a timely manner for the summer fishery. Harvest specifications for this stock will now be made each year in September.

Stock biomass and recruitment trends

Mature male biomass (MMB) showed an increasing trend since 1997, following a substantial decline in abundance from the peak in 1977 to 1982. However, uncertainty in historical biomass is considerable, which is in part a result of infrequent trawl surveys and a limited winter pot survey. Estimated recruitment has been highly variable, but there is an increasing trend in recruitment over recent years.

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

The team was concerned regarding the outcomes of the assessment when the length-frequency data from observer sampling during 2013 was included in the assessment (the “full” model). The abundance of crab in the smallest size-class was very high in the 2013 observer data, which the model interpreted as the largest year-class ever given there is no other information about the associated year-class. Most stock assessments impose a penalty on the extent of variation in recruitment about mean recruitment but this penalty is very weak in the current assessment. The high estimate of recruitment contributes to the OFL for the “full” model because this year class is assumed to growth into a size-class which is assumed to be mature but not retained. The CPT acknowledges that there are data indicating a strong recruitment event, but that substantial uncertainty surrounds this estimate which is not appropriately treated within the current model formulation. Given these concerns the CPT recommends the model without the 2013 data point for use in setting harvest specifications for 2013/14.

The team continues to recommend Tier 4 stock status for Norton Sound red king crab. The estimated legal biomass in 2014 based on “no observed data” model is 2.83 million lb (SD 1.18 million lb) while the estimated mature male biomass in 2014 is 3.72 million lb (SD 4.37 million lb). The average mature male biomasses during 1980-2014 (4.36 million lb) was used as the proxy for B_{MSY} . The F_{MSY} proxy is M (0.18 yr^{-1}) and F_{OFL} is F_{OFL}=0.15 yr^{-1} because the 2014 mature male biomass is less than the proxy for B_{MSY}.

The maximum permissible ABC in 2014 is 0.39 million lb. The CPT recommended an ABC less than the maximum permissible due to potential concerns with model specification, as well as issues noted with the *M* employed for the largest length group. The CPT recommended an ABC = 90% of the OFL (10% buffer) of 0.36 million pounds.

Status and catch specifications (million lbs.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2009/10	1.54	5.83[A]	0.38	0.40	0.43	0.71	
2010/11	1.56	5.44[A]	0.40	0.42	0.46	0.73	
2011/12	1.56	4.70[A]	0.36	0.40	0.43	0.66	0.59
2012/13	1.78	4.59[A]	0.47	0.47	0.47	0.53	0.48
2013	2.06[B]	5.00[B]	0.50	0.35	0.35	0.58[B]	0.52[B]
2013/14	2.18[C]	3.72[C]				0.39[C]	0.36[C]

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 - Calculated from the assessment reviewed by the Crab Plan Team in Sep 2013 for the 2013/14 winter fishery and the 2014 summer fishery. This represents projected biomass from the current stock assessment. This value will be updated next year.
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2013 for fishery of the 2013 summer fishery and the 2013/14 Winter fishery

Status and catch specifications (thousand t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2009/10	0.70	2.64[A]	0.17	0.18	0.22	0.32	
2010/11	0.71	2.47[A]	0.18	0.19	0.21	0.33	
2011/12	0.71	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	0.62[B]	2.16[B]	0.23	0.16	0.16	0.26[B]	0.24[B]
2013/14	0.99[C]	1.69[C]				0.18[C]	0.16[C]

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 - Calculated from the assessment reviewed by the Crab Plan Team in Sep 2013 for fishery of 2013/2014 (Winter fishery and 2014 Summer fishery). This represents projected biomass from the current stock assessment. This value will be updated next year.
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2013 for fishery of 2013 Summer fishery and 2013/2014 Winter fishery

Total catch in 2012/13 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 recommends for the next assessment:

- include a much stronger penalty on the extent to which recruitment can vary among years (e.g. by increasing the "lambda" on the recruitment penalty from 0.01 to 0.5;

- construct a likelihood profile for M;
- the assessment should report the OFL and report how much of this OFL is predicted to be retained and to be discarded; and
- evaluate whether selectivity should be assumed to differ for the NMFS and ADFG trawl surveys.

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 5.7 million lb for 2007/08, but was increased to 6.0 million lb for the 2008/09-2011/12 seasons, and to 6.3 million lb for the 2012/13 season. Average retained catch for the period 1996/97–2007/08 was 5.6 million lb, and 5.8 million lb for the period 2008/09-2010/11. The retained catch for 2011/12 was 6.0 million lb. This fishery is rationalized under the Crab Rationalization Program. The 2012/13 season remains open until 15 May 2013.

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 the weight of bycatch in the directed fishery. Total annual non-retained catch of golden king crab during crab fisheries has decreased relative to the retained catch since the 1990s. It decreased from 13.8 million lb in 1990/91 (199% of the retained catch) to 9.1 million lb in 1996/97 (156% of the retained catch), and to 4.3 million lb in the 2004/05 season (78% of the retained catch). Bycatch has ranged from 2.5 million lb in 2005/06 (46% of the retained catch) to 3.0 million lb for 2007/08 (55% of the retained catch) during the seven seasons prosecuted as rationalized fisheries (2005/06–2011/12). Bycatch mortality has correspondingly decreased since 1996/97 both in absolute weight and relative to the retained catch weight. Estimated total mortality (retained catch plus bycatch in crab and groundfish fisheries) ranged from 5.8-9.4 million lb over 1995/96–2011/12. Estimated total mortality in 2011/12 was 6.5 million lb.

Data and assessment methodology

Available data are from ADF&G fish tickets (retained catch numbers, retained catch weight, and pot lifts by ADF&G statistical area and landing date), size-frequencies from samples of landed crabs, at-sea observations from pot lifts sampled during the fishery (date, location, soak time, catch composition, size, sex, and reproductive condition of crabs, etc.), triennial pot surveys in the Yunaska-Amukta Island area of the Aleutian Islands approximately 171° W longitude, tag recoveries from crabs released during the triennial pot surveys, and bycatch from the groundfish fisheries. These data are available through the 2011/12 season and the 2006 triennial pot survey. Most of the available data were obtained from the fishery which targets legal-size (≥6-inch CW) males and trends in the data can be affected by changes in both fishery practices and the stock. The triennial survey is too limited in geographic scope and too infrequent to provide a reliable index of abundance for the Aleutian Islands area. An assessment model is currently being developed for this stock.

Stock biomass and recruitment trends

Although a stock assessment 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 have been updated with the results for 2011/12: 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 2013/14. B_{MSY} and MSST are not estimated for this stock. Observer data on bycatch from the directed fishery and groundfish fisheries provides the estimate of total bycatch mortality. Bycatch data from the directed fishery for years after the 1990/91 season (excluding 1993/94 and 1994/95 seasons due to insufficient data) and from the groundfish fisheries since the 1993/94 season 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 2013/14 total catch OFL as was used to determine the 2012/13 total catch OFL. 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):

$$OFL_{2013/14} = (1+R_{90/91\text{-}95/96}) \bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09} = 12{,}537{,}757 \text{ lb}$$

where,

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

The team concurred with the author's recommendation to set the ABC based on the maximum permissible from the ABC control rule which specifies an ABC based on a 10% buffer on the OFL. The recommended ABC is 11,283,981 lb.

Historical status and catch specifications (millions lb.) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	NA	NA	5.99	5.91	6.51	9.18 [A]	
2010/11	NA	NA	5.99	5.97	6.56	11.06	
2011/12	NA	NA	5.99	5.96	6.51	11.40	10.26
2012/13	NA	NA	6.29	6.27	6.87	12.54	11.28
2013/14	NA	NA	6.29			12.54	11.28

A – retained catch

Historical status and catch specifications (thousand t) of Aleutian Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	NA	NA	2.72	2.68	2.95	4.16 [A]	
2010/11	NA	NA	2.72	2.71	2.98	5.02	
2011/12	NA	NA	2.72	2.71	2.95	5.17	4.66
2012/13	NA	NA	2.85	2.84	3.12	5.69	5.12
2013/14	NA	NA	2.85			5.69	5.12

A – retained catch

No overfished determination is possible for this stock given the lack of biomass information. Catch in 2012/13 was below the OFL therefore overfishing did not occur..

Additional Plan Team recommendations

The CPT has reviewed draft versions of a developing stock assessment model for this stock. The most recent version of the model, along with the method for standardizing the CPUE data was reviewed at the February 2013 Crab Modeling Workshop. The team reviewed progress on standardizing the CPUE data in response to the suggestions from the February 2013 Workshop. The assessment author will further update the CPUE standardization and provide additional results and a revised assessment to the CPT in September 2013. The CPT also heard a presentation on a pilot study in which research pots were fished alongside commercial pots to assess differences in fishery selectivity and population structure in fished areas. The CPT noted the value of these data to confirm that small crab are present where the fishery is prosecuted and that the estimated retention function matches the selectivity patterns for the commercial fishery from the two most recent versions of the assessment model that is under development.

9 Pribilof District Golden King Crab

Fishery information relative to OFL setting

The Pribilof District fishery for male golden king crab ≥ 5.5 in carapace width (≥ 124 mm carapace length) developed in the 1981/82 season. The directed fishery mainly occurs in Pribilof Canyon of the continental slope. Peak directed harvest is 856-thousand lb during the 1983/84 season. Historical fishery participation has been sporadic and retained catches variable. The current fishing season is based on a calendar year. Since 2000, the fishery was managed for a guideline harvest level (GHL) of 150-thousand lb. Non-retained bycatch occurs in the directed fishery, Bering Sea snow crab, Bering Sea groundfish, and historical grooved Tanner crab fisheries. Estimated total fishing mortality in crab fisheries averages 78-thousand lb (2001-2011). Crab mortality in groundfish fisheries (July 1–June 30, 1991/92–2011/12) averages 6-thousand lb. There was no participation in the directed fishery from 2006-2009; two vessels participated in 2011 and 1 vessel in 2012. Pribilof District golden king crab is not included in the Crab Rationalization Program.

Data and assessment methodology

Total golden king crab biomass has been estimated during the NMFS upper-continental-slope trawl surveys in 2002, 2004, 2008, 2010 and 2012. There is no assessment model for this stock. Fish ticket and observer data are available (including retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date), size-frequency data from samples of landed crabs, and pot lifts sampled during the fishery (including date, location, soak time, catch composition, size, sex, and reproductive condition of crabs, etc.), and from the groundfish fisheries. Much of the directed fishery data are confidential due to low number of participants.

Stock biomass and recruitment trends

Estimates of stock biomass (all sizes, both sexes) were provided for the Pribilof Canyon. A separate report by W. Gaeuman on a proposed tier 4 analysis has a discussion of survey biomass estimates and is appended to the SAFE chapter.

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

The Team recommends this stock be managed under Tier 5 in 2014.

The assessment author presented two alternatives for establishing the OFL. The Team concurs with the author's recommendation for the 2014 OFL based on the same analysis as the 2013 OFL of 0.2 million lb and the maximum permissible ABC of 0.18 million lb. The ABC was derived by applying the Tier 5 control rule a 10% buffer of the OFL, ABC = 0.9 * OFL. The OFL was derived based on the following data:

$OFL_{TOT,2013} = (1+R_{2001\text{-}2010}) * RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93\text{-}98/99}$

- $R_{2001–2010}$ is the average of the estimated average annual ratio of pounds of bycatch mortality to pounds 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 (period of unconstrained catch).
- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998.
- $BM_{GF,1992/93–1998/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

The average of the estimated annual ratio of pounds of bycatch mortality to pounds of retained in the directed fishery during 2001–2010 is used 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 is 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.

Status and catch specifications (millions lb)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010	N/A	N/A	0.15	Conf.	Conf.	0.17[A]	
2011	N/A	N/A	0.15	Conf.	Conf.	0.18	
2012	N/A	N/A	0.15	Conf.	Conf.	0.20	0.18
2013	N/A	N/A	0.15			0.20	0.18
2014	N/A	N/A	0.15			0.20	0.18

A= Retained-catch OFL
Conf. = confidential

Status and catch specifications (t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010	N/A	N/A	68	Conf.	Conf.	77.1[A]	
2011	N/A	N/A	68	Conf.	Conf.	81.6	
2012	N/A	N/A	68	Conf.	Conf.	90.7	81.6
2013	N/A	N/A	68			90.7	81.6
2014	N/A	N/A	68			90.7	81.6

A= Retained-catch OFL
Conf. = confidential

No overfished determination is possible for this stock given the lack of biomass information. Although catch information is confidential under Alaska statute (AS 16.05.815) the assessment author indicated that the total catch did not exceed the OFL of 0.20 million lb therefore overfishing did not occur. The 2013 fishery is ongoing until the GHL is achieved or until December 31.

Additional Plan Team recommendations

The team reviewed the appendix on a proposed Tier 4 biomass calculation for catch specifications in September 2013. The team recommends that alternative OFL and ABC specifications based on this approach be included in the 2014 assessment. Additional recommendations are contained in the Crab Plan Team report.

10 Adak red king crab, Aleutian Islands

Fishery information relative to OFL and ABC setting

The domestic fishery has been prosecuted since 1960/61 and was opened every season through the 1995/96 season. Since 1995/96, the fishery was opened only in 1998/99, and from 2000/01-2003/04. 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° 15’ 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° 15’ W longitude.

Retained catch during the 10-year period, 1985/86 through 1994/95, averaged 0.94 million lb, but the retained catch during the 1995/96 season was low, only 0.04 million lb. 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 and 2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 0.50 million lb. 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 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). The fishery has been closed since the end of the 2003/04 season.

Non-retained catch of red king crabs occurs in both the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated bycatch mortality during the 1995/96-2011/12 seasons averaged 0.002 million lb in crab fisheries and 0.020 million lb in groundfish fisheries. Estimated annual total fishing mortality (in terms of total crab removal) during 1995/96-2011/12 averaged 0.095 million lb. The average retained catch during that period was 0.074 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 1960/61-2007/08 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 during 1995/96-2011/12 and from groundfish fisheries during 1993/94-2011/12 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 have been 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 the end of 2003/04 season due to apparent poor recruitment. An ADF&G-Industry survey was conducted as a commissioner’s permit fishery in the Adak-Atka-Amlia Islands area in November 2002 and provided no evidence of recruitment sufficient to support a commercial fishery. A pot survey conducted by ADF&G in the Petrel Bank area in 2006 provided no evidence of strong recruitment. A 2009 survey conducted by ADF&G in the Petrel Bank area encountered a smaller, ageing population with the catch of legal male crab occurring in a more limited area and at lower densities than were found in the 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.

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

The CPT recommends that this stock be managed under Tier 5 for the 2013/14 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 freeze the time period for computing the OFL at 1995/96–2007/08. The CPT recommends an OFL for 2013/14 of 0.12 million lb.

The Team continues to have concerns regarding the depleted status of this stock. Groundfish bycatch in recent years has accounted for the majority of the catch of this stock. The maximum permissible ABC is 0.11 million lb based on the Tier 5 control rule of a 10% buffer on the OFL.

The CPT recommends an ABC of 0.074 million lb for 2013/14, which is below the maximum permissible ABC (maxABC = 0.11 million lb). Industry has expressed interest in an exploratory fishery around the Adak area based on anecdotal information that there may be legal crab available in this stock.

Status and catch specifications (millions of lb) of Adak RKC.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	NA	NA	Closed	0	0.012	0.50[A]	
2010/11	NA	NA	Closed	0	0.004	0.12	
2011/12	NA	NA	Closed	0	0.002	0.12	0.03
2012/13	NA	NA	Closed	0	<0.001	0.12	0.07
2013/14	NA	NA	Closed			0.12	0.07

A-Retained catch OFL based on 1984/85-2007/08 mean retained catch

Status and catch specifications (t) of Adak RKC.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	NA	NA	Closed	0	5.44	226.8[A]	
2010/11	NA	NA	Closed	0	1.81	54.43	
2011/12	NA	NA	Closed	0	1.0	54.43	12.0
2012/13	NA	NA	Closed	0	<1.0	54.43	33.57
2013/14	NA	NA	Closed			54.43	33.57

A-Retained catch OFL based on 1984/85-2007/08 mean retained catch

No overfished determination is possible for this stock given the lack of biomass information. Catch in 2012/13 was below the OFL therefore overfishing did not occur..

Additional Plan Team discussion

The team reviewed a request from the ACDC regarding the ability to remove the eastern portion of the stock (east of 179 W) from the FMP. See the Crab Plan Team Report for additional discussion and recommendations.

Table 3 Crab Plan Team recommendations for September 2013 (stocks 1-7). Note that recommendations for stocks 6-10 represent those final values recommended by the SSC in June 2013. Note diagonal fill indicates parameters are not applicable for that tier level. Values in thousand metric tons (t).

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2013/14[2 3] MMB	2013 MMB / MMB_{MSY}	γ	Mortality (M)	2013/14 OFL	2013/14 ABC
1	EBS snow crab	3	a	1.58	154.2	1979-current [recruitment]	157.6	1.02		0.23(females) 0.386 (imm) 0.2613 (mat males)	78.1	70.3
2	BB red king crab	3	b	0.29	26.4	1984-current [recruitment]	25.0	0.95		0.18 default Estimated[4]	7.07	6.36
3	EBS Tanner crab	3	a	0.73	33.54	1982-current [recruitment]	59.4	1.77		0.34 (females), 0.25 (mat male), 0.247 (imm males and females)	25.35	17.82
4	Pribilof Islands red king crab	4	b	0.16	5.16	1991-current	4.68	0.91	1.0	0.18	0.90	0.72
5	Pribilof Islands blue king crab	4	c	0	3.99	1980-1984 1990-1997	0.28	0.07	1.0	0.18	0.00116	0.00104
6	St. Matthew Island blue king crab	4	b	0.18	3.1	1978-current	3.01	0.98	1.0	0.18	0.56 [total male catch]	0.45 [total male catch]
7	Norton Sound red king crab	4	a	0.15	2.00	1980-current [model estimate]	1.69	0.9	1.0	0.18 0.68 (>123 mm)	0.18 [total male]	0.16 [total male]
8	AI golden king crab	5				See intro chapter					5.69	5.12
9	Pribilof Island golden king crab	5				See intro chapter					0.09	0.08
10	Adak red king crab	5				1995/96–2007/08					0.05	0.03

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 2/15/2014 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 2013/14 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. Values are in 1000 t. Note that recommendations for Adak red king crab represent the final values recommended by the SSC in June 2013.

Stock	Tier	2013/14 *Max*ABC	2013/14 ABC
EBS Snow Crab	3a	78.03	70.30
BBRKC	3b	7.07	6.36
Tanner Crab	3a	25.31	17.82
PIRKC	4b	0.759	0.718
PIBKC	4c	0.00116	0.00104
SMBKC	4b	1.23	0.45
Norton Sound RKC	4a	0.18	0.16
Adak red king crab	5	0.05	0.03

Table 5. Stock status in relation to status determination criteria 2012/13. (Note diagonal fill indicates parameters not applicable for this tier level)

Chapter	Stock	Tier	MSST	B_{MSY} or $B_{MSYproxy}$	2012/13 MMB	2012/13 MMB / MMB_{MSY}	2012/13 OFL 1000 t	2012/13 Total catch	Rebuilding Status
1	EBS snow crab	3	77.1	154.2	170.1	1.10	67.8	32.4	
2	BB red king crab	3	13.19	26.4	29.05	1.10	7.96	3.90	
3	EBS Tanner crab	3	16.77	33.54	59.35	1.77	19.02	0.71	
4	Pribilof Islands red king crab	4	2.61	5.22	4.03	0.77	0.90	0.013	
5	Pribilof Islands blue king crab	4	1.99	3.98	0.58	0.15	0.00116	0.00061	overfished
6	St. Matthew Island blue king crab	4	1.8	3.6	2.85	0.79	1.02 [total male catch]	0.82 [total male catch]	
7	Norton Sound red king crab	4	0.80	1.6	2.08	1.30	0.24	0.21	
8	AI golden king crab	5					5.69	3.12	
9	Pribilof Island golden king crab	5					0.09	Conf.	
10	Adak red king crab	5					0.054	0.001	

MMB as estimated during this assessment for 2002/13 as of 2/15/2013.

Stock Assessment of eastern Bering Sea snow crab

Benjamin J. Turnock and Louis J. Rugolo
National Marine Fisheries Service
September 19, 2013

EXECUTIVE SUMMARY

A size based model was developed for eastern Bering Sea snow crab (*Chionoecetes opilio*) to estimate population biomass and harvest levels. Model estimates of total mature biomass of snow crab increased from the early 1980's to a peak in 1990 of about 1,026,300 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. The currency for estimating B_{MSY} changed during the 10 year rebuilding period from total mature survey biomass to model estimated mature male biomass at mating (MMB) as well as assessment model structure. Using the current definitions for estimating B_{MSY}, MMB at mating was above B35% in 2010/11 and the stock was declared rebuilt in 2011. The total mature observed survey biomass in 2011 was 447,400 t which was also above the Bmsy(418,150 t) in place under the rebuilding plan implemented in 2000. The increase in total mature biomass was mainly due to a large increase in observed female mature biomass in 2011.

Observed survey mature male biomass decreased from 120,800 t in 2012 to 96,100 t in 2013. Observed survey mature female biomass also decreased from 220,600 t in 2012 to 195,100 t in 2013. The 2013 estimate of males greater than 101 mm decreased to 73.6 million crab from87.0 million in 2012.

Base model estimates of mature male biomass at mating decreased from 185,300 t in 2011/12 to 170,100 t in 2012/13 (110% of B35% (154,167 t)).

Catch trends historically followed survey abundance estimates of large males, as the survey estimates were the basis for calculating the GHL (Guideline Harvest Level for retained catch). A TAC is currently set (from 2009) by 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 a simulation model previous to the development of the current stock assessment model, that has been used to set the GHL (TAC since 2009) since the 2000/01 fishery. Retained catch in the 2011/12 fishery

increased to 40,500 t, an increase from the 2010/11 fishery retained catch of 24,670 t. The total catch in the 2011/12 fishery was estimated at 44,600 t below the OFL of 73,800 t. The TAC and retained catch for the 2012/13 fishery was 30,060 t. Discard in the directed fishery was 7,350 t (no mortality applied).

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.

The assessment model used for the September 2012 assessment was the same model used in September 2011 and recommended by the CPT in May 2011 and the SSC in June 2011 ("Model 6"). The model structure of the Base model in the current assessment is the same as the September 2012 assessment, except discard mortality was changed to 30%, and growth data from the 2011 growth study (Somerton 2012) was fit by sex in the model to estimate growth parameters. Three alternative Model scenarios include fitting new growth data except 50% discard mortality, and the same model as the 2012 assessment (without the new growth data), with discard mortality at 30% and 50%.

The OFL for 2013/14 for the Base model was 78,100 t fishing at F_{OFL} = 1.58, an increase from the 2012/13 OFL of 67,800 t due to an increase in model estimated mature male biomass and an increase in F35%. The increase in F35% was due to the change in growth and reduction in discard mortality.

The MMB at mating projected for 2013/14 when fishing at the F35% control rule (OFL) was 100.2% of B35%. The ACL was estimated at 78,030 t using a p*=0.49. The total catch estimated at 90% of OFL (the ACL recommended by the SSC for 2012/13) was 70,290 t. The MMB projected for 2013/14 when fishing at 90% of the OFL catch was 104.5% of B35%. B35% for the Base model was estimated at 154,170 t and F35% was estimated at 1.58. MMB at mating for 2012/13 was estimated at 170,100 t above the estimated MMST of 77,100 t.

Historical status and catch specifications for snow crab (1000t).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	66.6	127.7[A]	21.8	21.8	23.9	33.1	
2010/11	73.7	196.6[B]	24.6	24.7	26.7	44.4	
2011/12	77.3	165.2[C]	40.3	40.5	44.7	73.5	66.2
2012/13	77.1	170.1[D]	30.1	30.1	32.4	67.8	61.0
2013/14		157.6[D]				78.1	70.3

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2009/10	146.8	281.5 [A]	48.1	48.1	52.7	73.0	
2010/11	162.5	433.4 [B]	54.2	54.5	58.9	97.9	
2011/12	170.4	364.2 [C]	88.8	89.3	98.5	162.0	145.8
2012/13	169.9	374.9 [D]	66.3	66.3	71.4	149.5	134.5
2013/14		347.4 [D]				172.1	154.9

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2010
B– Calculated from the assessment reviewed by the Crab Plan Team in September 2011
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2013

Changes to the Model

The Base model was changed to include a likelihood component fitting a linear model to the 2011 growth study data in the model separately for males and females. In addition the directed fishery discard mortality was reduced from 0.5 to 0.3.

Changes to the Data

2013 Bering Sea survey biomass and length frequency data added to the model. 2012/13 directed fishery retained and discard catch and length frequencies for retained and discard catch were added to the model. Groundfish discard length frequency and discard catch from 2012/13 were added to the model.

CPT May 2013 Recommendations for next assessment:

1. *Use a handling mortality of 0.3 in the assessment.*

2. *The use of a penalty for the break point in the linear models is not the best approach. For the September assessment, re-parameterize the growth model to eliminate the need for this penalty.*

3. *Instead of using Somerton et al's parameter estimates as priors, use the actual data sets in the assessment model.*

4. *Omit female data from Somerton et al's data set for growth estimation.*

Authors response

The Base model has the directed fishery discard mortality set at 0.3. Alternative scenarios use 0.5 for comparison. The 2011 growth data are fit by sex in the model using a linear function with two parameters for each sex. A four parameter model for each sex was attempted, however, convergence was not achieved fitting the data in the model.

SSC recommendations

When conducting the next snow crab assessment, the SSC requests that the stock assessment authors present fits of the base model using (1) total handling mortality estimates of 0.5 (status quo), (2) 0.3 (Team recommendation), and (3) a "best" estimate of total handling mortality derived by adding the average annual short-term estimate (0.04) to the average injury rate, and multiplying this sum by a factor corresponding to the best guess of additional long-term mortality. The SSC also requests inclusion of an appendix on recent RAMP studies in the snow crab SAFE chapter. The appendix should include a brief review of previous studies on handling mortality, including work by Carls and O'Clair, Warrenchuk and Shirley, and modeling by van Tamelen. Laboratory studies on red king crab and Tanner crab by Carls and O'Clair indicated that delayed mortality was experienced at relatively high rates during the molt following cold air exposure for one of these two species. Such delayed effects should be considered and discussed when judging the relative contribution of long-term vs. short-term handling mortality rates.

Therefore the SSC recommends bringing forward two models in September that fit both a two-piece model and a simple linear model for growth, each with separate parameters for males and females (except initial intercept).

The SSC concurs with the CPT that the actual data should be incorporated in the assessment model instead of using priors to constrain parameters.

Authors Response

The CPT discussion in May 2013 covered the known information on discard mortality and recommended 0.3 as a "best" estimate as requested by the SSC. The CPT discussion is included as Appendix A to support that estimate. Two models with discard mortality at 0.3 and 0.5 are included in this assessment. A model with a two-piece growth function is not included in this assessment as that model failed to converge when fitting growth data inside the model. A linear growth model fitting the growth data by sex is included in this assessment.

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 1980's 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. The total catch for the 2010/11 fishery was estimated at 26,600 t. Total catch increased in 2011/12 to 44,600 t, due to an increase in stock biomass and increase in the retained catch to 40,500 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). Female discard catch is very low 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 2011/12 and 2012/13 was 170 t and 220 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 was 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, and most recently about 110 mm to 111 mm. 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 GHL (Guideline Harvest Level of retained crab only) previous to 2000 was 58% of the number of male crab over 101 mm carapace width 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 (using survey numbers) ranging from about 60% to 100% for most years (Figure 2). The exploitation fraction is calculated using the abundance for male crab over 101 mm estimated from the survey data reduced by the natural mortality from the time of the survey until the fishery occurs, approximately 7 months later, since the late 1980's. The historical GHL calculation did not include the correction for time lapsed between the survey and the fishery. In 1986 and 1987 the exploitation rate exceeded 1.0 because some crabs are retained that are less than 102 mm, discard mortality of small crabs is also included, and survey catchability is estimated in the model at less than 1.0. The exploitation fraction was derived using the total catch divided by the mature male biomass estimated from the model, ranged from 10% to 60% (Figure 3). The exploitation fraction estimated by dividing the total catch by the model estimate of the crabs over 101 mm ranged from about 15% to 85% (Figure 3). The total exploitation rate on males > 101 mm was 50% to 85% for 1988 to 1994 and 50% to 60% for 1998 and 1999 (year when fishery occurred).

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 2000/1 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. The fishing mortality rate that results from this harvest strategy depends on the relationship between mature male size numbers and male numbers greater than 101 mm.

DATA

Data Sources

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from 1978 to the 2012/13 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 to 2012/13. Total discarded catch was estimated from observer data from 1992 to 2012/13 (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 2012/13. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The mortality of discarded crab was to be 30% in the Base model. This estimate differs from the current rebuilding harvest strategy used since 2001, 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	1978/79-2012/13
Discarded male and female crab pot fishery size frequency	1992/3-2012/13
Trawl fishery bycatch size frequencies by sex	1991-2012/2013
Survey size frequencies by sex and shell condition	1978-2013
Retained catch estimates	1978/79-2012/13
Discard catch estimates from snow crab pot fishery	1992/93-2012/13 from observer data
Trawl bycatch estimates	1973-2012/13
Total survey biomass estimates and coefficients of variation	1978-2013
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 a 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 245,000 t in 2009 to 447,400 t in 2011 and has declined the last two years to 291,200 t in 2013.

Survey mature male biomass increased from 157,300 t in 2010 and 167,400 t in 2011, then declined to 96,100 t in 2013. The observed survey estimate of males greater than 101 mm increased from 137.6 million in 2010 and 150.7 million in 2011 then declined to 73.6 million in 2013 (Table 3). Survey mature female biomass increased from 145,100 t in 2010 and 280,000 t in 2011 then declined to 195,100 t in 2013.

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 noted 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 recent increase in abundance. (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 8a). However, in 2012 and 2013, the progress of the recruitment is not evident. Observed survey mature biomass for both males and females declined in 2013, which has resulted in estimated recent recruitments to be lower than in previous assessments. 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.

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. In 2004 78% of the catch was south of 58.5^o N. In 2003 and 2004 the ice edge was farther north than past years, allowing some fishing to occur as far north as 60-61^o N. Catch in the 2006/07 fishery was similar to recent years (Figure 9) with most catch south of 58 ^{o} N. and west of the Pribilof Islands between about 171^o W and 173^o W. The pattern of catch was similar to previous years for the 2008/09 fishery however, about 3,580 t of retained catch was taken east and south of the Pribilof Islands at 168 to 167 ^{o} longitude and 55.5 to 56.6 ^{o} latitude which has not occurred in recent years (Figure 11). About 93% of the retained catch came from south of 58.5^o N. The directed fishery catch in 2012/13 is shown in Figure 11b showing some catch from east of the Pribilof Islands, however, the majority of catch is west and north of the Pribilof Islands.

CPUE of survey catch by tow for 2011 to 2013 are shown in Figures 12 through 25h. Immature female and small male (<78mm) distributions in 2012 and 2013 are farther south than in previous years with higher tows just north of the Pribilof Islands (Figures 20, 22, 25c and 25e). Legal males (>77mm) and large males (>101mm) are distributed farther south and east of the Pribilof Islands than in previous years (Figures 19, 21, 25b and 25d). 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 23 and 25h).

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. 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 2000's.

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 1990's the centroids were about 59.5 ^{o} N. The centroids of old shell male distribution was south of 58 ^{o} N in the early 1980's, moved north in the late 1980's and early 1990's then shifted back to the south in the late 1990's. The distribution of males>101 mm was about at 58 ^{o} N in the early 1980's, then was farther north (58.5 to 59 ^{o} N) in the late 1980's and early 1990's, 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 1980's and most of the 1990's. 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 sq nm, 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 are 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. accounted for area swept, sediment type, depth and crab size. 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. In order to analyze this 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 NMFS to sum of density is equivalent to a catchability of 1.0 and 0.33 is 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 was fixed in the September 2009 assessment. 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 (Fu and Quinn 2000, Schnute and Richards 1995).

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, 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 upper 99th percentile of the distribution of ages in an unexploited population if observable. Under negative exponential depletion, the 99th percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method 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 probably 3 or 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 grow 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. Additional radiometric aging for male and female snow crab shells is being investigated to improve the estimate of radiometric ages from Orensanz (unpub. data).

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. Resorbtion 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 1990's then decreased in the mid- 1990's then increased again in the late 1990's (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 1990's, the rate of production from the stock may have been reduced due to the spatial distribution of the catch relative 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 of female snow crab collected in waters colder than 1.5 ^{o} C from the Bering Sea 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.

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 last three years (2007, 2008 and 2009) have all been cold years.

The clutch fullness and fraction of unmated females however, does not account for the fraction of females that may have unfertilized eggs. 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. 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 length bins based on a pre-molt to post-molt length 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,

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

$\psi^s_{l',l}$	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,
$N^s_{t,l}$	abundance of immature crab in year *t*, sex *s* and length bin *l*,
$N^s_{t-1,l'}$	abundance of immature crab in year *t-1*, sex s and length bin *l'*,
$Z^s_{l'}$	total instantaneous mortality by sex *s* and length bin *l'*,
ϕ^s_l	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.

Model scenarios 3 and 4 growth was modeled using a linear function to estimate the mean width after molting given the mean width before molting (Same as the 2012 assessment, Figure 55),

$$Width_{t+1} = a + b^* \ width_t$$

Where a = 6.773 , b = 1.16 , for males and a= 6.773 , b= 1.05 , for females.

The parameters a and b were estimated from the observed growth data for Bering Sea male snow crab (Rugolo, pers. Com.). However, the intercept for both male and female crab was estimated as the average of the intercepts estimated for males from the Bering Sea data and the value assumed for females. Equal intercepts were used because growth of both sexes is probably equal at some small size. The growth parameters are estimated in the model using the observed values as constraints, with standard errors estimated from Canadian growth data.

The Base model fits the growth data by sex reported by Somerton (2013) within the assessment model by adding a sum of squared deviations likelihood component. Sample sizes were 17 for males and 18 for females. A linear function for each sex was estimated resulting in four parameters (an intercept and slope by sex) (Figures 54b and 54c).

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 lower significantly lower than the above four data sets.

Some data points were excluded from 1, 2 and 3 above (35 is 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

Model convergence could not be achieved fitting the data in the model by sex and a two segment model.

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*,

$$\Lambda^{s}_{t,l} = e^{-Z_l^{s,old}} \Lambda^{s}_{t-1,l} + e^{-Z_l^{s,new}} \Omega^{s}_{t-1,l}$$

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_1	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 fixed at 0.01 (average F)
$TrawlSel_l$	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).

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

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.

Penalty on average F for males (low weight in later phases),

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

Fishing mortality deviations for males,

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

Female bycatch fishing mortality penalty.

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

Trawl bycatch fishing mortality penalty

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

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.

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

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.

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

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

Growth parameters were estimated in model scenarios 3 and 4 the same as used in the September 2012 assessment using a penalty which assumes a normal distribution,

$$0.5\left(\frac{a - 6.773}{0.3}\right)^2$$

Where a is the intercept parameter of the linear growth equation and is the same for males and females.

Likelihood equations for the slope parameters assumed sd=0.1 for both males (bm)and females (bf).

$$0.5\left(\frac{bm - 1.16}{0.1}\right)^2$$

$$0.5\left(\frac{bf - 1.05}{0.1}\right)^2$$

There were a total of 311 parameters estimated in the Base model (Table 10) for the 36 years of data (1978-2013). The 102 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 36 recruitment parameters estimated in the model, one for the mean recruitment, 35 for each year from 1979 to 2013 (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 4 growth parameters were also estimated in the Base model. Model scenarios 3 and 4 estimated 3 growth parameters.

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 reduced to 30% for the Base model as recommended by the CPT in May 2013, with scenarios 2 and 4 using 50% for comparison. 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 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 and the September 2012 assessment estimated 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 Berring 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),

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

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

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

The maximum survey selectivity (Q) estimated for the entire Bering Sea area in Somerton et al. 2010 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

Variability in recruitment, as well as implementation error, was simulated with temporal autocorrelation. Recruitment was generated from a Beverton-Holt stock-recruitment model,

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

$spr_{F=0}$	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,

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

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 Bmsy and Fmsy equal to B35% and F35% 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,

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

$B_t^{'}$ 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 Base model estimated immature M at 0.386 and mature male M at 0.261. Model scenario 4 (discard mortality 0.3 and growth estimated same as the September 2012 assessment) estimated immature M at 0.353 and mature male M at 0.268. Changes in natural mortality are mostly due to the reduction in discard mortality to 0.3 (Table 13).

The model estimated total mature biomass increased from about 394,600 t in 1978 to the peak biomass of 1,026,300 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 1997 to about 404,300 t in 2003. Total mature biomass increased from 534,800 t in 2012 to 557,300 t in 2013 (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 to 2012 was about 9.1% of the retained catch (with 30% mortality applied). The average observed discards from 1992 to 2012 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 from 2.5% in 2010 to 3.9% in 2011 and 7.3% in 2012.

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 increased from about 200,000 t in the period 2002 to 2006, to 2003 to 306,600 t in 2009, declined to 236,700 t in 2012, then increased slightly to 263,100 t in 2013. Observed survey mature male biomass has declined from 167,400 t in 2011 to 120,800 t in 2012 and 96,100 t in 2013. Mature female biomass observed from the survey increased from 86,400 t in 2008 to 280,000 t in 2011 then declined to 195,100 t in 2012. Model estimates of mature female biomass have an increasing trend from 224,200 t in 2009 to 298,100 t in 2012, then a slight decline to 294,300 t in 2013.

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 2012 assessment survey Q for the 1989 to present period was estimated at 0.59 for male crab (Turnock and Rugolo 2012). The Base model estimate for survey Q was 0.55. 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 0.386 (2012 assessment 0.329) and mature male M 0.261 (2012 assessment 0.273). 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 declined 150.7 million crab in 2011 to 87.0 million in 2012, then to 73.2 million in 2013 (Table 3). Model estimates of large males show a decreasing trend from 276.3 million in 2009 to 166.5 million in 2012, then an increase to 190.3 million in 2013.

Several periods of above average recruitment were estimated by the model in 1979-1981, 1983, 1987-1988, 1998-99, and 2004-2005 (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 1997, 2000 to 2003, 2006-2007. The 1998-1999 and 2004 and 2005 year classes appear to be near or above average recruitment and have resulted in an increase in biomass in recent years. However, above average recruits in 2004 and 2005 are not evident in the 2013 survey data for male crab (Figure 8a). Projections from the 2012 assessment estimated an increase in biomass in 2013/14, while the observed survey biomass declined. The Base model still estimates a small increase in biomass from 2012 to 2013 which doesn't follow the declining trend of the observed biomass.

The size at 50% selected for the pot fishery for total catch (retained plus discarded) was 106.7 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 0.15 to 2.7 (Figure 85 and Table 6). Fishing mortality rates ranged from 0.59 to 2.7, for the 1986/87 to 1998/99 fishery seasons. For the period after the snow crab stock was declared overfished (1999/2000 to 20010/11), full selection fishing mortality ranged from 0.18 to 0.54. Fishing mortality rate increased from 0.26 in 2010/11 to 0.56 in 2011/12 and 0.59 in 2012/13 due to the increases in the TAC.

Base Model estimates of mature male biomass at mating decreased from 223,800 t in 2010/11 to 170,100 t in 2012/13 (110% of B35% (154,170 t), Table 6 and Figure 87). MMB at mating for the Base model are higher than the 2012 assessment (Figure 103). Recruitment estimates were also higher for the Base model than the 2012 assessment, except the 2009 recruitment (2004 fertilization year) was estimated lower in the Base model.

Likelihood values for the Base model (discard mortality 0.3) and Scenario 2 (discard mortality 0.5) with the new growth data as well as Scenarios 3 (old growth and discard mortality 0.3) and 4 (old growth and discard mortality 0.5) are shown in Table 13. The Base model and Scenario 2 have one more parameter than scenarios 3 and 4 with the 2012 assessment growth. The total likelihoods cannot be compared since the likelihood equations for growth are different for the Base model and Scenario 2 compared to Scenarios 3 and 4.
The estimated male growth for the base model is slightly less than Scenario 3. The estimate female growth is higher for the Base model resulting in worse fit the survey length data for females. Likelihood values show a better fit with discard mortality 0.3 compared to 0.5. 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 F35% control rule for the Base model estimates the 2012/13 F to be below the overfishing level and MMB at mating just above B35%(Figure 101).

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, Bmsy was defined as the average total mature survey biomass for 1983 to 1997. MSST was defined as ½ Bmsy. 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*Bmsy), 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.

B35% was estimated using average recruitment from1978 to 2013 and mature male biomass per recruit fishing at F35%.

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 2013/14 was estimated at 78,100 t total catch (68,800 t retained catch). The previous year's OFL (2012/13) was 67,800 t of total catch (48,100 t retained 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 78,030 t, based on a probability of overfishing of 49% from the projection model with a cv= 0.08 on 2012/13 biomass estimated from the Hessian matrix by the ADMB software and the median of the projected distribution of catch fishing at F35% as the estimate of OFL (Table 9a and Table 14). The SSC in 2012 recommended an ACL of 90% of the OFL (60,800 t) for the 2012/13 fishing season. 90% of the 2012/13 Base Model OFL is 70,290 t of total catch.

F35% in the September 2012 assessment was estimated at 1.32 and B35% at 154,669 t. F35% for the Base model was 1.58 and B35% 154,170 t. The MMB at mating projected for 2013/14 when fishing at the F35% control rule (OFL) was 100.2% of B35%. Reference points for scenarios with discard mortality at 0.5 have lower OFL, lower F35% and slightly lower B35% (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 F35% control rule and fishing at a catch of 90% of the OFL (the SSC recommended ACL method in 2011/12 to 2012/13). Steepness of the Beverton and Holt spawner recruit curve used in projections was estimated at 0.75 and R_0 at 1.52 billion crab, by equating F35% with Fmsy and B35% with Bmsy.

Median MMB at mating was projected to increase in 2012/13 based on projections from the September 2012 assessment (Turnock and Rugolo 2012). Projections using the Base model estimate MMB at mating to remain relatively the same over the next several years at about 100% of B35% fishing at F35% (Tables 9a and 9b). Fishing at 90% of the OFL also results in little change in MMB over the next several years at about 105% to 108% of B35%.

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.

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)	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	7.30		
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	0.60	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	0.00	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	151.09	
1992/93	104.71	56.65	161.37	1992	1.84	94.01	
1993/94	67.96	17.66	85.62	1993	1.81	48.00	
1994/95	34.14	13.36	47.50	1994	3.55	25.27	
1995/96	29.82	19.10	48.92	1995	1.35	23.00	
1996/97	54.24	24.68	78.92	1996	0.93	53.09	
1997/98	110.41	19.05	129.46	1997	1.50	102.50	
1998/99	88.02	15.50	103.52	1998	1.02	84.48	
1999/00	15.20	1.72	16.92	1999	0.61	12.93	
2000/01	11.46	2.06	13.52	2000	0.53	12.39	
2001/02	14.85	6.27	21.12	2001	0.39	13.97	
2002/03	12.84	4.51	17.35	2002	0.23	11.62	
2003/04	10.86	1.90	12.77	2003	0.76	9.44	
2004/05	11.29	1.69	12.98	2004	0.96	9.48	
2005/06	16.78	4.52	21.30	2005	0.37	16.74	
2006/07	16.50	5.90	22.39	2006	0.84	16.42	
2007/08	28.60	8.42	37.02	2007	0.44	28.58	
2008/09	26.56	6.86	33.42	2008	0.30	26.59	35.07
2009/10	21.82	4.09	25.91	2009/10	0.66	21.80	33.10
2010/11	24.67	2.05	26.72	2010/11	0.18	24.62	44.40
2011/12	40.3	5.21	45.51	2011/12	0.17	40.3	73.5
2012/13	30.06	7.35	37.41	2012/13	0.22	30.06	67.8

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	0.0	3.8	25.3	29.2
1979/80	34.1	1.7	0.0	3	35.9	38.9
1980/81	30.5	3.8	0.0	2.1	34.3	36.4
1981/82	13.4	3.9	0.0	0.7	17.3	18
1982/83	11.9	2	0.0	0.2	13.9	14.2
1983/84	12.2	0.9	0.0	0.4	13.1	13.5
1984/85	30	1.5	0.0	0.4	31.5	32
1985/86	44.5	2	0.0	0.4	46.6	47
1986/87	46.3	2.7	0.0	1.8	49	50.9
1987/88	61.5	6.7	0.1	0.2	68.2	68.4
1988/89	67.9	9.7	0.1	0.6	77.6	78.3
1989/90	73.6	9.3	0.1	0.7	82.9	83.7
1990/91	149.4	16.9	0.1	0.6	166.3	166.9
1991/92	143.3	19.4	0.1	1.9	162.7	164.7
1992/93	105	16.5	0.2	1.7	121.5	123.4
1993/94	67.9	6.4	0.1	1.7	74.4	76.2
1994/95	34.2	4.1	0.1	3.5	38.3	41.9
1995/96	29.9	5.5	0.1	1.2	35.5	36.8
1996/97	54.5	6	0.1	0.8	60.5	61.4
1997/98	114.5	7.3	0.0	1.4	121.8	123.2
1998/99	88.3	5	0.0	0.9	93.2	94.2
1999/00	15.1	0.8	0.0	0.5	15.9	16.4
2000/01	11.5	0.6	0.0	0.4	12.1	12.5
2001/02	14.9	0.9	0.0	0.2	15.9	16.1
2002/03	12.9	1	0.0	0.2	13.9	14.1
2003/04	10.9	0.7	0.0	0.6	11.6	12.1
2004/05	11.3	0.5	0.0	0.8	11.9	12.6
2005/06	16.9	0.9	0.0	0.2	17.7	18
2006/07	16.6	1.3	0.0	0.6	17.8	18.5
2007/08	28.6	2.6	0.0	0.3	31.3	31.6
2008/09	26.6	1.8	0.0	0.3	28.5	28.8
2009/10	21.8	1.1	0.0	0.5	22.9	23.4
2010/11	24.6	1.1	0.0	0.2	25.7	26
2011/12	40.4	1.8	0.3	0.2	42.3	42.8
2012/13	30.1	2.4	0.0	0.2	32.5	32.7

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

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 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 Obs	12.2	68.4	11.9	32.3
2009 Pred	12.6	54.4	10.3	41.0
2010 Obs	279.0	193.3	91.5	77.7
2010 Pred	203.9	176.3	163.3	132.7

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	633.1	12478.3	200.6	193.9	394.6	140.8	1782.9	140	0.47	0.15
1979/80	705.7	12324.2	251.1	177.7	428.8	120.6	1524.7	113.5	0.83	0.24
1980/81	781.6	11781.4	366.3	135.8	502.1	64.6	1007.3	81.4	2.2	0.3
1981/82	815.3	10532.5	395.4	129.3	524.7	35.9	354.1	95.4	1.54	0.16
1982/83	822.4	8436.4	376.9	189	565.9	94.5	1407.3	148.7	0.4	0.09
1983/84	847.4	9114.2	333.3	283.1	616.3	225.4	2414.2	228	0.15	0.05
1984/85	901.5	11544	310.4	329.6	640	296.9	3011.8	249.3	0.29	0.11
1985/86	983.5	14338	332.3	317.9	650.2	285.1	5146	224.5	0.48	0.17
1986/87	1184.2	20515.7	386.4	283.8	670.2	223.3	614.3	192.4	0.69	0.2
1987/88	1259.7	15719.4	496.7	283.6	780.3	183.2	4848.2	177.9	1.39	0.28
1988/89	1448.6	21063.6	514.4	322.4	836.9	192	290.9	205.2	1.53	0.28
1989/90	1465	15587.5	561.5	397.1	958.6	256.2	513.8	263.5	1.11	0.25
1990/91	1400	12395.2	543.5	482.8	1026.3	362	977.1	259.8	2	0.41
1991/92	1197.9	10993.2	470.8	433.8	904.7	300.1	6840.2	221.2	2.71	0.44
1992/93	1256.9	21643.7	410.1	356.8	766.9	225.5	2179	195.5	2.52	0.4
1993/94	1291.7	19522.1	512.2	310.3	822.6	193.4	1233.5	192.9	1.49	0.28
1994/95	1317.2	16436.4	585	273.9	859	120	299.9	194.8	1.05	0.16
1995/96	1302.1	12623.5	563.1	316	879.1	133.4	171.1	237.5	0.79	0.13
1996/97	1241.3	9756.6	488.7	447.8	936.5	308.4	232.4	325.9	0.59	0.16
1997/98	1092	7805.1	404	531.4	935.4	463.3	896.9	335	0.88	0.27
1998/99	864.5	7599.5	331.4	425.6	757	358.2	1258.6	270.4	0.86	0.26
1999/00	711.9	8103.4	290.1	299.4	589.5	224.4	366.1	238.3	0.19	0.06
2000/01	642.1	6700.9	278.1	246.6	524.7	178.9	357.4	197.2	0.18	0.06
2001/02	585.3	5709.4	256.1	210.6	466.7	142.9	614	163.3	0.31	0.09
2002/03	545	5502.2	224.4	196.7	421.1	133.3	1765.6	153.7	0.29	0.08
2003/04	569	7617.8	201.7	202.6	404.3	156.3	2576.6	160.7	0.2	0.07
2004/05	659	10648.1	215.9	202.5	418.4	167	836.6	159.9	0.19	0.07
2005/06	708.1	9249.5	268.3	194.5	462.8	149.1	1184	147.8	0.33	0.11
2006/07	754.1	9065	287	200	486.9	135.9	213.5	152.6	0.37	0.1

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(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
2007/08	752.1	7024.1	283.6	240.4	524	172.4	470.3	175.3	0.54	0.15
2008/09	715.7	6131.6	256.1	287.1	543.2	236.9	2538.8	217	0.34	0.12
2009/10	747.9	9634.2	224.2	306.6	530.9	276.3	1809.2	238	0.23	0.09
2010/11	787.2	10519.5	249.8	293.1	542.9	267.3	1030.3	223.8	0.26	0.1
2011/12	803.6	9598.6	289.5	267	556.6	228.3	1243.1	185.3	0.56	0.19
2012/13	807.9	9425.8	298.1	236.7	534.8	166.5	1580.7	170.1	0.59	0.16
2013/14	845.1	10005.2	294.3	263.1	557.3	190.3	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 males>101 (millions)
1978	155.1	193.2	348.3	140.8
1979	187.8	176.1	363.9	120.6
1980	276.0	133.0	409.1	64.6
1981	301.7	126.0	427.7	35.9
1982	165.2	115.1	280.3	59.9
1983	146.6	175.0	321.6	142.9
1984	136.3	204.7	341.0	188.2
1985	145.3	196.8	342.2	180.8
1986	168.8	174.2	342.9	141.6
1987	216.5	172.1	388.5	116.2
1988	226.1	195.8	421.9	121.7
1989	275.2	214.3	489.5	139.8
1990	266.7	261.1	527.8	197.5
1991	231.2	234.7	465.9	163.7
1992	201.3	193.0	394.3	123.0
1993	250.8	167.2	417.9	105.5
1994	286.8	147.0	433.8	65.5
1995	276.4	170.0	446.4	72.8
1996	240.0	242.3	482.2	168.3
1997	198.4	288.3	486.7	252.8
1998	162.8	230.9	393.7	195.4
1999	142.4	162.2	304.6	122.5
2000	136.4	133.4	269.9	97.6
2001	125.7	113.9	239.6	78.0
2002	110.2	106.4	216.6	72.7
2003	99.0	109.8	208.8	85.3
2004	105.8	109.6	215.5	91.1
2005	131.4	105.0	236.4	81.4
2006	140.8	107.9	248.7	74.1
2007	139.1	130.0	269.1	94.1
2008	125.7	155.6	281.3	129.2
2009	110.1	166.4	276.5	150.8
2010	122.4	158.9	281.3	145.9
2011	141.9	144.4	286.4	124.6
2012	146.2	127.9	274.1	90.9
2013	144.4	142.3	286.6	103.8

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 F35% control rule for 2013/14 to 2023/24 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 $B_{35\%}$ = 154,170 t. $F_{35\%}$ = 1.58.

a) 100%OFL Base Model, 100% $F_{35\%}$ B35% = 154,170 t F35%=1.58

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2013/14	78.1(63.2,88.1)	68.8(55.9,77.7)	100.2(90.1,113)	1.58
2014/15	77.8(53.3,95.5)	69.3(48.1,84.2)	102.2(87.7,118)	1.51
2015/16	67.2(45.3,84.2)	59.9(40.5,74.7)	99.1(83,119.3)	1.5
2016/17	57.2(37.8,73.3)	49.1(33.4,63.1)	101.9(82.1,129.8)	1.47
2017/18	64.3(40.6,85.1)	54.2(35.7,70.1)	111.6(83.9,174.4)	1.5
2018/19	78.4(42.8,158.7)	67.5(38.6,134.7)	125.3(82.5,234)	1.51
2019/20	92.1(39,228.1)	80.4(34.6,203)	134.2(77.5,293.5)	1.49
2020/21	93(32.7,237)	81.5(28.8,215.9)	134.6(72.5,298.9)	1.5
2021/22	86.3(27.5,220.2)	75.5(24.5,194.6)	132.9(66.6,287.5)	1.47
2022/23	81.8(22.6,208.8)	71.5(19.7,183.3)	133.5(63.8,288.4)	1.45
2023/24	78(21,195.6)	67.4(18.3,168.9)	127.3(63.2,287)	1.45

b) 90% Catch at FOFL Base Model, B35% = 154,170 t F35%=1.58

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2013/14	70.3(58,79.3)	62.2(51.5,70.2)	104.5(93,117.9)	1.35
2014/15	73.6(50.9,90.8)	66.2(46.1,81)	107.8(93,124.1)	1.31
2015/16	65.6(44.1,81.3)	58.8(39.9,72.5)	104.9(88.2,125.5)	1.31
2016/17	56(37,70.9)	48.7(32.8,61.9)	107.3(86.9,136)	1.28
2017/18	61.3(39.3,80.5)	52.6(35,68.2)	117.4(88.8,181.3)	1.29
2018/19	74.3(42.4,147.8)	64.4(37.8,127.8)	132(87.5,245.6)	1.29
2019/20	87.5(37.8,215.8)	77.4(34.1,193.8)	142.6(81.5,310.6)	1.28
2020/21	89.4(32.3,227.8)	79.3(28.8,206.6)	143.6(76.5,320.5)	1.29
2021/22	82.9(27.3,214)	73.5(24.2,190.5)	143.2(69.9,309.1)	1.26
2022/23	79.3(22.5,198.7)	70.1(20.2,178.8)	144.1(67,310.1)	1.25
2023/24	76.9(21.7,190)	67.1(18.9,167.5)	136.3(66.7,309)	1.25

Table 10. Base Model Parameters values (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	0.386	0.017	Y	0.05,0.46
Natural Mortality mature females and males	0.230		N	
	0.261	0.008	Y	0.05,0.46
Female intercept (a) growth	4.559	0.728	set equal to male	0,10
Male intercept(a) growth	5.406	0.381	Y	0,10
Female slope(b) growth	1.161	0.018	Y	1,1.3
Male slope (b) growth	1.169	0.006	Y	1,1.3
Alpha for gamma distribution of recruits	11.5		N	
Beta for gamma distribution of recruits	4		N	
Beta for gamma distribution female growth	0.75		N	
Beta for gamma distribution male growth	0.75		N	
Fishery selectivity total males slope	0.18	0.00	Y	0.1,0.5
Fishery selectivity total males length at 50%	106.69	0.12	Y	55,148
Fishery selectivity retention curve males slope	0.37	0.02	Y	0.05,0.5
Fishery selectivity retention curve males length at 50%	95.61	0.19	Y	85,120
Pot Fishery discard selectivity female slope	0.32	0.01	Y	0.1,0.7
Pot Fishery discard selectivity female length at 50%	66.70		N	
Trawl Fishery selectivity slope	0.10	0.00	Y	0.01,.3
Trawl Fishery selectivity length at 50%	96.23	1.51	Y	30,120
Survey Q 1978-1981 male	1.00	0.00	Y	0.2,1.0
Survey 1978-1981 length at 95% of Q male	62.22	2.79	Y	30,150
Survey 1978-1981 length at 50% of Q male	43.48	1.25	Y	0,150
Survey Q 1978-1981 Female	0.92	0.03	Y	0.04,2.0
Survey 1978-1981 length at 95% of Q female	62.22		Set equal to Male	
Survey 1978-1981 length at 50% of Q female	43.48		Set equal to Male	
Survey Q 1982-1988 male	0.63	0.05	Y	0.2,1.0
Survey 1982-1988 length at 95% of Q male	71.55	4.66	Y	50,160
Survey 1982-1988 length at 50% of Q male	44.60	1.88	Y	0,80
Survey Q 1982-1988 female	0.58		Y	0.04,2.0
Survey 1982-1988 length at 95% of Q female	71.55		Set equal to Male	50,160
Survey 1982-1988 length at 50% of Q female	44.60		Set equal to Male	0,80

Table 10 cont. Base Model Parameters values for the base model (Model 1), 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	0.55	0.03	Y	0.2,1.0
Survey 1989-present, length at 95% of Q male	58.09	2.76	Y	40,200
Survey 1989-present length at 50% of Q male	38.77	1.01	Y	20,90
Female Survey Q 1989-present	0.50	0.03	Y	0.04,2.0
Female Survey 1989-present, length at 95% of Q	48.40	1.51	Y	40,150
Female Survey 1989-present length at 50% of Q	35.45	0.66	Y	0,90
Male BSFRF 2009 Study area Q (availability)	0.30	0.08	Y	0.1,1.0
Female BSFRF 2009 Study area Q (availability)	0.13		Y	
Female BSFRF 2009 Study area length at 95% of Q	60.00	0.00	Y	0.01,1.0
Female BSFRF 2009 Study are length at 50% of Q	52.24	0.50	Y	50,120
				-50.0,60.0
male BSFRF 2010 Study area Q (availability)	1.00	0.00	Y	
				0.2,1.0
Female BSFRF 2010 Study area Q (availability)	1.05	0.12	Y	
Female BSFRF 2010 Study area length at 95% of Q	25.00		N	
Female BSFRF 2010 Study are length at 50% of Q	25.00		N	0.5,2.0

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
Fishing mortality average	1	SD=0.70
Fishing mortality deviations	0.1	CV=2.2
Initial length comp smoothness	1	SD=0.7

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			140.02	11.27
1979/80	1,782.90	416.05	113.51	7.36
1980/81	1,524.70	344.96	81.43	5.62
1981/82	1,007.30	273.22	95.37	6.03
1982/83	354.09	155.88	148.71	9.92
1983/84	1,407.30	273.3	228.04	15.53
1984/85	2,414.20	407.57	249.34	18.14
1985/86	3,011.80	488.04	224.48	17.25
1986/87	5,146.00	561.33	192.42	14.62
1987/88	614.29	253.35	177.93	12.37
1988/89	4,848.20	411.43	205.21	12.68
1989/90	290.91	123.51	263.54	13.98
1990/91	513.76	126.3	259.76	13.05
1991/92	977.14	200.51	221.20	11.47
1992/93	6,840.20	621	195.54	10.93
1993/94	2,179.00	390.74	192.90	11.20
1994/95	1,233.60	212.19	194.81	12.11
1995/96	299.90	100.72	237.49	14.95
1996/97	171.10	62.18	325.92	19.35
1997/98	232.38	84.091	335.04	20.78
1998/99	896.92	177.24	270.43	18.95
1999/00	1,258.60	205.77	238.31	16.38
2000/01	366.13	108.26	197.20	13.86
2001/02	357.43	104.6	163.25	12.09
2002/03	613.95	153.16	153.70	11.33
2003/04	1,765.60	279.37	160.67	11.23
2004/05	2,576.60	339.32	159.90	10.89
2005/06	836.60	227.08	147.76	10.38
2006/07	1,184.00	204.26	152.56	10.72
2007/08	213.48	81.885	175.25	12.49
2008/09	470.28	118.58	217.05	14.56
2009/10	2,538.80	305.72	238.01	14.85
2010/11	1,809.10	309.22	223.79	13.83
2011/12	1,030.30	279.01	185.29	13.14
2012/13	1,243.10	315.91	170.14	13.68
2013/14	1,580.70	399.82		

Table 13. Likelihood values for base model and model 1 with new growth function.

Likelihood Component		New growth	Old growth	Old growth
Scenario	Base	2	3	4
Discard mortality	0.3	0.5	0.3	0.5
Recruitment	30.20	32.55	30.27	32.68
Initial numbers old shell males small length bins	2.23	2.26	2.21	2.24
ret fishery length	346.48	342.48	342.45	339.86
total fish length	747.09	820.53	745.38	819.45
female fish length	200.73	200.36	203.13	203.17
survey length	3571.40	3621.90	3556.53	3604.09
trawl length	257.74	265.85	255.95	264.29
2009 BSFRF length	-81.14	-82.26	-80.98	-81.82
2009 NMFS study area length	-70.42	-70.84	-70.83	-71.12
M prior	3.29	4.49	3.59	4.78
maturity smooth	45.71	48.40	45.04	47.97
growth males (Base model and Scenario 2)	35.76	43.28	-	-
growth females (Base model and Scenario 2)	52.09	52.26	-	-
Scenarios 3 and 4 parameter a (males and females)	-	-	0.31	0.04
Scenarios 3 and 4 parameter b (males and females)	-	-	14.28	18.76
2009 BSFRF biomass	0.12	0.14	0.11	0.13
2009 NMFS study area biomass	0.03	0.05	0.03	0.05
retained catch	0.98	3.42	0.95	3.36
discard catch	86.14	141.16	83.46	138.85
trawl catch	9.53	9.75	9.36	9.61
female discard catch	3.78	4.73	3.81	4.75
survey biomass	189.73	178.26	188.86	177.66
F penalty	83.22	85.75	83.26	86.03
2010 BSFRF Biomass	0.47	0.80	0.44	0.77
2010 NMFS Biomass	1.25	1.71	1.24	1.69
initial numbers fit	506.63	506.39	505.91	505.84
2010 BSFRF length	-60.48	-60.58	-60.87	-61.22
2010 NMFS length	-73.24	-72.54	-74.53	-73.99
male survey selectivity smooth constraint	3.62	3.58	3.59	3.55
init nos smooth constraint	39.04	40.30	38.77	40.11
Total	5931.963	6124.1818	5831.713	6021.593
Total without growth likelihoods	5844.117	6028.6419	5817.12	6002.795
Q	0.546	0.583	0.540	0.578
no. parameters	311	311	310	310
immat M	0.386	0.349	0.387	0.353
M mature females	0.230	0.230	0.230	0.230
M mature males	0.261	0.267	0.262	0.268
Growth intercept female	4.559	4.368	6.019	6.398
Growth intercept male	5.406	6.040	6.019	6.398
Growth slope female	1.160	1.164	1.107	1.099
Growth slope male	1.168	1.158	1.156	1.151

Table 14. Reference values for scenarios with new growth, old growth, discard mortality in directed pot fishery of 0.3 and 0.5.

	Base –new growth	Scenario 2 New Growth	Scenario 3 Old growth	Scenario 4 Old growth
	DM=0.3	DM=0.5	DM=0.3	DM=0.5
B35%	154.17	151.53	154.20	151.30
F35%	1.58	1.24	1.68	1.31
OFL 2013/14	78.10	69.10	78.70	69.30
ABC(p*=.49)	78.03	68.95	78.50	69.10
ABC(90%OFL)	70.29	62.19	70.83	62.37
Percent MMB/B35% 2013/14	100.2	95.8	99.6	95.3

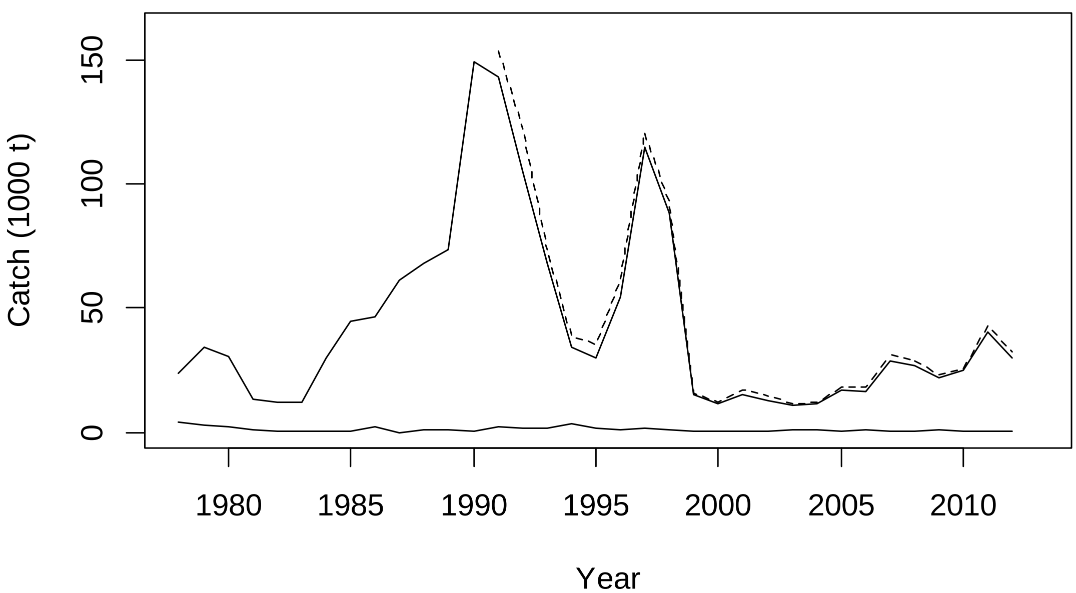

Figure 1. Catch (1000 t) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch (dashed line) is retained catch(solid line) plus discarded catch after 30% discard mortality was applied. Trawl bycatch (lower solid line) is male and female bycatch from groundfish trawl fisheries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

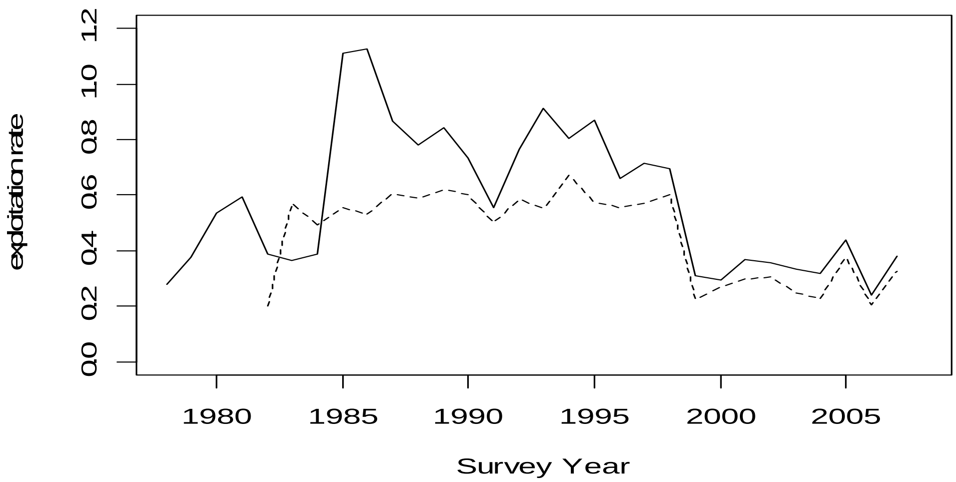

Figure 2. Exploitation rate estimated as the preseason GHL divided by the survey estimate of large male biomass (>101 mm) at the time the survey occurs (dotted line). The solid line is the retained catch divided by the survey estimate of large male biomass at the time the fishery occurs. Year is the survey year.

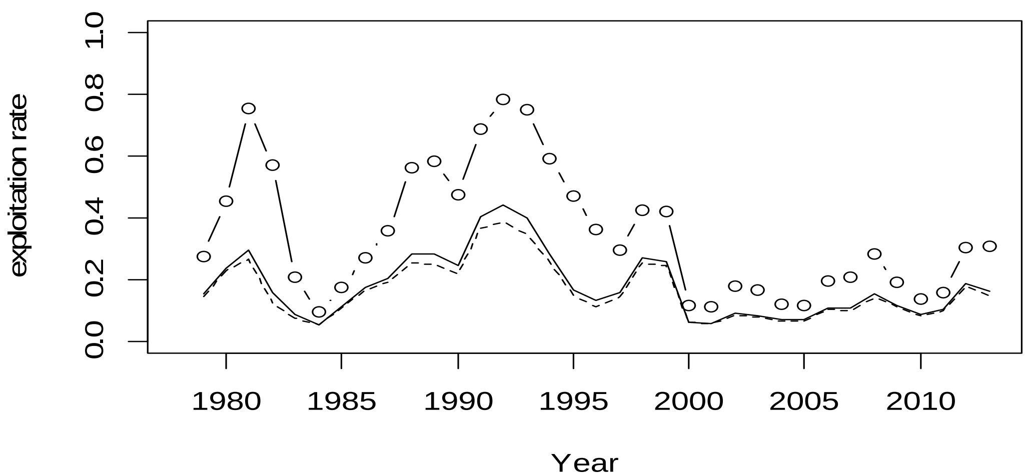

Figure 3. Base Model. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line is total and dotted line is retained). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the solid line with dots. Year is the year of the fishery.

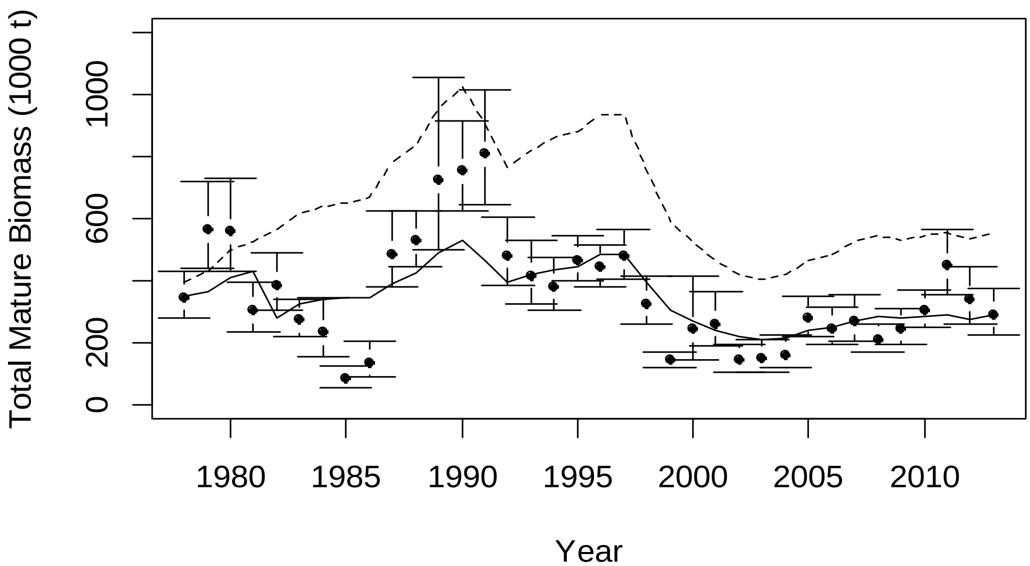

Figure 4. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

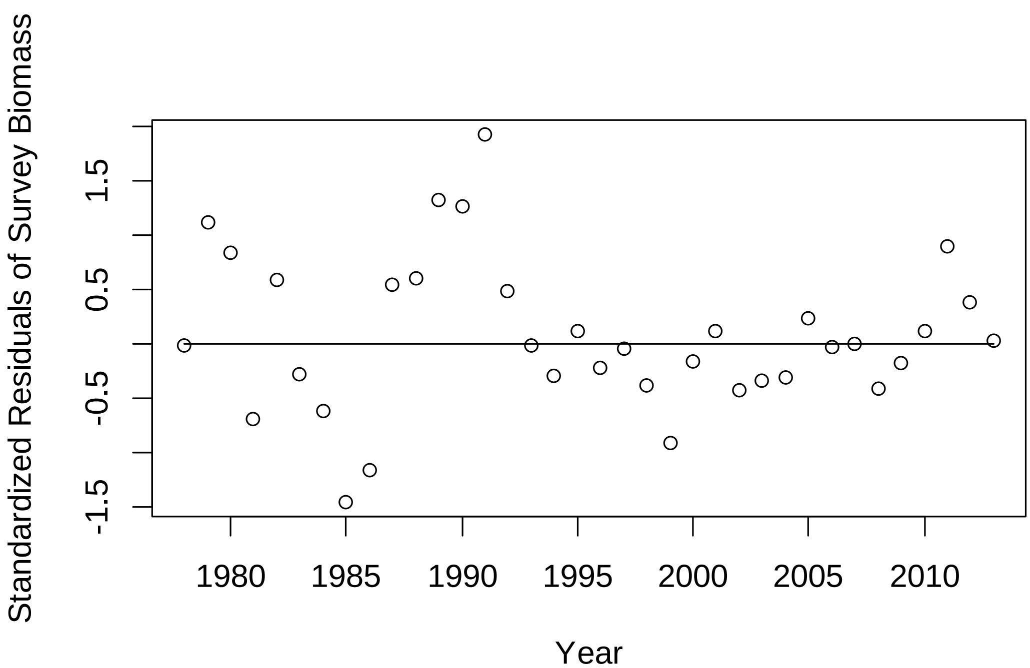

Figure 5. Standardized residuals for model fit to total mature biomass from Figure 4.

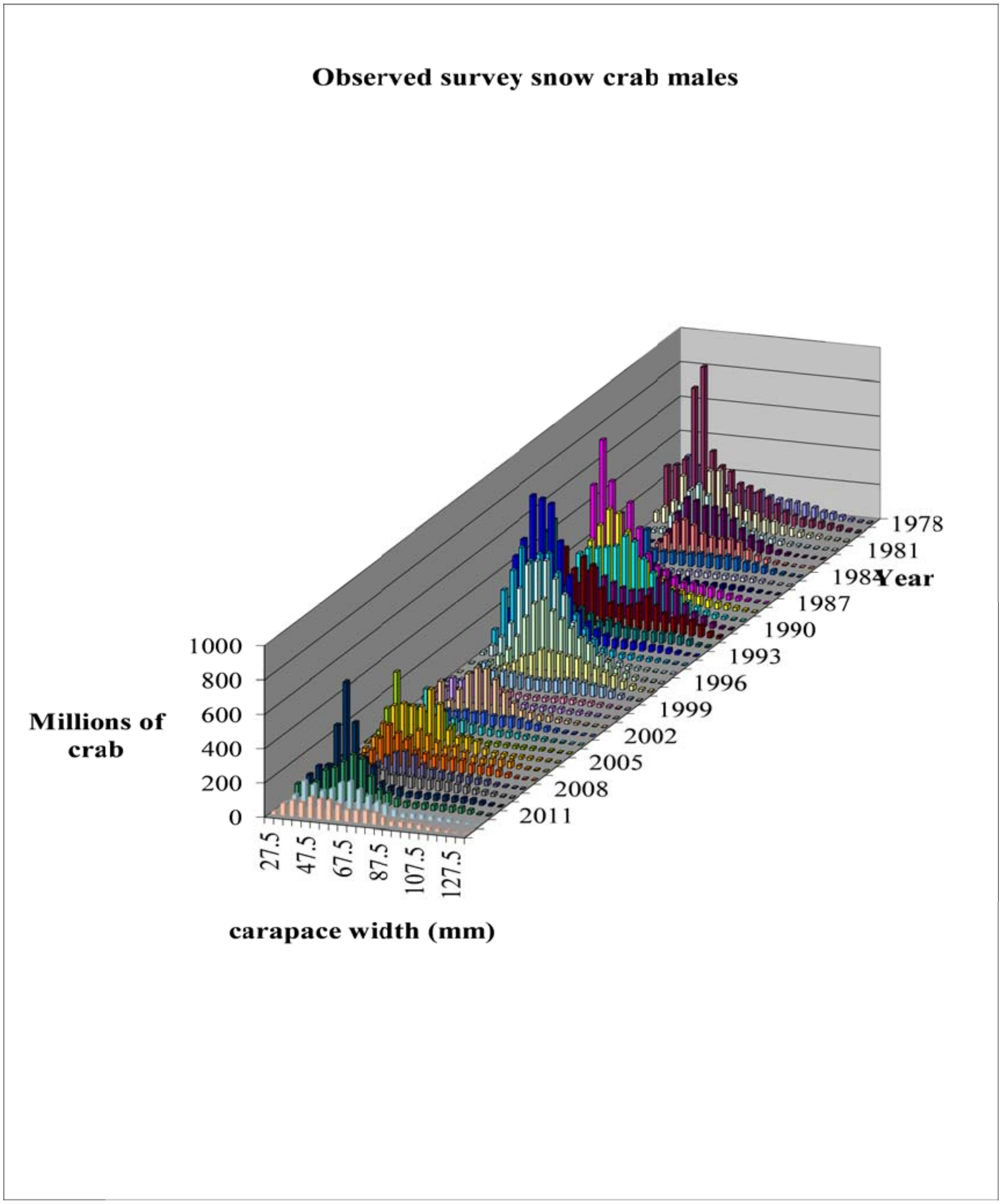

Figure 6. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

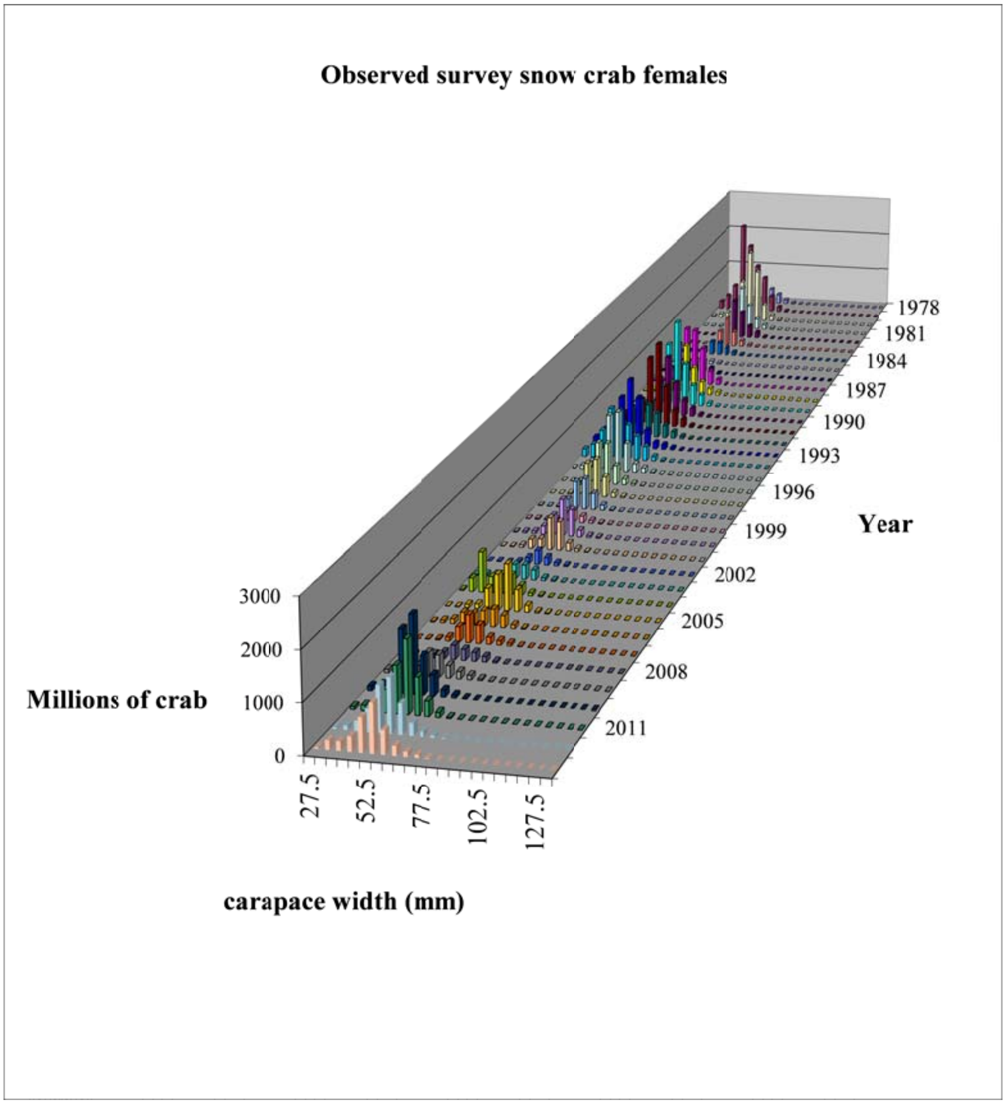

Figure 7. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

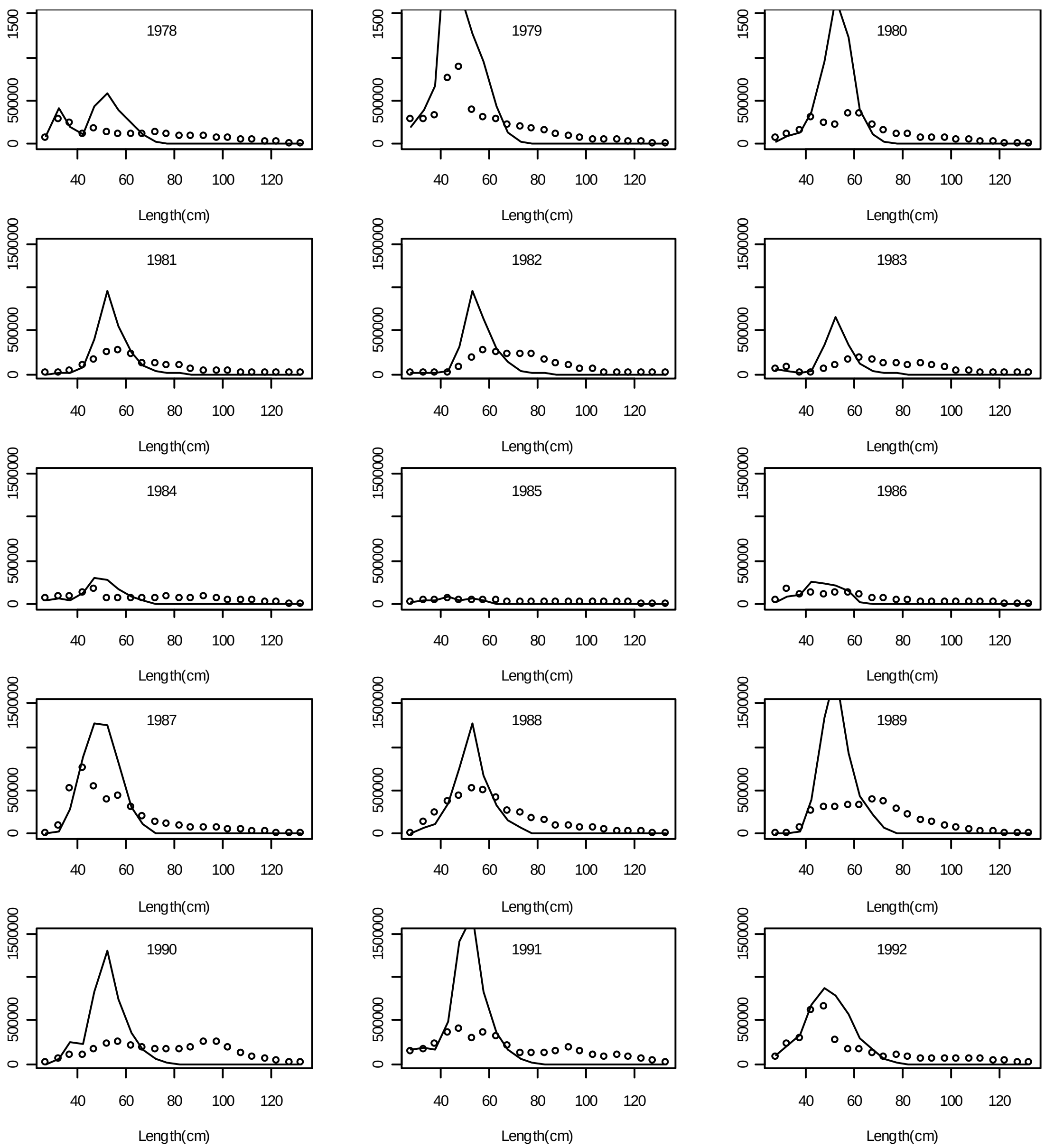

Figure 8. Observed survey numbers 1978 to 1992 by length, males circles, females solid line.

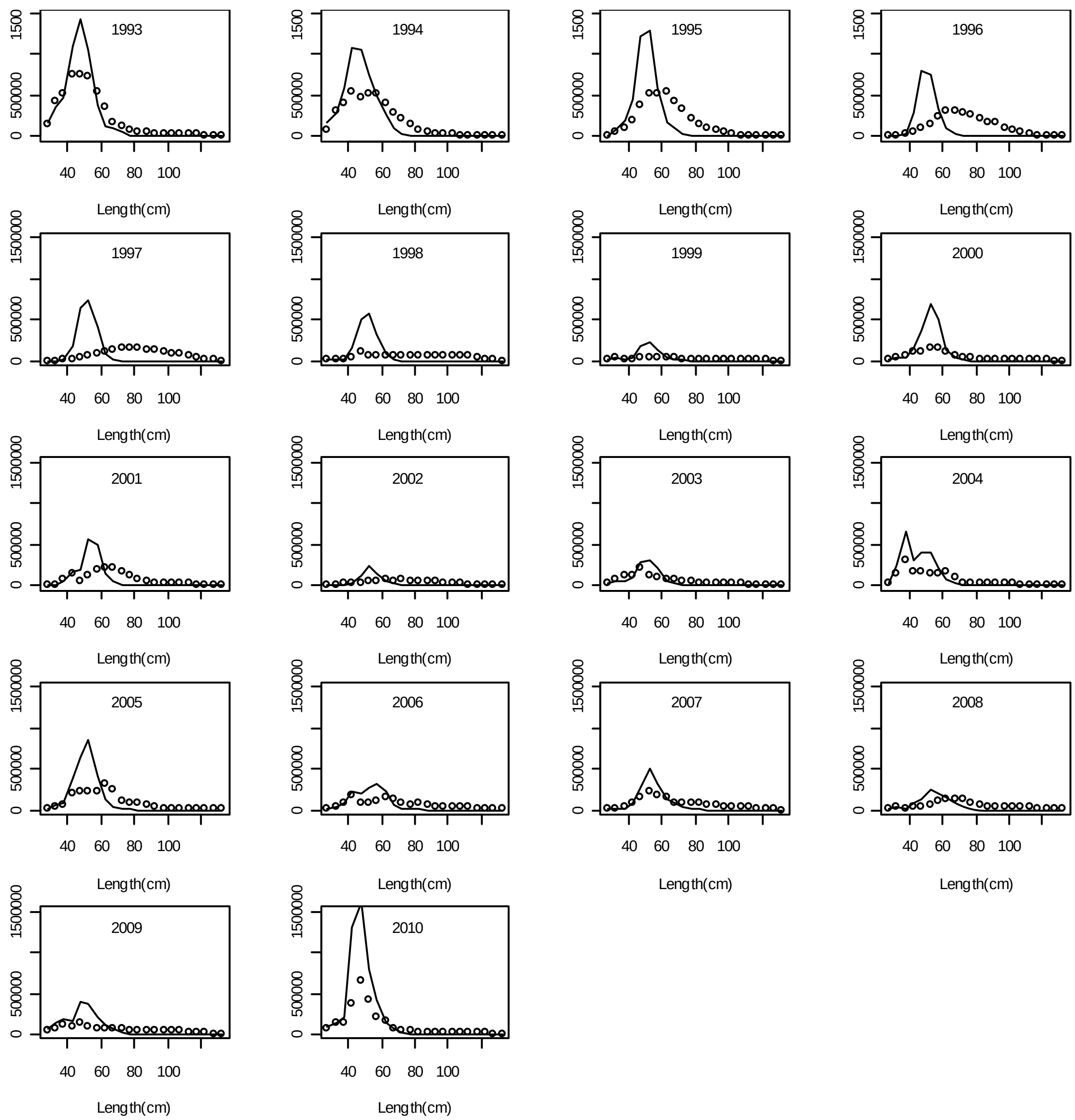

Figure 8 continued. Observed survey numbers 1993 to 2010 by length, males circles, females solid line.

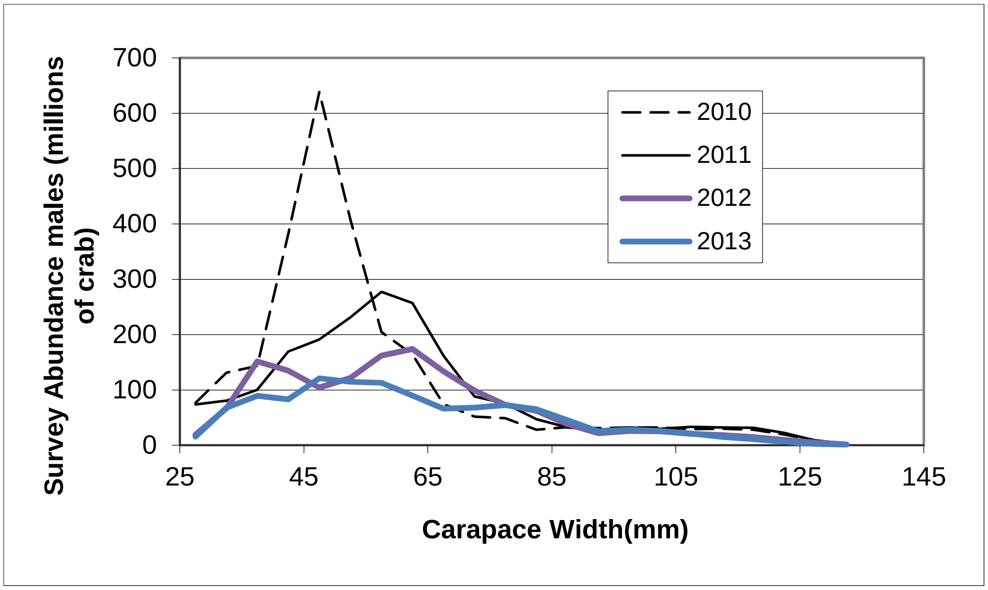

Figure 8a. Survey male abundance by length for 2010, 2011, 2012 and 2013.

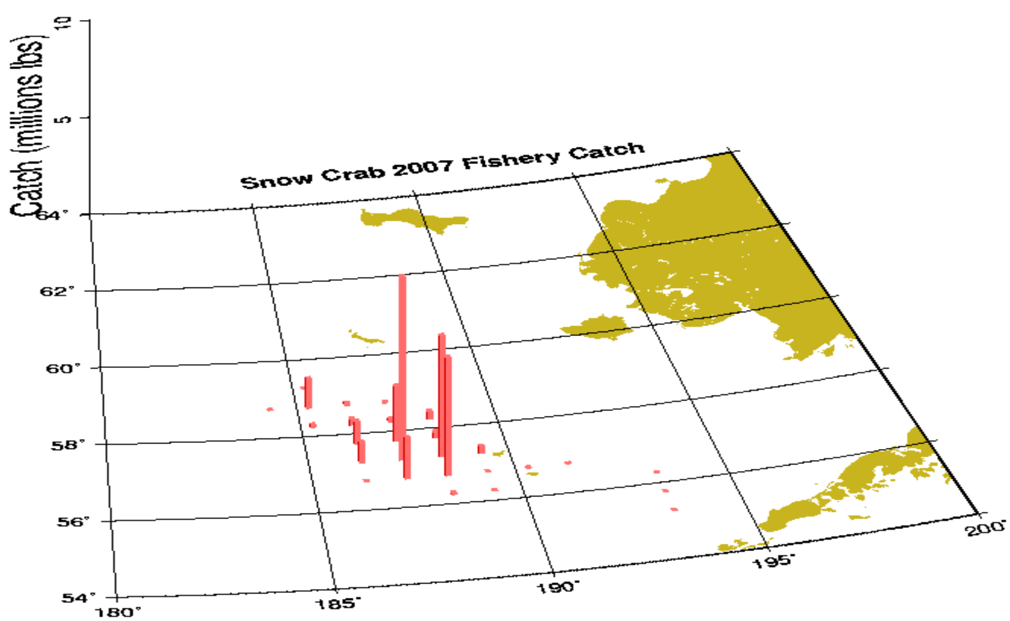

Figure 9. 2006/07 snow crab pot fishery retained catch(million lbs) by statistical area. Longitude increases from west to east (190 degrees = 170 degrees W longitude). Areas are 1 degree longitude by 0.5 degree latitude.

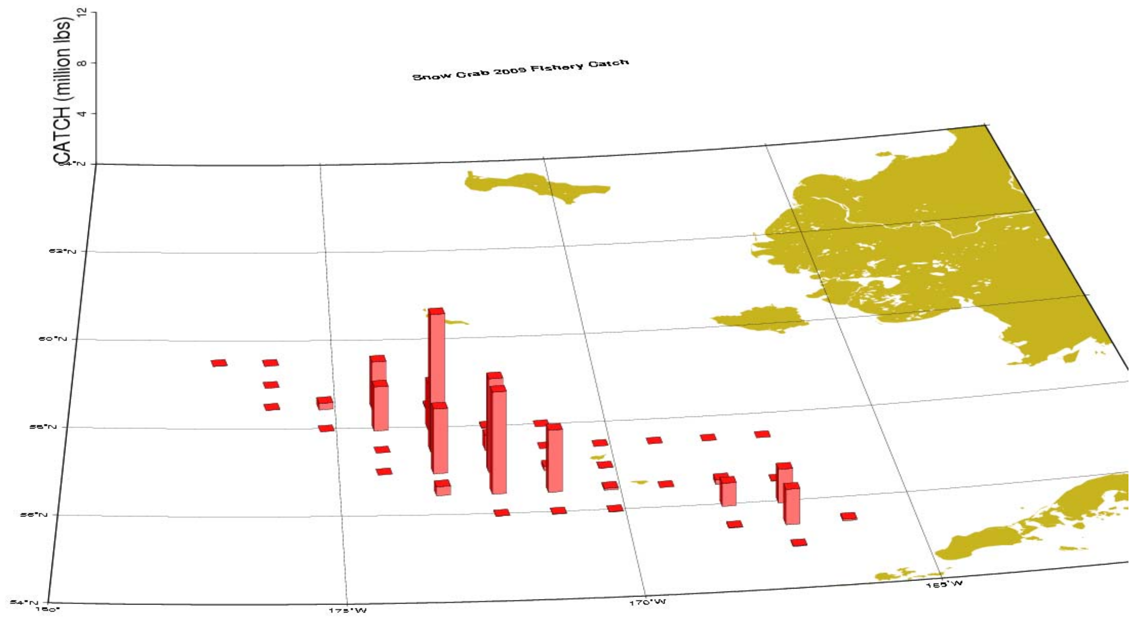

Figure 10. 2008/09 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

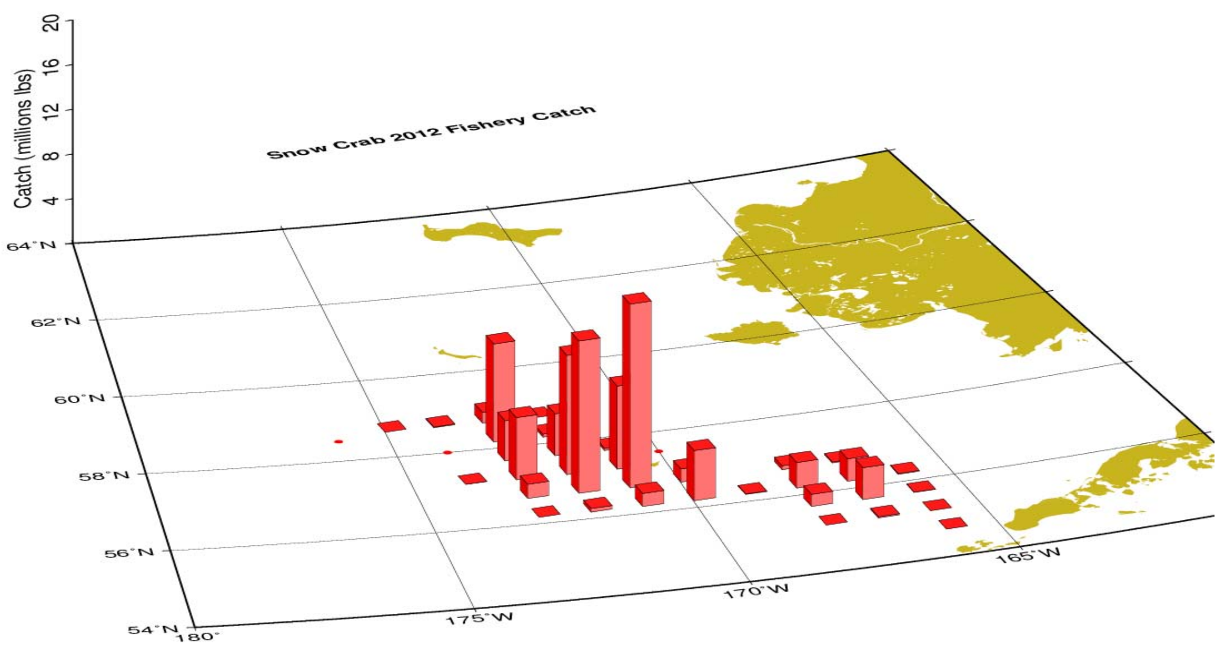

Figure 11. 2011/12 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

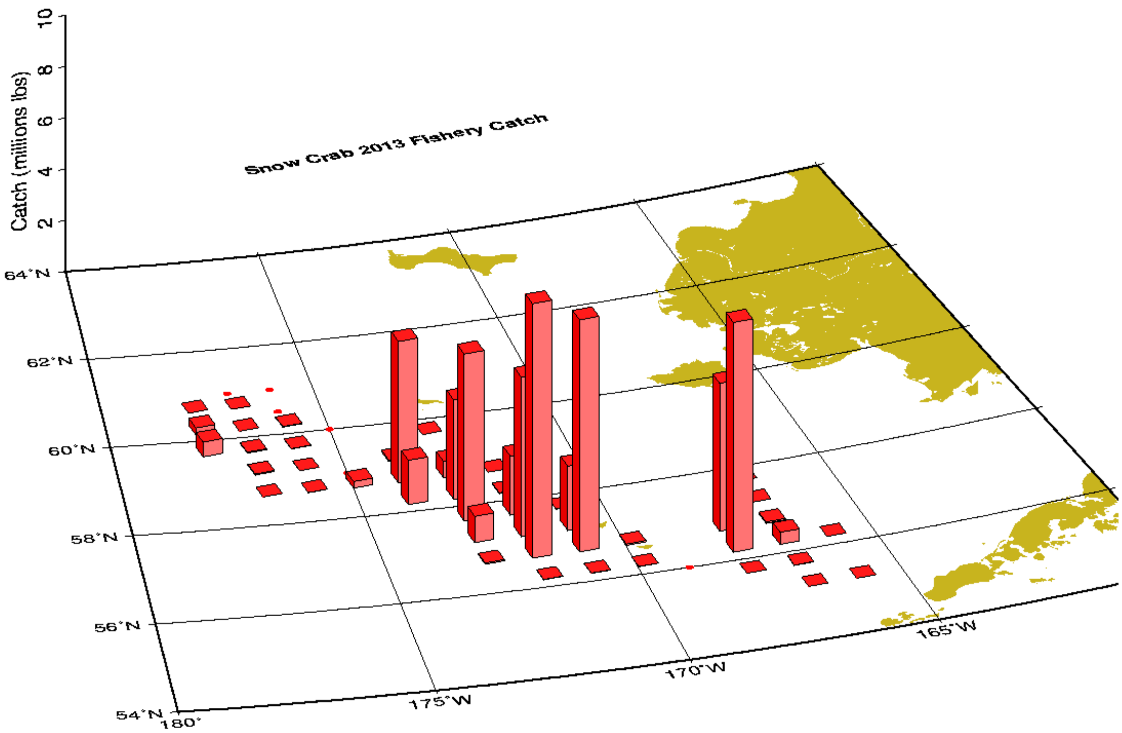

Figure 11b. 2012/13 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

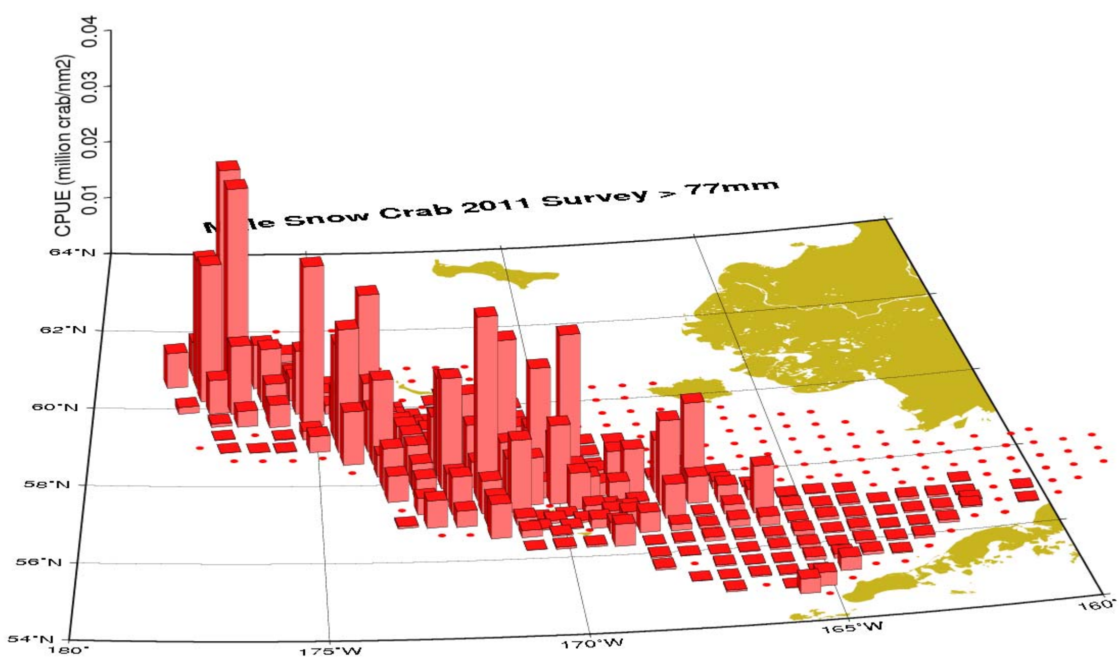

Figure 12. 2011 Survey CPUE (million crab per nm2) of males > 77 mm by tow. Filled circles are tows with 0 cpue

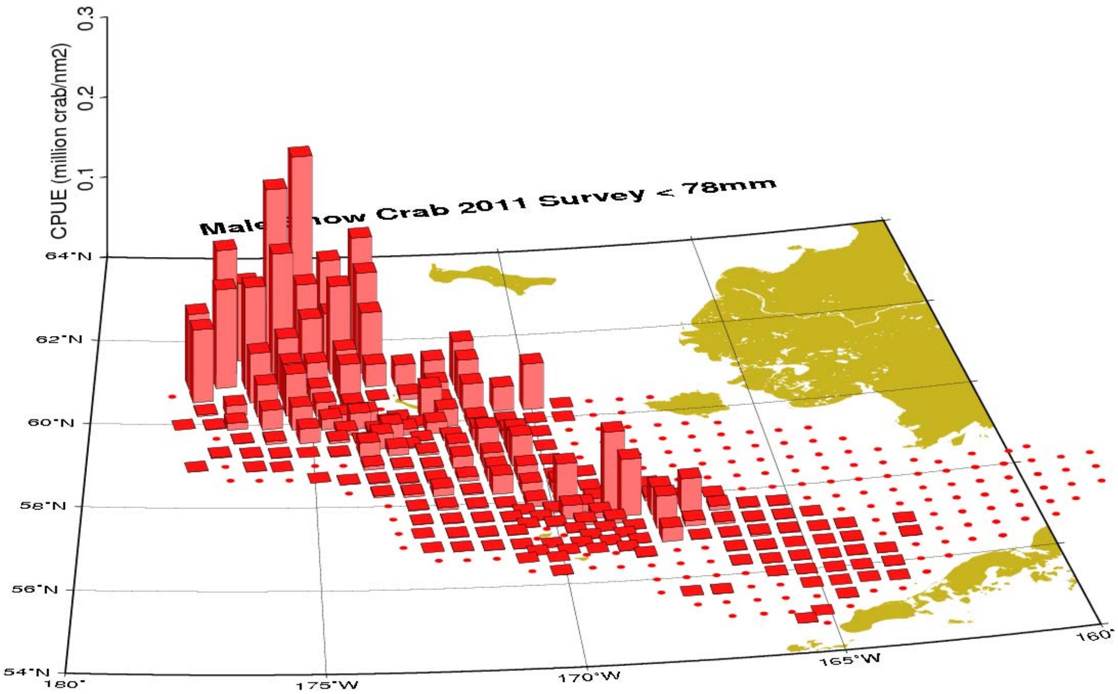

Figure 13. 2011 Survey CPUE (million crab per nm2) of males < 78 mm by tow. Filled circles are tows with 0 cpue

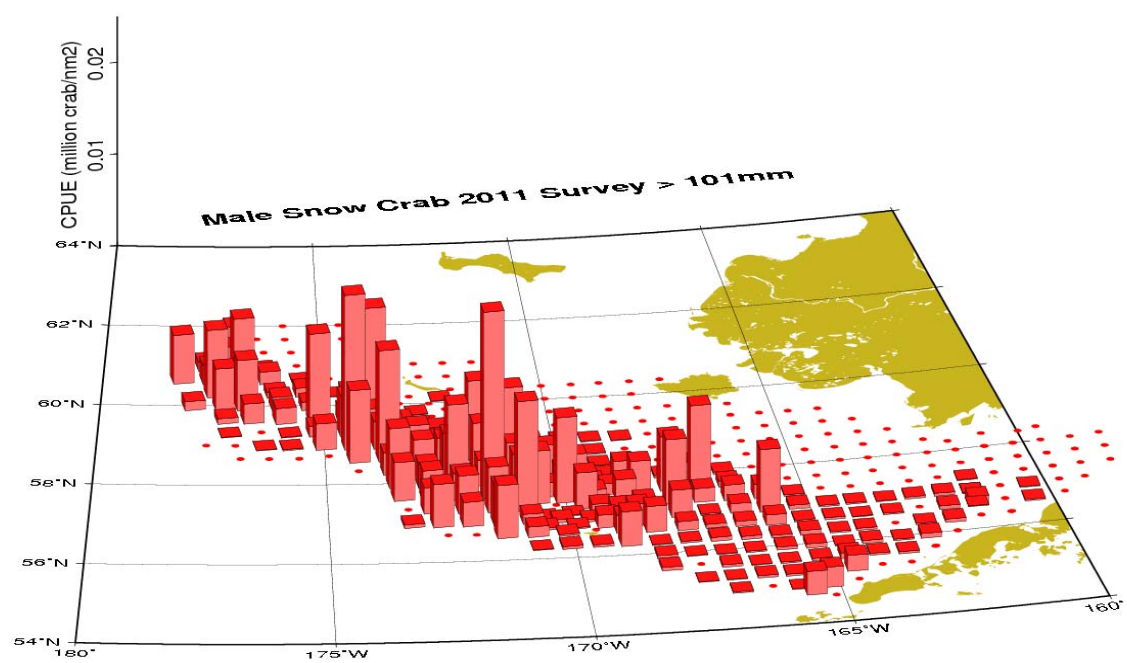

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Figure 14. 2011 Survey CPUE (million crab per nm2) of males > 101 mm by tow. Filled circles are tows with 0 cpue.

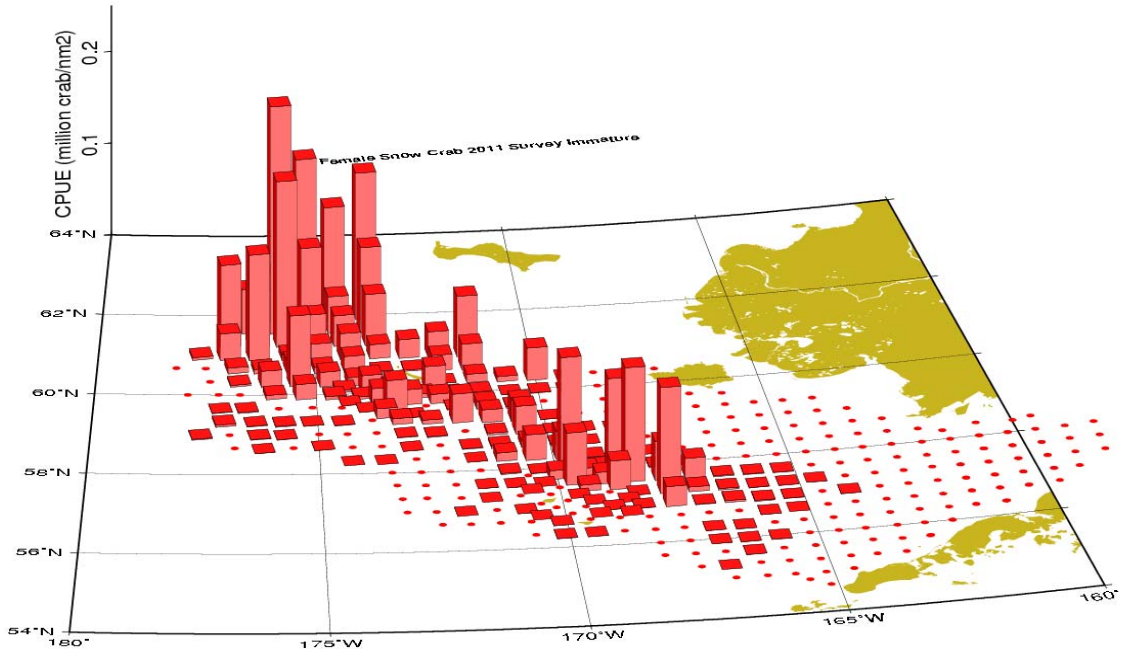

Figure 15. 2011 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

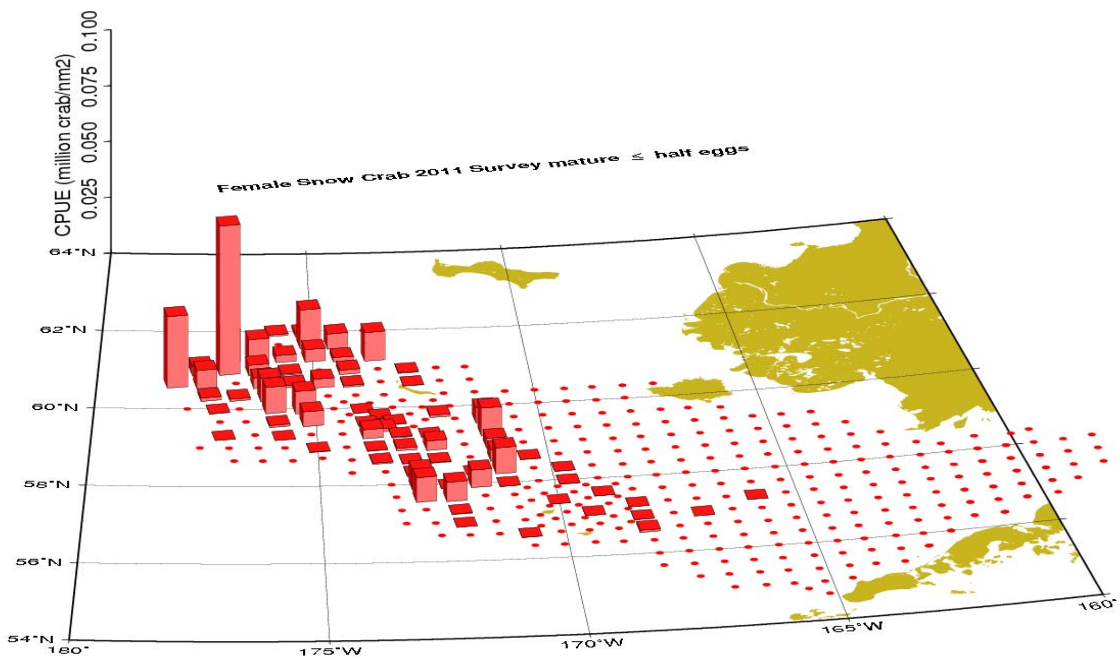

Figure 16. 2011 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

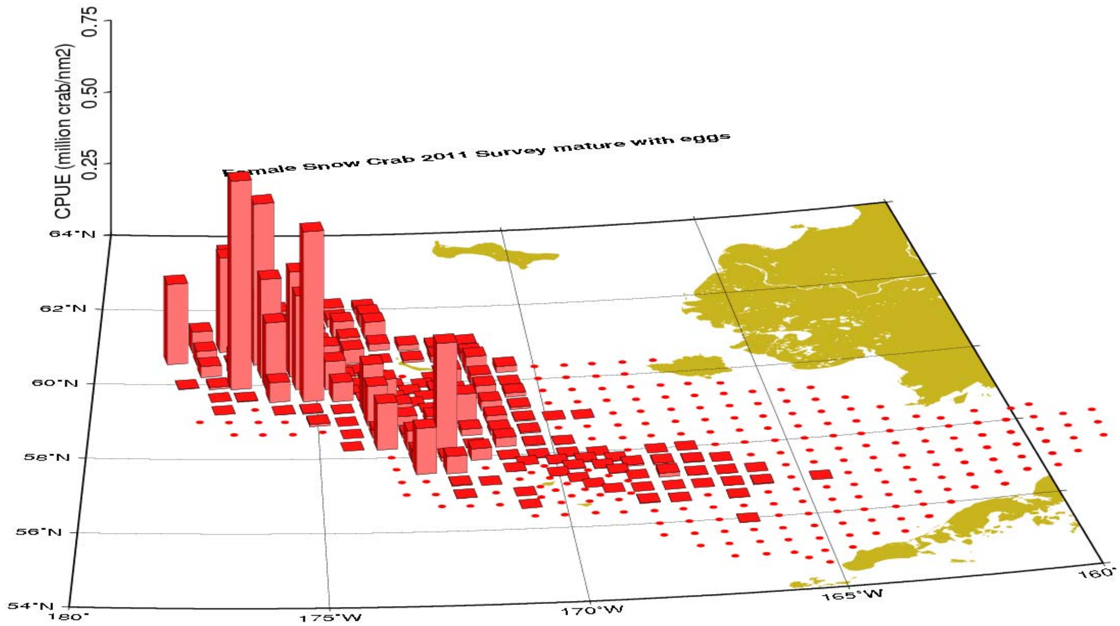

Figure 17. 2011 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

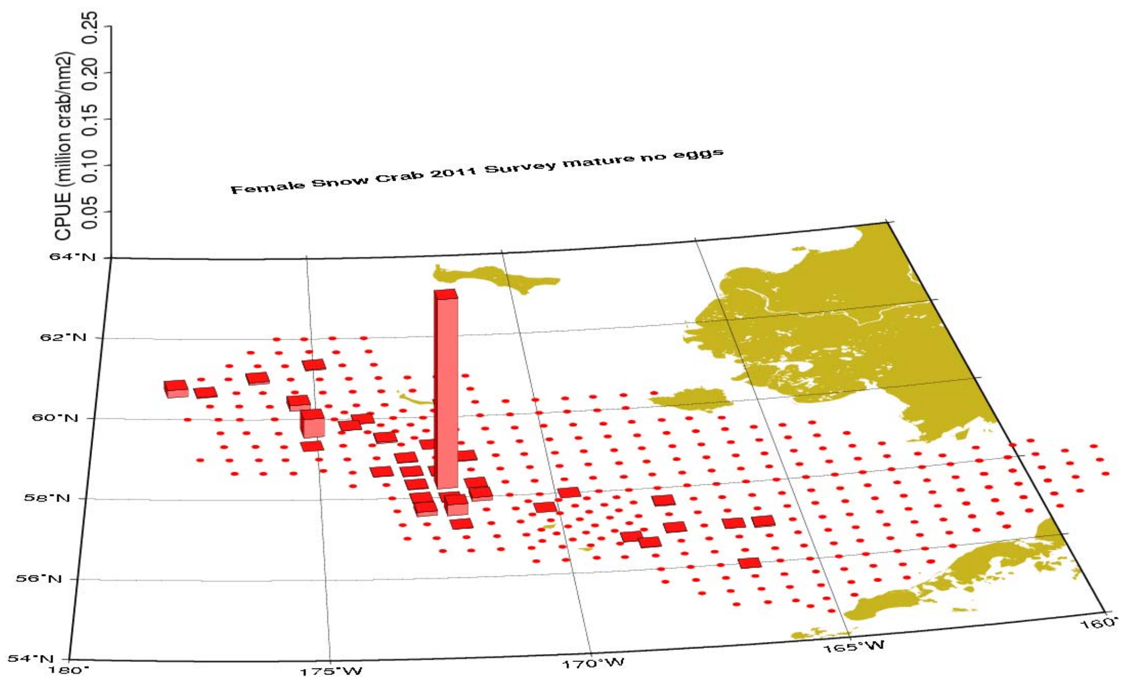

Figure 18. 2011 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

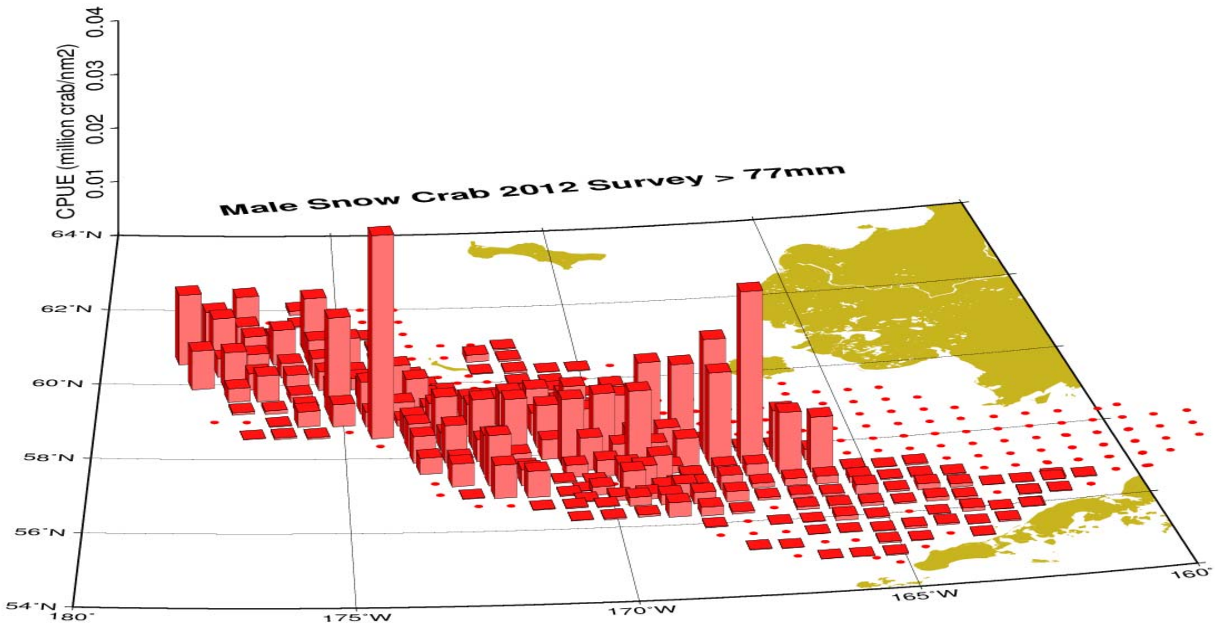

Figure 19. 2012 Survey CPUE (million crab per nm2) of males > 77 mm by tow. Filled circles are tows with 0 cpue

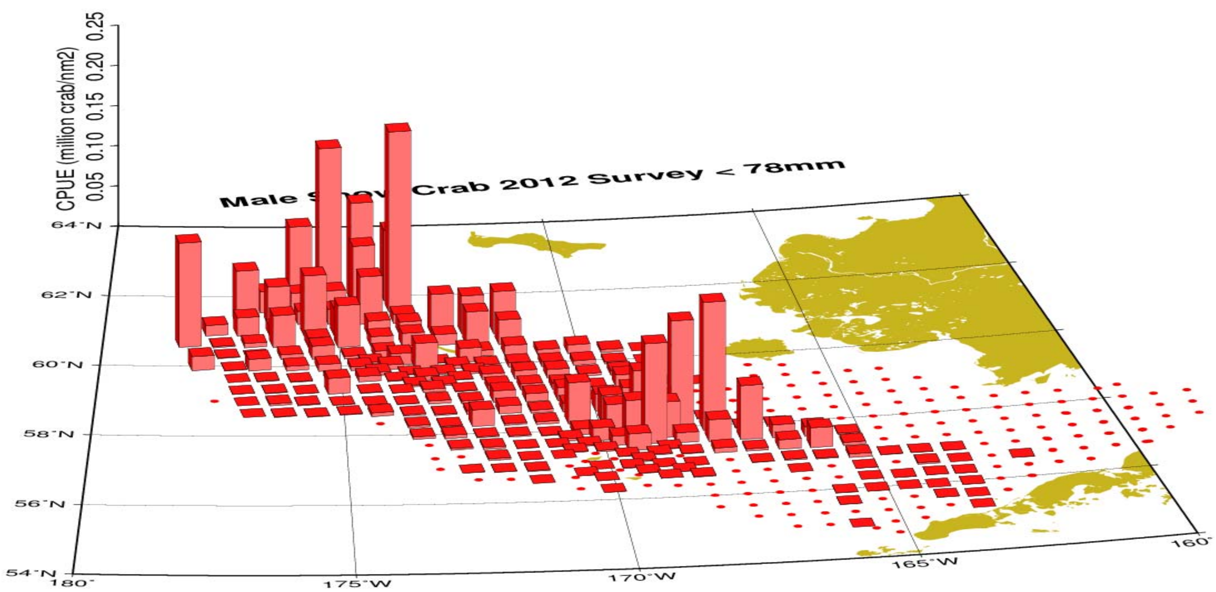

Figure 20. 2012 Survey CPUE (million crab per nm2) of males < 78 mm by tow. Filled circles are tows with 0 cpue.

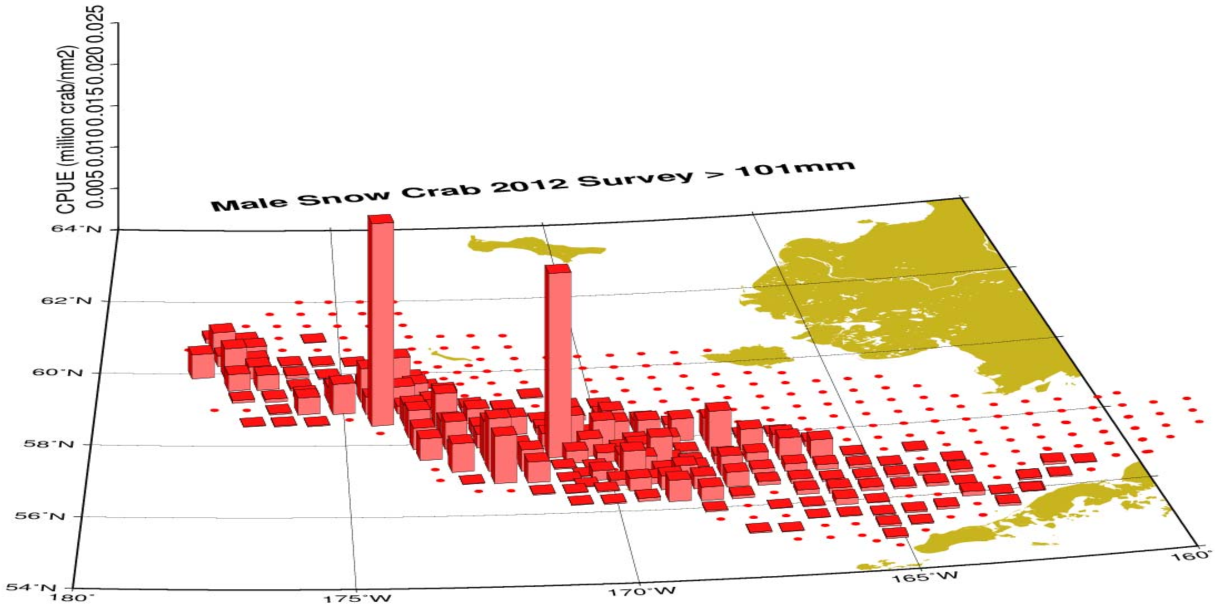

Figure 21. 2012 Survey CPUE (million crab per nm2) of males > 101 mm by tow. Filled circles are tows with 0 cpue

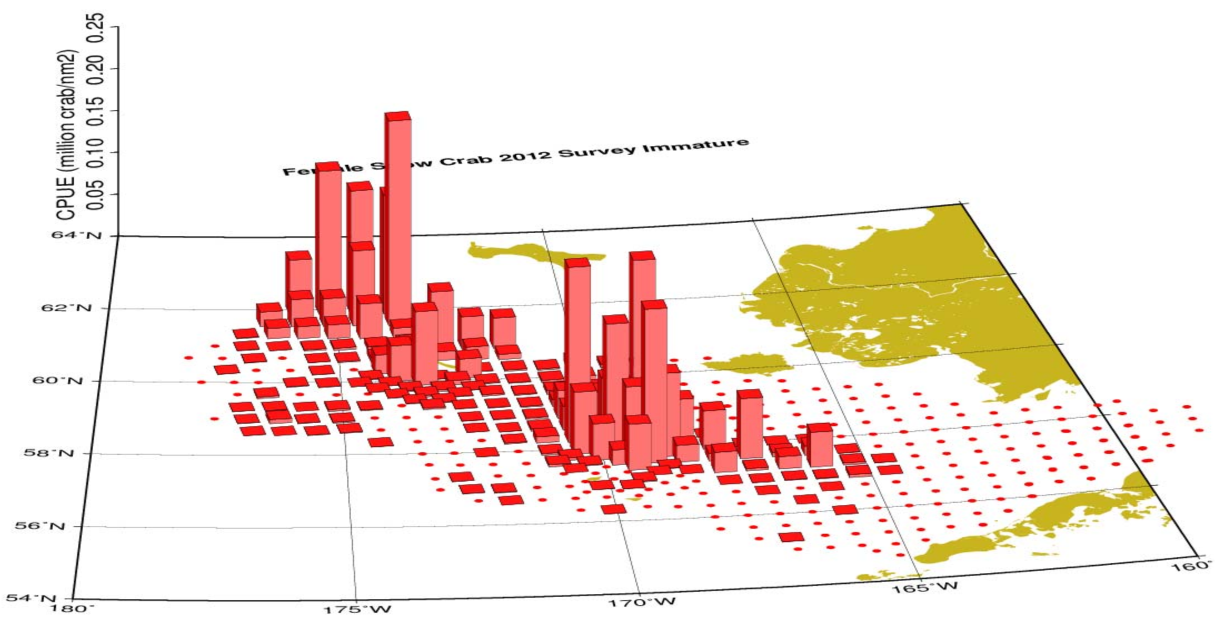

Figure 22. 2012 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue

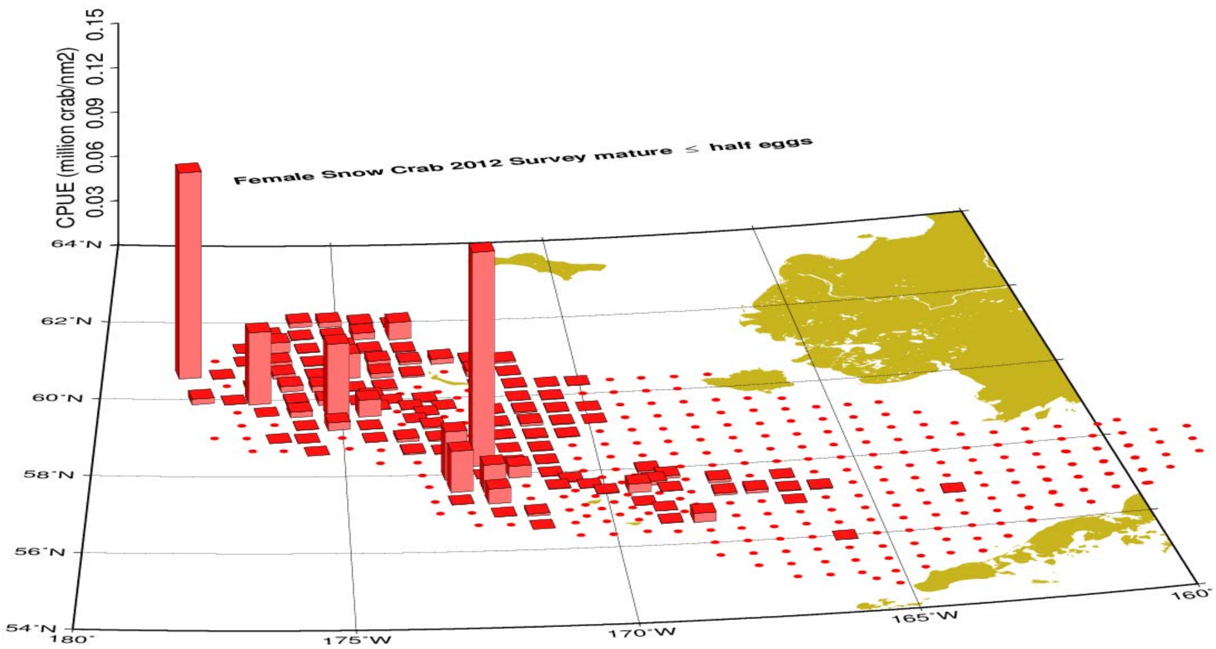

Figure 23. 2012 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

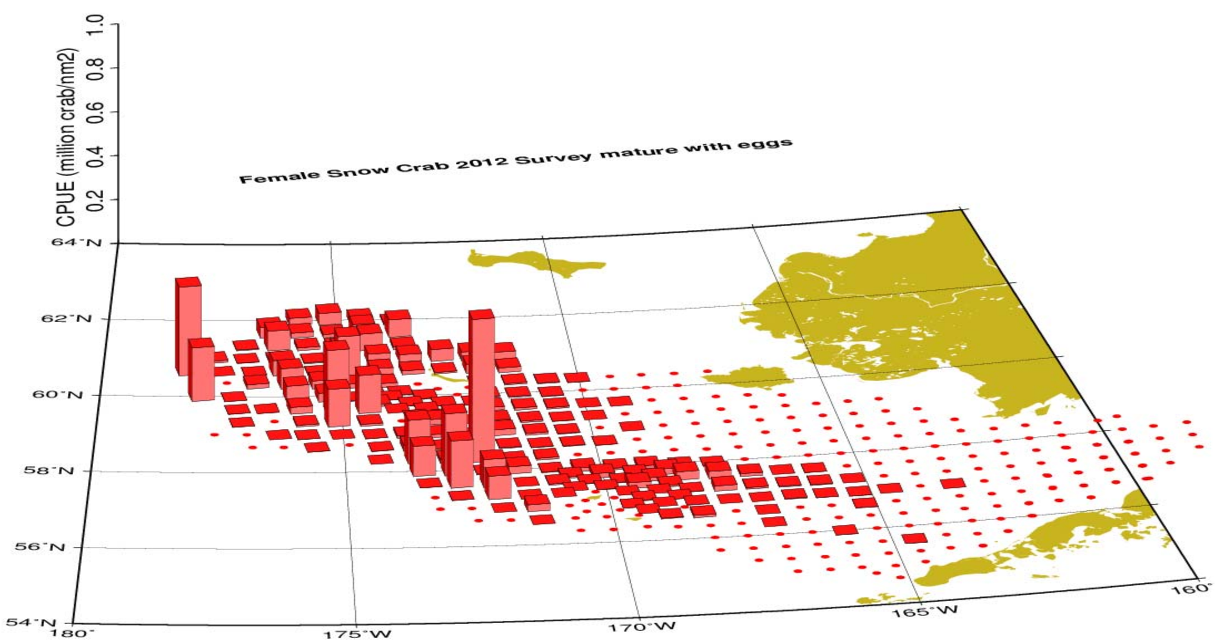

Figure 24. 2012 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

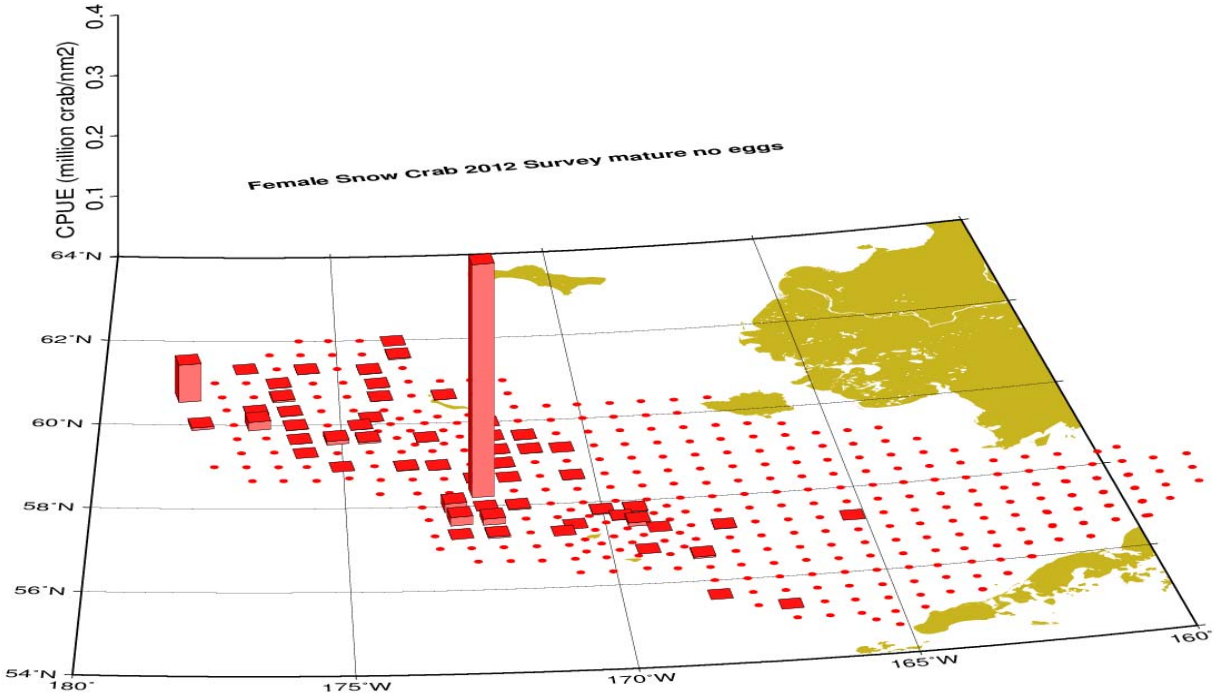

Figure 25. 2012 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

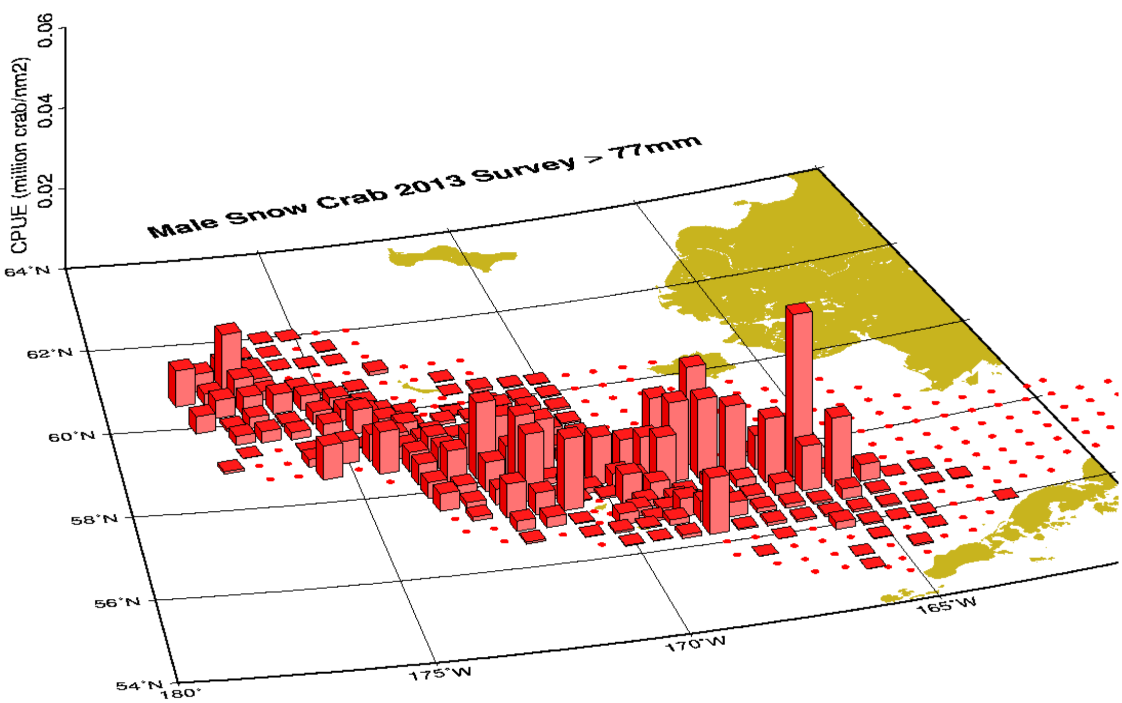

Figure 25b. 2013 Survey CPUE (million crab per nm2) of males > 77mm by tow. Filled circles are tows with 0 cpue.

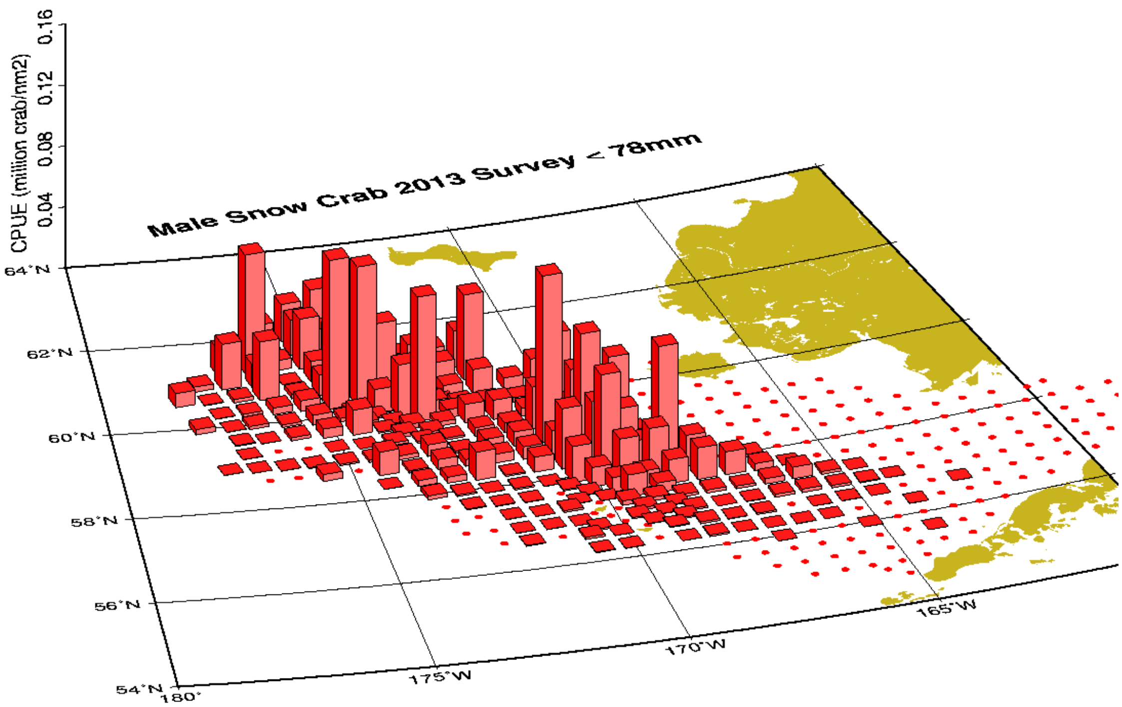

Figure 25c. 2013 Survey CPUE (million crab per nm2) of males < 78mm by tow. Filled circles are tows with 0 cpue.

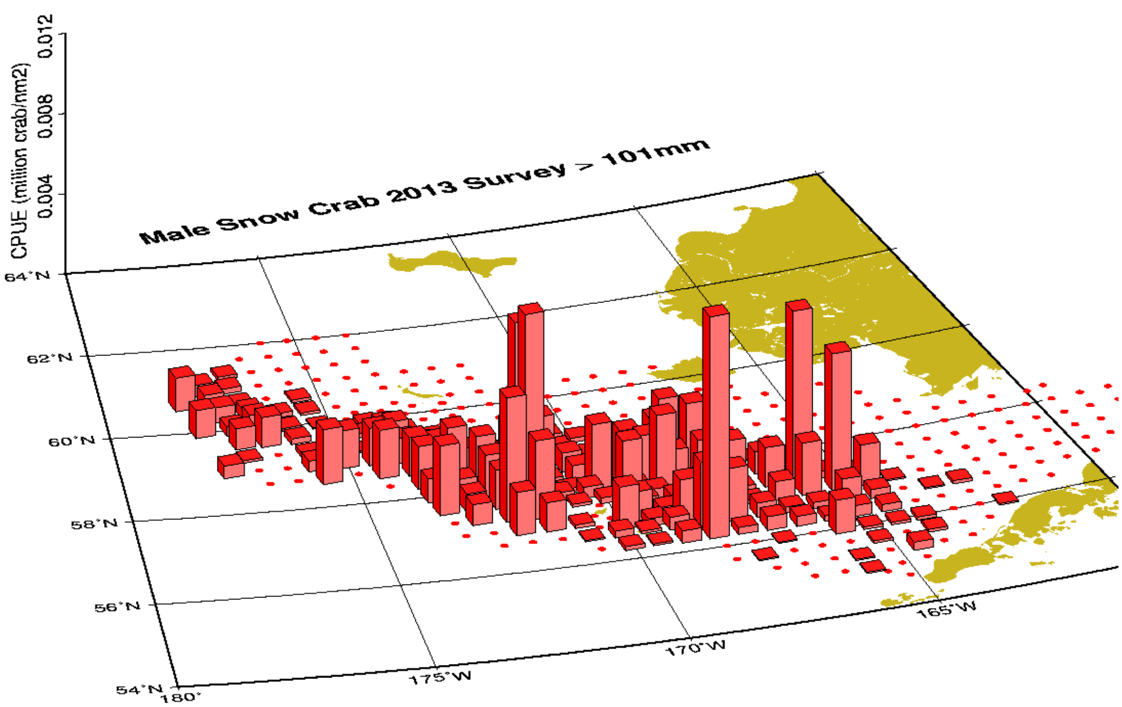

Figure 25d. 2013 Survey CPUE (million crab per nm2) of males > 101mm by tow. Filled circles are tows with 0 cpue.

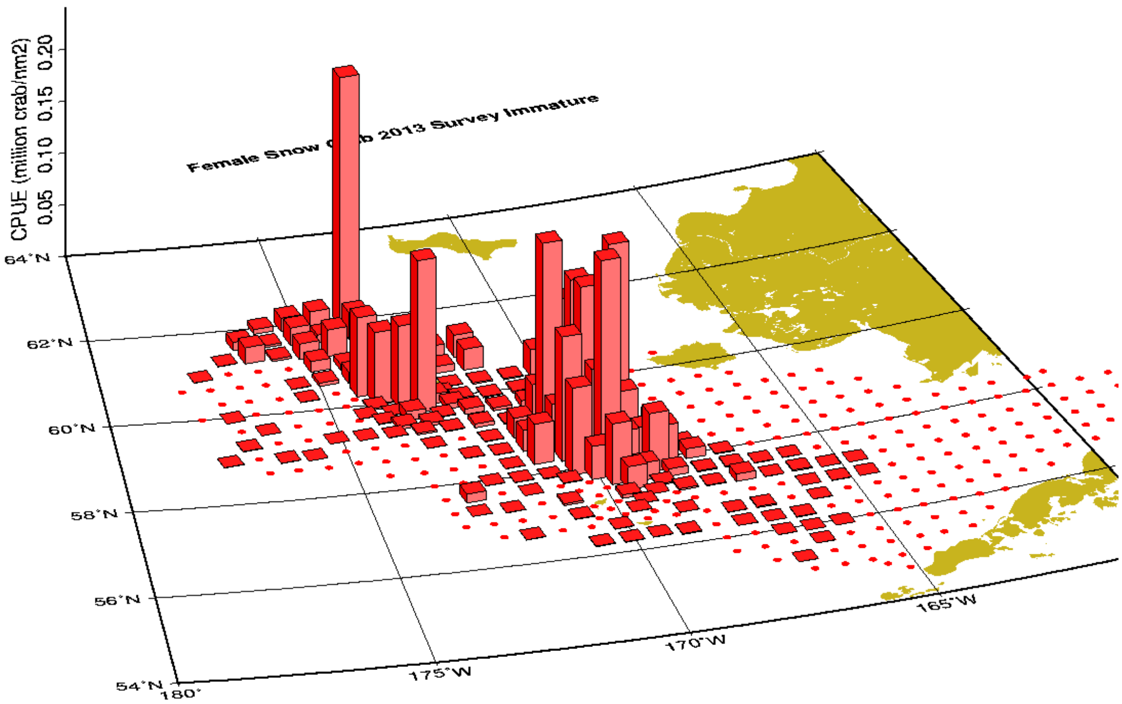

Figure 25e. 2013 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

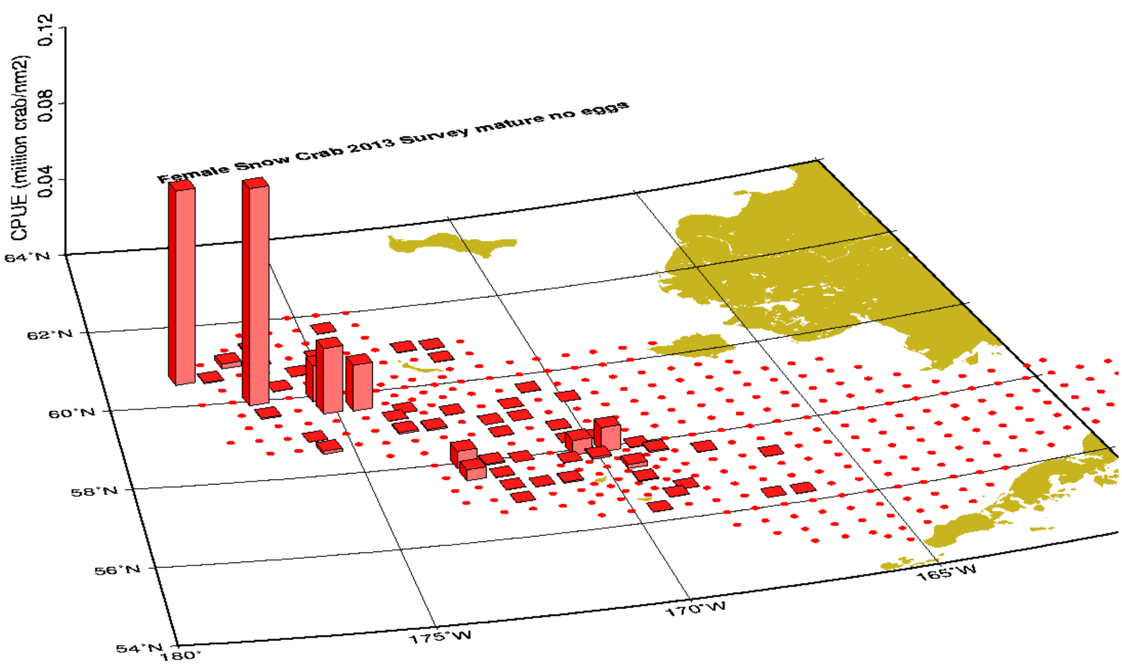

Figure 25f. 2013 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

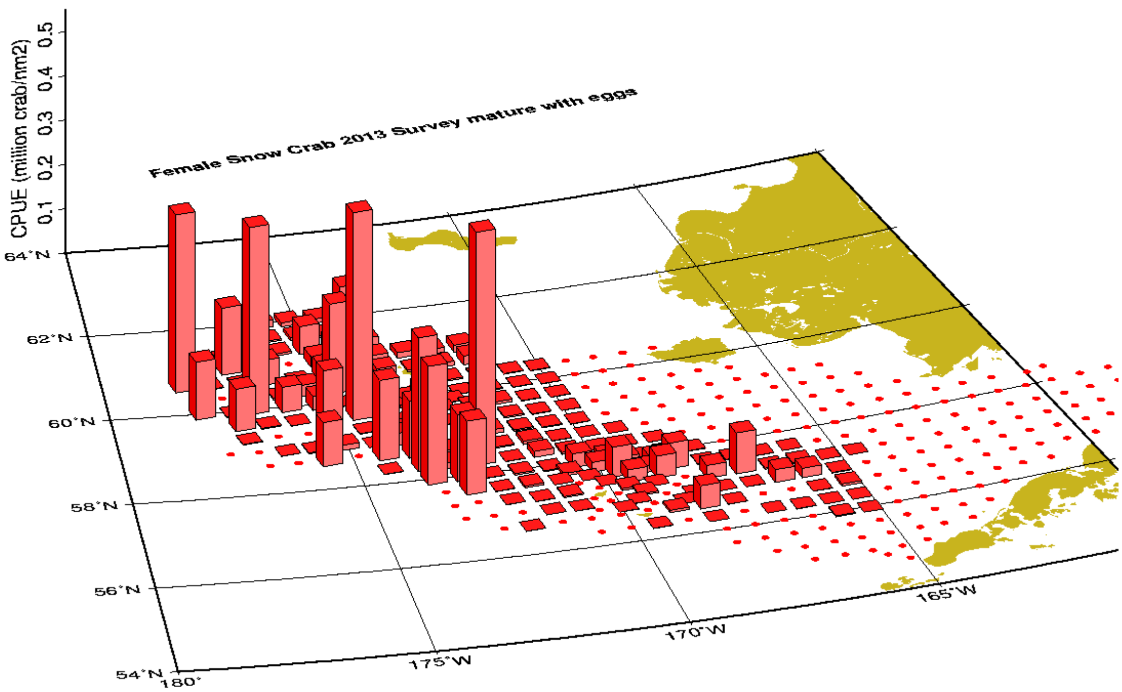

Figure 25g. 2013 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

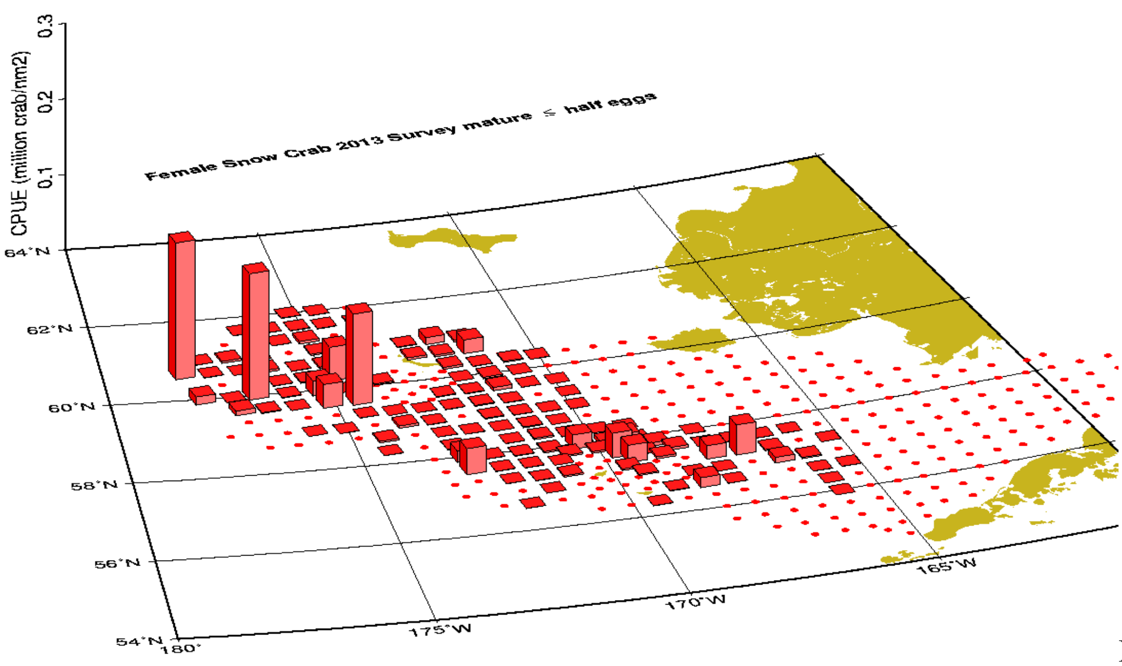

Figure 25h. 2013 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

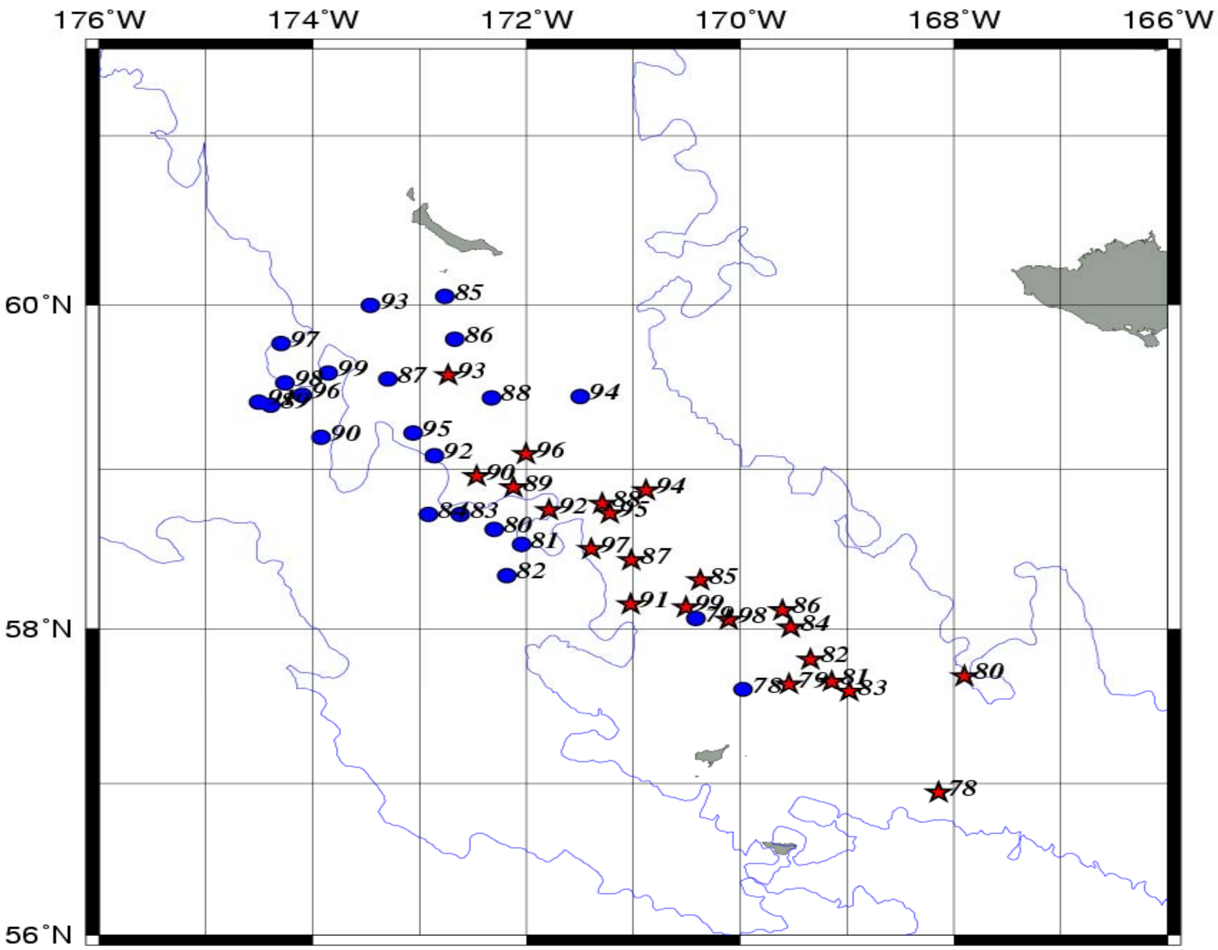

Figure 26. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars (Ernst, et al. 2005).

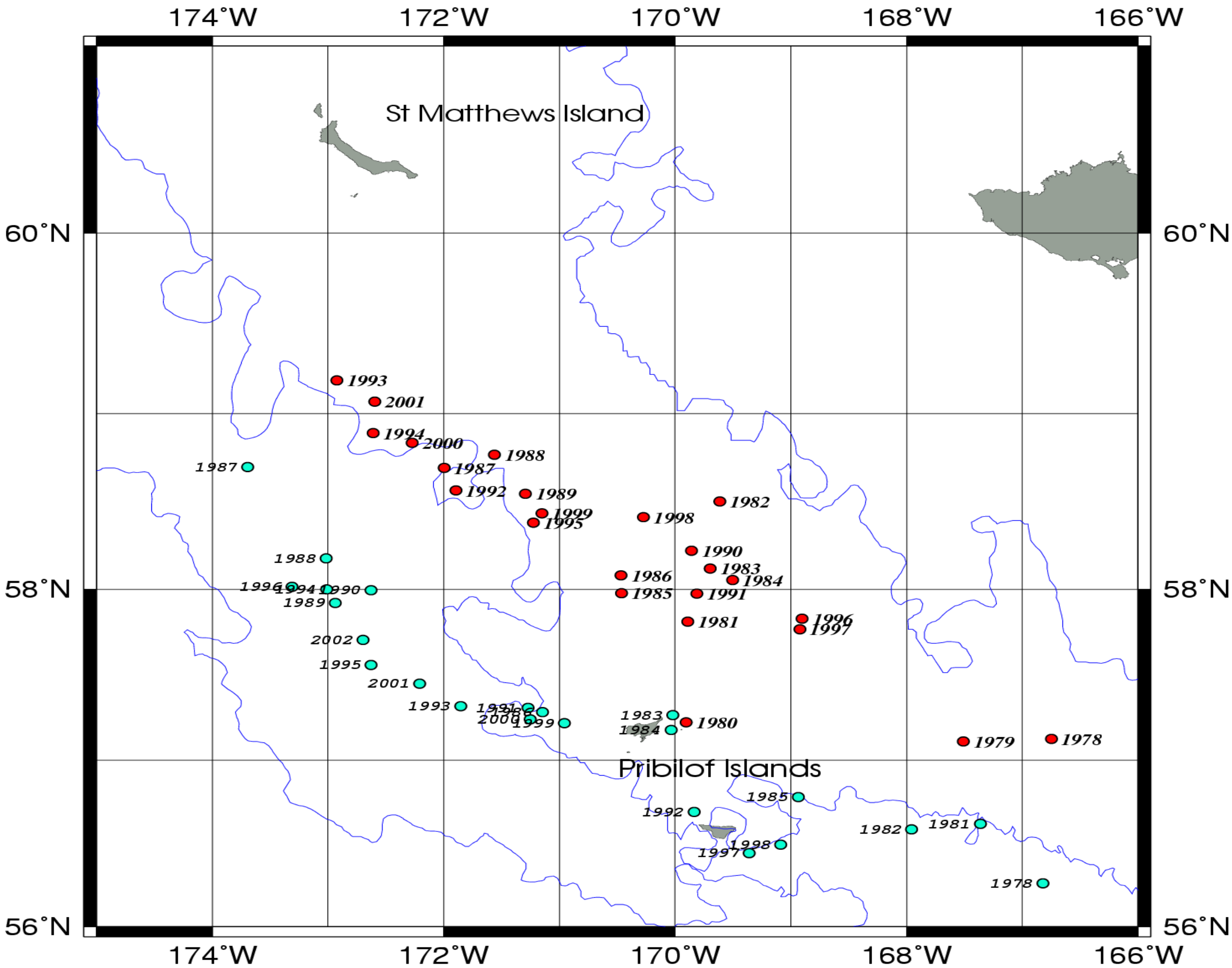

Figure 27. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green) (Ernst, et al. 2005).

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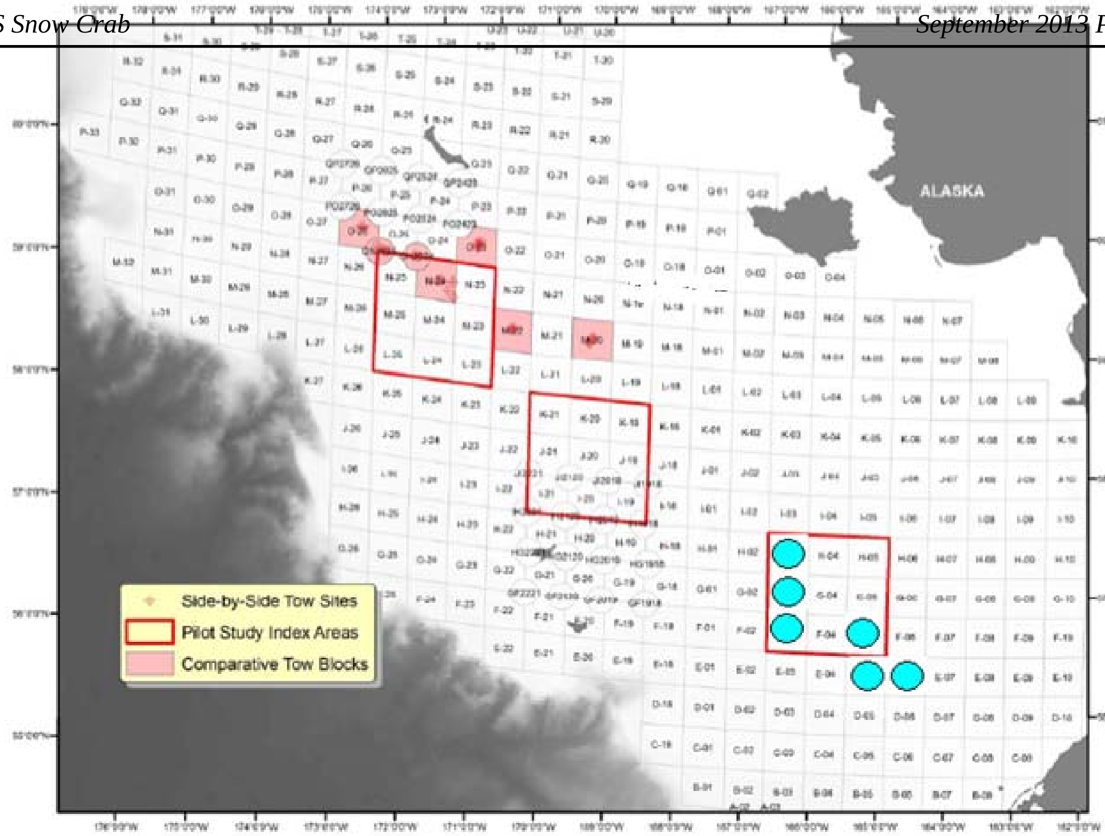

Figure 28. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas are the blue circles.

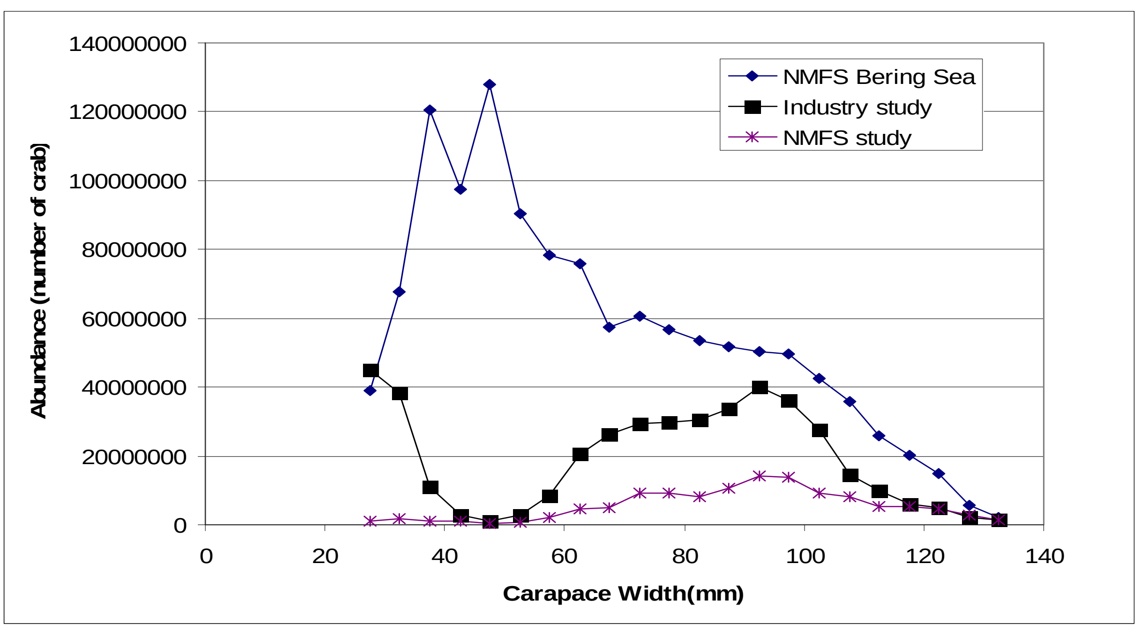

Figure 29. Abundance estimates of male snow crab by 5 mm carapace width(>=25mm) for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

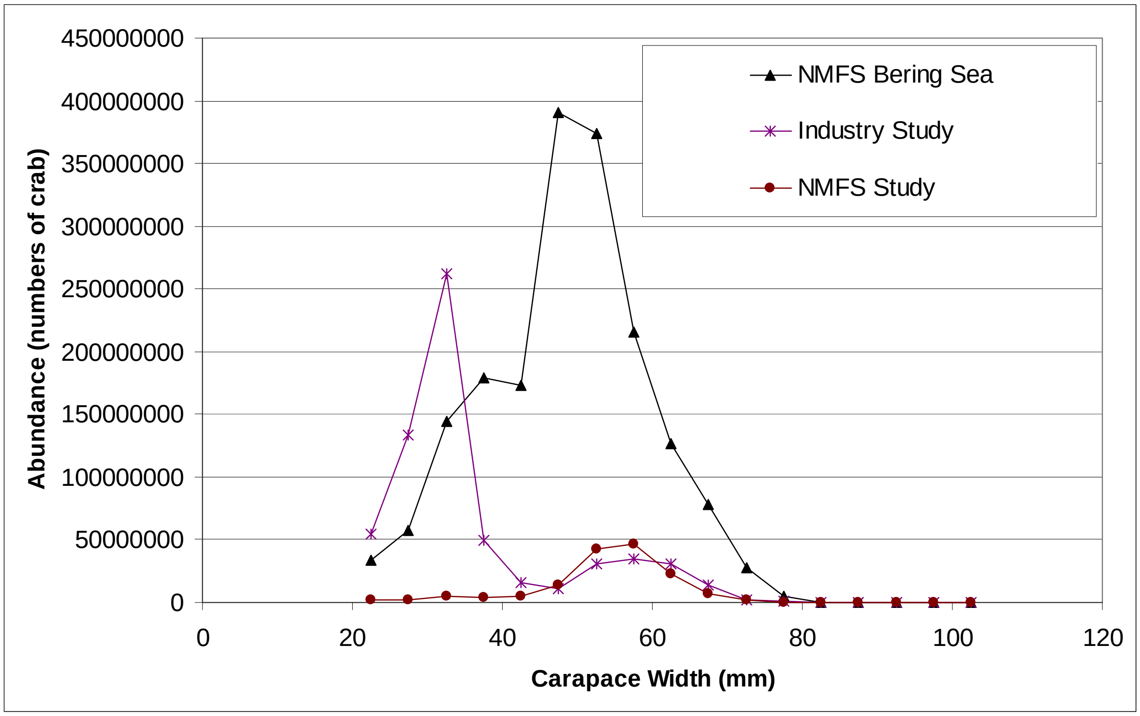

Figure 30. Abundance estimates of female snow crab by 5 mm carapace width for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

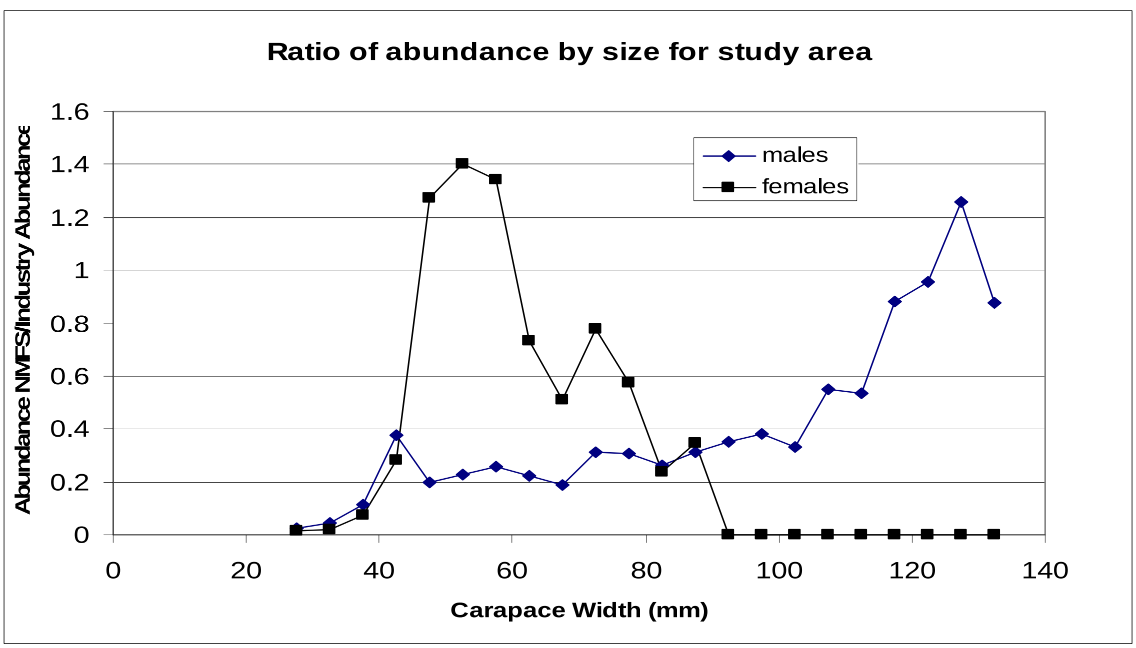

Figure 31. Ratio of abundance in the 2009 study area from the NMFS net to the BSFRF net for male and female crab.

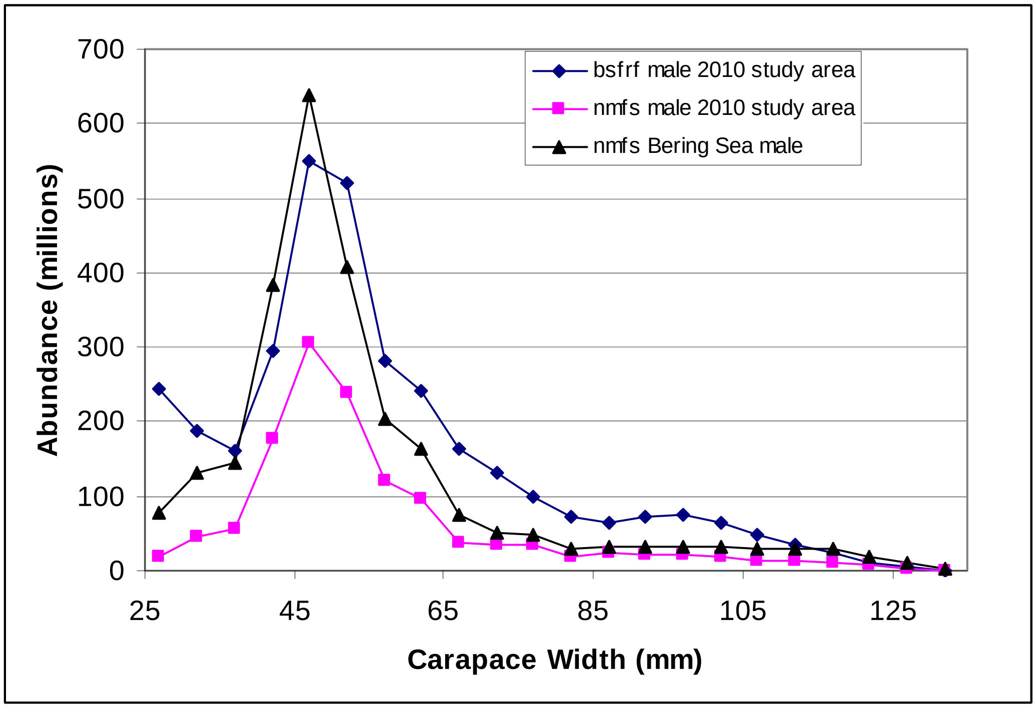

Figure 32. 2010 study area Male abundance.

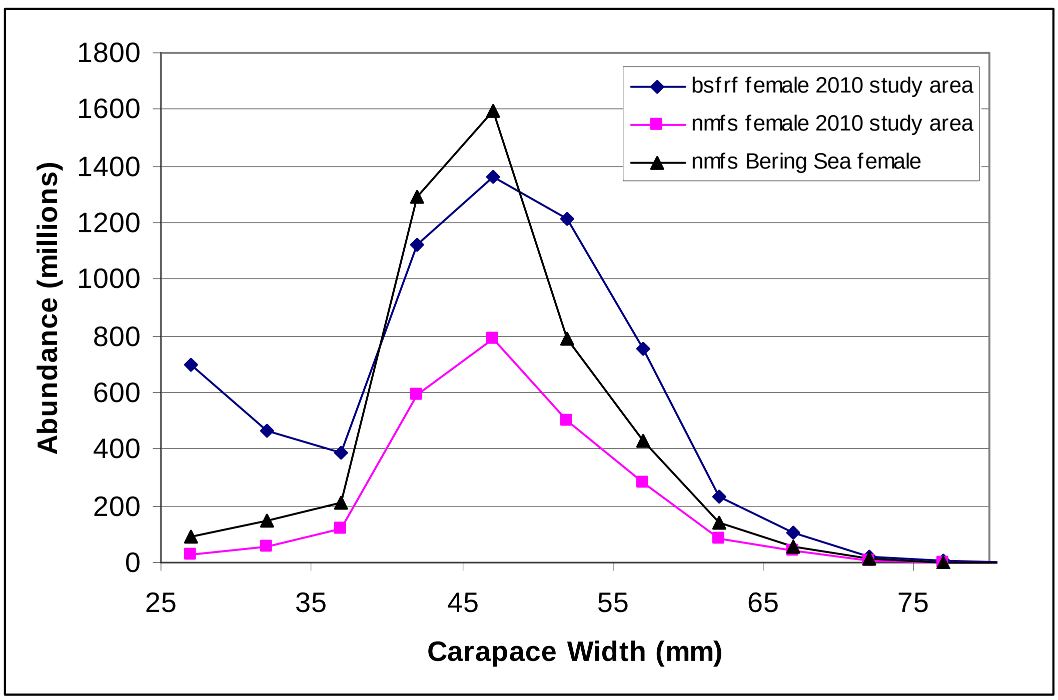

Figure 33. 2010 study area Female abundance.

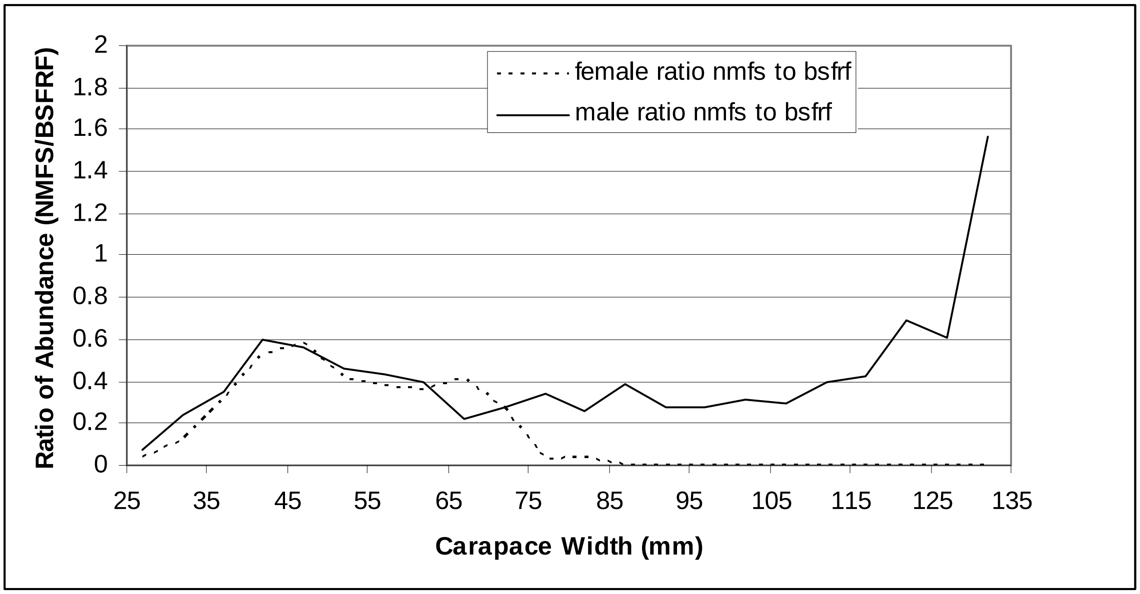

Figure 34. 2010 study area ratio of abundance

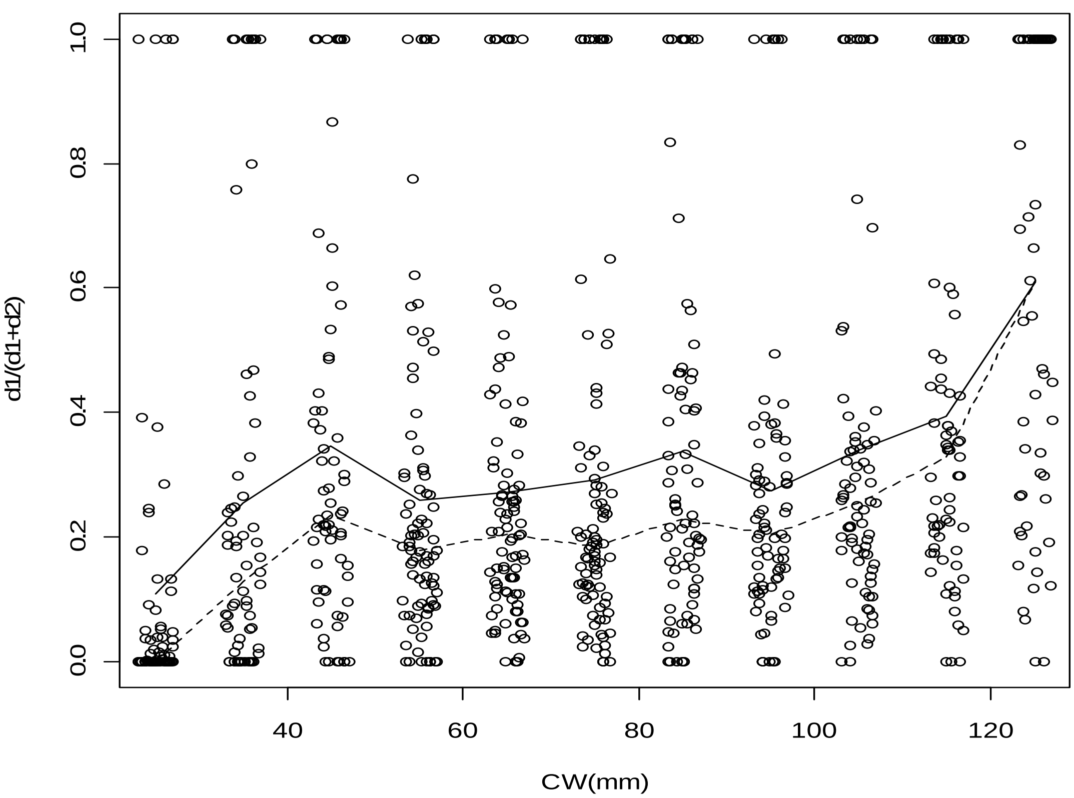

Figure 35. Male crab. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is unweighted mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

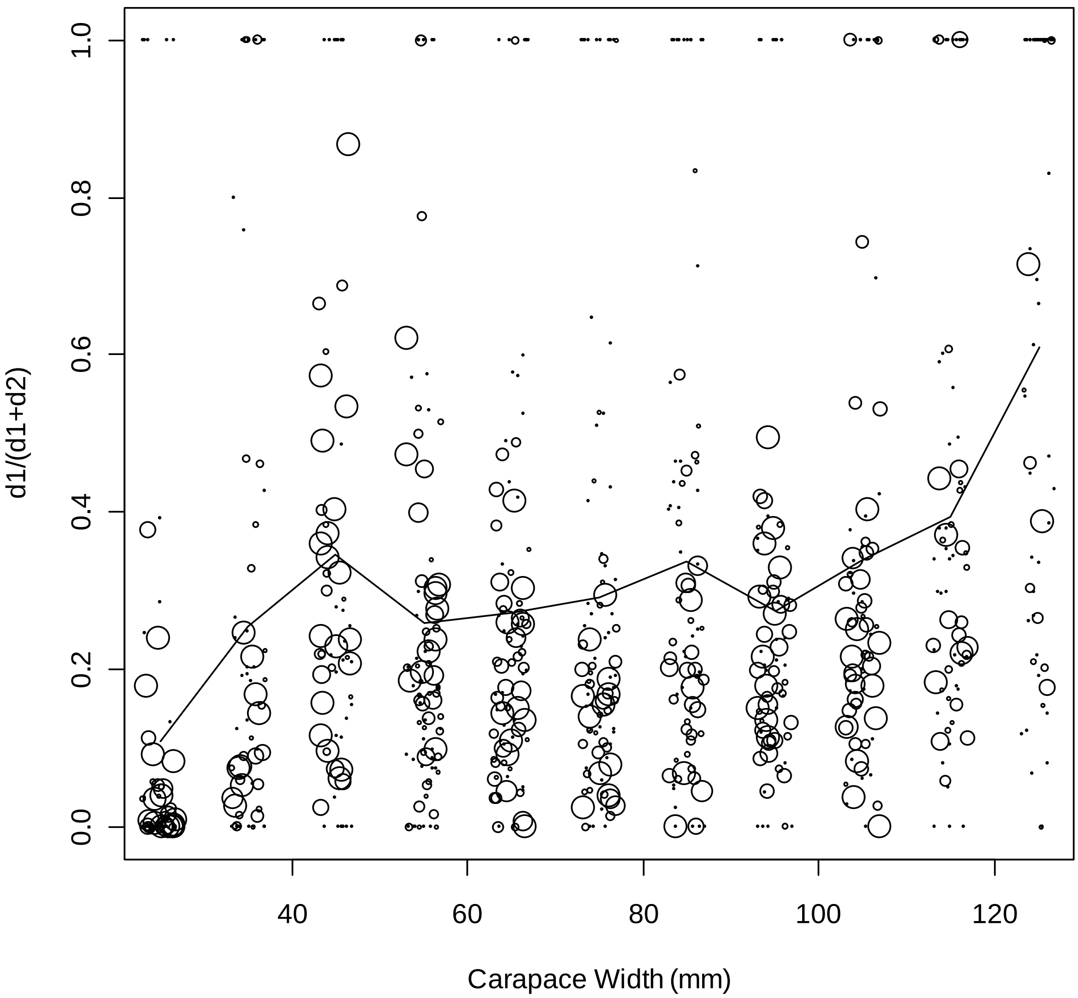

Figure 36. Density of NMFS tow (d1) divided by the sum of the density of the NMFS tow (d1) and the Industry tow (d2). The radius of the circle at each point is proportional to the sum of the catch in numbers where the Industry numbers are adjusted by the ratio of the NMFS area swept to the Industry area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

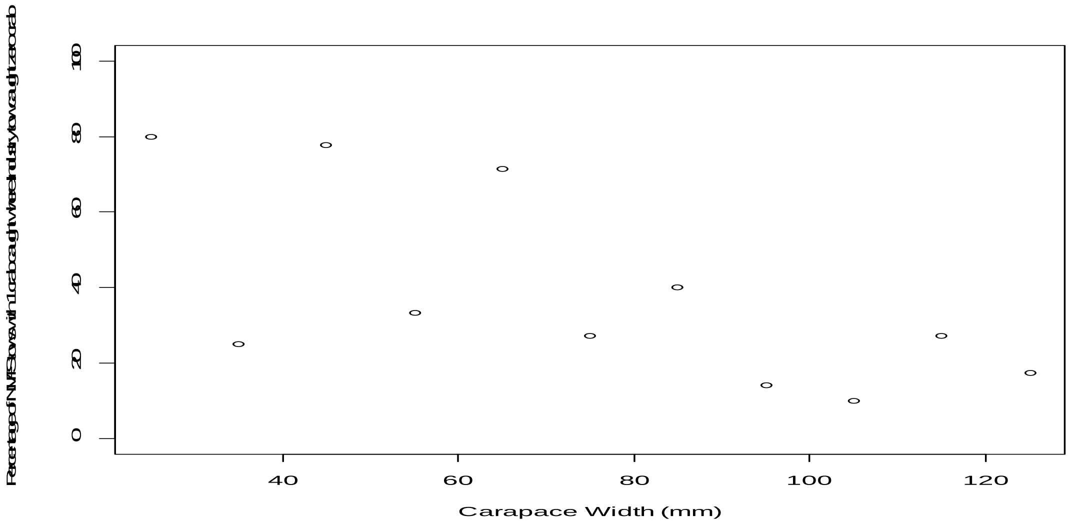

Figure 37. Percentage of paired tows where BSFRF caught no crab and NMFS caught only 1 crab.

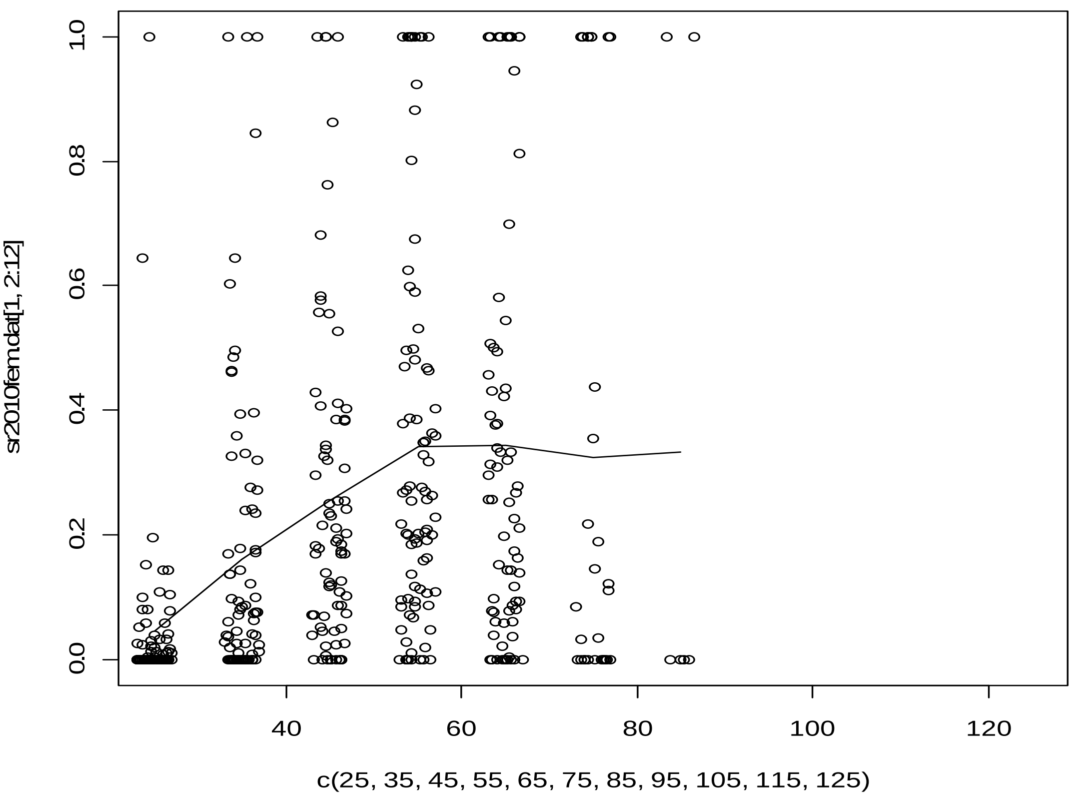

Figure 38. Female d1/(d1+d2) with mean. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

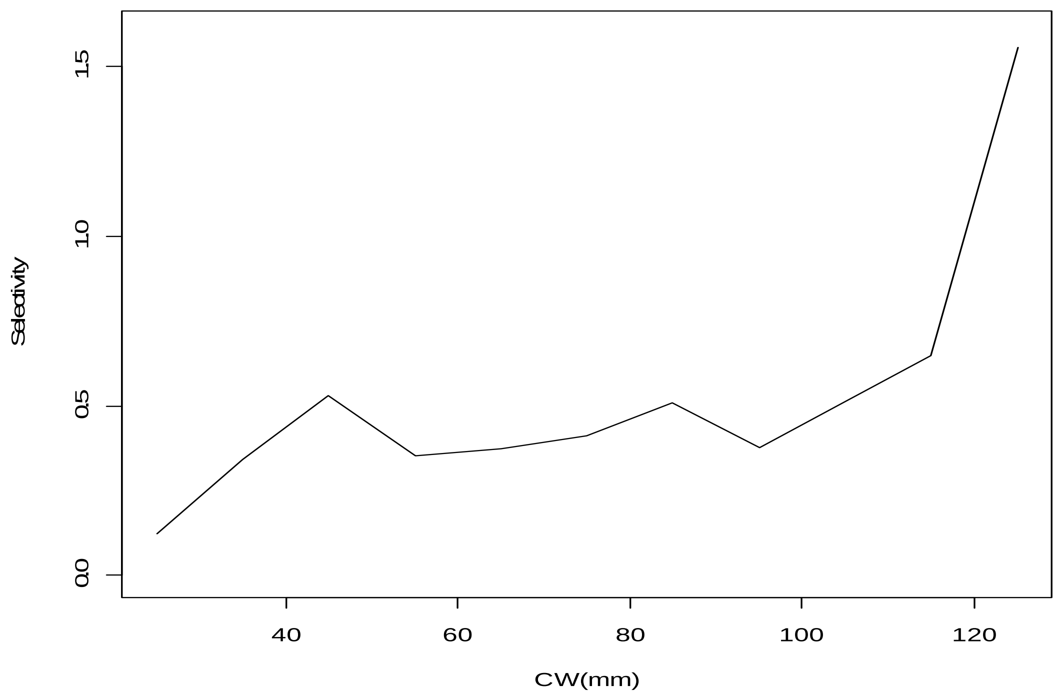

Figure 39. Mean from Figure 9 translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2)).

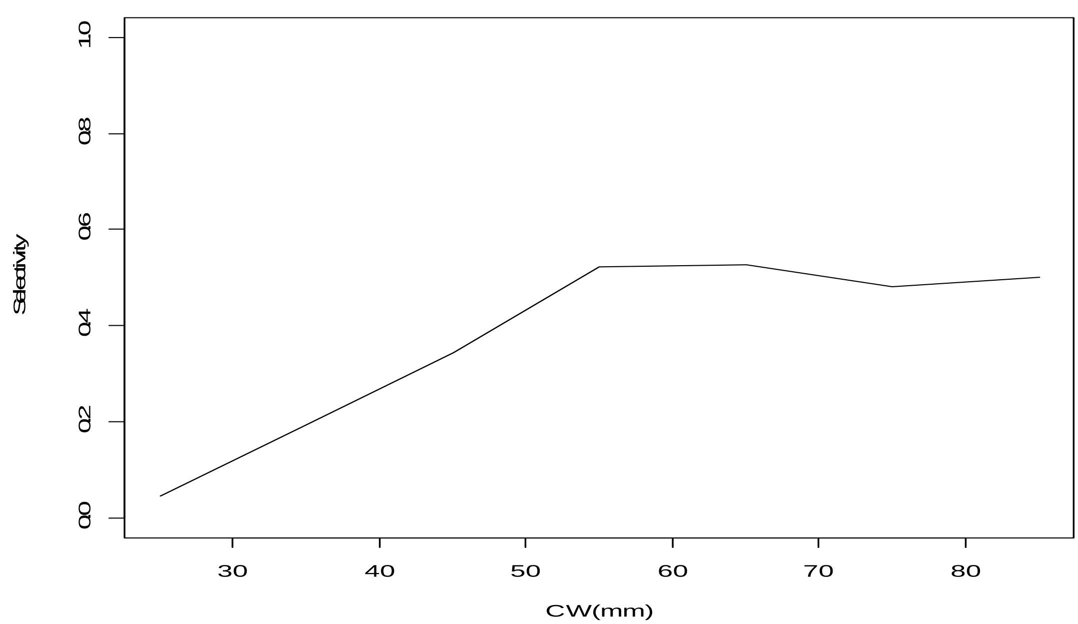

Figure 40. Mean from Figure 38, female crab translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2))

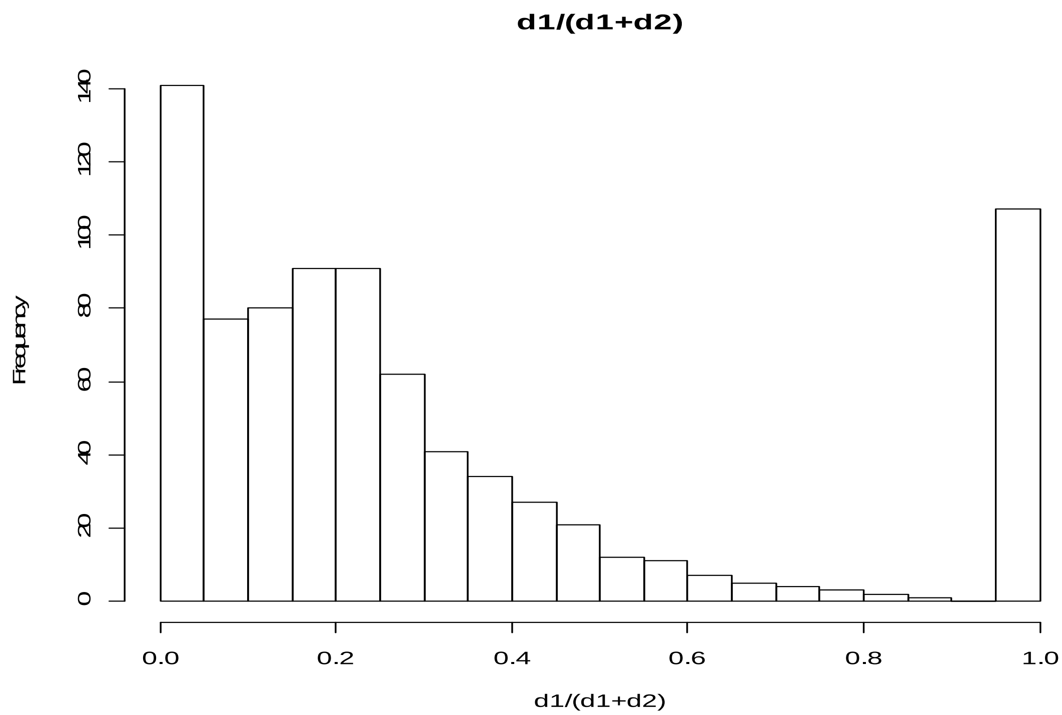

Figure 41. Histogram of d1/(d1+d2) over all sizes and tows. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

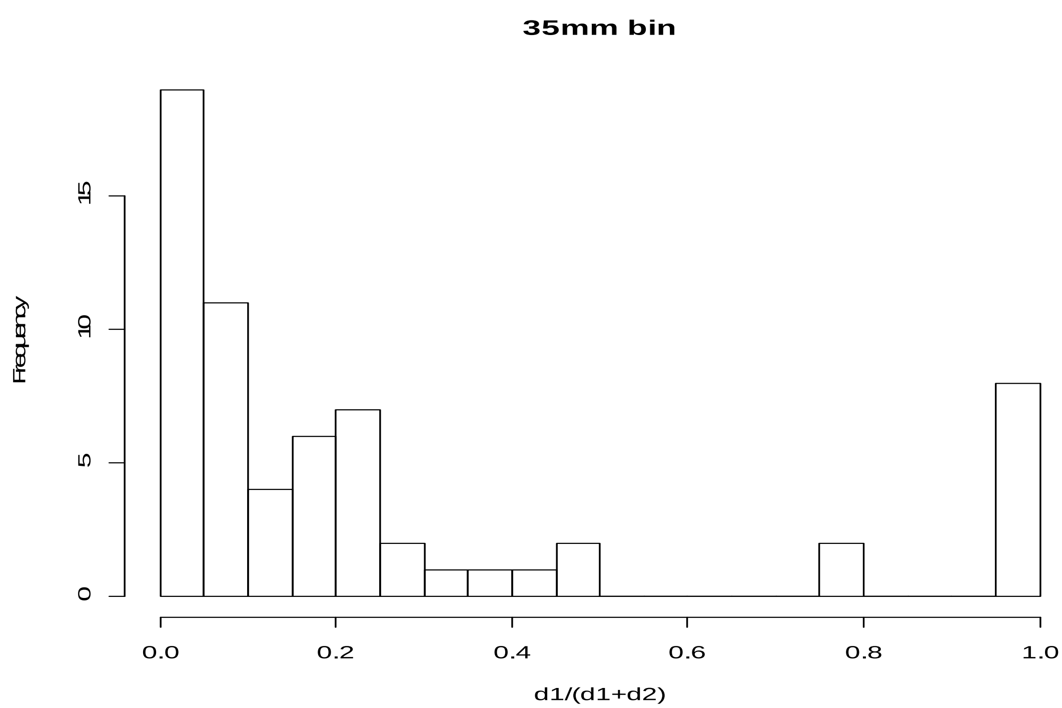

Figure 42. Histogram of d1/(d1+d2) for the 30 to 40 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

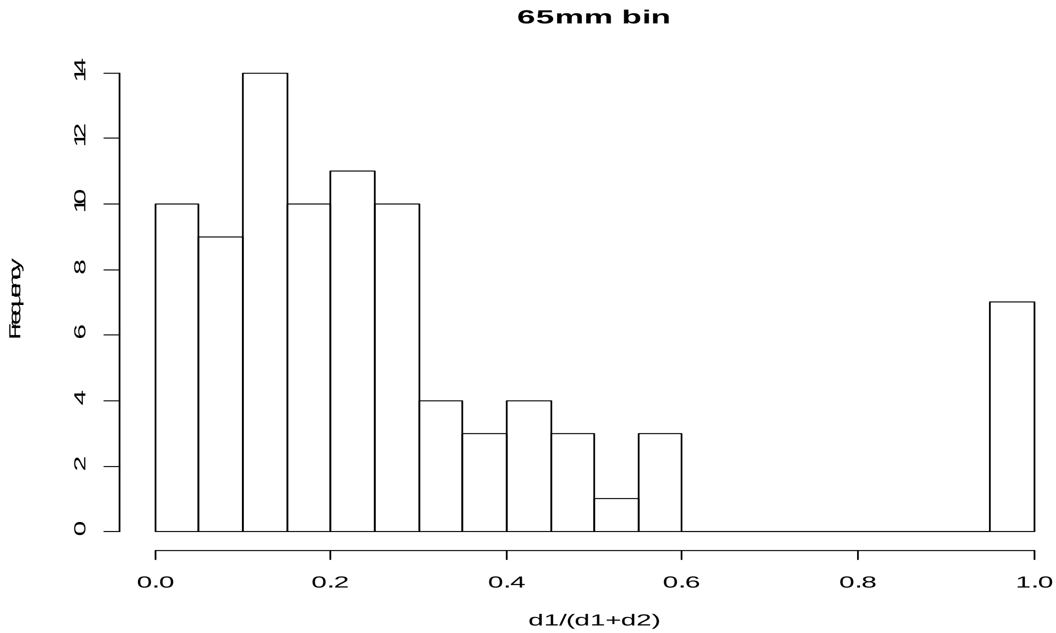

Figure 43. Histogram of d1/(d1+d2) for the 60 to 70 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

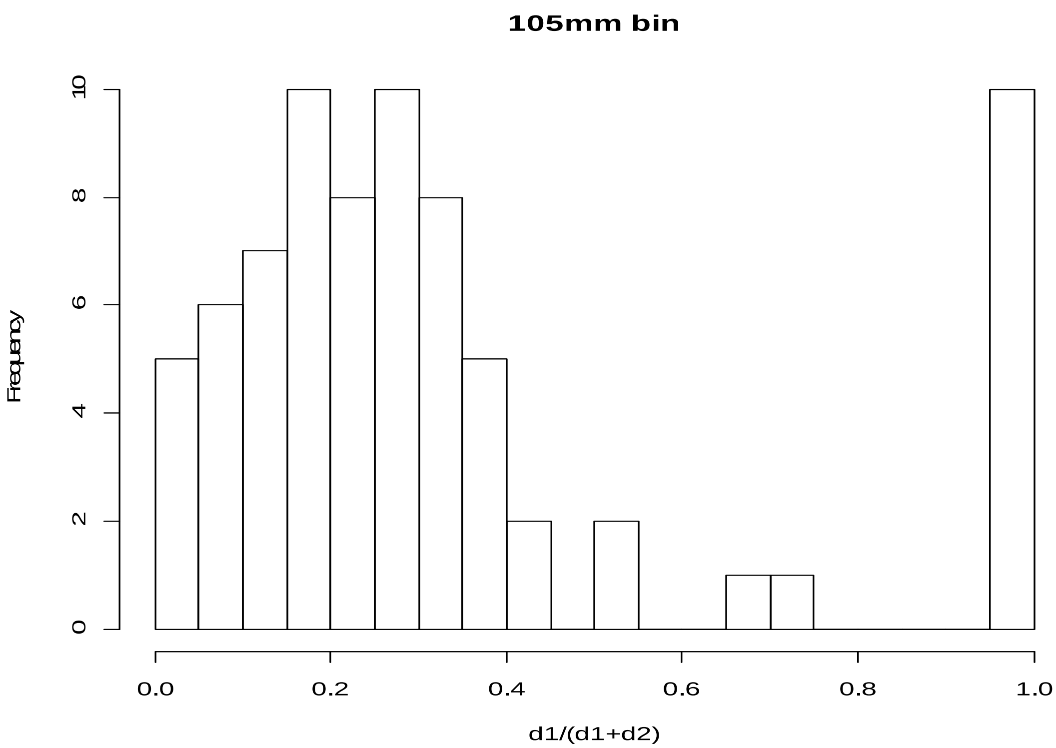

Figure 44. Histogram of d1/(d1+d2) for the 100 to 110 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

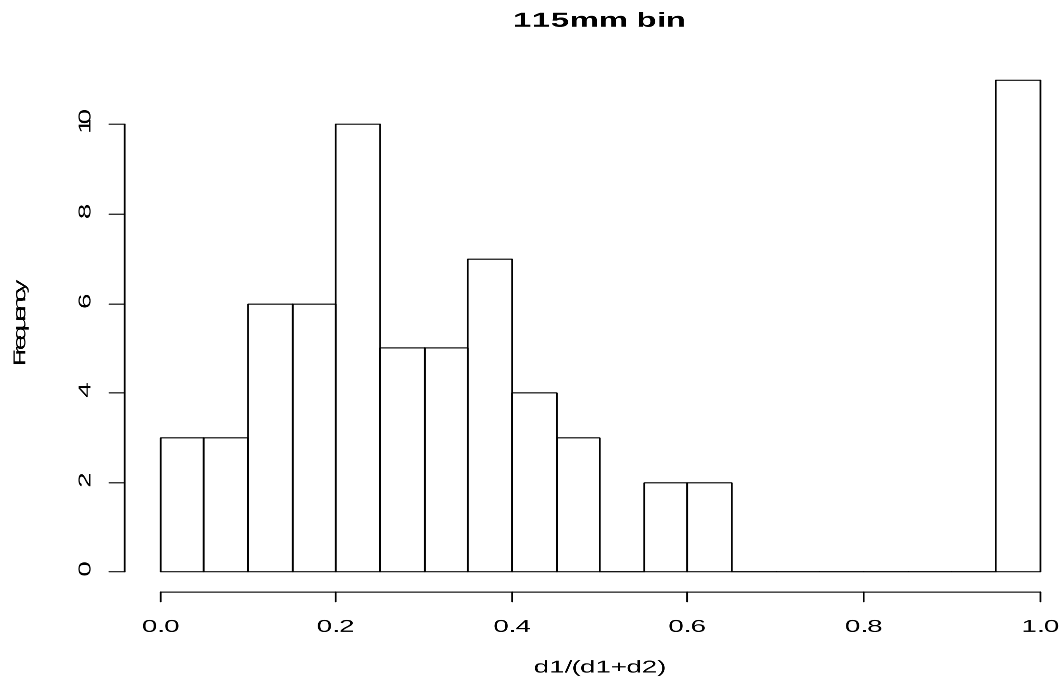

Figure 45. Histogram of d1/(d1+d2) for the 100 to 120 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

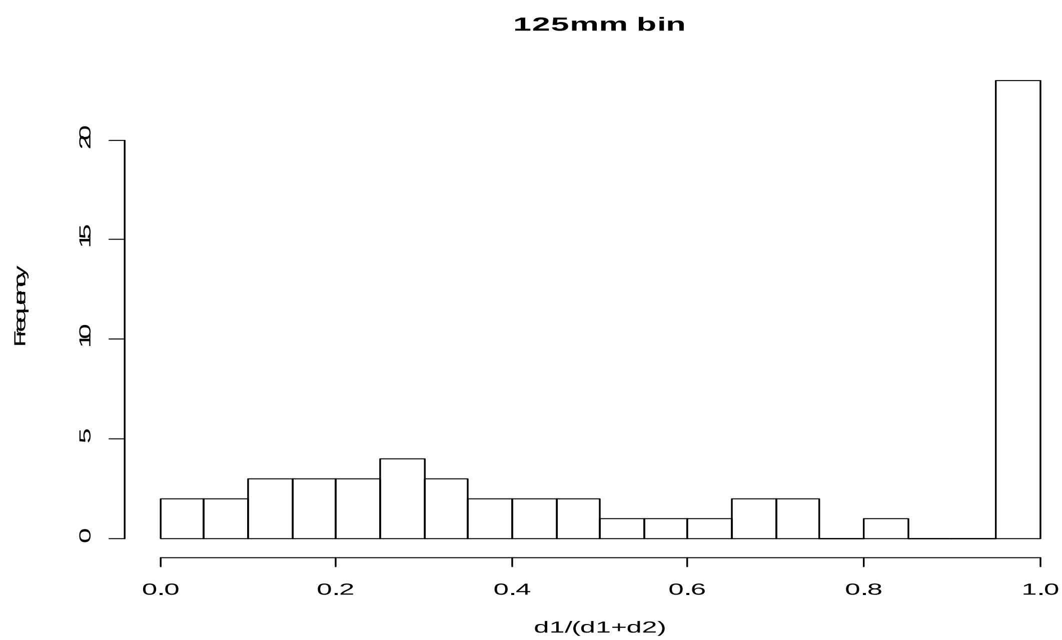

Figure 46. Histogram of d1/(d1+d2) for the 120+mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

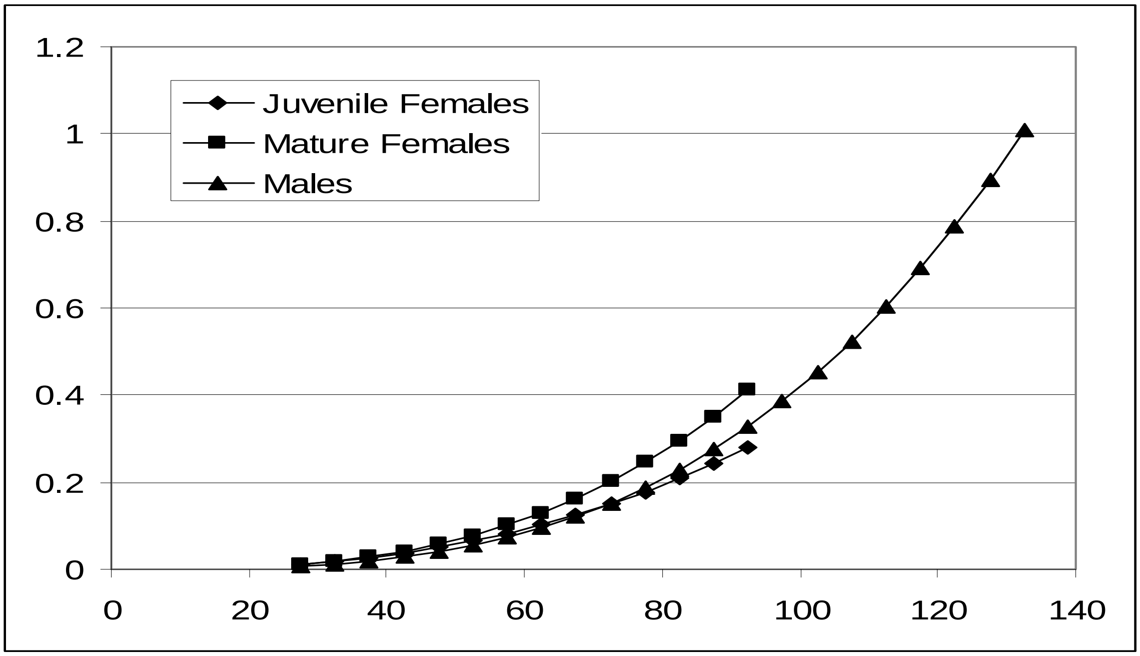

Figure 47. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

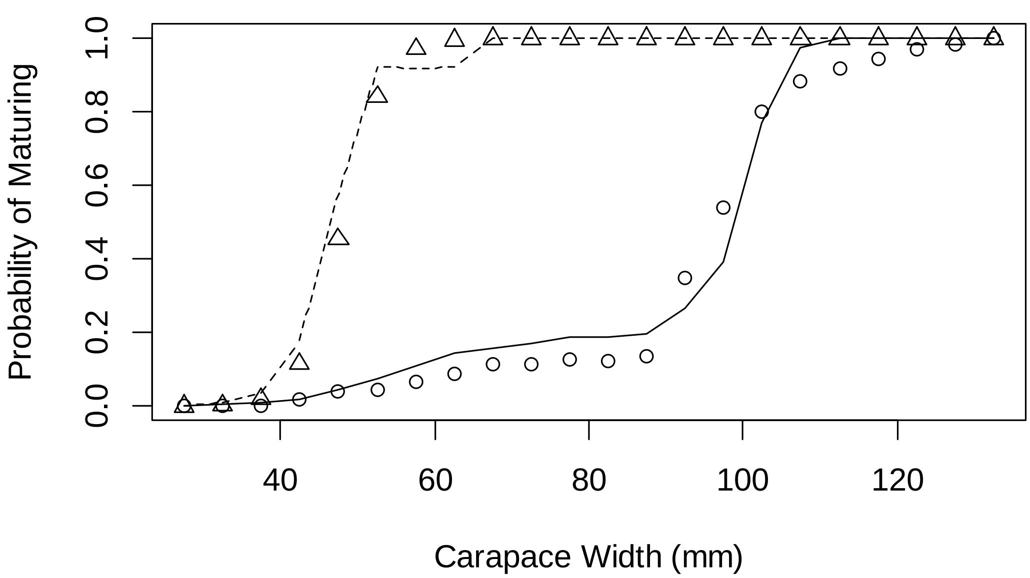

Figure 48. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (not the average fraction mature). Triangles are values for females used in the 2009 assessment. Circles are values for males used in the 2009 assessment.

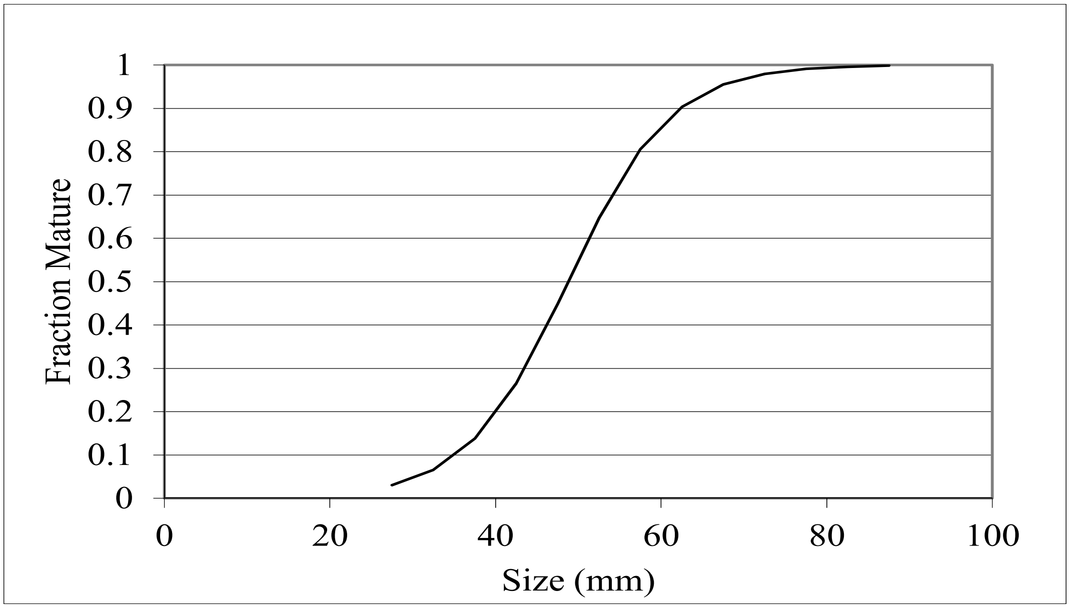

Figure 48b. Logistic fit to fraction mature for female snow crab (not used in model).

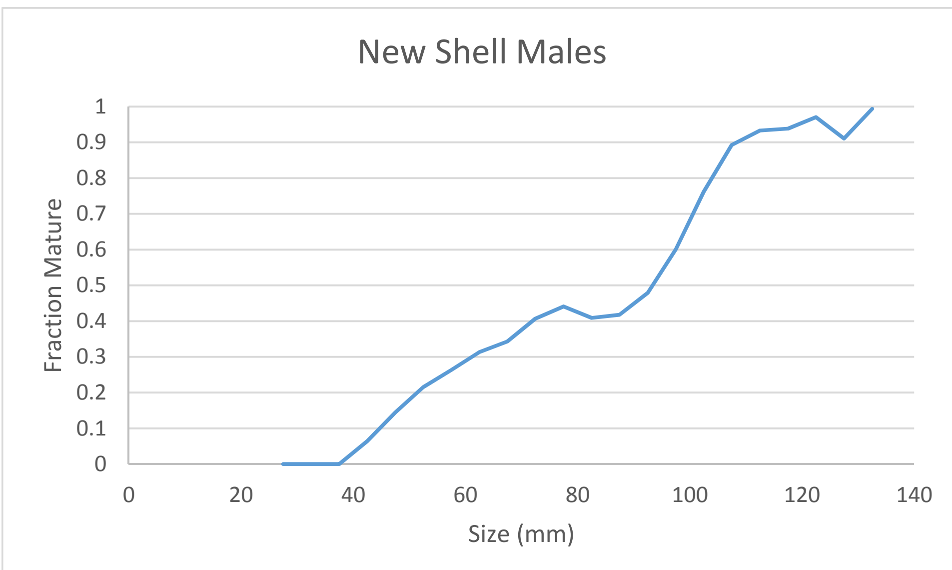

Figure 48c. Average fraction mature for new shell males from chela height data 1992-2008.

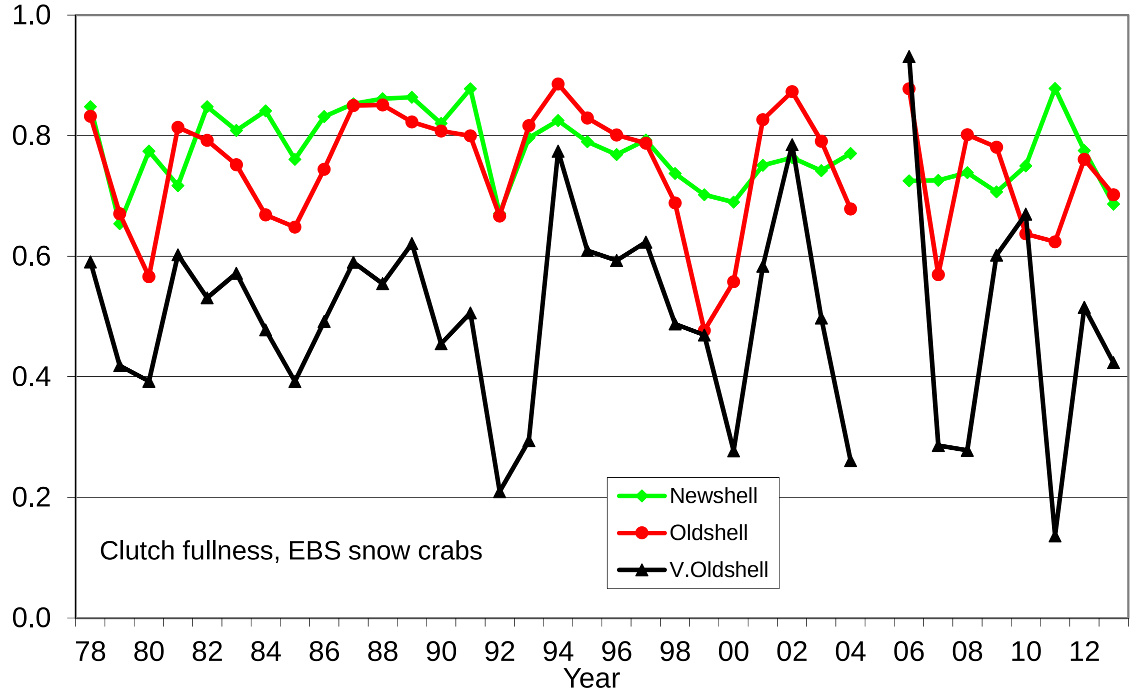

Figure 49. Clutch fullness for Bering Sea snow crab survey data by shell condition for 1978 to 2013.

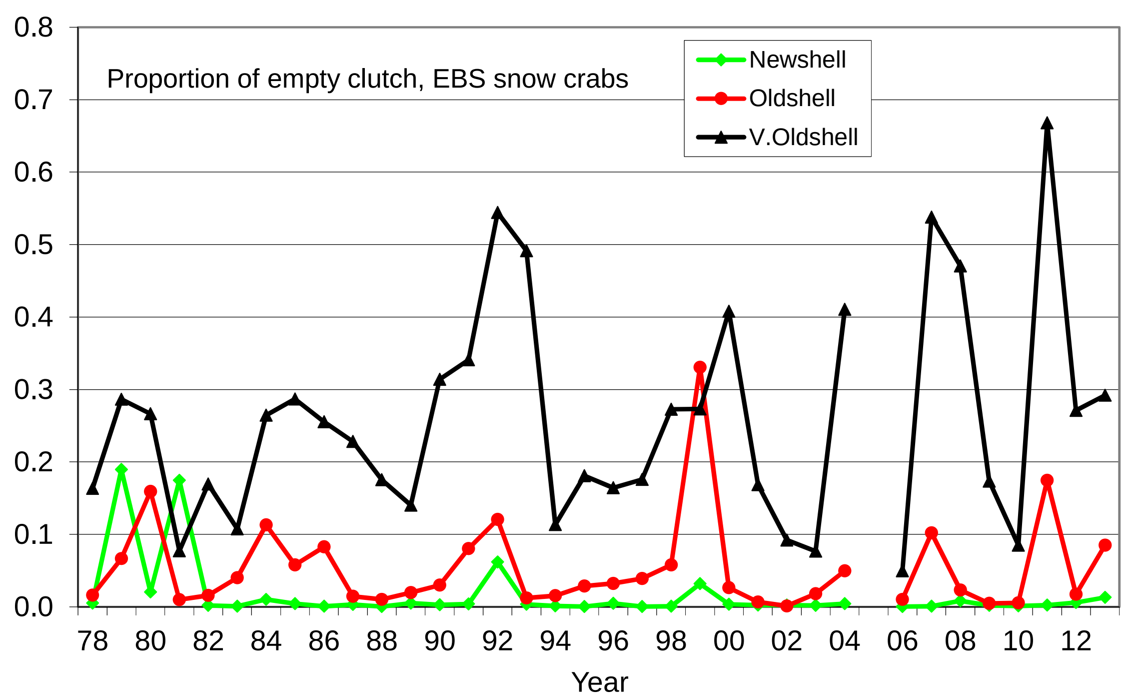

Figure 50. Proportion of barren females by shell condition from survey data 1978 to 2013.

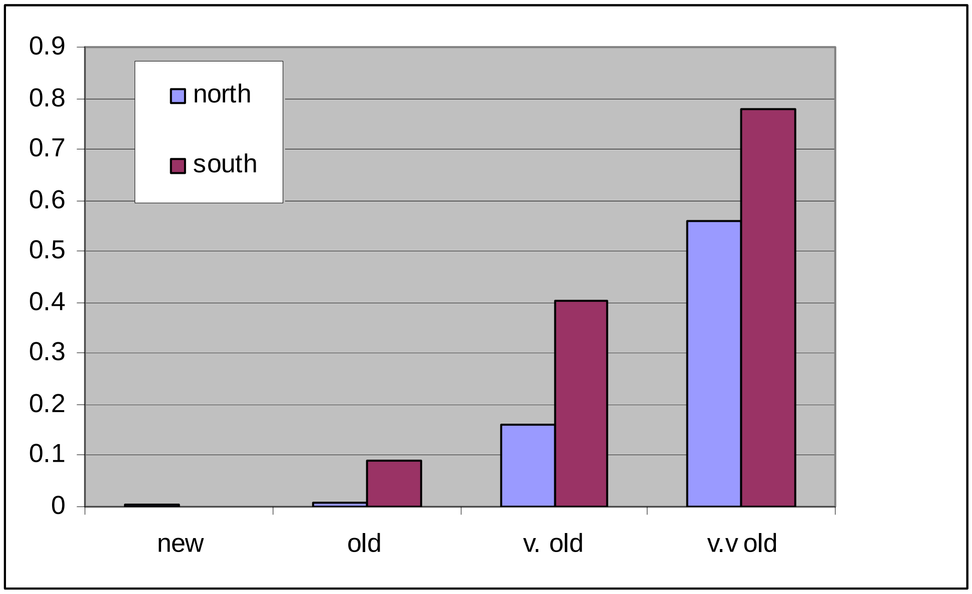

Figure 51. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

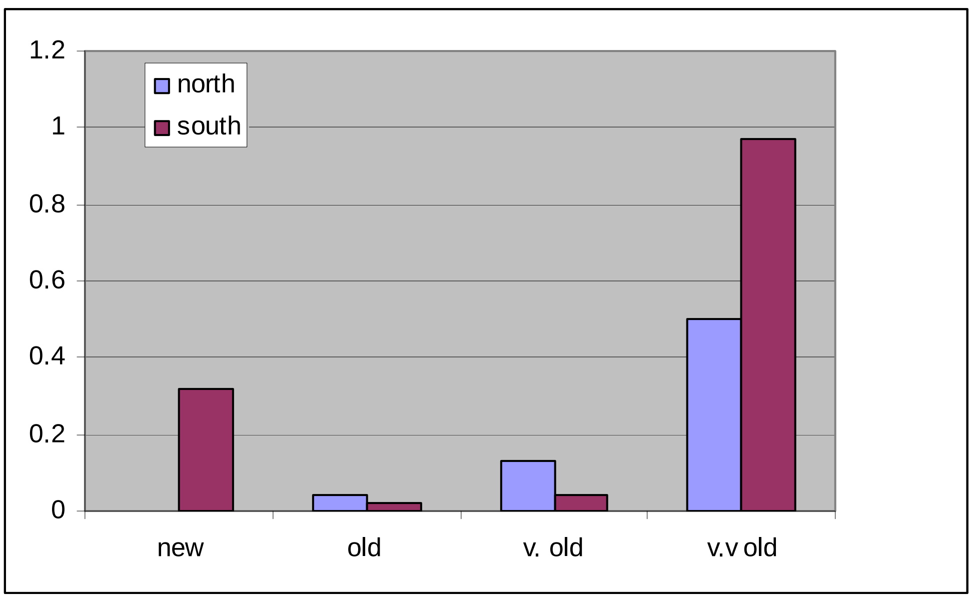

Figure 52. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

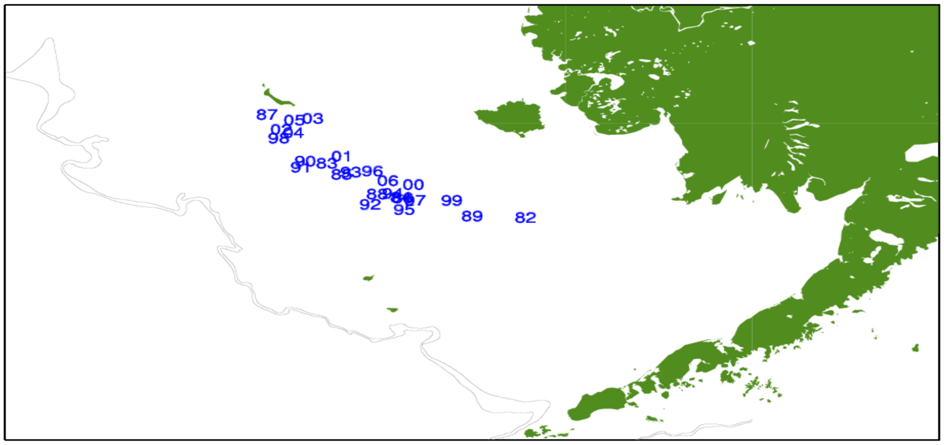

Figure 53. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

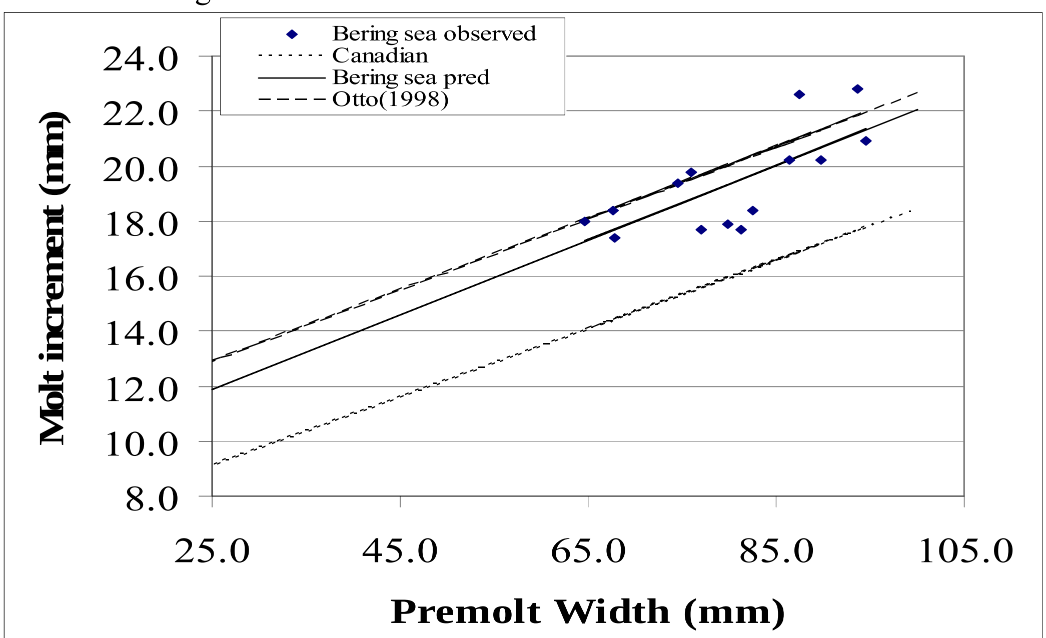

Figure 54. Growth increment as a function of premolt size for male snow crab. Points labeled Bering Sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering Sea pred is the predicted line from the Bering Sea observed growth, which was used as a prior for the growth 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.

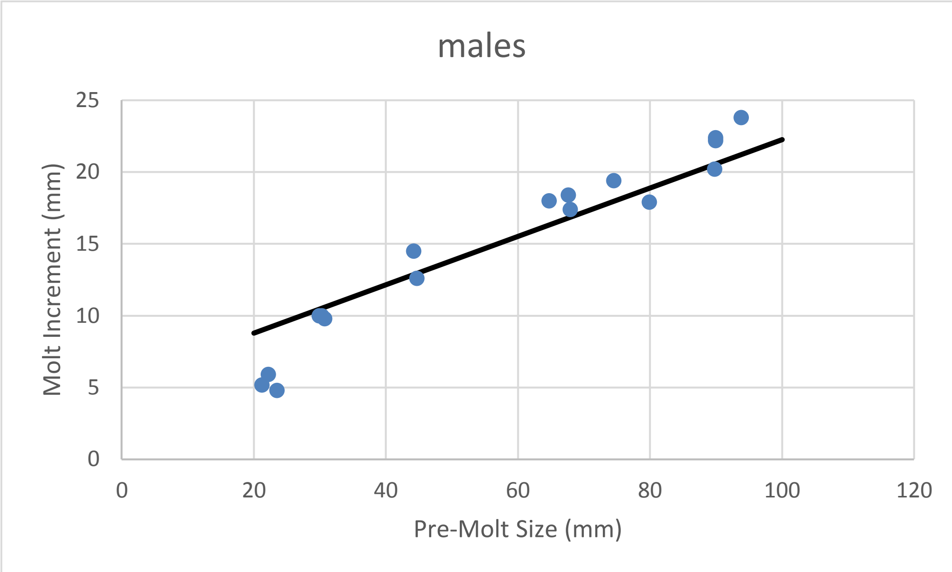

Figure 54b. Male growth data from 2011 growth study with estimated linear growth function from Base model.

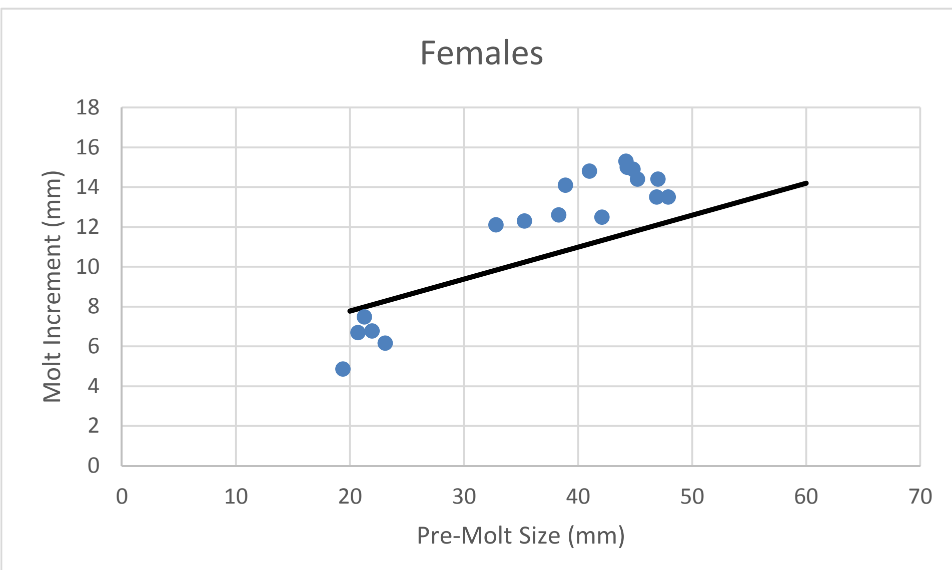

Figure 54c. . Female growth data from 2011 growth study with estimated linear growth function from Base model.

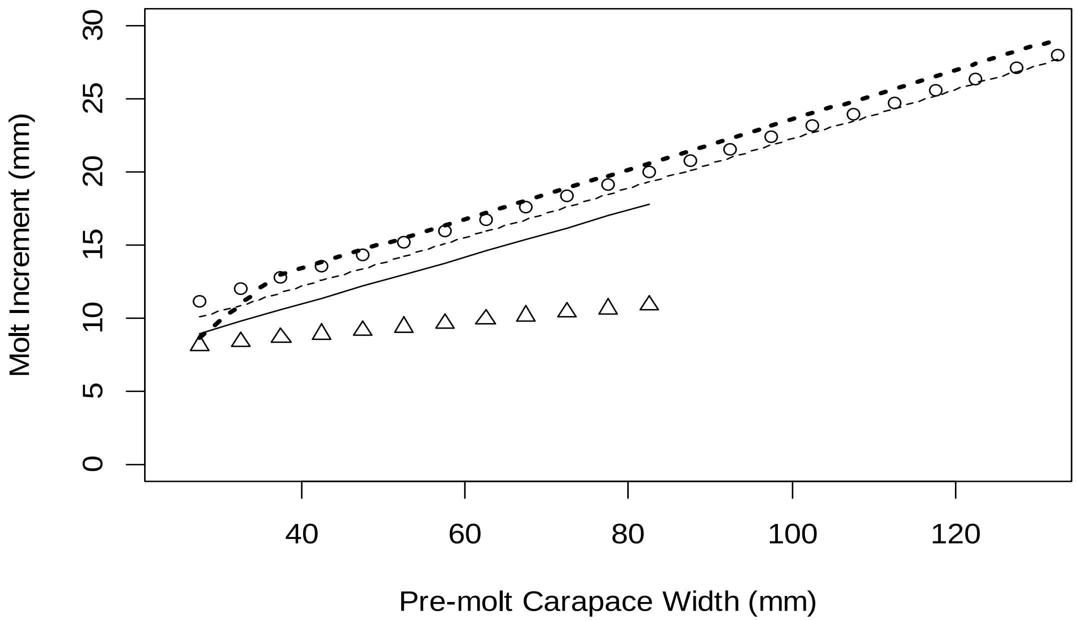

Figure 55. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the base model. The priors for the growth curve used in Scenarios 3 and 4 are circles (males) and triangle (females). Heavy dotted line is the growth curve estimated by Somerton for males and females from the 2011 growth study (Somerton 2012).

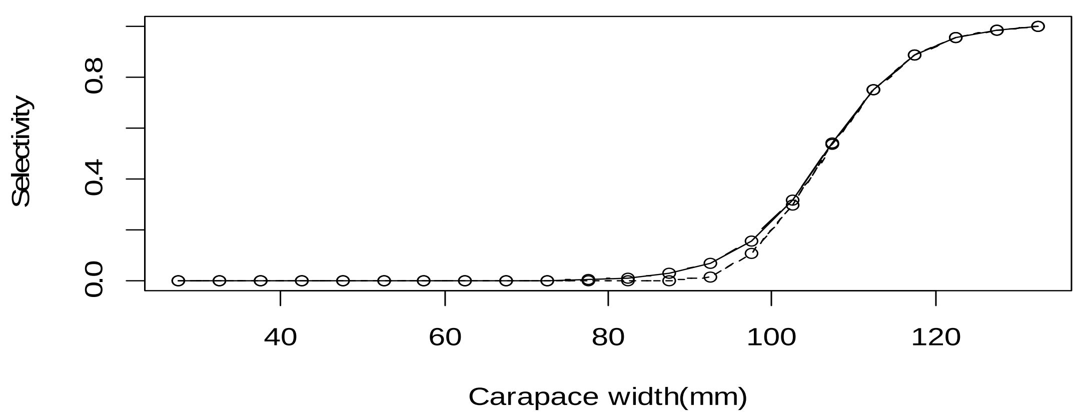

Figure 56. Base Model. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

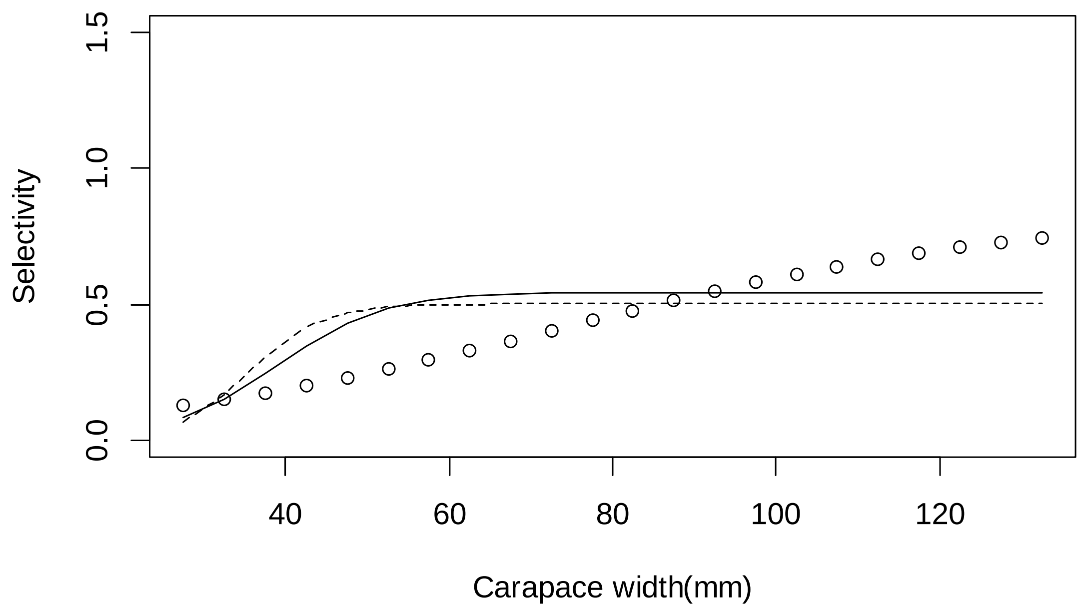

Figure 57. Base Model. Survey selectivity curves for female (dotted lines) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton from 2009 study area data (2010) are the circles.

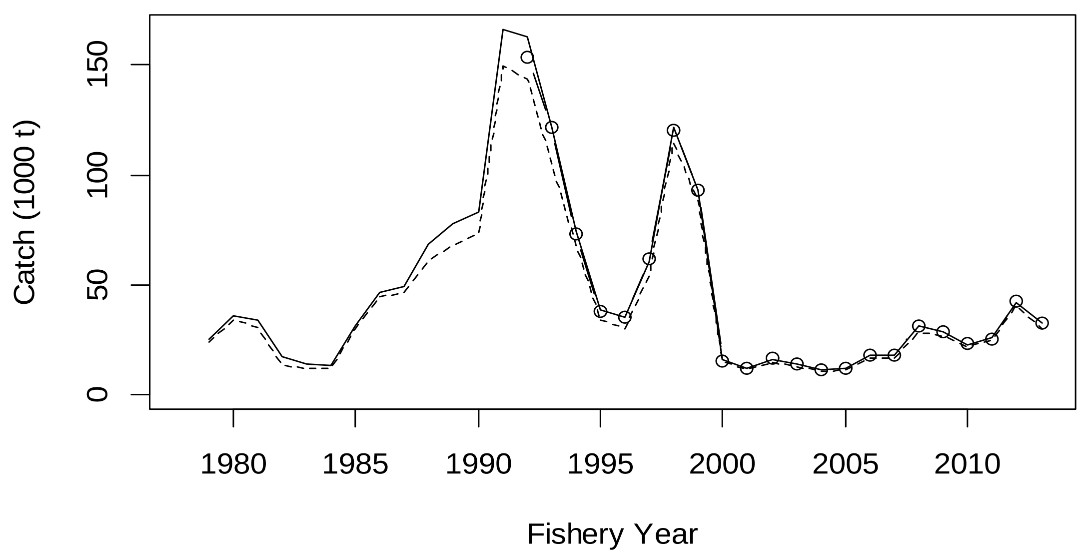

Figure 58. Base Model. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 50% mortality of discarded crab) and observed retained catch (dotted line).

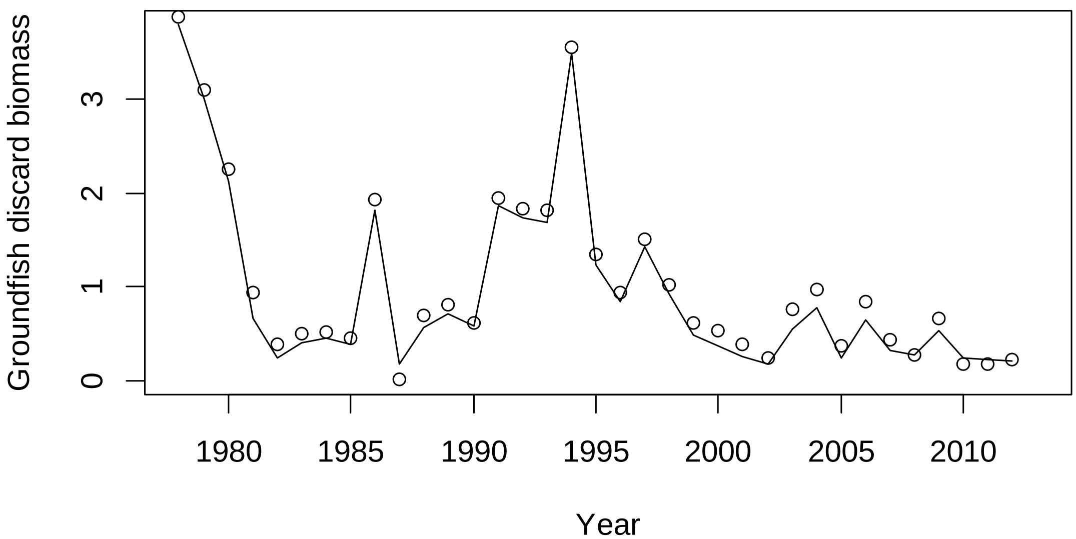

Figure 59. Base Model. Model fit to groundfish bycatch. Circles are observed catch, line is model estimate.

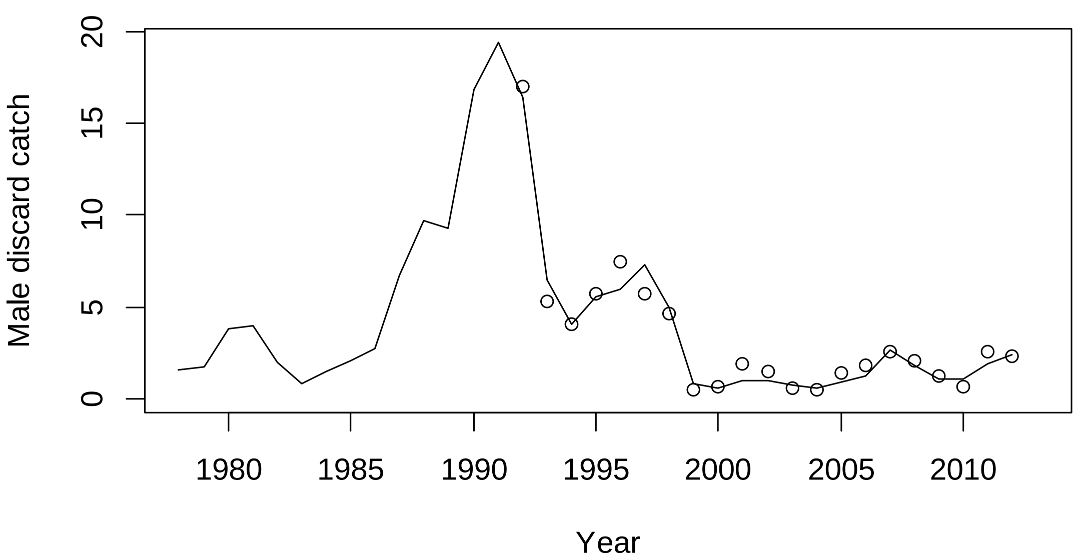

Figure 60. Base Model. Model fit to male directed discard catch for 1992/93 to 2012/13 and estimated male discard catch from 1978 to 1991.

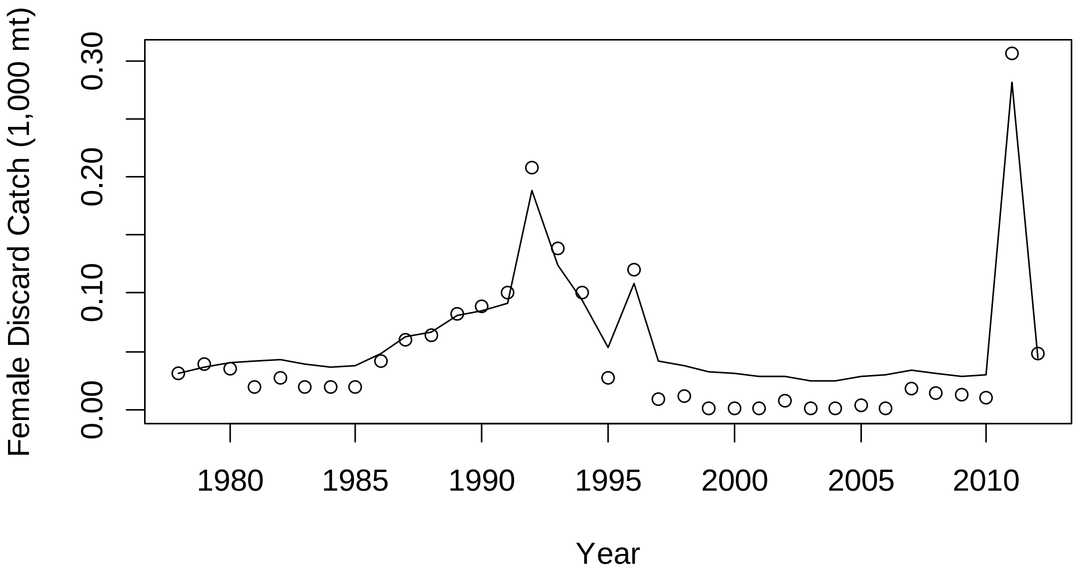

Figure 61. Base Model. Model fit to female discard bycatch in the directed fishery from 1992/93 to 2012/13 and model estimates of discard from 1978 to 1991.

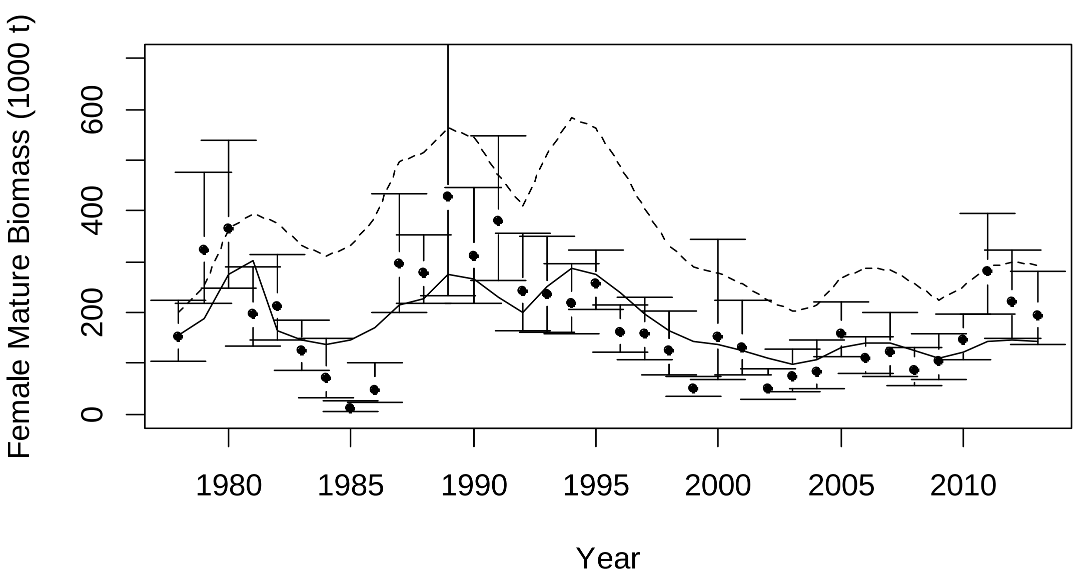

Figure 62. Base Model. Population female mature biomass (1000 t, dotted line), model estimate of survey female mature biomass (solid line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

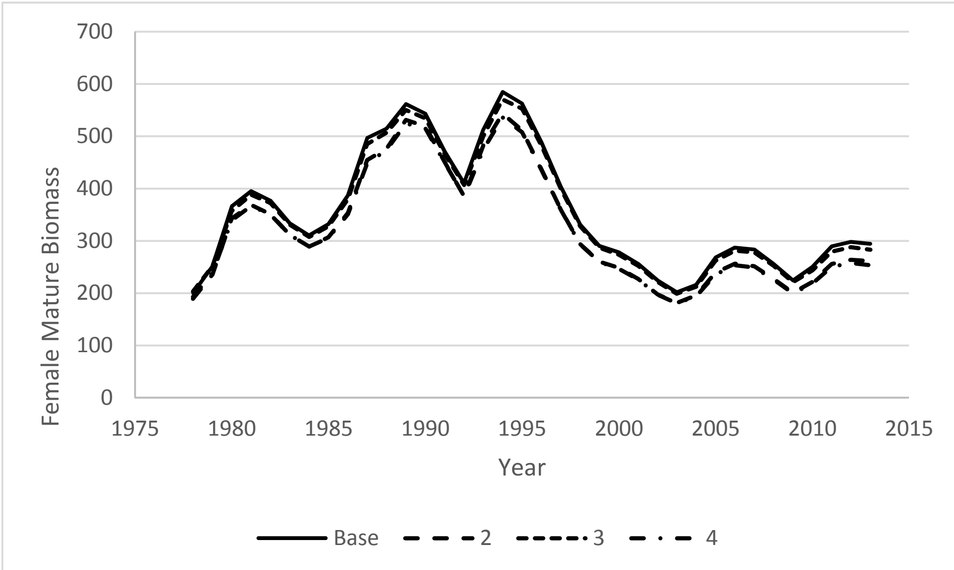

Figure 63. Population female mature biomass for the Base model and scenarios 2, 3 and 4.

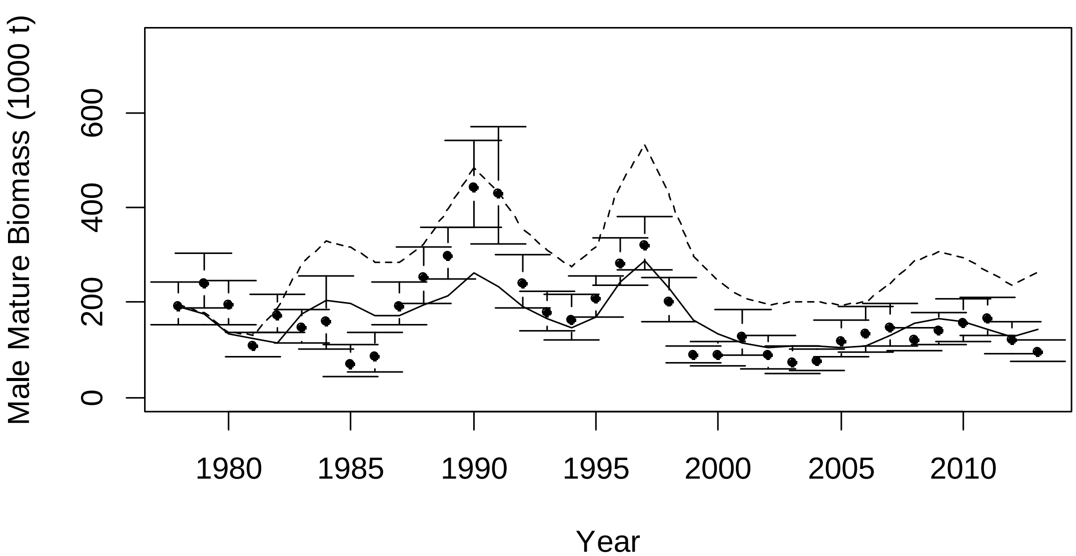

Figure 64. Base Model. Population male mature biomass (1000 t, dotted line), model estimate of survey male mature biomass (solid line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

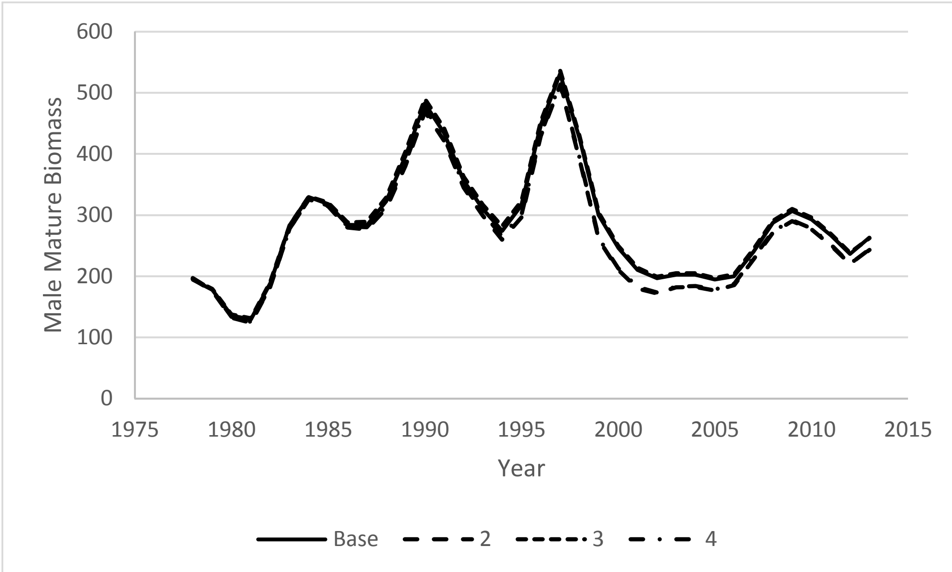

Figure 65. Population male mature for the Base model and scenarios 2, 3 and 4.

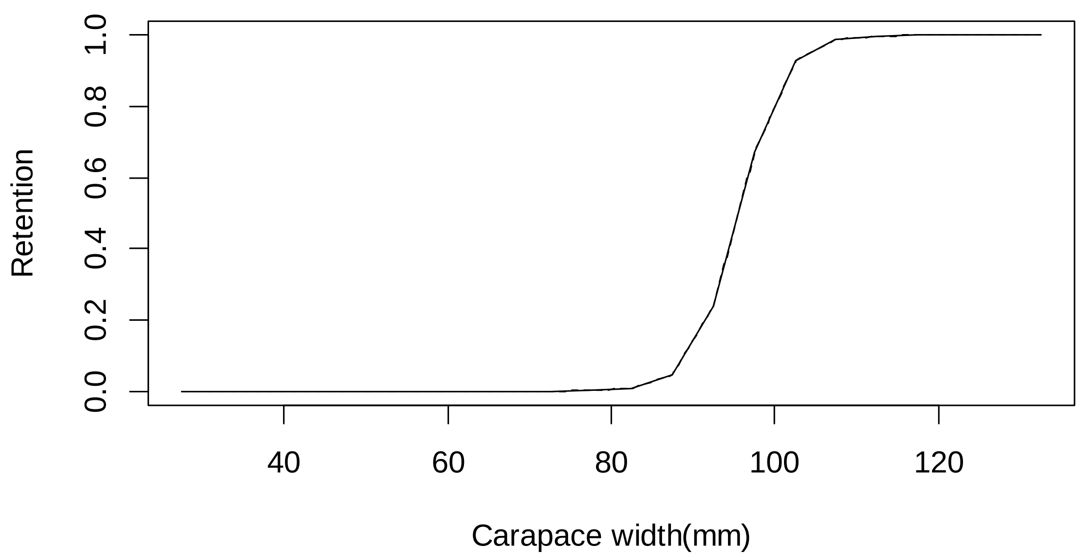

Figure 66. Base Model. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

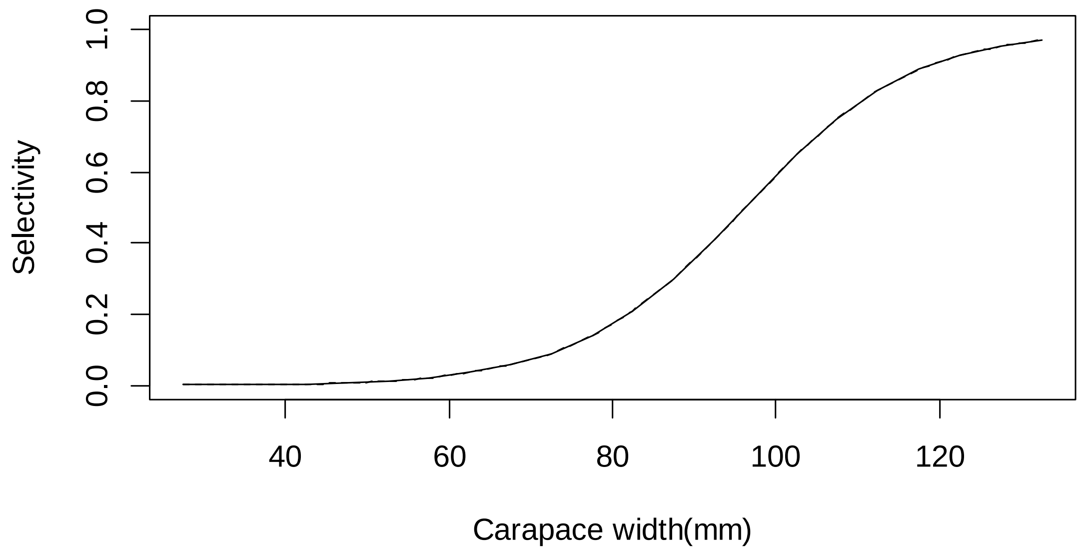

Figure 67. Base Model. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

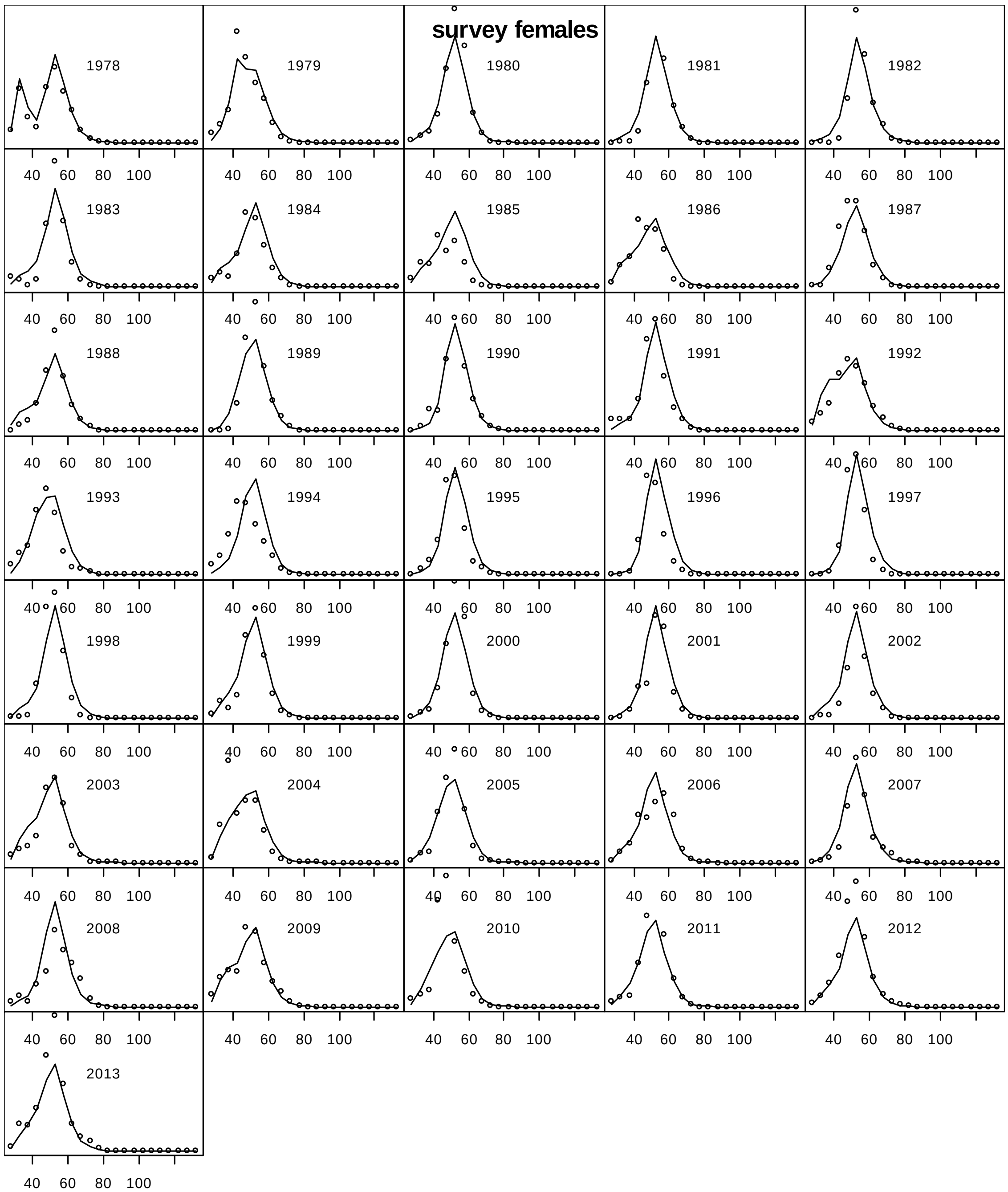

Figure 68. Base Model. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

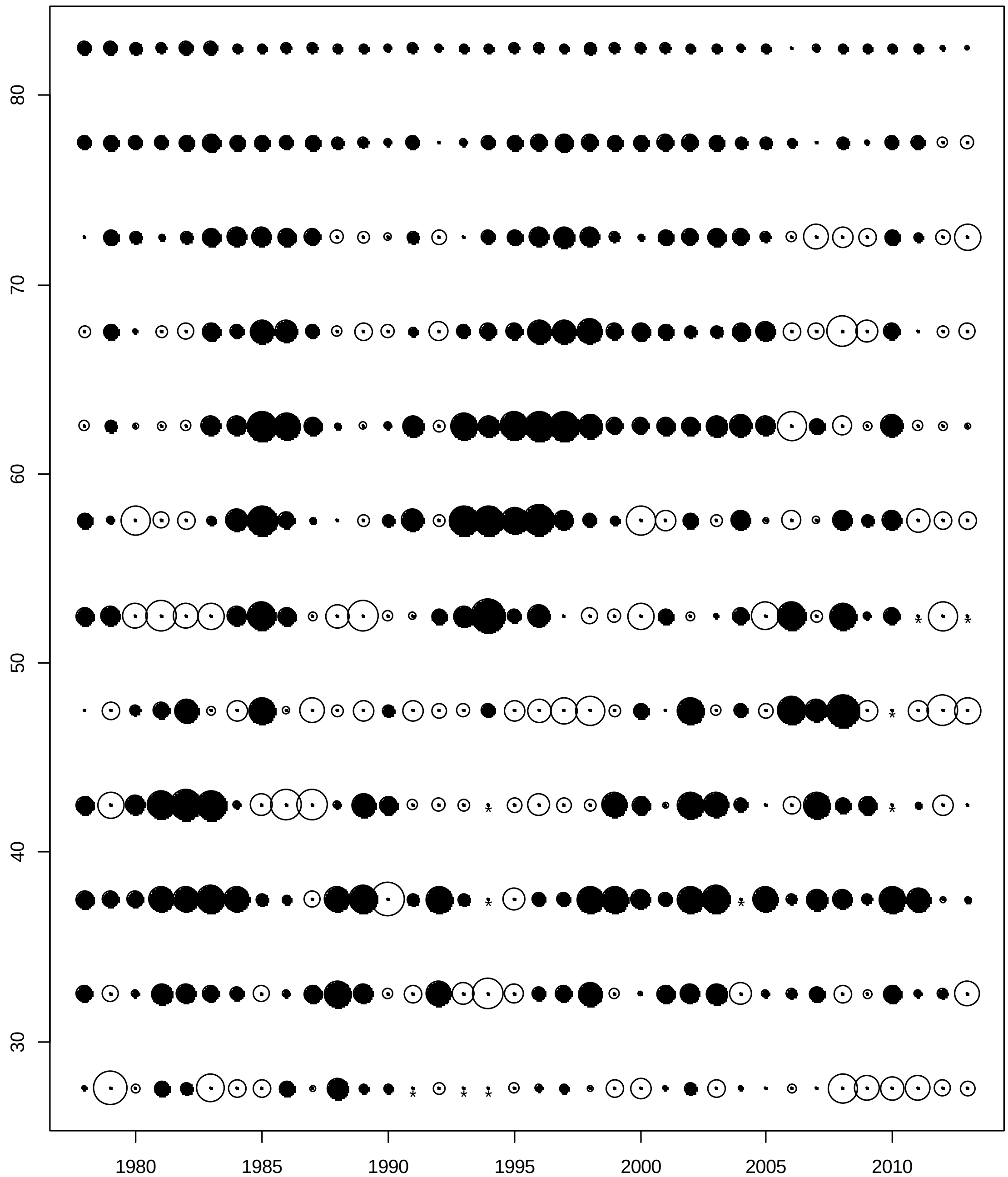

Figure 69. Base Model. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

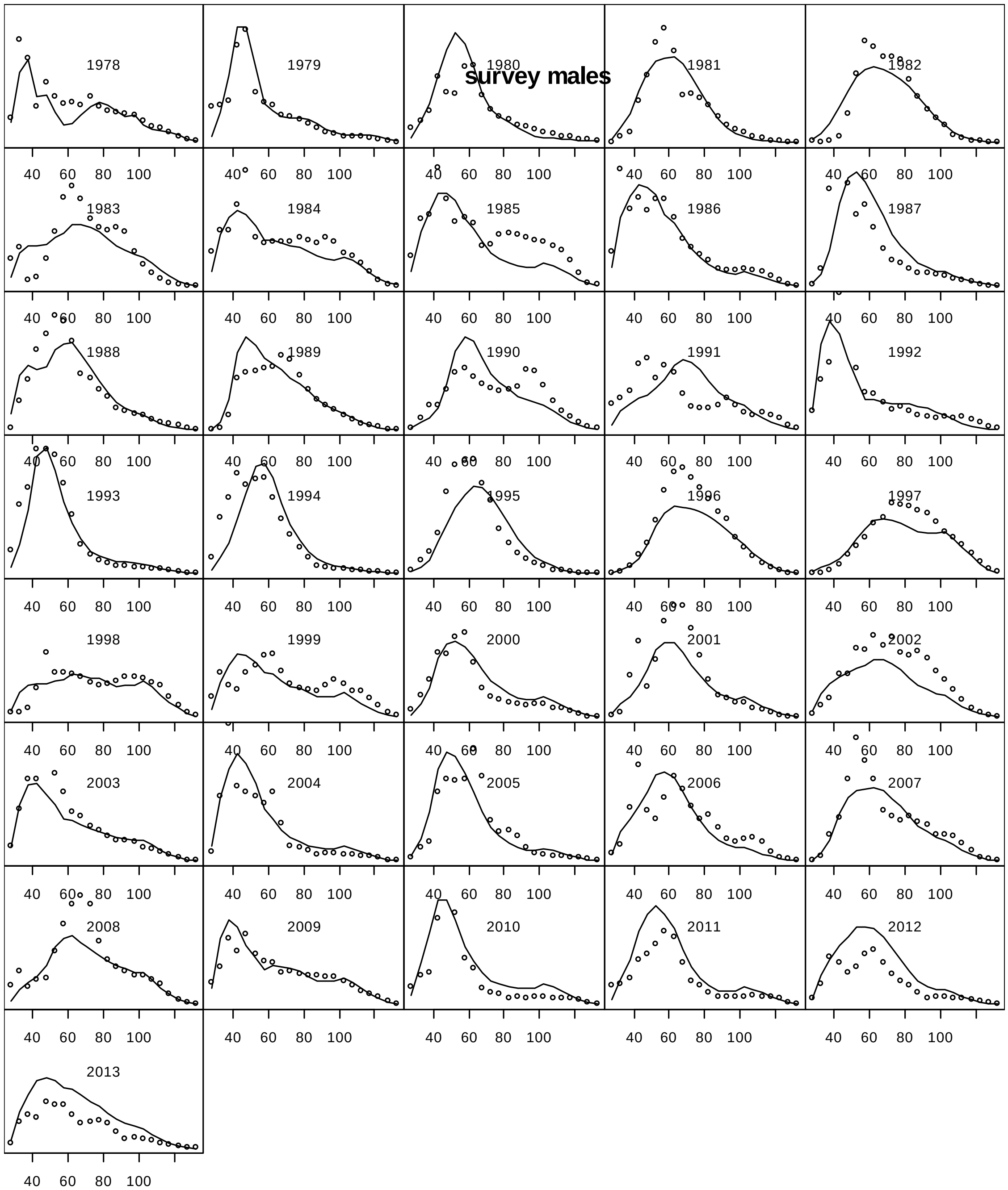

Figure 70. Base Model. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

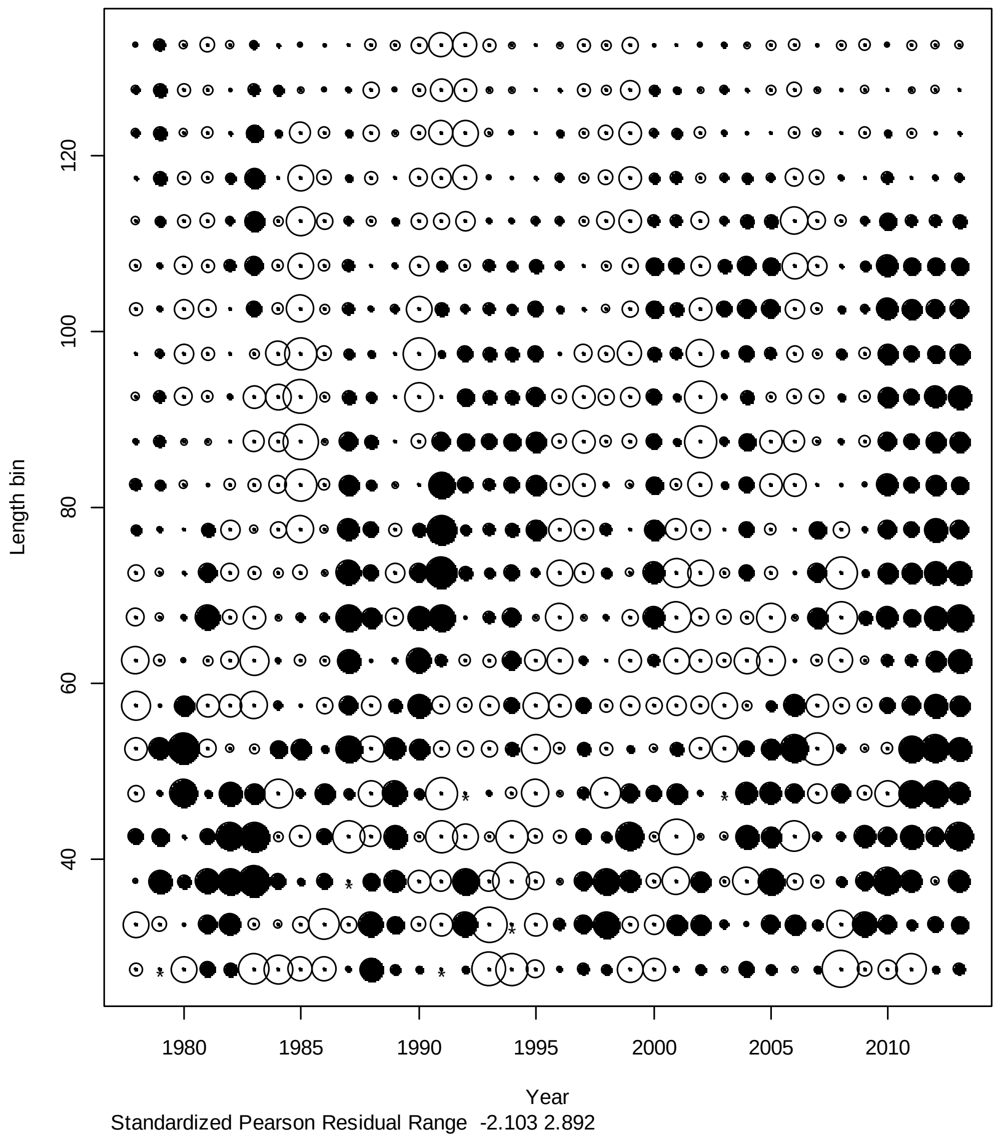

Figure 71. Base Model. Residuals for fit to survey male size frequency. . Filled circles are negative residuals (predicted higher than observed).

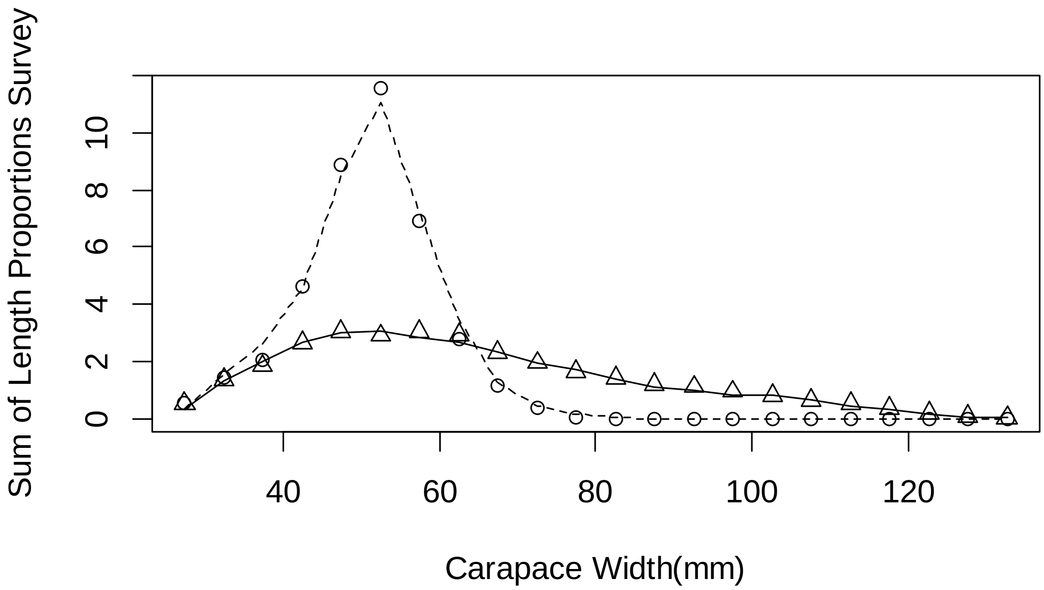

Figure 72. Base Model. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

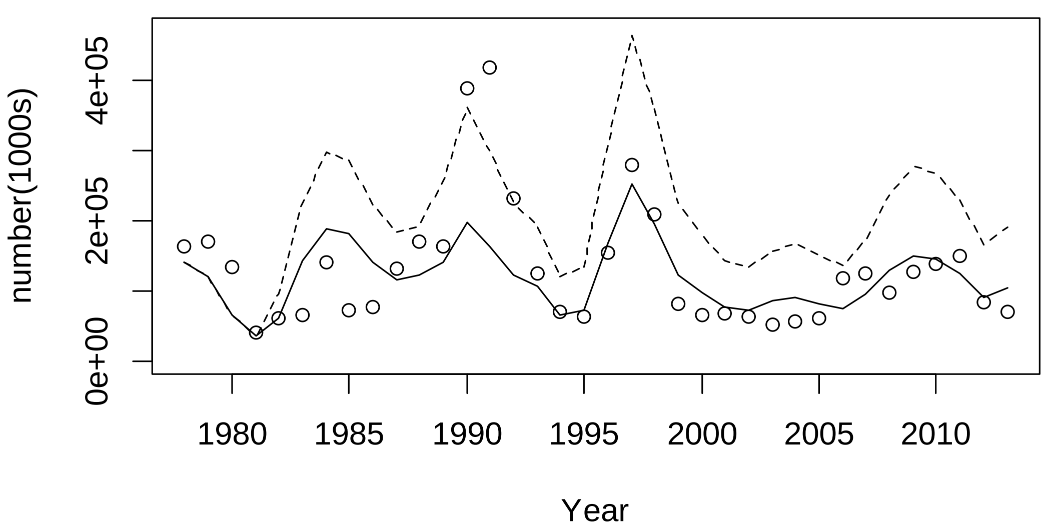

Figure 73. Base Model. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

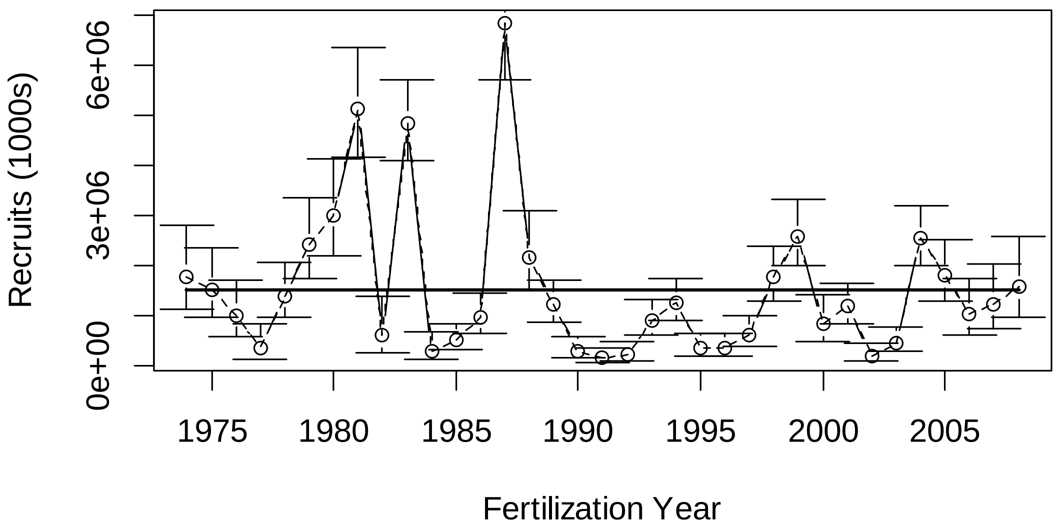

Figure 74. Base Model. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

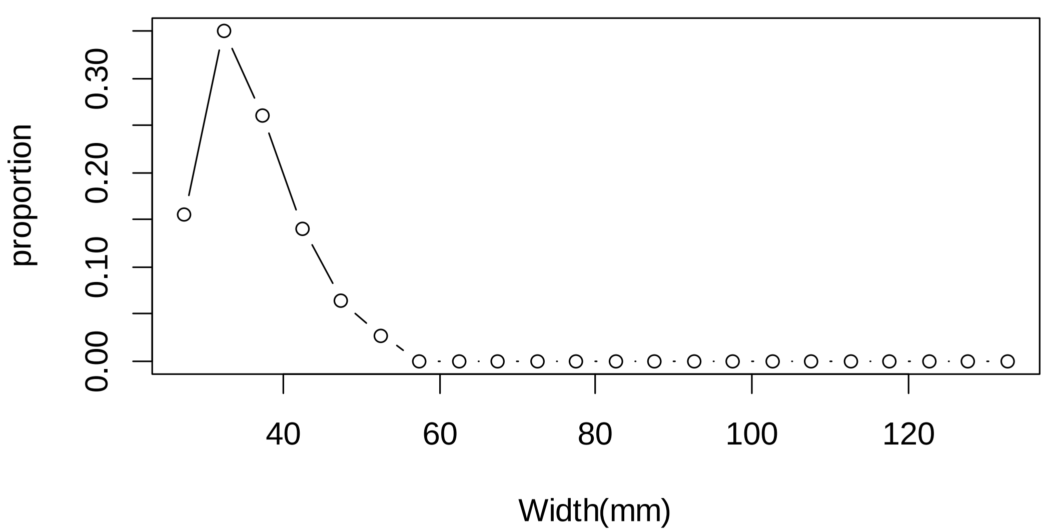

Figure 75. Base Model. Distribution of recruits to length bins estimated by the model.

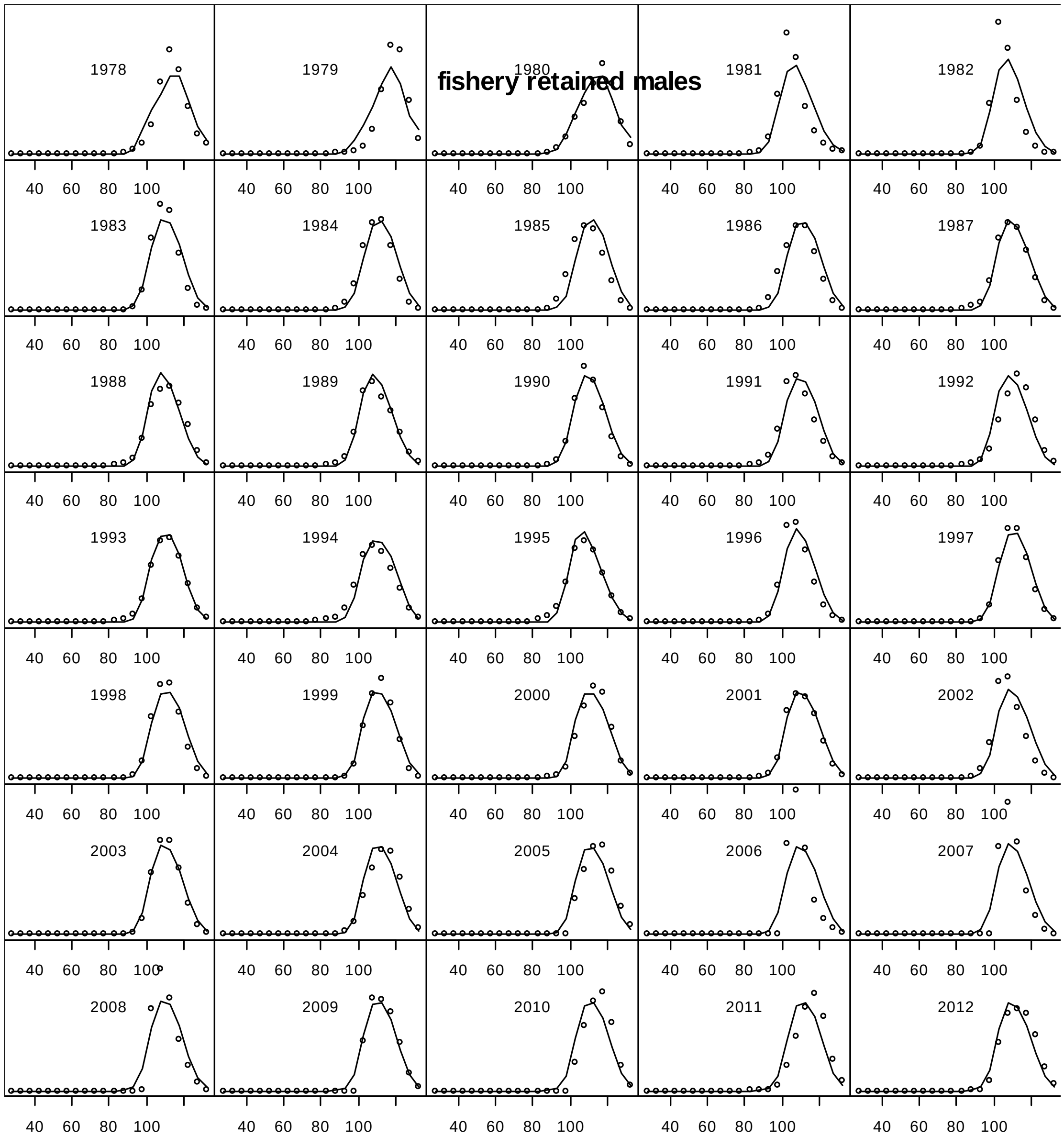

Figure 76. Base Model. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

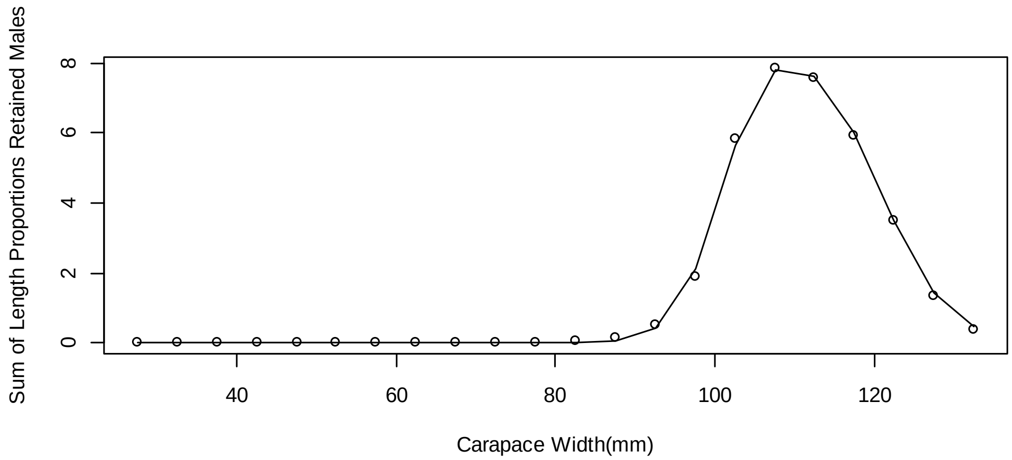

Figure 77. Base Model. Summary fit to retained male length.

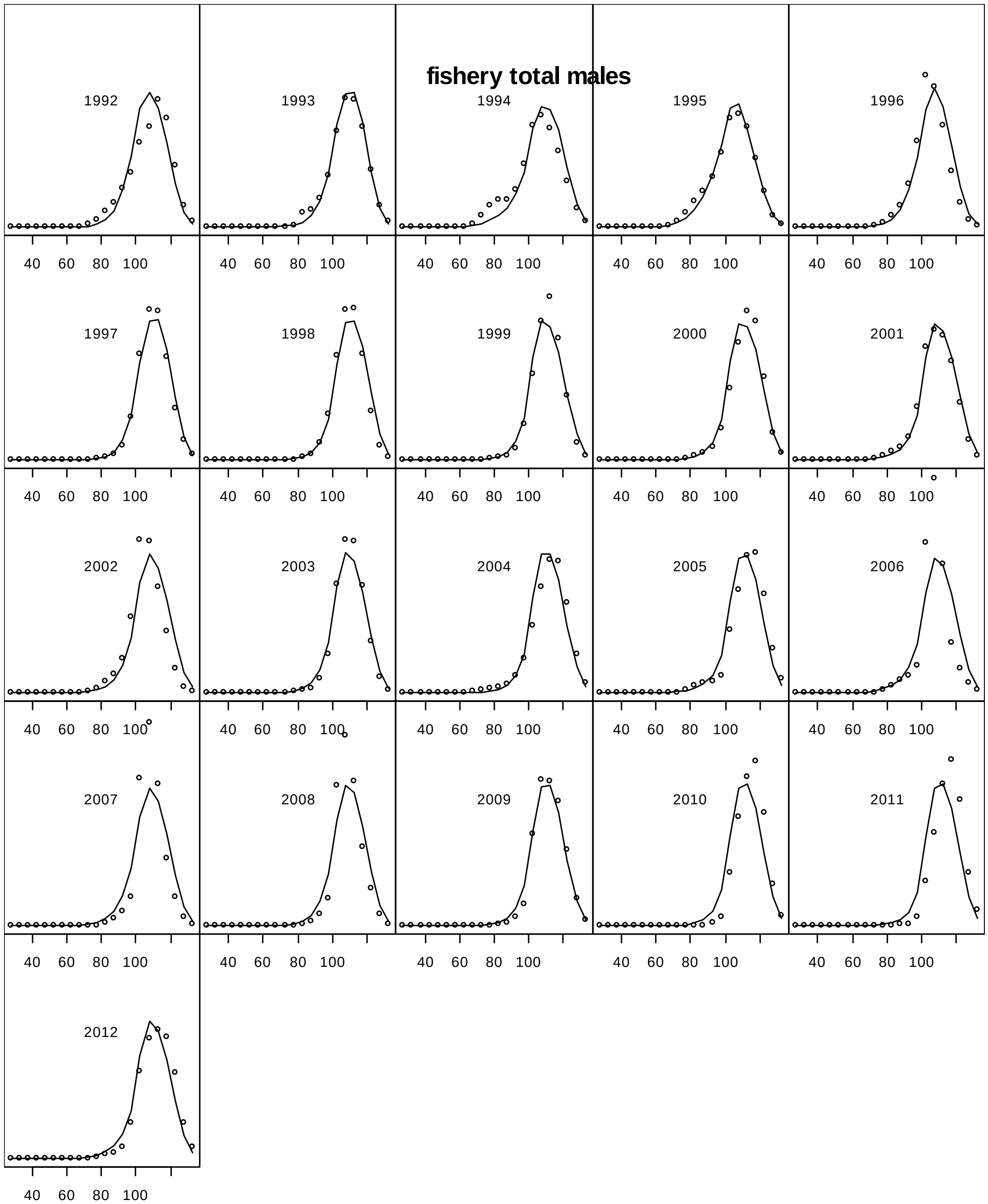

Figure 78. Base Model. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

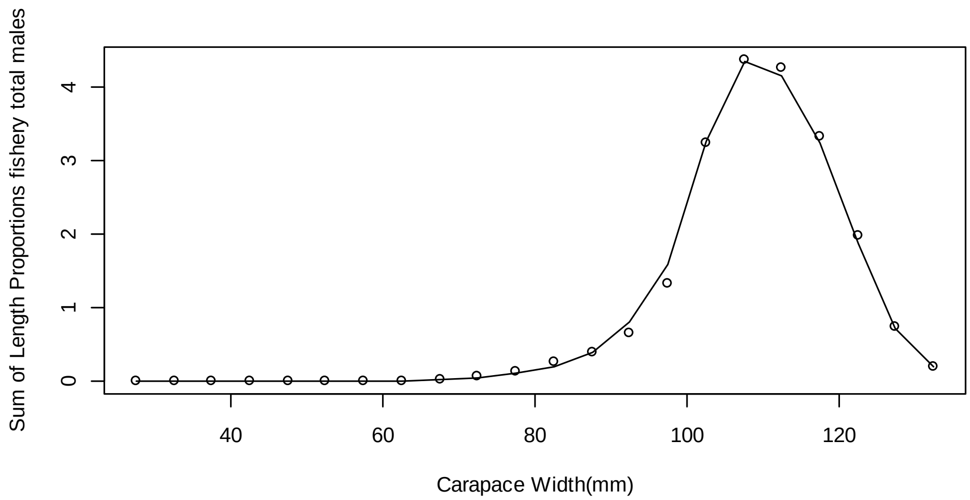

Figure 79. Base Model. Summary fit to total length frequency male catch.

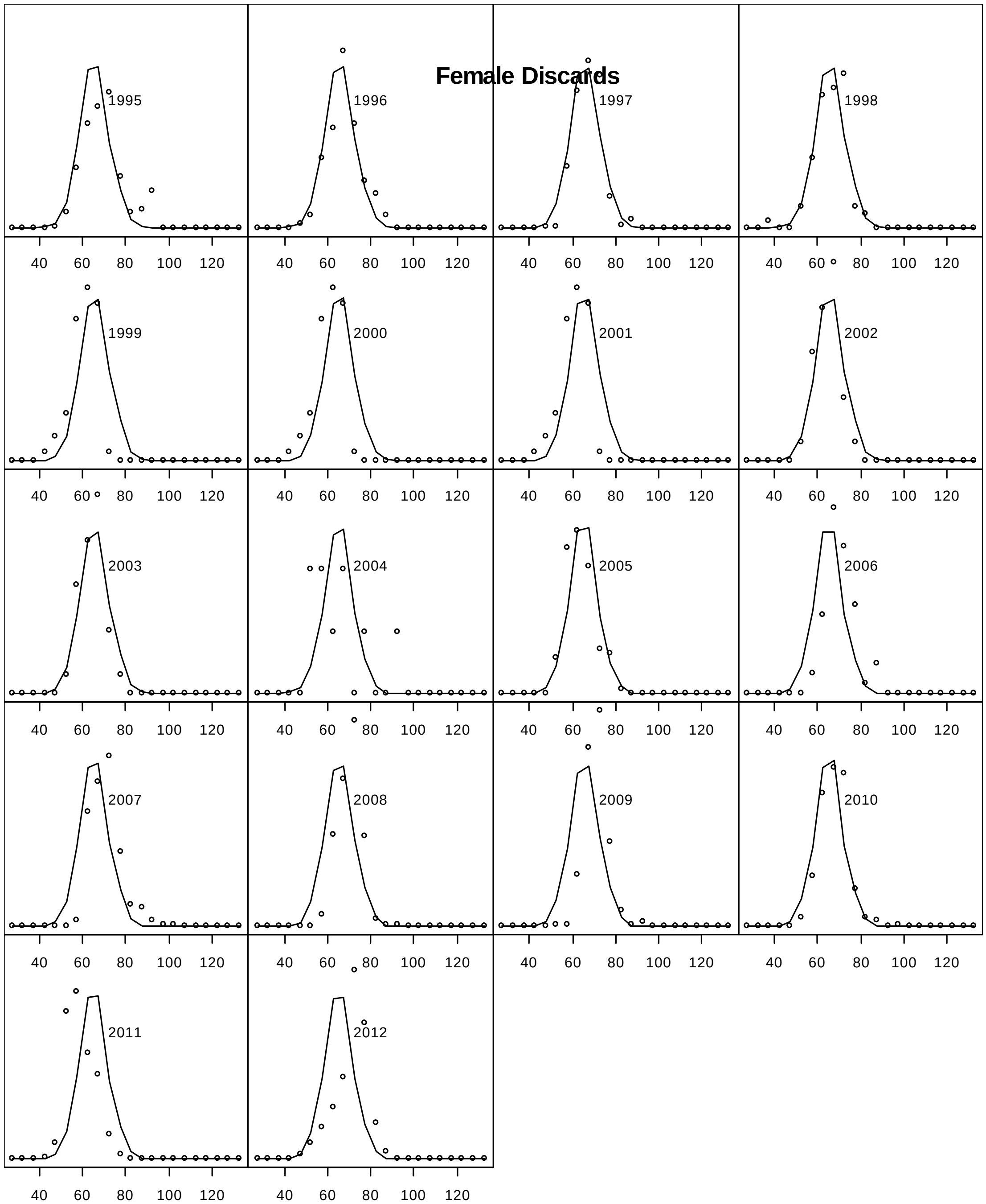

Figure 80. Base Model. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

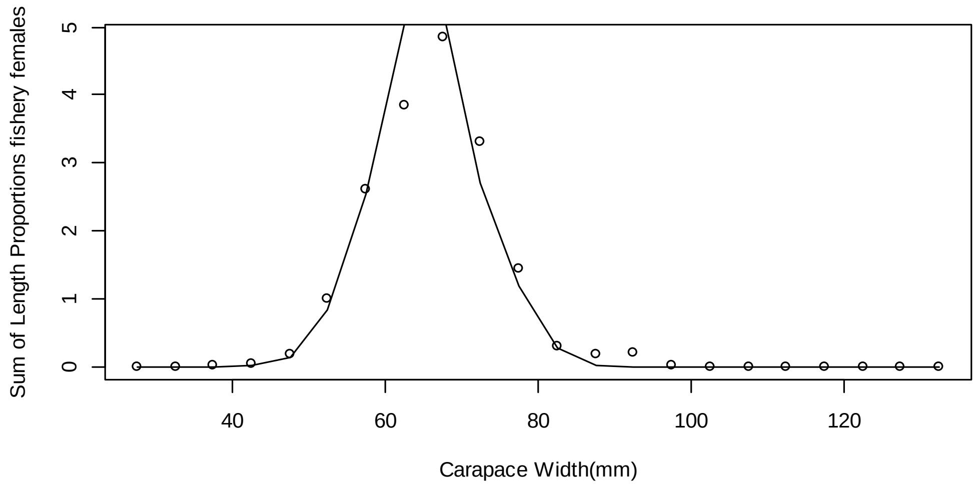

Figure 81. Base Model. Summary fit to directed fishery female discards.

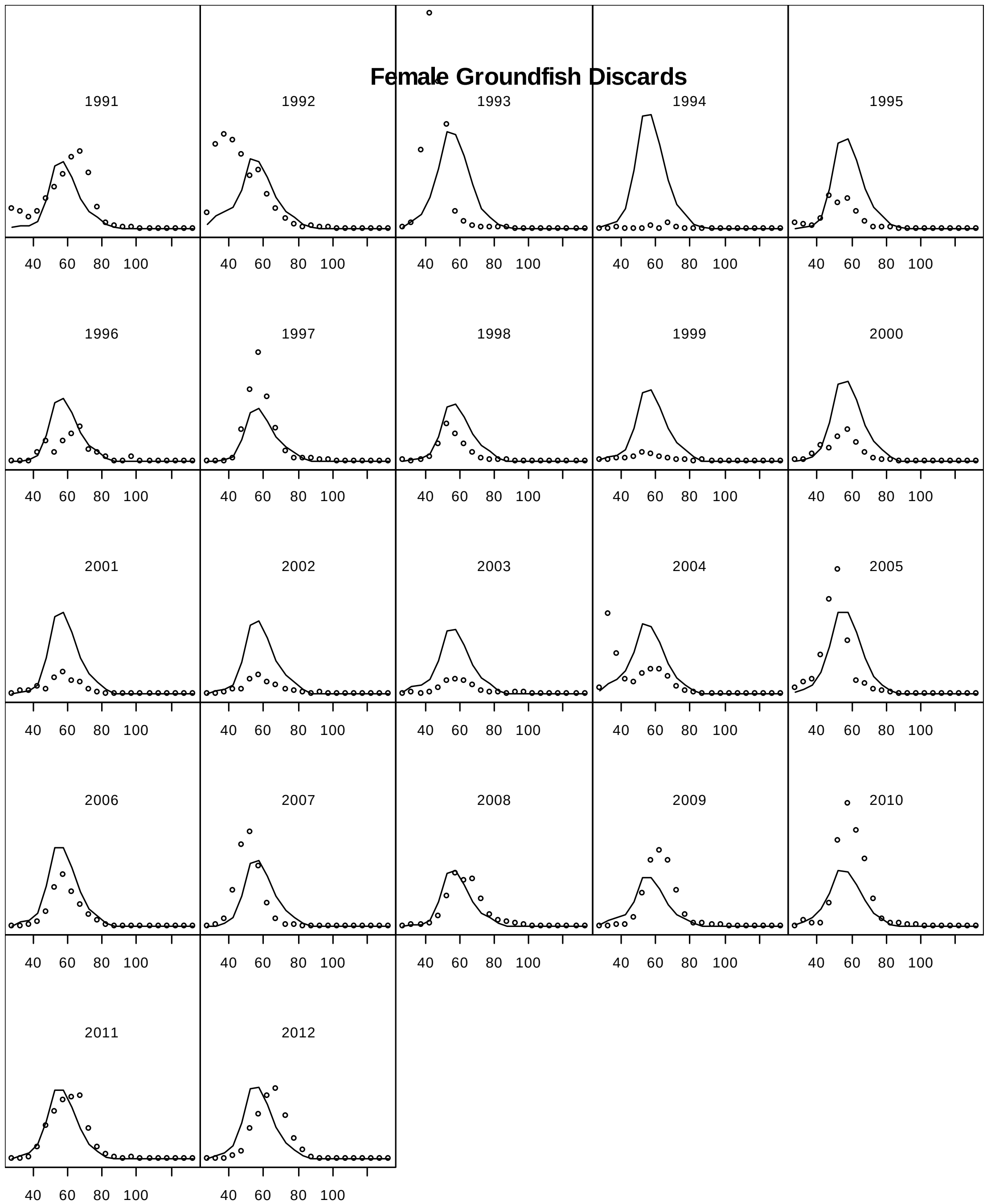

Figure 82. Base Model. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

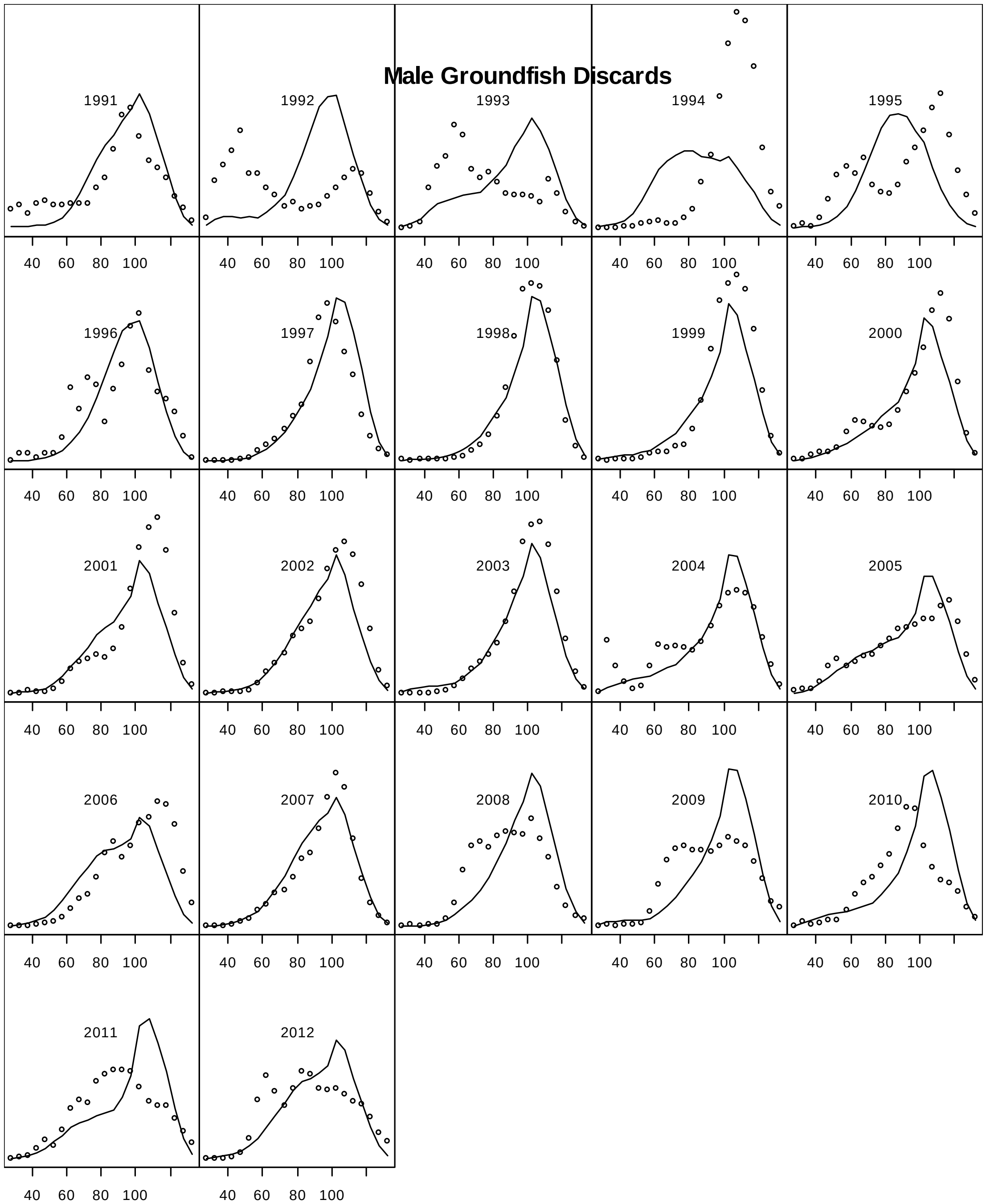

Figure 83. Base Model. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

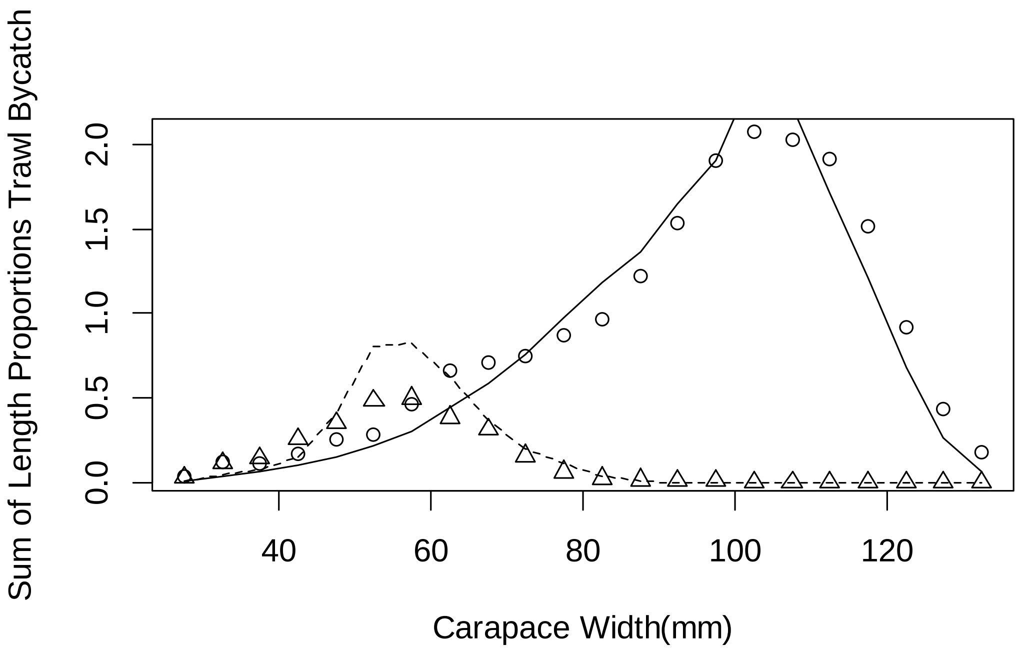

Figure 84. Base Model. Summary fit to groundfish length frequency.

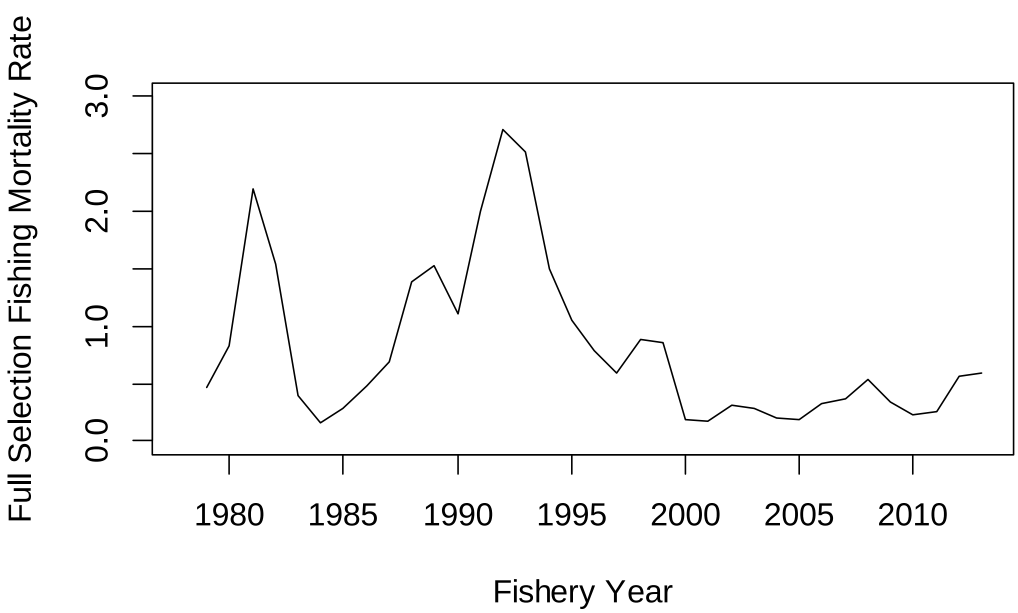

Figure 85. Base Model. Full selection fishing mortality estimated in the model from 1978/79 to 2011/12 fishery seasons.

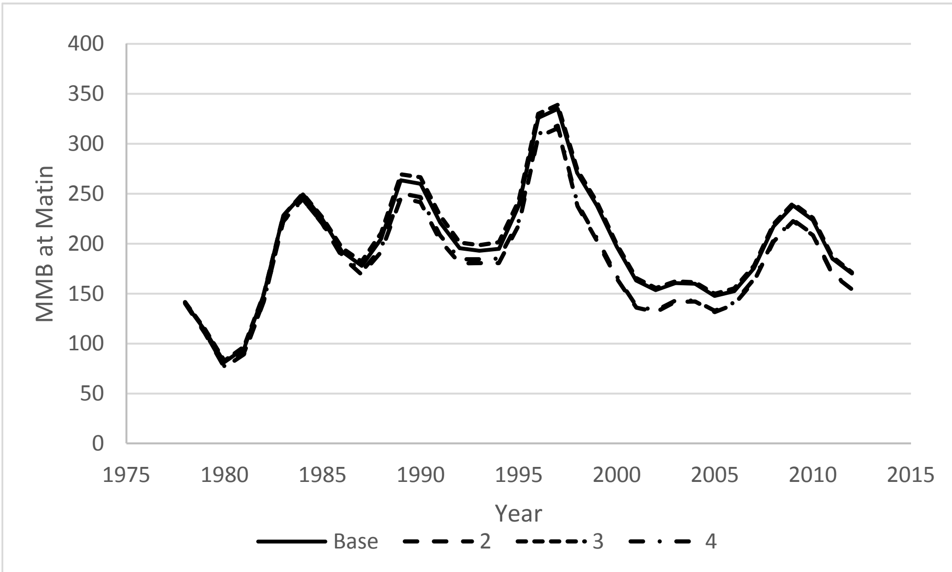

Figure 87. Mature male biomass at mating for the Base model and scenarios 2, 3 and 4.

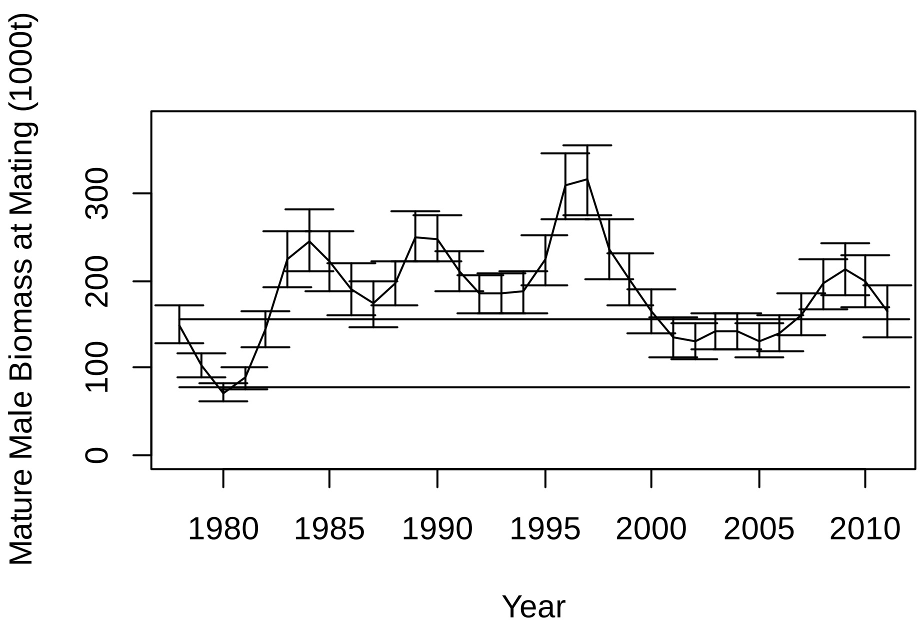

Figure 88. Base Model. Mature Male Biomass at mating with 95% confidence intervals. Top horizontal line is B35%, lower line is ½ B35%.

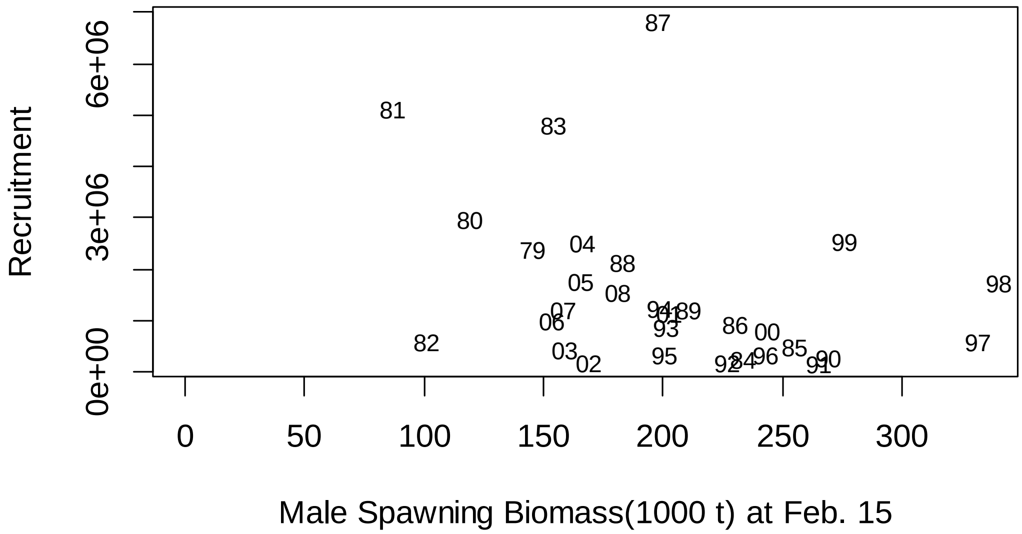

Figure 89. Base Model. Spawner recruit estimates using male mature biomass at time of mating (1000t). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

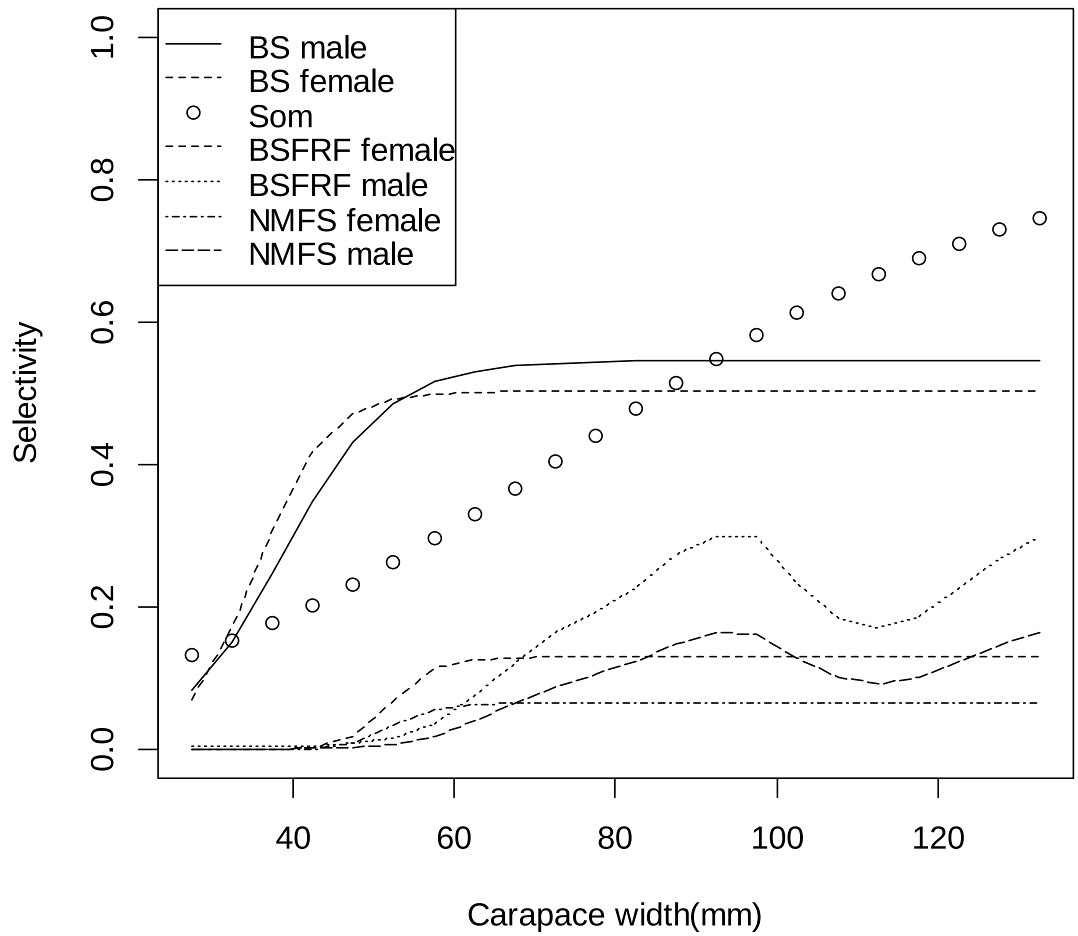

Figure 90. Base Model. Survey selectivity curves entire Bering Sea survey for female (upper dashed line) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton(2010) from 2009 study area data are the circles. Lower lines are survey selectivities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

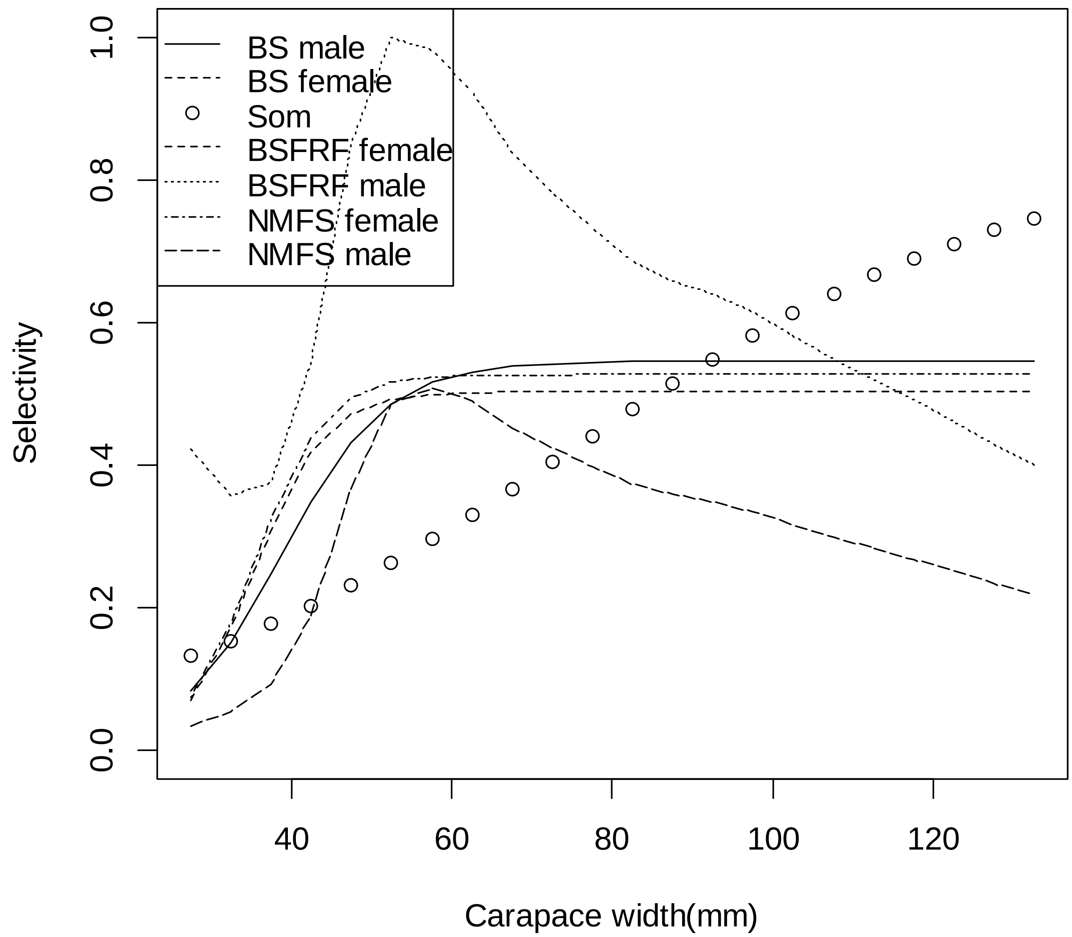

Figure 91. Base Model. 2010 study area survey selectivity curves (BSFRF and NMFS). BS are survey selectivity curves for the entire Bering Sea. Som is the selectivity curve estimated by Somerton from the 2009 study area data.

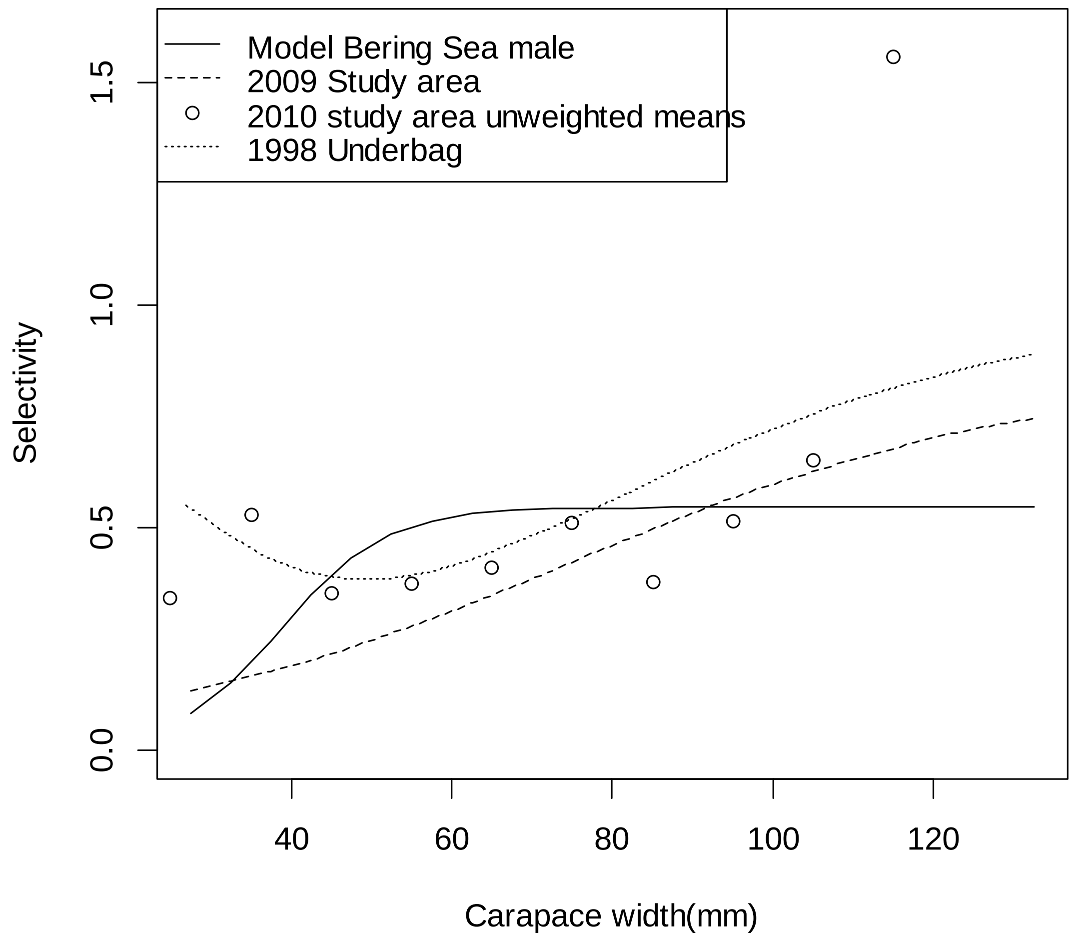

Figure 92. Base Model. Survey selectivity for male crab 1989- present (Model Bering Sea male), with selectivity curves estimated outside the model. 2009 study area is the curve estimated by Somerton from the 2009 study area data.

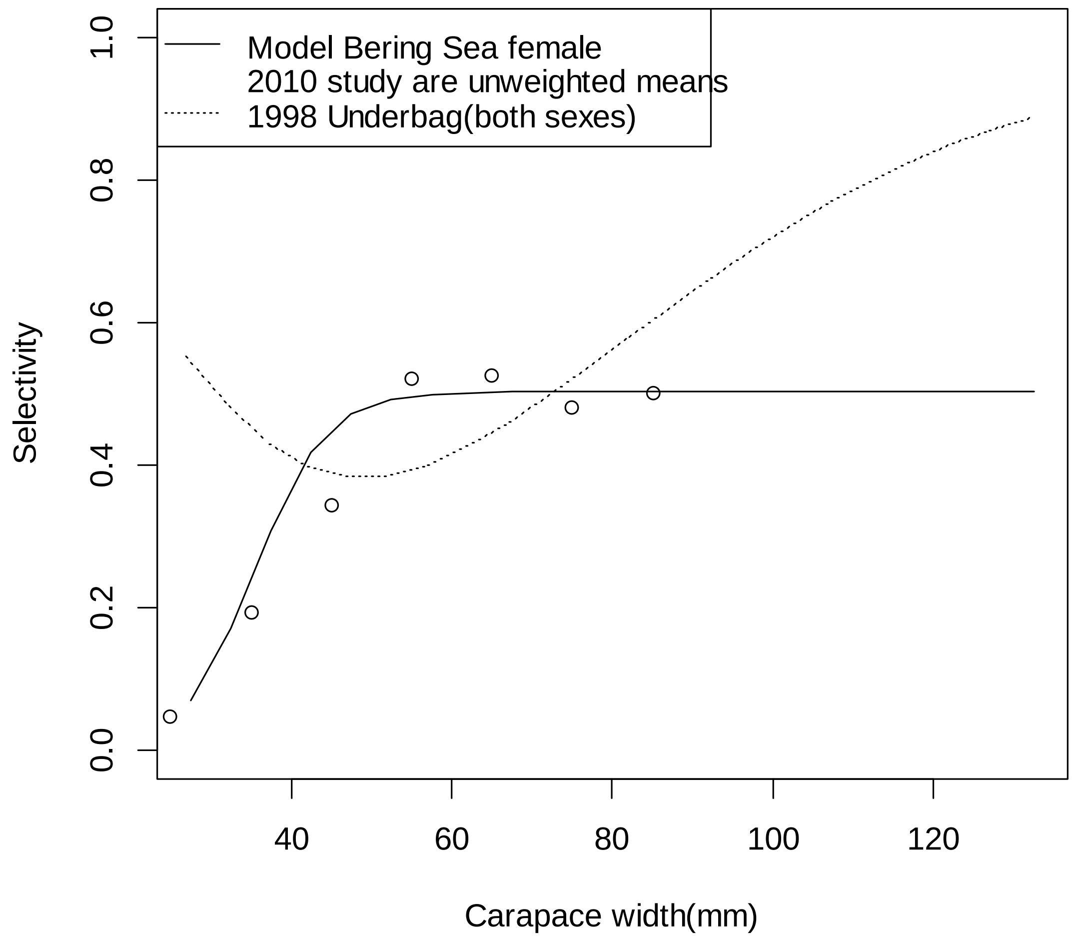

Figure 93. Base Model. Survey selectivity for female crab 1989- present (Model Bering Sea female).

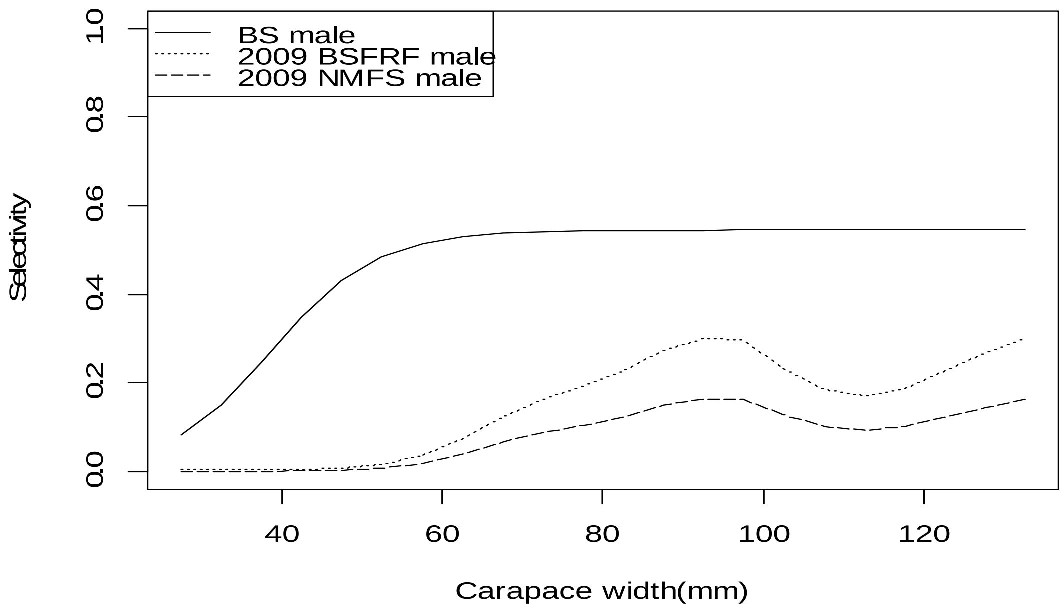

Figure 94. Base Model. Survey selectivity curves for male crab in the entire Bering sea 1989-present (BS male), 2009 study area BSFRF male and 2009 study area NMFS male.

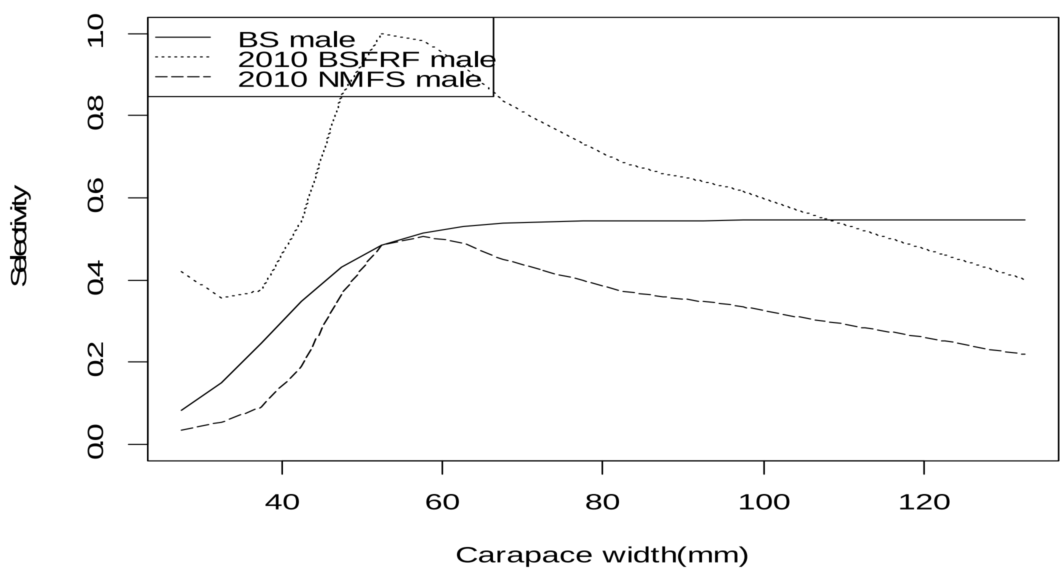

Figure 95. Base Model. Survey selectivity curves for male crab in the entire Bering sea 1989-present (BS male), 2010 study area BSFRF male and 2010 study area NMFS male.

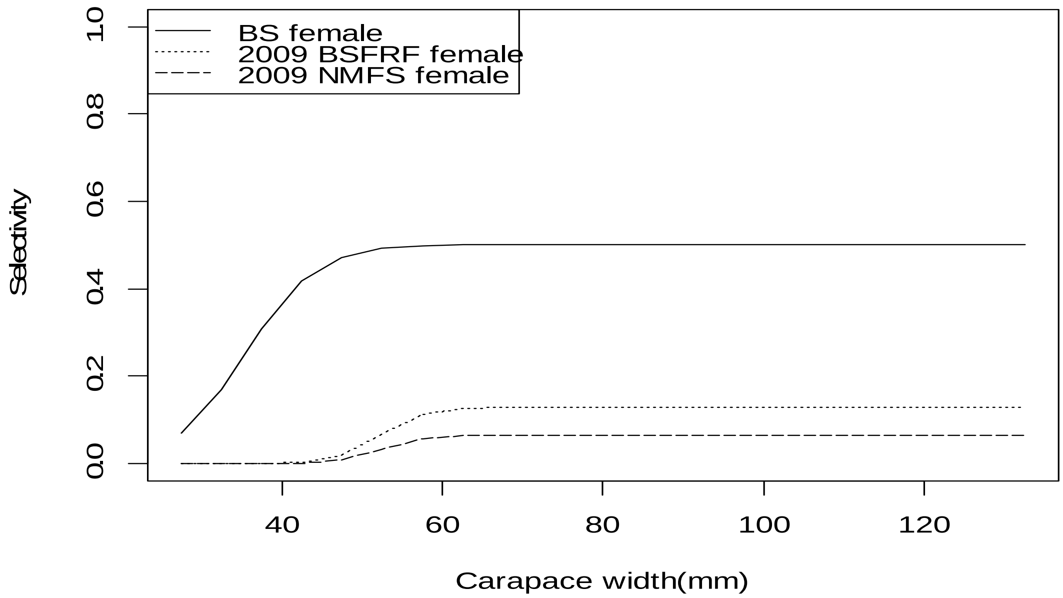

Figure 96. Base Model. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2009 study area BSFRF female and 2009 study area NMFS female.

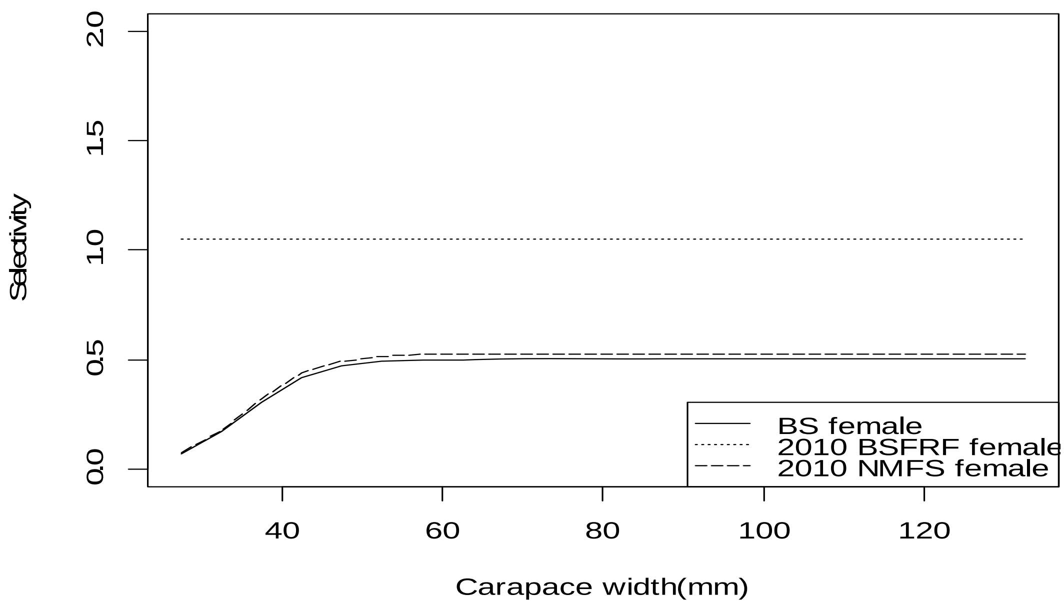

Figure 97. Base Model. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2010 study area BSFRF female and 2010 study area NMFS female.

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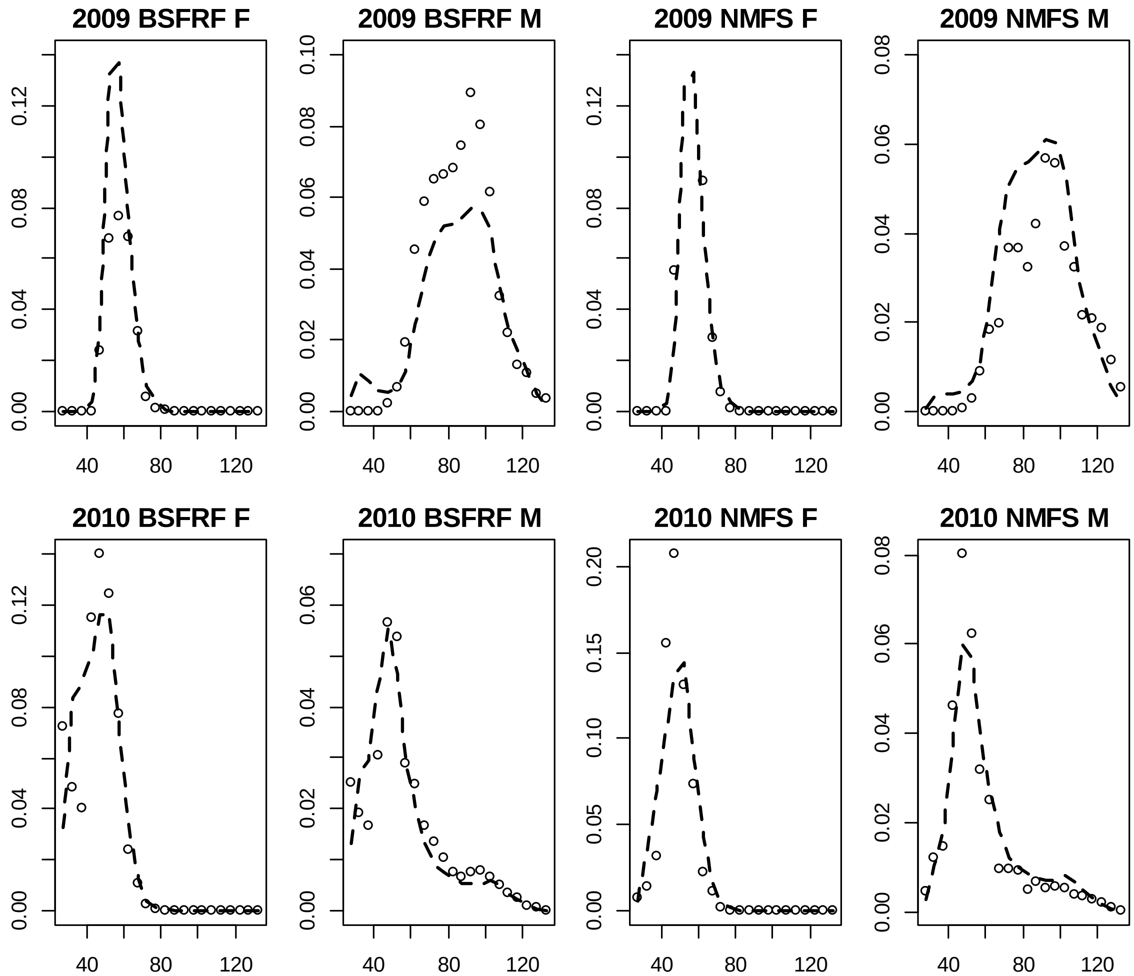


Figure 98. Base Model. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

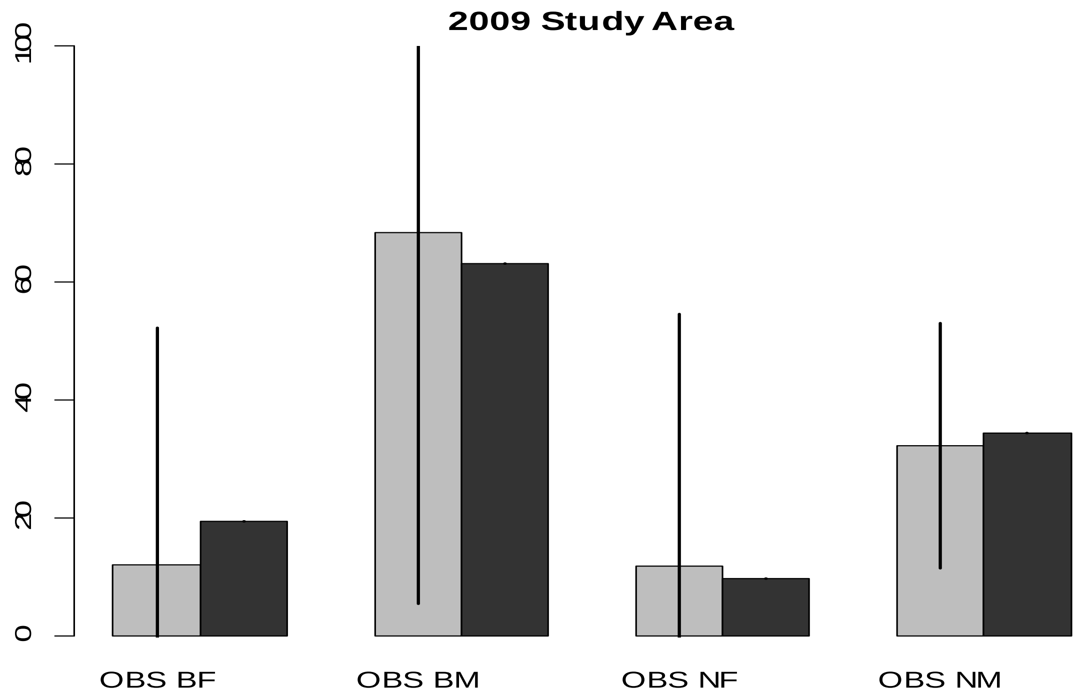


Figure 99. Base Model. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

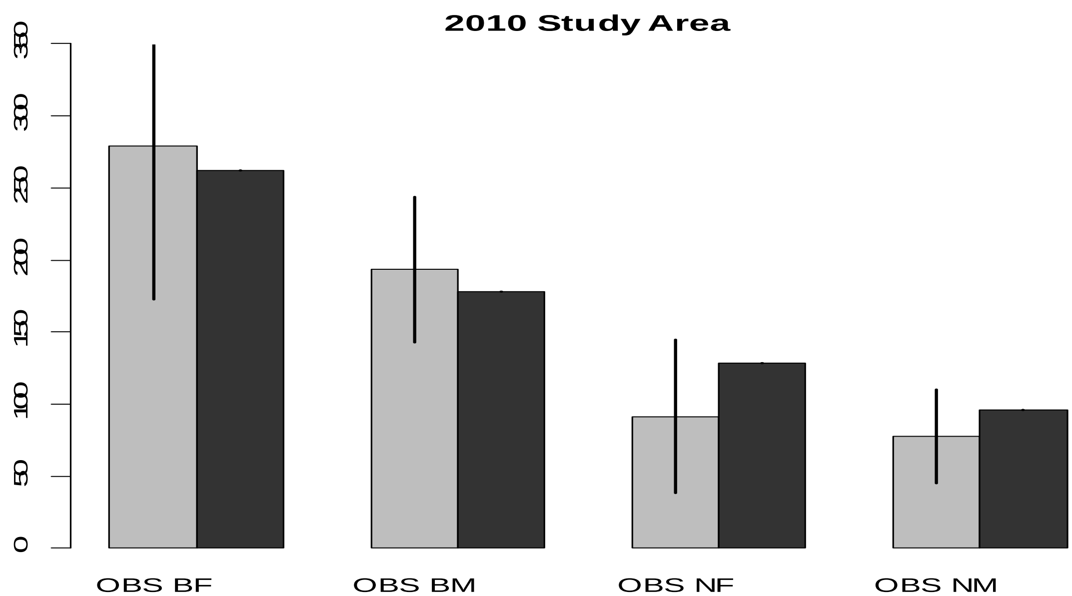


Figure 100. Base Model. Fits to 2010 study area mature biomass by sex for BSFRF and NMFS data.

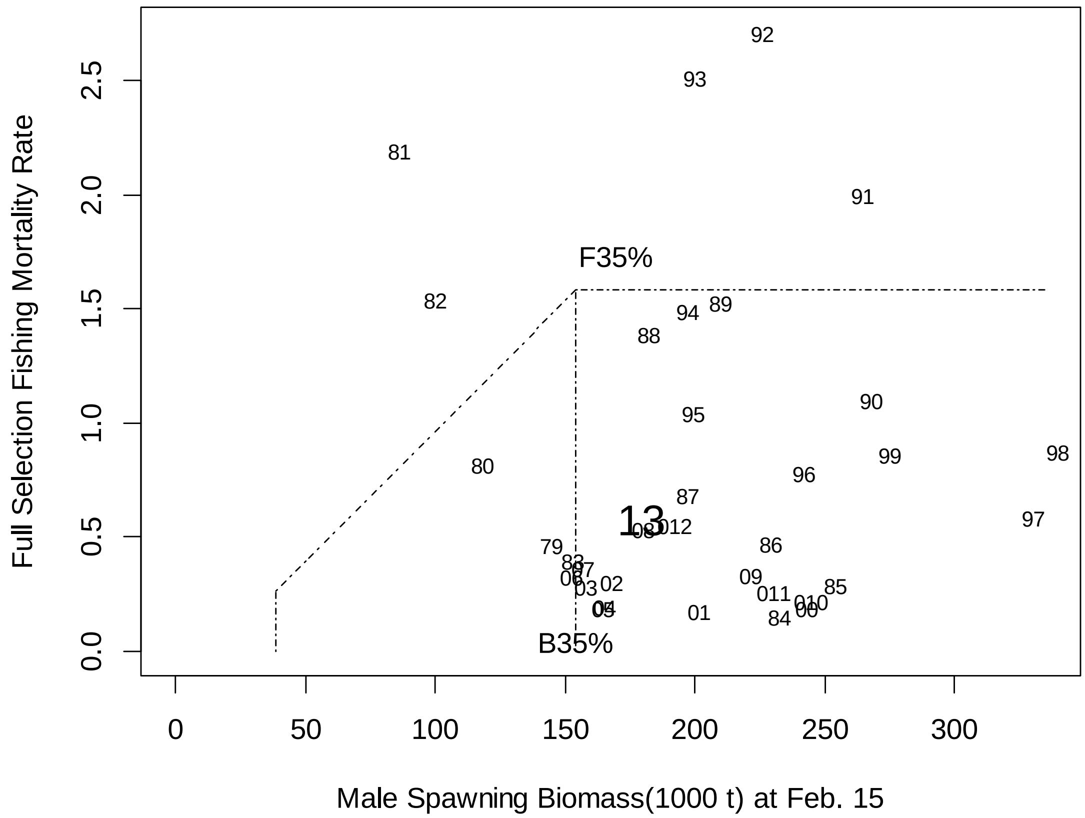


Figure 101. Base Model. Fishing mortality estimated from fishing years 1979 to 20012/13 (labeled 13 in the plot). The OFL control rule (F35%) is shown for comparison. The vertical line is B35%, estimated from the product of spawning biomass per recruit fishing at F35% and mean recruitment from the stock assessment model.

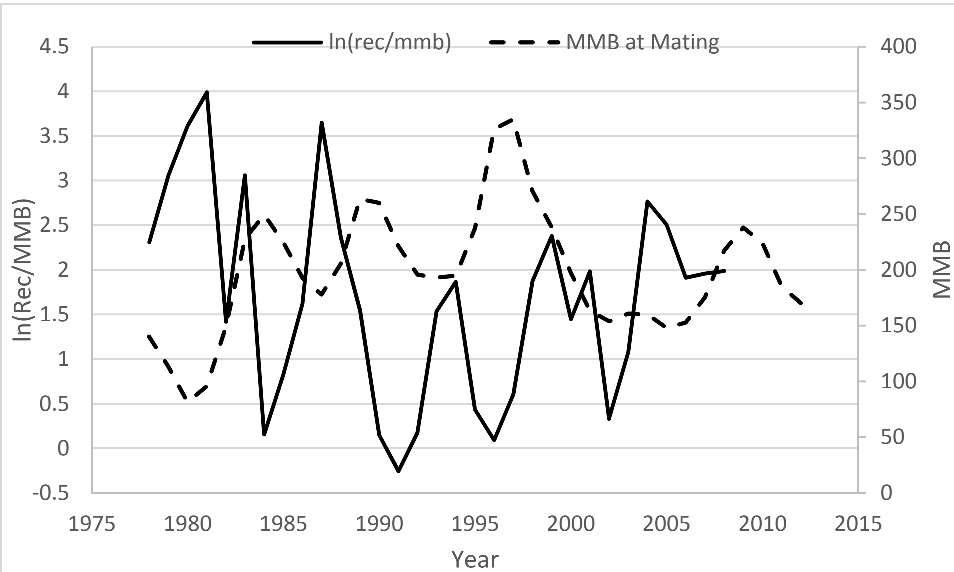


Figure 102. Log of recruits/MMB at mating with a 5 yr lag for recruitment and mature male biomass at mating.

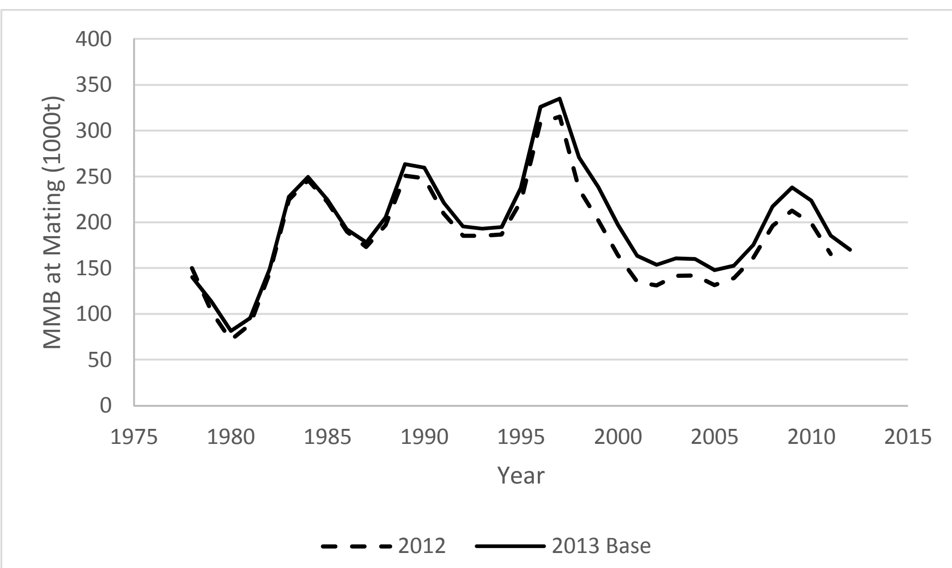


Figure 103. MMB at mating from the 2012 assessment and the Base model.

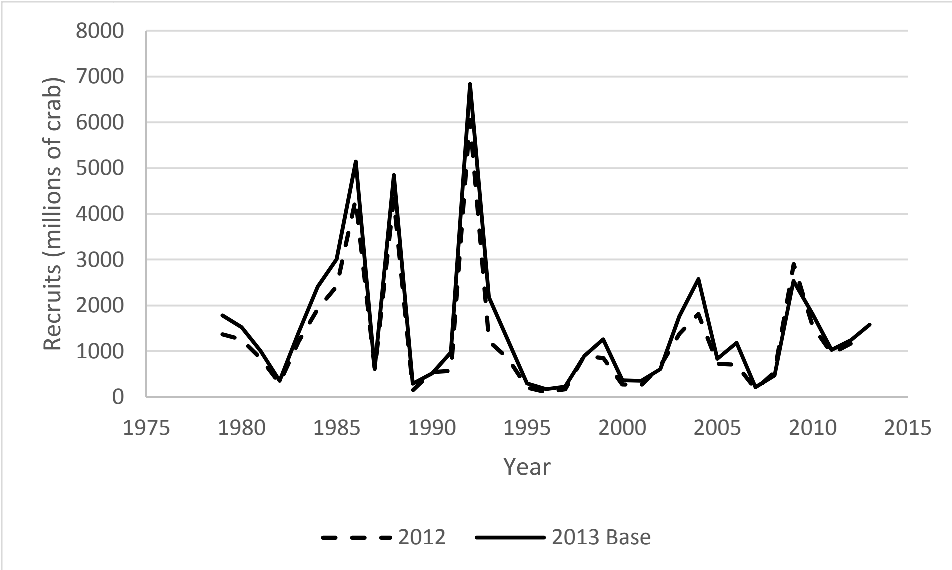


Figure 104. Recruitment estimates from the 2012 assessment and the Base model.

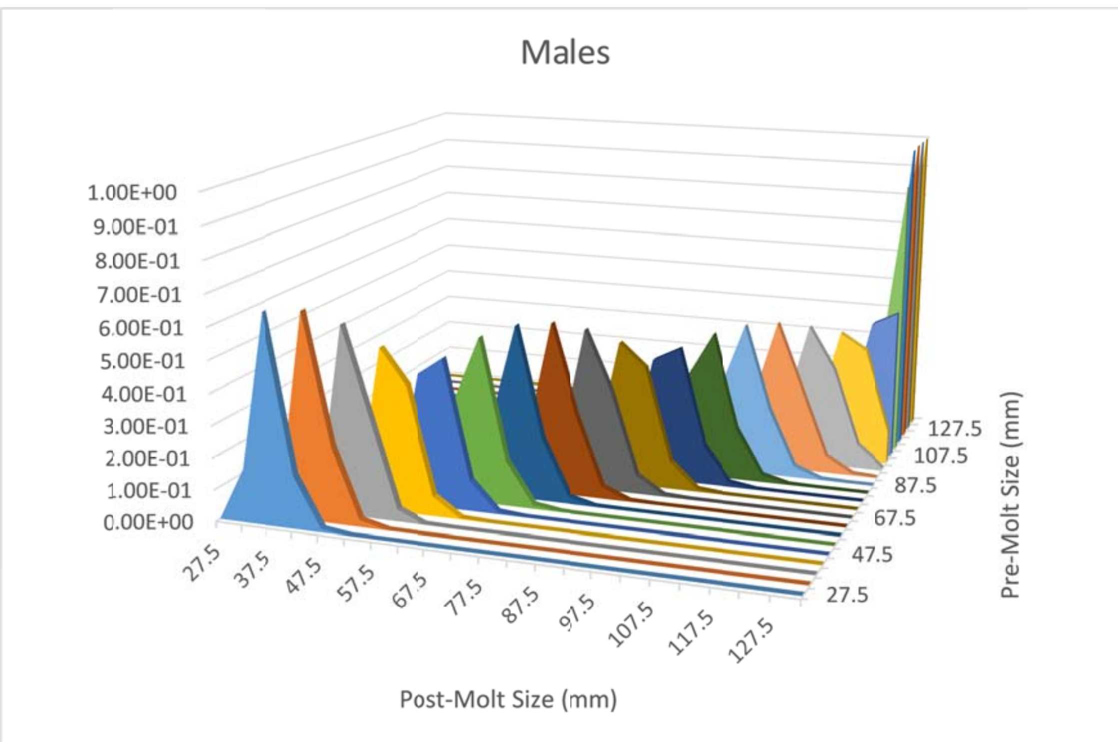


Figure 105. Male growth matrix for the Base model.

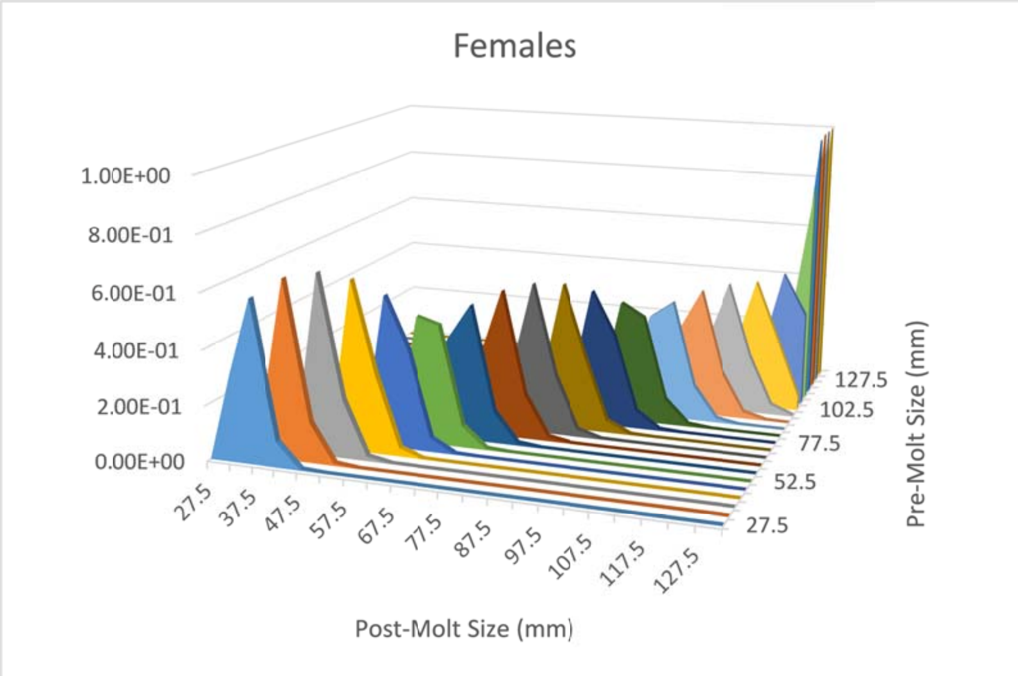


Figure 106. Female growth matrix for the Base model.

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 2013

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

Executive Summary

1. Stock: red king crab (RKC), *Paralithodes camtschaticus,* in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades. Catches during recent years until 2010/11 were among the high catches in last 15 years. The retained catch was about 7 million lbs (3,154 t) less in 2011/12 and 2012/13 than in 2010/11. Bycatch from groundfish trawl fisheries were steady and small 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 has increased during the last 25 years with mature females being 3.3 times more abundant in 2009 than in 1985 and mature males being 2.4 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 1984-2013, only estimated recruitment in 1984, 1995, 2002 and 2005 was above the historical average for 1969-2013. Estimated recruitment was extremely low during the last 7 years.
5. Management performance:

Status and catch specifications (1000 t):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2006/07			7.04	7.14	7.81	N/A	N/A
2007/08		37.69[A]	9.24	9.30	10.54	N/A	N/A
2008/09	15.56[B]	39.83[B]	9.24	9.22	10.48	10.98	N/A
2009/10	14.22[C]	40.37[C]	7.26	7.27	8.31	10.23	N/A
2010/11	13.63[D]	32.64[D]	6.73	6.76	7.71	10.66	N/A
2011/12	13.77[E]	30.88[E]	3.55	3.61	4.09	8.80	7.92
2012/13[1]	13.62[F]	33.79[F]	3.56	3.62	3.90	7.96	7.17
2012/13[2]	13.12[F]	28.33[F]	3.56	3.62	3.90	7.96	7.17
2012/13[3]	13.19[F]	29.05[F]	3.56	3.62	3.90	7.96	7.17
2013/14[1]		28.22[F]	NA	NA	NA	9.11	8.20
2013/14[2]		24.46[F]	NA	NA	NA	6.80	6.12
2013/14[3]		24.95[F]	NA	NA	NA	7.07	6.36

The stock was above MSST in 2012/13 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
2006/07			15.53	15.75	17.22	N/A	N/A
2007/08		83.1[A]	20.38	20.51	23.23	N/A	N/A
2008/09	34.2[B]	87.8[B]	20.37	20.32	23.43	24.20	N/A
2009/10	31.3[C]	89.0[C]	16.00	16.03	18.32	22.56	N/A
2010/11	30.0[D]	72.0[D]	14.84	14.91	17.00	23.52	N/A
2011/12	30.4[E]	68.1[E]	7.83	7.95	9.01	19.39	17.46
2012/13[1]	30.0[F]	74.5[F]	7.85	7.98	8.59	17.55	15.80
2012/13[2]	28.9[F]	62.5[F]	7.85	7.98	8.59	17.55	15.80
2012/13[3]	29.1[F]	64.0[F]	7.85	7.98	8.59	17.55	15.80
2013/14[1]		62.2[F]	NA	NA	NA	20.09	18.09
2013/14[2]		53.9[F]	NA	NA	NA	14.99	13.49
2013/14[3]		55.0[F]	NA	NA	NA	15.58	14.02

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2008
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2009
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2010
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2011
E – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
F – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
1 – Scenario 0
2 – Scenario 1
3 – Scenario 4

6. Basis for the OFL: All table values are in 1000 t.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2008/09	3a	34.1	43.4	1.27	0.33	1995–2008	0.18
2009/10	3a	31.1	43.2	1.39	0.32	1995–2009	0.18
2010/11	3a	28.4	37.7	1.33	0.32	1995-2010	0.18
2011/12	3a	27.3	29.8	1.09	0.32	1984-2011	0.18
2012/13	3a	27.5	26.3	0.96	0.31	1984-2012	0.18
2013/14[1]	3a	27.2	28.2	1.04	0.31	1984-2013	0.18
2013/14[2]	3b	26.2	24.5	0.93	0.27	1984-2013	0.18
2013/14[3]	3b	26.4	25.0	0.95	0.27	1984-2013	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
2008/09	3a	75.1	95.6	1.27	0.33	1995–2008	0.18
2009/10	3a	68.5	95.2	1.39	0.32	1995–2009	0.18
2010/11	3a	62.7	83.1	1.33	0.32	1995-2010	0.18
2011/12	3a	60.1	65.6	1.09	0.32	1984-2011	0.18
2012/13	3a	60.7	58.0	0.96	0.31	1984-2012	0.18
2013/14[1]	3a	60.1	62.2	1.04	0.31	1984-2013	0.18
2013/14[2]	3b	57.9	54.2	0.93	0.27	1984-2013	0.18
2013/14[3]	3b	58.2	55.0	0.95	0.27	1984-2013	0.18

1- Scenario 0; 2 – scenario 1; 3 – scenario 4.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1969-1983, 1969-present, and 1984-present. 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. There are several reasons for supporting 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. Finally, stock productivity (recruitment/mature male biomass) was much higher before the 1976/1977 regime shift: the mean value was 3.753 during brood years 1968-1977 and 0.771 during 1978-2006. The two-tail t-tests with unequal variances show that ln(recruitment) and ln(recruitment/mature male biomass) between brood years 1968-1977 and 1978-2006 are strongly, statistically different with p values of 0.0000000007725 and 0.000708, respectively.

A. Summary of Major Changes

1. Change to management of the fishery: None.

2. Changes to the input data:

a. Catch and bycatch were updated through August 2013 and the 2013 summer trawl survey data were added. Length/sex compositions and area-swept biomasses of BSFRF surveys in 2007 and 2008 are used for some scenarios.

b. New NMFS length-weight relationships are used.

3. Changes to the assessment methodology:

Seven model scenarios are evaluated in this report:

Scenario 0: base scenario (7ac). The 7ac scenario includes: (1) basic M = 0.18, and additional mortalities as one level (1980-1984) for males and two levels (1980-1984 and 76-79 & 85-93) for females; (2) including BSFRF survey data in 2007 and 2008; (3) estimating NMFS survey catchability for 1970-72 and assuming it to be 0.896 for all other years; (4) three levels of molting probabilities for males; (5) estimating effective sample size from observed sample sizes; (6) standard survey data for males and retow data for females; and (7) estimating initial year length compositions.

Scenario 01: The same as Scenario 0 except that: effective sample sizes are 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.

Scenario 02: The same as Scenario 01 except that: newshell and oldshell males are combined to compute likelihood and parameters of molting probabilities are estimated separately for periods 1968-1978 and 1979-2013 (total 4 parameters, two for each period).

Scenario 1: The same as scenario 02 except starting in 1975.

Scenario 4: The same as scenario 1 except that length/sex compositions and survey biomasses from BSFRF surveys are used instead of mature male abundances.

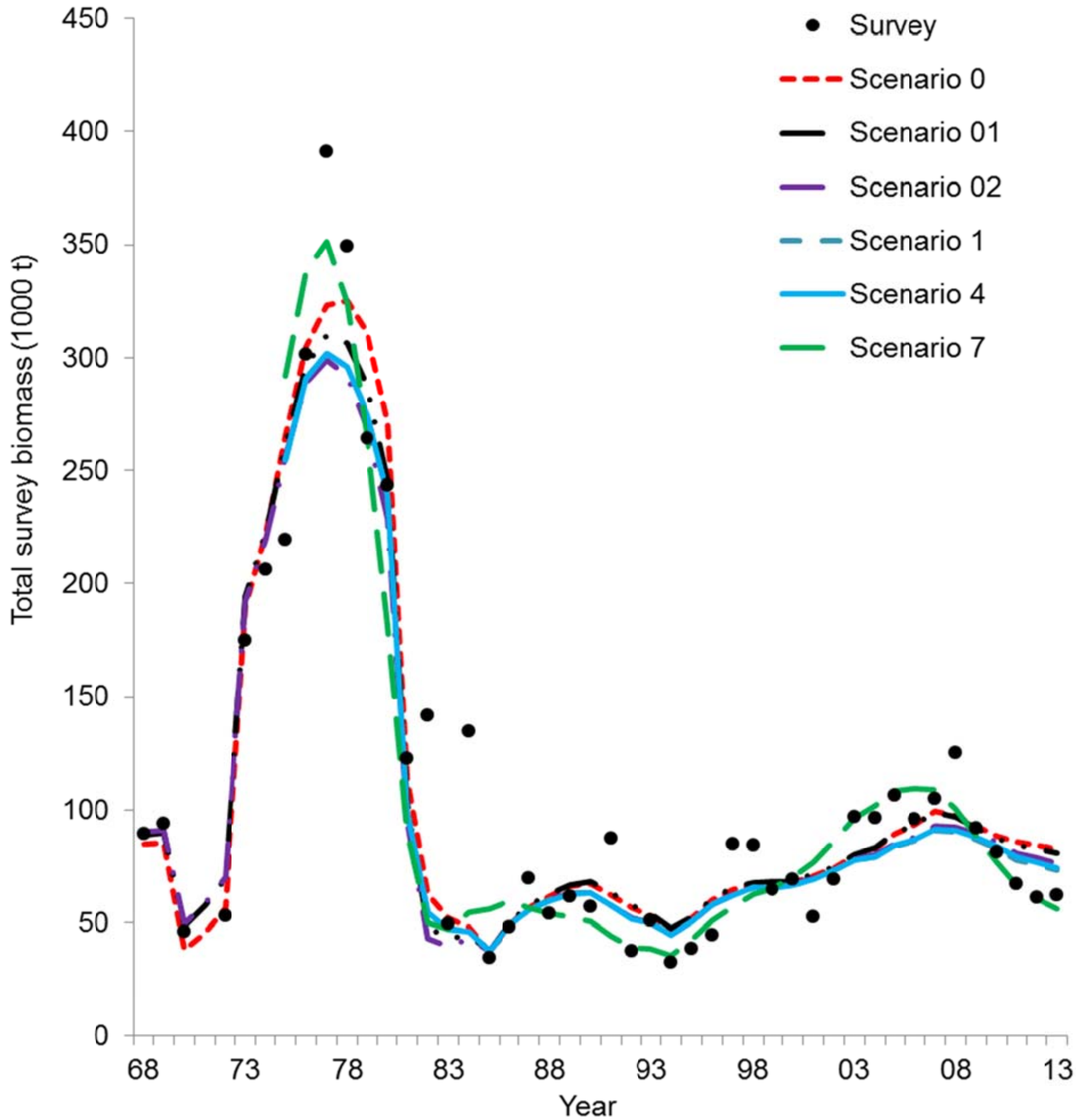
Scenario 7: The same as scenario 1 except that a random walk approach is used to estimate annual M with a penalty weight of 50: $M(s,i+1) = M(s,i)*exp(-Dev(s,i+1))$, where s is sex, i is year and Dev are annual natural mortality deviations. The penalty function is $50.0*Dev^2$.

4. Changes to assessment results:

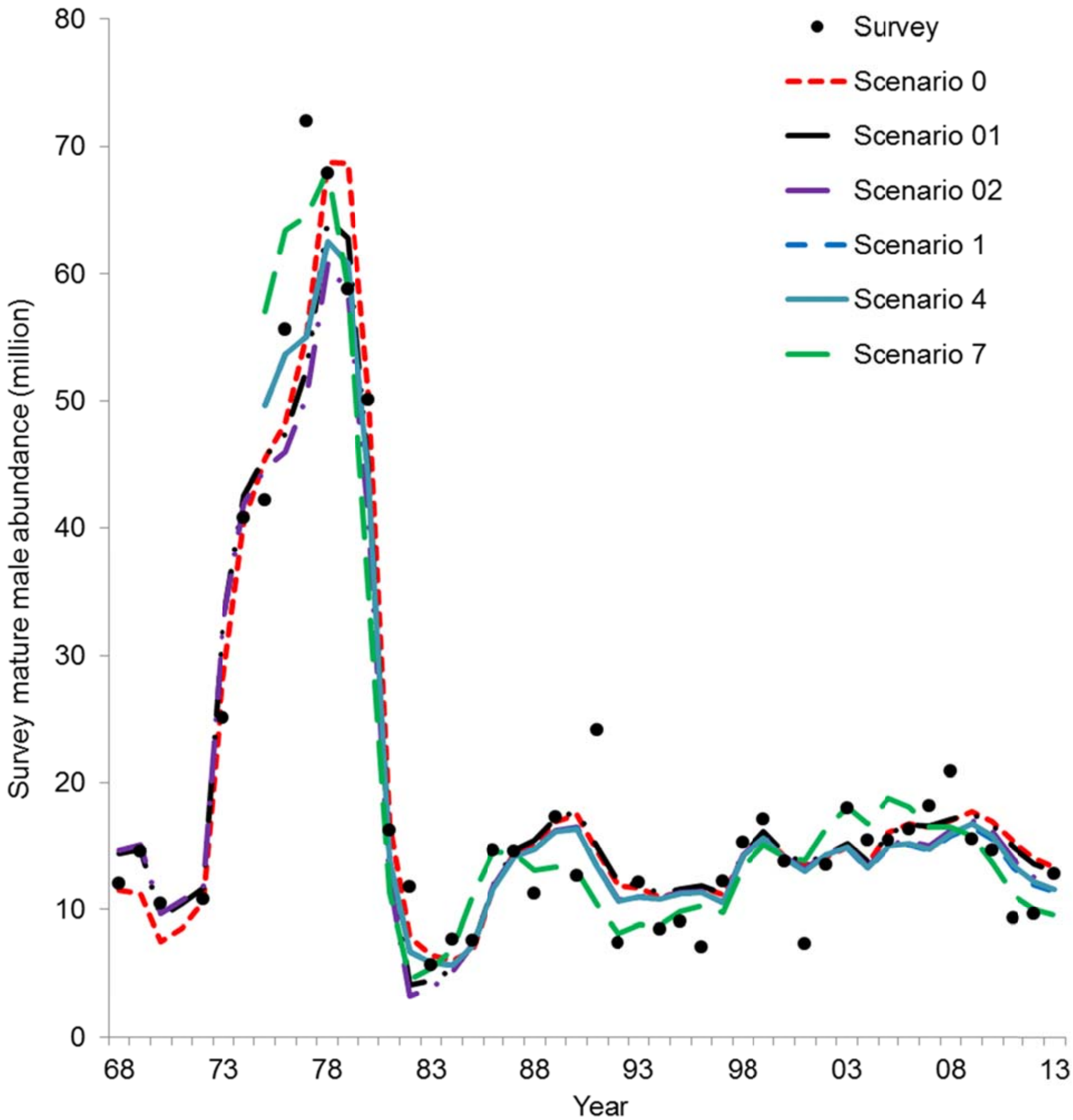
The following table summarizes the results for these scenarios.

	Scenario					
Negative log-likelihood	0	01	02	1	4	7
R-variation	116.84	103.18	101.25	73.77	73.60	86.51
Length-like-retained	-1111.45	-1099.20	-1092.83	-920.07	-919.98	-921.43
Length-like-discmale	-928.40	-909.21	-909.58	-909.52	-909.45	-907.86
Length-like-discfemale	-2218.55	-2201.83	-2195.68	-2174.15	-2174.05	-2175.35
Length-like-survey	-56584.1	-56326.8	-50435.3	-43598.7	-43599.6	-43806.0
Length-like-disctrawl	-1903.68	-1910.86	-1904.46	-1836.29	-1836.07	-1840.29
Length-like-discTanner	-272.42	-272.27	-272.98	-263.98	-263.91	-264.16
Length-like-bsfrfsurvey					-236.95	
Catchbio_retained	46.06	45.52	49.59	47.67	47.88	44.27
Catchbio_discmale	206.37	207.43	217.54	216.76	217.24	201.24
Catchbio-discfemale	0.12	0.12	0.11	0.15	0.15	0.06
Catchbio-disctrawl	1.70	1.70	1.70	0.84	0.84	0.80
Biomass-trawl survey	86.84	100.42	105.15	82.78	83.11	86.72
Biomass-bsfrfsurvey					-5.01	
Others	16.97	17.59	18.57	18.95	21.11	127.08
Total	-62543.7	-62244.2	-56316.9	-49261.7	-49501.1	-49368.4
B35 (t)	27247.7	26887.7	26745.4	26244.1	26382.2	28412.4
F35	0.31	0.31	0.29	0.29	0.29	0.30
MMB2013 (t)	28221.7	27513.2	25684.2	24464.9	24952.3	21411.8
F_OFL2013	0.31	0.31	0.28	0.27	0.27	0.22

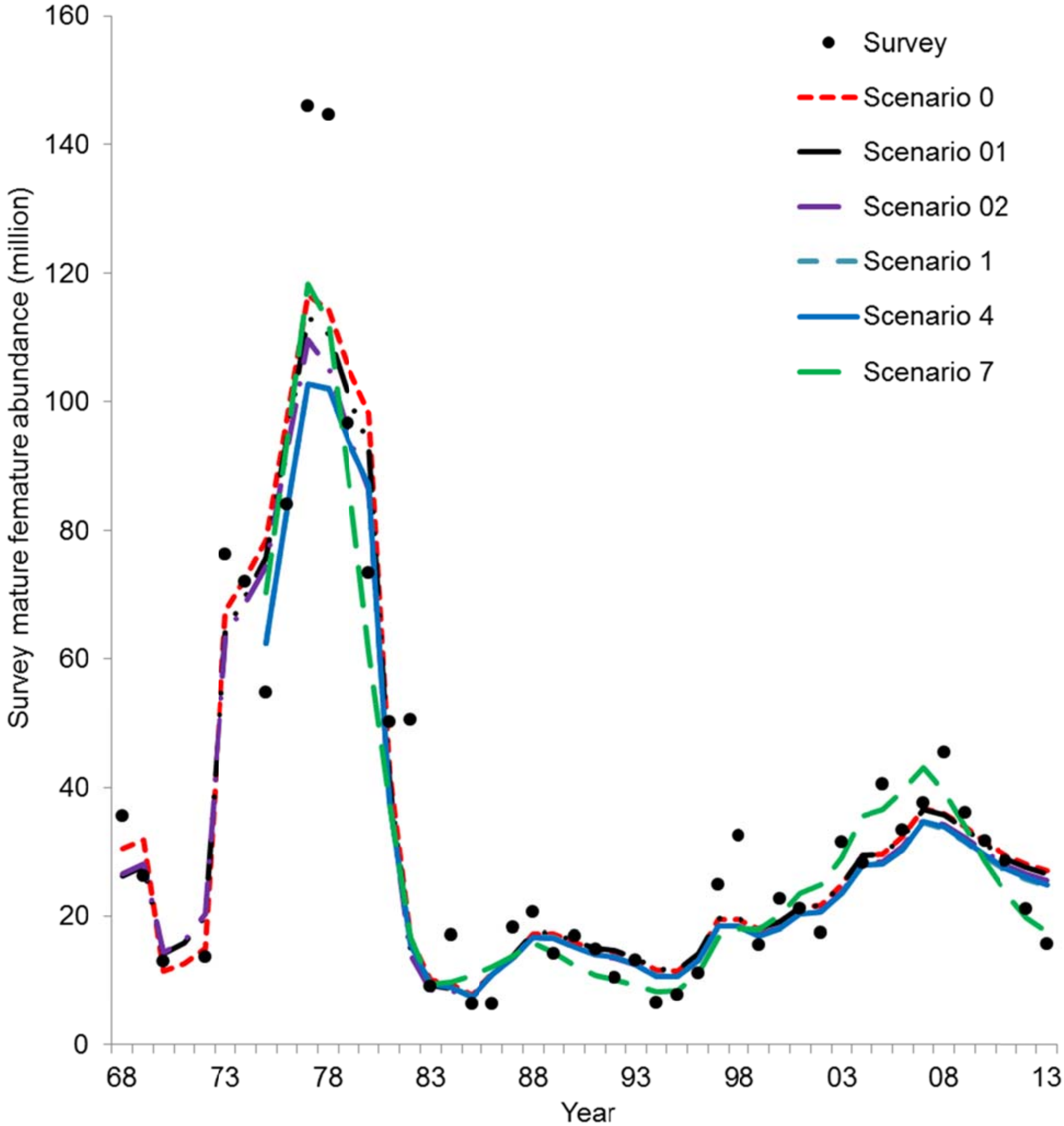
The following figures compare the biomass and abundance estimates for different scenarios.


Survey
Scenario 0
Scenario 01
Scenario 02
Scenario 1
Scenario 4
Scenario 7
Total survey biomass (1000 t)
450
400
350
300
250
200
150
100
50
0
68
73
78
83
88
93
98
03
08
13
Year

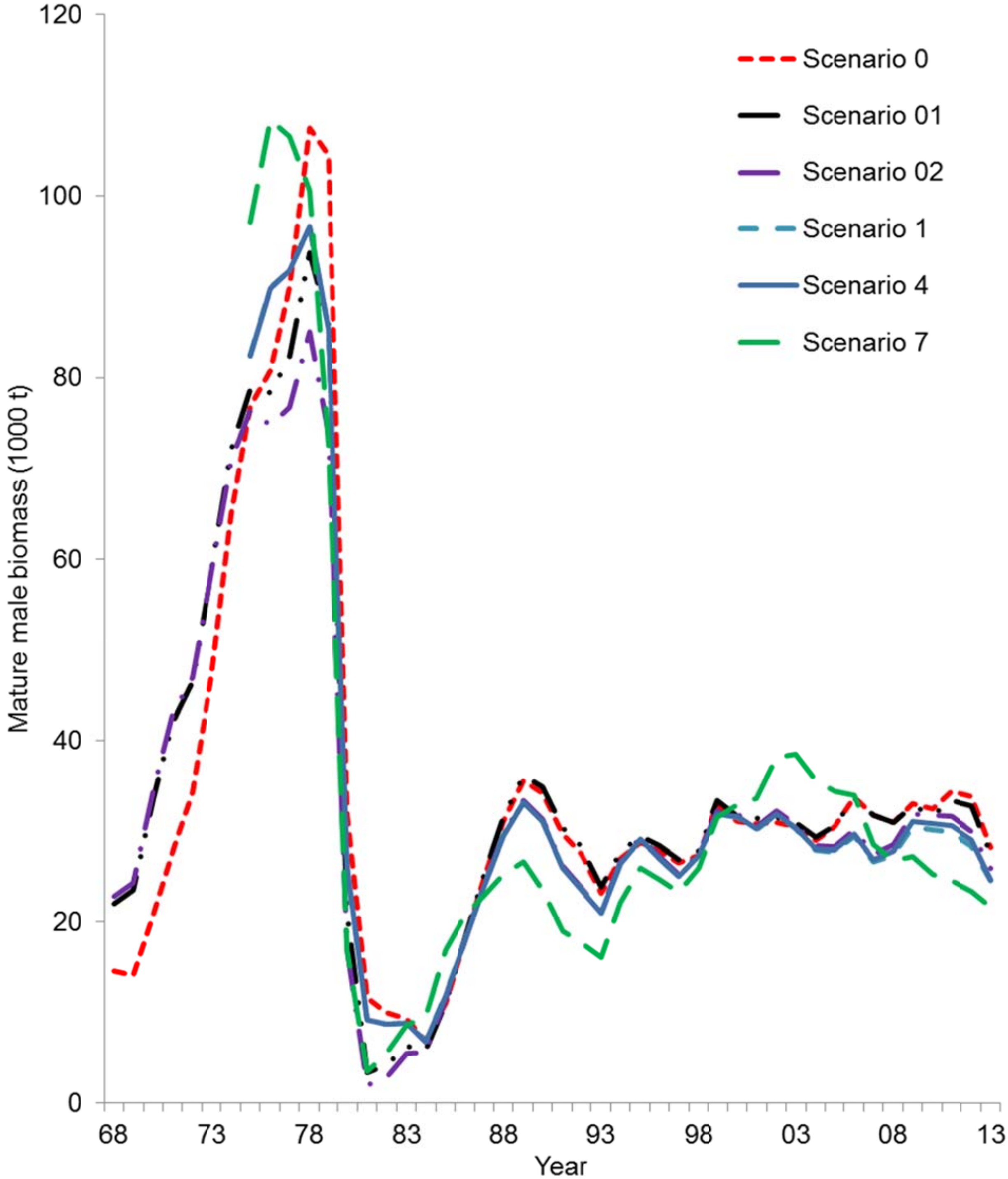
6


80
70
60
50
40
30
20
10
0
Survey mature male abundance (million)
68
73
78
83
88
93
98
03
08
13
Year
Survey
Scenario 0
Scenario 01
Scenario 02
Scenario 1
Scenario 4
Scenario 7

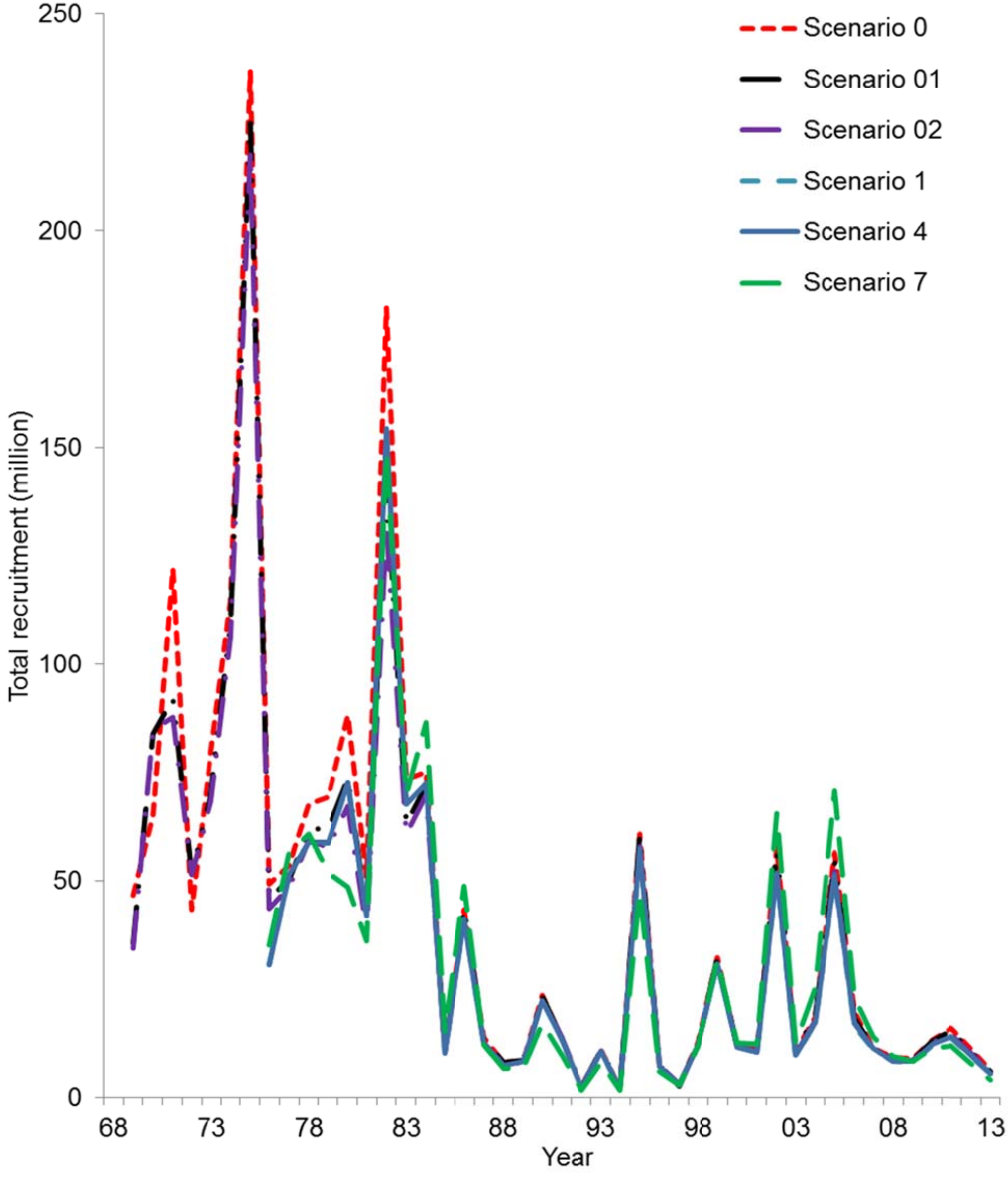
7


160
140
120
100
80
60
40
20
0
Survey mature femature abundance (million)
68
73
78
83
88
93
98
03
08
13
Year
Survey
Scenario 0
Scenario 01
Scenario 02
Scenario 1
Scenario 4
Scenario 7

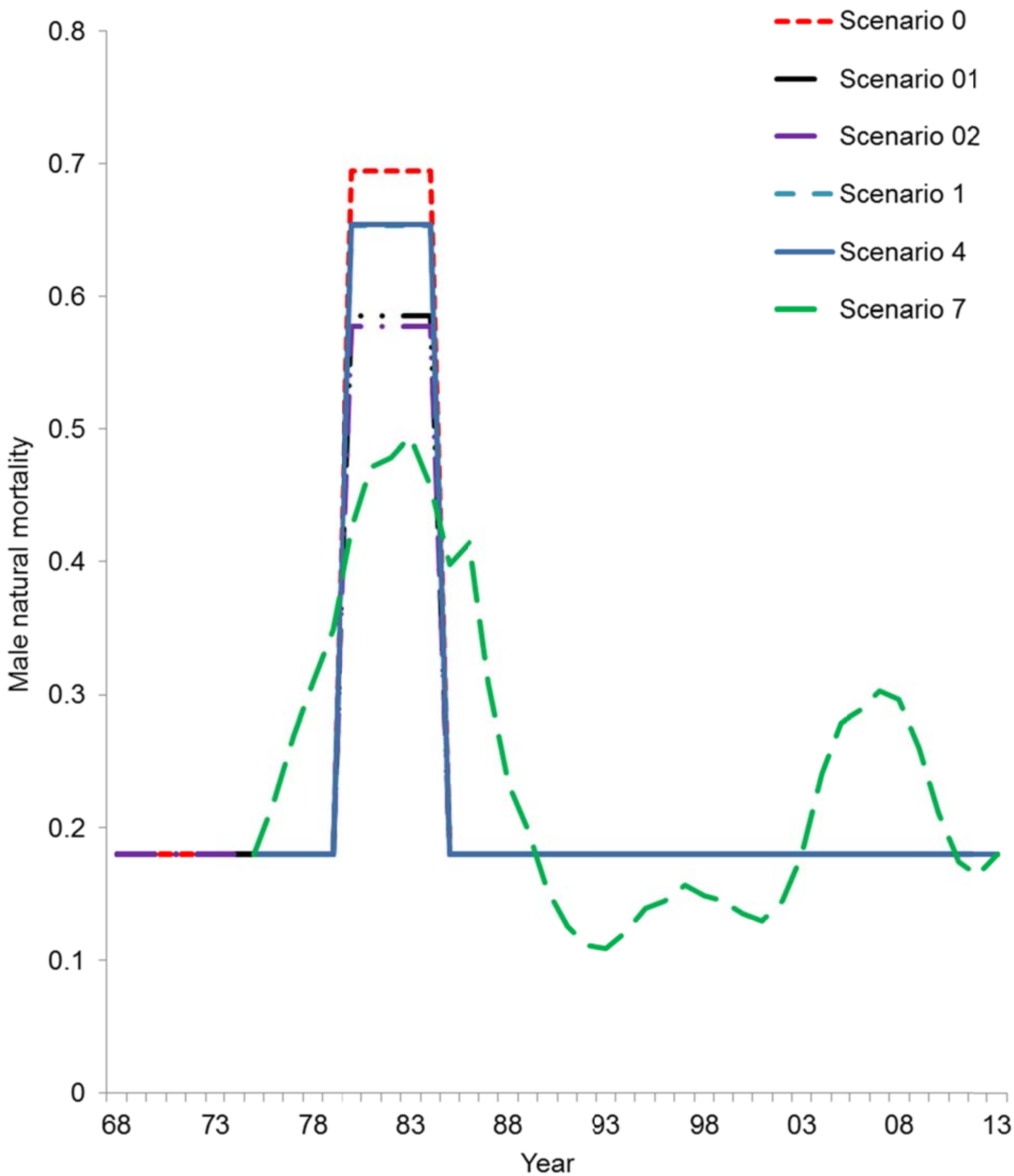
8


Scenario 0
Scenario 01
Scenario 02
Scenario 1
Scenario 4
Scenario 7
Mature male biomass (1000 t)
Year
0
20
40
60
80
100
120
68
73
78
83
88
93
98
03
08
13

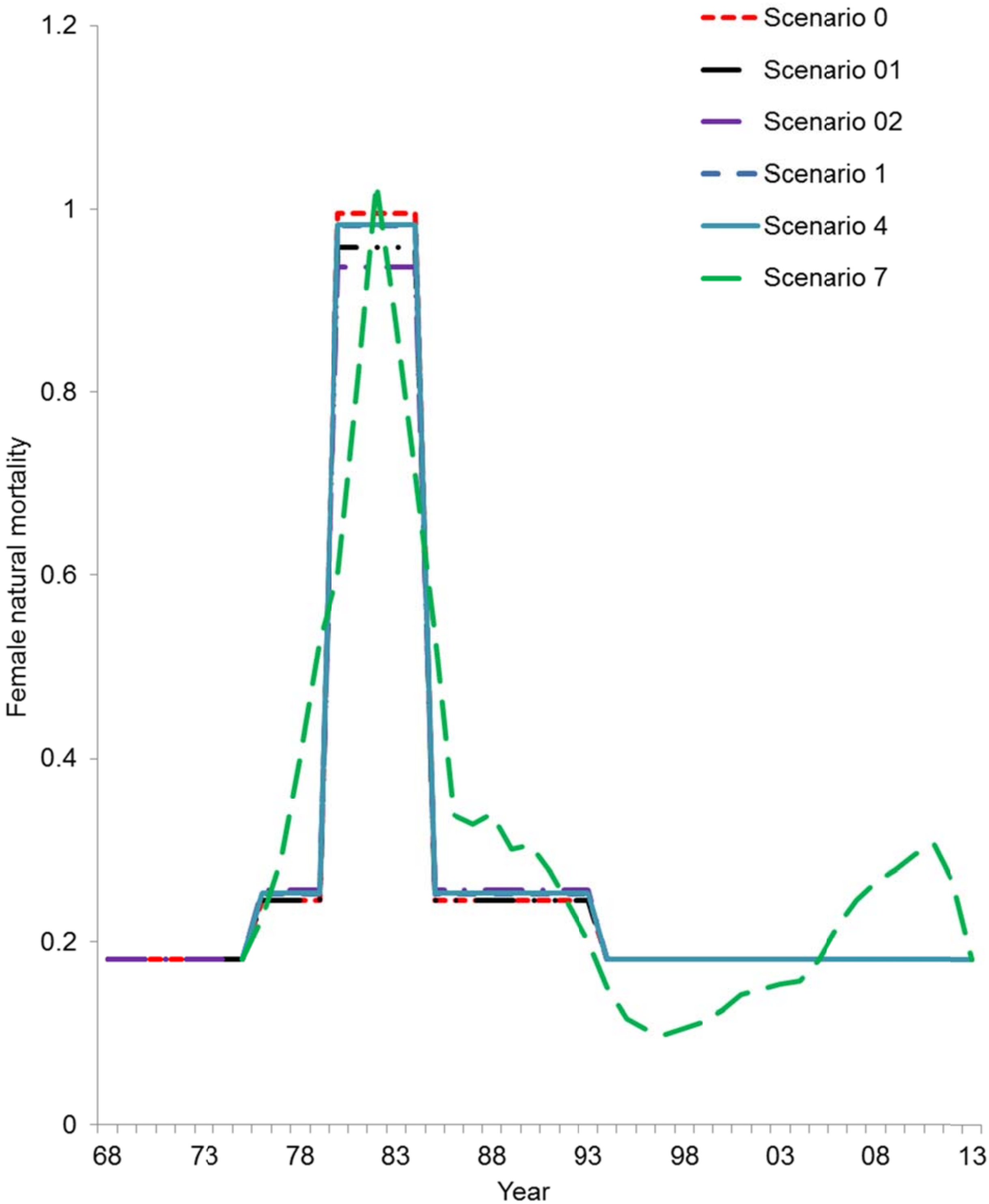
9


Scenario 0
Scenario 01
Scenario 02
Scenario 1
Scenario 4
Scenario 7
Total recruitment (million)
0
50
100
150
200
250
68
73
78
83
88
93
98
03
08
13
Year

10


Scenario 0
Scenario 01
Scenario 02
Scenario 1
Scenario 4
Scenario 7
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Male natural mortality
68
73
78
83
88
93
98
03
08
13
Year

11


Scenario 0
Scenario 01
Scenario 02
Scenario 1
Scenario 4
Scenario 7
Female natural mortality
Year
1.2
1
0.8
0.6
0.4
0.2
0
68
73
78
83
88
93
98
03
08
13

12

In summary, model estimates of abundance and biomass are very similar among scenarios 0-4. Scenario 0(7ac) has a higher abundance and biomass estimates in recent years than those of scenarios 01-4.

Scenario 1 or 4 is recommended for overfishing determination this year. Both scenarios 1 and 4 have very similar results and scenario 4 uses almost all BSFRF survey information.

The full results for scenarios 0, 1 and 4 are presented.

The effective sample sizes for scenarios 01, 02 and 1, 4 and 7 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 28 in 2003, 14 in 2004, 19 in 2005, 22 in 2006, 24 in 2011 and 14 in 2012, and for females 31 in 2003, 12 in 2004, 12 in 2005, 17 in 2006, 22 in 2011 and 13 in 2012.
(6) For scenario 2 with BSFRF survey: 200 for the BSFRF survey males and females.

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 2011)

"… The CPT ***recommends*** *that an analysis be prepared for May 2012that includes a constant-M model (i.e., no periods of increased natural mortality) so that the effect of the Scenario 7ac mortality estimates on the estimates of and trends in recruitment and R/MMB can be assessed; overall, it is* ***recommended*** *that a constant-M always be included as one of the scenarios in assessments for this stock so that the effects of, and need for, the variable-M models on the stock assessment can be assessed."*

The model comparison is done in this report in May 2013.

Response to CPT Comments (from September 2012)

"Look at a model beginning in 1983 to see what – if any – impact there would be on results for current and recent years. It seems that there are many issues with the data prior to 1983 (e.g., survey catchability) and the assessment is using post-1983 for the recruitment period to estimate $B_{35\%}$.."

Scenario 5 (May 2013 report) starts in 1983. The results are not much different from scenarios 1 and 4 (May 2013).

"Give more explanation on the Q for 1968-1972. One question to address is, 'why is the Q different in 3 particular years – 1970-1972, but not for 1968 and 1969?'"

Some changes were made to the survey gear in 1973 and 1982, and survey timings were different in 1968-1969 from those in 1970-1972. We suspect that there might be spatial coverage problems for the surveys during 1970-1972, which had much lower survey abundances than those during 1968-69 and during 1973-1980. There are many problems with the survey data before 1975, and we suggest starting the model in 1975 in the future.

"Include plots of effective sample sizes."

The effective sample sizes were plotted in Figure 7 in the past report. In this report, estimated effective sample sizes based on the two variances are plotted against the effective sample sizes used in the model.

"Include more explanation on the use of two levels of molting probability during 1980-2012."

The years for each level are explained in section "3. Model Selection and Evaluation".
In this report, scenarios 1, 4 and 7 have one set of molting probabilities during 1980-2013.

"Look at fitting the model to biomass rather than to number of crab to see what effects – if any – there are on results. Fitting to biomass may lower the influence of large, "hot spot" survey catches of small crab that do not track in the survey and that could change our assessment of the model fit in recent years."

We always fit the model to the biomass except the BSFRF survey data. Scenario 4 fits the BSFRF survey biomass as well.

"Incorporate the BSFRF data on BBRKC survey catchability going back to the 2007 and 2008 work (NOT the nearshore work outside of the survey area) for estimating on survey catchability for the 1982-2012 trawl survey using the approach that was used for snow crab (i.e., bring the data into the model rather than estimating catchability outside of the model)."

Scenario 4 does this. BSFRF surveys are treated as a different survey with different survey selectivities and a catchabiliy of 1.0.

"Table 5 ("summary of parameter estimates) should have the upper and lower bounds (constraints) imposed on the parameter so that it can be seen if an estimate is hitting a parameter bound."

Done for the new tables.

Response to CPT Comments (from May 2013)

"The Terms of Reference should be followed as a rule, not an option."

???

"The author should step-through all the changes between the base model and scenario 1 and present the key outputs after each change (trajectory of MMB, fit to survey, and likelihoods)."

Two scenarios, 01 and 02, are added to address this.

"How the molt probabilities are estimated in scenario 1 should be described better."

Text has been revised to further clarify this.

"Model 3 had the poorest fit to the data, leading the CPT to wonder if there is a retrospective pattern in the recruitment estimates. The author should present a retrospective analysis of recruitment estimates in the next report."

Add plots of retrospective recruitment estimates for scenarios 1 and 4.

"In relation to scenario 4, the CPT was unsure whether catchability for the NMFS survey was estimated rather than being pre-specified."

The catchability for the NMFS survey was fixed to 0.896.

"The CPT would like to see more detail in both the SAFE and by presenting the likelihoods since what was provided to date made it difficult to know what was done.

All likelihood values have been summarized in a table and the equations to compute likelihoods are listed in the SAFE report.

"The model should be run to allow estimation of Q for the NMFS survey."

We may try this in the future. Generally, Q and M are confounded and it is difficult to estimate both in a model.

"The rationale for the extra CV of 0.5 in scenario 4 should be given and the author should use the maximum likelihood estimate for the log CV term in equation 12."

We estimated the extra CV in the report.

"Scenarios 2, 3, 5 and 6 should not be considered further."

OK.

"Plots to validate sample sizes should be included in the assessment document."

OK. These plots are added.

"Along with presenting the base model in September 2013, the author should focus on scenario 1 which has a better retrospective pattern and fits the trawl survey better, and scenario 4 which includes almost all of the BSFRF survey information (but was incorrectly implemented for the May 2013 meeting)."

The complete likelihood for the BSFRF survey biomass is used and we present the complete results for these three scenarios.

Response to SSC Comments specific to this assessment (from October 2012)

"(1) an option with no additional M periods and (2) an option without additional M periods and an additional survey selectivity period in the early 1980s."

The options are included in this report (scenarios 2 and 3). We had tried repeatedly to run these options in the past and had failed to make them converge. After simplifying the model and reducing effective sample sizes for some years, we made them converge this time. However, the fits of data are bad and some parameter estimates are biologically not plausible (for example, survey selectivities and molting probabilities).

"Research:
1. Shifts in the center of distribution of BBRKC can be a function of depletion of the stock, the crab closure area, shifts in larval drift, habitat selection, or fishing. Study which of these potential causes contributes to the selection of a time period.
2. Work with flatfish authors to come up with a consistent approach to treatment of biomass outside of the survey area.
3. Look at changes in maturity, molting probability, and selectivity over time.
4. Look at impact of dropping hotspots as per CIE review.
5. Look at impact of corner stations for hotspots as per CIE review.
6. Look at BBRKC – impact of re-tows as per CIE review.

7. Conduct field studies of catchability (side-by-side tows)."

These are good suggestions for future research. We will work on these issues in the future.

Response to SSC Comments specific to this assessment (from June 2013)

"The SSC notes that the arbitrary time blocking to fix poor fits to the data is conditional on the initial model set up. ***Therefore the SSC requests that the authors explore a model that allows for interannual variations in M.*** *This could be accomplished with a random walk model for natural mortality or a model that allows independent deviations around the base M with the additional constraint that these deviations sum to 0. Results from this run could be used to explore objectively whether the time blocks selected for additional mortality were correctly specified. We recognize that there are tradeoffs with modeling M, survey Q, and survey selectivity; thus, we ask the authors to carefully consider which parameters should be fixed for this run to enable the desired temporal exploration of time varying M."*

We added a scenario of using a random walk to estimate annual *M*. The time blocks used in the current models came from the results from the model first developed 19 years ago and that model did not include some small length groups the current models have. It is time to re-consider these blocks. The time blocks for females seem to match well with the results from the random walk approach. However, the blocks do not match very well for males.

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. RKC 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) 2005). The Aleutian Islands area covers two stocks, Adak and Dutch Harbor, and the Bering Sea area contains two other stocks, the Pribilof Islands and Norton Sound. The largest stock is found in the Bristol Bay area, which includes all waters north of the latitude of Cape Sarichef (54^{o}36' N lat.), east of 168^{o}00' W long., and south of the latitude of Cape Newenham (58^{o}39' N lat.) (ADF&G 2005). Besides these five stocks, RKC stocks elsewhere in the Aleutian Islands and eastern Bering Sea are currently too small to support a commercial fishery. This report summarizes the stock assessment results for the Bristol Bay RKC stock.

4. Life History

Life history of RKC is complex. Fecundity is a function of female size, ranging from several tens of thousands to a few hundreds of thousands (Haynes 1968). The eggs are extruded by females and fertilized in the spring and are held by females for about 11 months (Powell and Nickerson 1965). Fertilized eggs are hatched in spring, most during the April to June period (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). The RKC mature at 5–12 years old, depending on stock and temperature (Stevens 1990) and may live >20 years (Matsuura and Takeshita 1990), with males and females attaining a maximum size of 227 and 195 mm carapace length (CL), respectively (Powell and Nickerson 1965). 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. After maturing, male molting frequency declines.

5. Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States (Bowers et al. 2008). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974 (Bowers et al. 2008). The Russian fleet fished for RKC from 1959 through 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 to fish for Bristol Bay RKC in 1947, and effort and catch declined in the 1950s (Bowers et al. 2008). 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 (Bowers et al. 2008). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades (Table 1). After the stock collapse in the early 1980s, 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 in the previous summer (Zheng and Kruse 2002). As a result of new regulations for crab rationalization, the fishery was open longer from October 15 to January 15, beginning with the 2005/2006 season. With the implementation of crab rationalization, historical guideline harvest levels (GHL) were changed to a total allowable catch (TAC). The GHL/TAC and actual catch are compared in Table 2. The implementation errors are quite high for some years, and total actual catch from 1980 to 2007 is about 6% less than the sum of GHL/TAC over that period (Table 2).

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 developing harvest strategies to determine 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 2005). 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 2005). 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 el al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. An additional 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. In 2003, 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. The current harvest strategy is illustrated in Figure 1.

D. Data

1. Summary of New Information

New data include commercial catch and bycatch in 2012/2013 and the 2013 summer trawl survey and updated trawl bycatch estimates during 2009-2012. The new NMFS length-weight relationships are used.

2. Catch Data

Data on landings of Bristol Bay RKC by length and year and catch per unit effort were obtained from annual reports of the International North Pacific Fisheries Commission from 1960 to 1973 (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the ADF&G from 1974 to 2008 (Bowers et al. 2008). Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Bowers et al. 2008; Burt and Barnard 2006). 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. Retained catch and estimated bycatch from the directed fishery include both the general open access fishery (i.e., harvest not allocated to Community Development Quota [CDQ] groups) and the CDQ fishery. 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 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.

(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 crabs per tan (a unit fishing effort for tanglenets) for the Japanese and Russian fisheries and the number of retained crabs 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 crabs per tan. The U.S. CPUE data have similar trends as survey legal abundance after 1971 (Figure 3). Due to the difficulty in estimating commercial fishing catchability and the ready availability of 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, conduct this multispecies, crab-groundfish survey during the summer. Stations are sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972 the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2011 were provided by NMFS.

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach without post-stratification (Figures 4 and 5). If multiple tows were made for a single station in a given year, the average of the abundances from all tows was used as the estimate of abundance for that station. Until the late 1980s, NMFS used a post-stratification approach, but subsequently treated Bristol Bay as a single stratum. If more than one tow was conducted in a station because of high RKC abundance (i.e., the station is a "hot spot"), NMFS regards the station as a separate stratum. Due to poor documentation, it is difficult to duplicate past NMFS post-stratifications. A "hot spot" was not surveyed with multiple tows during the early years. Two such "hot spots" affected the survey abundance estimates greatly: station H13 in 1984 (mostly juvenile crabs 75-90 mm CL) and station F06 in 1991 (mostly newshell legal males). The tow at station F06 was discarded in the older NMFS abundance estimates (Stevens et al. 1991). In this study, all tow data were used. NMFS re-estimated historic areas-swept in 2008 and re-estimated area-swept abundance as well, using all tow data.

In addition to standard surveys, NMFS also conducted some surveys after the standard surveys to assess mature female abundance. Two surveys were conducted for Bristol Bay RKC in 1999, 2000, 2006-2011: the standard survey that was performed in late May and early June (about two weeks earlier than historic surveys) in 1999 and 2000 and the standard survey that was performed in early June in 2006-2010 and resurveys of 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), 32 stations (2007-2009), 23 tows (2010) and 20 stations (2011 and 2012) with high female density that was performed in late July, about six weeks after the standard survey. The resurveys were necessary because a high proportion of mature females had not yet molted or mated prior to the standard surveys (Figure 6). 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 between the standard survey and resurvey (P=0.74, 0.74 and 0.95) based on paired t-tests of sample means. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 are significantly different between the standard survey and resurvey (P=0.03) based on the t-test. However, the re-tow 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 abundance during these resurvey years.

For 1968-1970 and 1972-1974, abundance estimates were obtained from NMFS directly because the original survey data by tow were not available. There were spring and fall surveys in 1968 and 1969. The average of estimated abundances from spring and fall surveys was used for those two years. Different catchabilities were assumed for survey data before 1973 because of an apparent change in survey catchability. A footrope chain was added to the trawl gear starting in 1973, and the crab abundances in all length classes during 1973-1979 were much greater than those estimated prior to 1973 (Reeves et al. 1977).

4. Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay red king crab in 2007 and 2008 with a small-mesh trawl net and 5-minute tows. The surveys occurred at similar times with the NMFS standard surveys and covered about 97% of the Bristol Bay area. Few Bristol Bay red king crab were outside of the BSFRF survey area. Because of small mesh size, the BSFRF surveys weree expected to catch nearly all red king crabs 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 and 19.747 million in 2007 and 2008 with a CV 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, the 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 1968 to 2010.

2. Model Description

a. 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, and catchabilities, catches and bycatch of the commercial pot fisheries and groundfish trawl fisheries. A full model description is provided in Appendix A.

b-f. See appendix.

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 a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Four different survey selectivities were estimated: (1) 1968-69 (surveys at different times), (2) 1970-72 (surveys without a footrope chain), (3) 1973-1981, and (4) 1982-2012 (modifying approaches to surveys).

iii. Growth is a function of length and did not change over time for males. For females, three growth increments per molt as a function of length were estimated based on sizes at maturity (1968-1982, 1983-1993, and 1994-2012). Once mature, female red king crabs 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. Survey catchability (*Q*) was estimated to be 0.896, based on a trawl experiment by Weinberg et al. (2004). *Q* was assumed to be constant over time except during 1970-1972. Q during 1970-1972 was estimated in the model.

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

viii. For summer trawl survey data, shell ages of newshell crabs were 12 months or less, and shell ages of oldshell and very oldshell crabs were more than 12 months.

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

3. Model Selection and Evaluation

a. Alternative model configurations:

Seven scenarios were compared for this report:

Scenario 0: base scenario (7ac). The 7ac scenario includes:

(1) Basic M = 0.18, and additional mortalities as one level (1980-1984) for males and two levels (1980-1984 and 76-79 & 85-93) for females.

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

(3) Estimating NMFS survey catchability for 1970-72 and assuming it to be 0.896 for all other years.

(4) Three levels of molting probabilities for males: one before 1979, one for 1979-84, 1992-94, 1997, 1999, 2001, 2007-2009, and one for 1985-91, 1995-96, 1998, 2000, 2002-2006, and 2010-2013. Each level has two parameters.

(5) Estimating effective sample size from observed sample sizes. Effective sample sizes are estimated through two steps:

(i) Initial effective sample sizes are estimated as

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

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

(ii) We assume n_y has a Beverton-Holt relationship with observed sample sizes, N_y:

$$n_y = N_y / (\alpha + \beta N_y)$$

where α and β are parameters. Different α and β parameter values are estimated for survey males, survey females, retained catch, male directed pot bycatch and female directed pot bycatch. Due to unreliable observed sample sizes for trawl bycatch, effective sample sizes are not estimated. Effective sample sizes are also not estimated for Tanner crab bycatch due to short observed time series.

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

(7) Estimating initial year length compositions.

Scenario 01: The same as Scenario 0 except that: effective sample sizes are 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.

Scenario 02: The same as Scenario 01 except that: newshell and oldshell males are combined to compute likelihood and parameters of molting probabilities are estimated separately for periods 1968-1979 and 1980-2013 (total 4 parameters, two for each period).

Scenario 1: The same as scenario 02 except starting in 1975.

Scenario 4: The same as scenario 1 except that length/sex compositions and survey biomasses from BSFRF surveys are used instead of mature male abundances.

Scenario 7: The same as scenario 1 except that a random walk approach is used to estimate annual M with a penalty weight of 50: $M(s,i+1) = M(s,i)*exp(-Dev(s,i+1))$, where s is sex, i is year and Dev are annual natural mortality deviations. The penalty function is $50.0*Dev^2$.

Only the full results for scenarios 0, 1 and 4 are presented in this report. Each figure or table is indicated with a scenario. If not indicating scenario, it is for scenario 0(7ac).

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. Estimated sample sizes and effective sample sizes are summarized in tables.

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. For scenarios 0(7ac), 1, and 4, effective sample sizes are illustrated in Figure 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.

b. Tables of estimates.

   i. Parameter estimates for scenarios 0(7ac), 1 and 4 are summarized in Tables 4 and 5.

   ii. Abundance and biomass time series are provided in Table 6 for scenarios 0(7ac), 1 and 4.

   iii. Recruitment time series for scenarios 0(7ac), 1 and 4 are provided in Table 6.

   iv. Time series of catch/biomass are 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 its selectivity 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 0(7ac), 1 and 4.

   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. NMFS survey catchability was estimated to be 0.896 from the trawl experiment and 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 0, 1 and 4, estimated molting probabilities during 1968-2013 (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 crabs 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.

Estimated survey biomass, mature male and female abundances are similar between the assessment made in 2012 and 2013 (Figure 10a).

The model did not fit the mature crab abundance directly and depicted the trends of the mature abundance well (Figure 10b). Estimated mature crab abundance increased dramatically in the mid 1970s then decreased precipitously in the early 1980s. Estimated mature crab abundance has increased during the last 27 years with mature females being 3.3 times more abundant in 2009 than in 1985 and mature males being 2.4 times more abundant in 2009 than in 1985 (Figure 10b). Mature abundances have declined since the late 2000s.

iii. Estimated recruitment time series are plotted in Figure 11 for scenarios 0, 1 and 4.

iv. Estimated harvest rates are plotted against mature male biomass in Figure 12 for scenarios 0, 1 and 4.

The average of estimated male recruits from 1984 to 2013 (Figure 11) and mature male biomass per recruit were used to estimate $B_{35\%}$. Alternative periods of 1969-present and 1969-1983 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 12). Before the current harvest strategy was adopted in 1996, many fishing mortalities were above $F_{35\%}$ (Figure 12). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, 2007-2010 but below the $F_{35\%}$ limits in the other post-1995 years.

Estimated full pot fishing mortalities ranged from 0.00 to 1.50 during 1968-2012, with estimated values over 0.40 during 1968-1981, 1985-1987, and 2008 (Table 5, Figure 12). 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 7ac (Figure 13a). Annual stock productivities are illustrated in Figure 13b.

Stock productivity (recruitment/mature male biomass) was much higher before the 1976/1977 regime shift: the mean value was 3.753 during 1968-1977 and 0.771 during 1978-2013.

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 14). 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 14). The average clutch fullness was close for these two periods (Figure 14).

d. Graphic evaluation of the fit to the data.

   i. Observed vs. estimated catches are plotted in Figure 15.

   ii. Model fits to total survey biomass are shown in Figure 10 with a standardized residual plot in Figure 16.

   iii. Model fits to catch and survey proportions by length are illustrated in Figures 17-24 and residual bubble plots are shown in Figures 25-27.

The model (scenarios 0, 1 and 4) fit the fishery biomass data well and the survey biomass reasonably well (Figures 10 and 15). Because the model estimates annual fishing mortality for pot male catch, 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 and shell composition data well (Figures 17-24). Model fit of length compositions in the trawl survey was better for newshell males and females than for oldshell males. The model predicted lower proportions of oldshell males in 1993, 1994, 2002, 2007 and 2008, and higher proportions of oldshell males in 1997, 2001, 2003, 2004, 2006 and 2010 than the area-swept estimates (Figure 18). In addition to size, molting probability may also be affected by age and environmental conditions. Tagging data show that molting probability changed over time (Balsiger 1974). Therefore, the relatively poor fit to oldshell males may be due to use of changes in molting probabilities as well as shell aging errors. It is surprising that the model 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 17 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 and shell condition 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 16). Standardized residuals of proportions of survey newshell males appear to be random over length and year (Figure 25). Standardized residuals of proportions of survey oldshell males were mostly positive or negative for some years (Figure 26). Changes in molting probability over time or shell aging errors would create such residual patterns. There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females during 1969-1987 (Figure 27). 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.

Further study for female growth and availability for survey gears due to different molting times may be needed.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) historical results and (2) the 2013 model hindcast results. 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 2013 estimates as the baseline values, we can also evaluate how well the model had done in the past. The 2013 model results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data.

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

The performance of the 2013 model includes sequentially excluding one-year of data. The model with scenarios 1 and 4 performed reasonably well during 2008-2012 with a lower terminal year estimate in 2012 and higher estimates during 2008-2010 (Figure 28).

Overall, both historical results and the 2013 model results performed reasonably well. No great overestimates or underestimates occurred as was observed in Pacific halibut (*Hippoglossus stenolepis*) (Parma 1993) or 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).

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, six historical assessment results are available. The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1000 for survey biomass, 2000 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 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 3000 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.

f. Uncertainty and sensitivity analyses

i. Estimated standard deviations of parameters are summarized in Table 5 for scenarios 0, 1 and 4. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for mature male biomass in 2013 are illustrated in Figure 30 for scenarios 1 and 4 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 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 were reported in the SAFE report in May 2011 and based on the data up to 2010. Estimating length proportions in the initial year (scenario 1a) results in mainly 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 with scenario 1 that does not estimate initial length proportions. 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 2013), six scenarios are compared and the results are summarized at the beginning of the report.

F. Calculation of the OFL and ABC

1. Bristol Bay RKC is currently placed in Tier 3 (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 2000 to 2012 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 1990-2012. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2007-2012 than in 2005 after the fishing industry minimized discards of legal males. Thus, the average of retained selectivities and discard male selectivities during 2009-2012 were used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2001-2012 were used for per recruit analysis and projections.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1969-1983, 1969-2013, and 1984-2013 (Figure 11). 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. There are several reasons for supporting 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 much higher before the 1976/1977 regime shift: the mean value was 4.054 during brood years 1968-1977 and 0.828 during 1978-2006 (Figure 13a-c). The two-tail t-tests with unequal variances show that ln(recruitment) and ln(recruitment/mature male biomass) between brood years 1968-1977 and 1978-2006 are strongly, statistically different with p values of 0.0000000007725 and 0.000708, respectively. There are several potential reasons for the recruitment and productivity differences between these two periods:

a. The 1976/77 regime shift created different environmental conditions before 1978 and after 1977. The PDO index matched crab recruitment strength very well (Figure 13d). The Aleutian Low index has the similar feature. Before 1978, the summer bottom temperatures in Bristol Bay were generally lower than those after 1977 (Figure 13d). Red king crab distributions changed greatly after the regime shift (Figure 13e). High recruitments during the late 1960s and 1970s (before brood year 1978) generally occurred when the spawning stock was primarily located in southern Bristol Bay while the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in southern Bristol Bay and these larvae settled within the juvenile nursery areas (Figure 13f). A proportion of the larvae hatched in central Bristol Bay may be carried away and settle outside of the juvenile nursery areas.
b. Predation on juvenile crabs may have increased after the 1976/77 regime shift. The biomass of the main crab predator, Pacific cod, increased greatly after the regime shift (Figure 13g). Yellowfin sole biomass also increased substantially during this period. The recruitment strength is statistically associated with the predator biomass (Figure 13h), but we lack stomach samples in shallow waters (juvenile habitat) to quantify the predation mortality.

c. Zheng and Kruse (2000) hypothesized that the strength of the Aleutian Low affects food availability for red king crab larvae. Strong Aleutian Lows may have effects on species composition of the spring bloom that are adverse for red king crab larvae. Diatoms such as *Thalassiosira* are important food for first-feeding red king crab larvae (Paul et al., 1989), and they predominate in the spring bloom in years of light winds when the water column is stable (Ziemann et al., 1991; Bienfang and Ziemann, 1995). Years of strong wind mixing associated with intensified Aleutian Lows may depress red king crab larval survival and subsequent recruitment. All strong year classes occurred before 1978 when the Aleutian Low was weak.

If we believe that the productivity differences and differences of other population characteristics before 1978 were caused by fishing, not by the regime shift, then we should use the recruitment from 1969-1983 (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 1984-2013 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 probabilities are illustrated for the MMB in 2013 (Figure 30) and the normal approximation is used to estimate the 49 percentile for the OFL in 2012 (Figure 31). Based the SSC suggestion in 2011, ABC = 0.9*OFL is used to estimate ABC.

Status and catch specifications (1000 t):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2006/07			7.04	7.14	7.81	N/A	N/A
2007/08		37.69[A]	9.24	9.30	10.54	N/A	N/A
2008/09	15.56[B]	39.83[B]	9.24	9.22	10.48	10.98	N/A
2009/10	14.22[C]	40.37[C]	7.26	7.27	8.31	10.23	N/A
2010/11	13.63[D]	32.64[D]	6.73	6.76	7.71	10.66	N/A
2011/12	13.77[E]	30.88[E]	3.55	3.61	4.09	8.80	7.92
2012/13[1]	13.62[F]	33.79[F]	3.56	3.62	3.90	7.96	7.17
2012/13[2]	13.12[F]	28.33[F]	3.56	3.62	3.90	7.96	7.17
2012/13[3]	13.19[F]	29.05[F]	3.56	3.62	3.90	7.96	7.17
2013/14[1]		28.22[F]	NA	NA	NA	9.11	8.20
2013/14[2]		24.46[F]	NA	NA	NA	6.80	6.12
2013/14[3]		24.95[F]	NA	NA	NA	7.07	6.36

The stock was above MSST in 2012/13 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
2006/07			15.53	15.75	17.22	N/A	N/A
2007/08		83.1[A]	20.38	20.51	23.23	N/A	N/A
2008/09	34.2[B]	87.8[B]	20.37	20.32	23.43	24.20	N/A
2009/10	31.3[C]	89.0[C]	16.00	16.03	18.32	22.56	N/A
2010/11	30.0[D]	72.0[D]	14.84	14.91	17.00	23.52	N/A
2011/12	30.4[E]	68.1[E]	7.83	7.95	9.01	19.39	17.46
2012/13[1]	30.0[F]	74.5[F]	7.85	7.98	8.59	17.55	15.80
2012/13[2]	28.9[F]	62.5[F]	7.85	7.98	8.59	17.55	15.80
2012/13[3]	29.1[F]	64.0[F]	7.85	7.98	8.59	17.55	15.80
2013/14[1]		62.2[F]	NA	NA	NA	20.09	18.09
2013/14[2]		53.9[F]	NA	NA	NA	14.99	13.49
2013/14[3]		55.0[F]	NA	NA	NA	15.58	14.02

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2008
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2009
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2010
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2011
E – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
F – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
1 – Scenario 0
2 – Scenario 1
3 – Scenario 4

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2013, the biological reference points and OFL were estimated as follows:

	Scenario 0(7ac)		Scenario 1		Scenario 4	
	1000t	Million lbs	1000t	Million lbs	1000t	Million lbs
$B_{35\%}$	27.248	60.071	26.244	57.858	26.382	58.163
$F_{35\%}$	0.31		0.29		0.29	
MMB_{2013}	28.222	62.218	24.465	53.936	24.952	55.010
OFL_{2013}	9.113	20.091	6.798	14.987	7.066	15.579
ABC_{2013}	8.204	18.087	6.118	13.489	6.360	14.021

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

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G. Rebuilding Analyses

NA.

H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:

   d. Information about changes in natural mortality in the early 1980s;

   e. Un-observed trawl bycatch in the early 1980s;

   f. Natural mortality;

   g. Crab availability to the trawl surveys;

   h. Juvenile crab abundance.

2. Research priorities:

   a. Estimating natural mortality;

   b. Estimating crab availability to the trawl surveys;

   c. Surveying juvenile crab abundance in near shore;

   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 1984-2013. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2013. The 2013 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 1000 times and projections made over 10 years beginning in 2013 (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 during 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 this year (Figure 34). No strong cohorts have been observed in the survey data after this cohort until last year (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011. We are disappointed that no huge tows of juvenile crab were caught in the 2012 and 2013 surveys. Because this is one tow only, it is unlikely an indicator for a strong cohort. Due to lack of recruitment, mature and legal crabs should continue to decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

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Table 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 pot and 80% for trawl was assumed to estimate bycatch mortality biomass.

Year	Retained Catch				Pot Bycatch		Trawl	Total
	U.S.	Cost-recovery	Foreign	Total	Males	Females	Bycatch	Catch
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			203.6	5371.8
1987	5574.2		0	5574.2			148.3	5722.5
1988	3351.1		0	3351.1			559.9	3910.9
1989	4656.0		0	4656.0			178.7	4834.7
1990	9236.2	36.6	0	9272.8	526.9	651.5	240.3	10691.4
1991	7791.8	93.4	0	7885.1	407.8	75.0	281.1	10080.3
1992	3648.2	33.6	0	3681.8	552.0	418.5	295.9	5405.0
1993	6635.4	24.1	0	6659.6	763.2	637.1	415.6	8671.5
1994	0.0	42.3	0	42.3	3.8	1.9	88.0	136.0
1995	0.0	36.4	0	36.4	3.3	1.6	115.4	156.6
1996	3812.7	49.0	0	3861.7	164.6	1.0	115.0	4142.3
1997	3971.9	70.2	0	4042.1	244.7	19.6	83.5	4389.9
1998	6693.8	85.4	0	6779.2	959.7	864.9	171.9	8775.7
1999	5293.5	84.3	0	5377.9	314.2	8.8	197.3	5898.1
2000	3698.8	39.1	0	3737.9	360.8	40.5	111.1	4250.3
2001	3811.5	54.6	0	3866.2	417.9	173.5	163.5	4621.0
2002	4340.9	43.6	0	4384.5	442.7	7.3	124.6	4959.1
2003	7120.0	15.3	0	7135.3	918.9	430.4	150.0	8634.6
2004	6915.2	91.4	0	7006.7	345.5	187.0	110.1	7649.4
2005	8305.0	94.7	0	8399.7	1359.5	498.3	159.1	10416.6
2006	7005.3	137.9	0	7143.2	563.8	37.0	101.7	7845.6
2007	9237.9	66.1	0	9303.9	1001.3	186.1	130.2	10621.6
2008	9216.1	0.0	0	9216.1	1165.5	148.4	165.3	10695.3
2009	7226.9	45.5	0	7272.5	888.1	85.2	105.0	8350.7
2010	6728.5	33.0	0	6761.5	797.5	122.6	89.0	7770.7
2011	3553.3	53.8	0.0	3607.1	395.0	24.0	76.4	4102.4
2012	3560.6	61.1	0.0	3621.7	205.2	12.3	57.1	3896.3

Table 2. Annual sample sizes (>64 mm CL) for catch by length and shell condition for retained catch and bycatch of Bristol Bay red king crab.

	Trawl Survey		Retained	Pot Bycatch		Trawl Bycatch	
Year	Males	Females	Catch	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			62,023	20,800
1987	1,168	1,018	4,230			60,606	32,734
1988	1,834	546	9,833			102,037	57,564
1989	1,257	550	32,858			47,905	17,355
1990	858	603	7,218	873	699	5,876	2,665
1991	1,378	491	36,820	1,801	375	2,964	962
1992	513	360	23,552	3,248	2,389	1,157	2,678
1993	1,009	534	32,777	5,803	5,942		
1994	443	266	0	0	0	4,953	3,341
1995	2,154	1,718	0	0	0	1,729	6,006
1996	835	816	8,896	230	11	24,583	9,373
1997	1,282	707	15,747	4,102	906	9,035	5,759
1998	1,097	1,150	16,131	11,079	9,130	25,051	9,594
1999	764	540	17,666	1,048	36	16,653	5,187
2000	731	1,225	14,091	8,970	1,486	36,972	10,673
2001	611	743	12,854	9,102	4,567	56,070	32,745
2002	1,032	896	15,932	9,943	302	27,705	25,425
2003	1,669	1,311	16,212	17,998	10,327	281	307
2004	2,871	1,599	20,038	8,258	4,112	137	120
2005	1,283	1,682	21,938	55,019	26,775	186	124
2006	1,171	2,672	18,027	32,252	3,980	217	168
2007	1,219	2,499	22,387	59,769	12,661	1,981	2,880
2008	1,221	3,352	14,567	49,315	8,488	1,013	673
2009	830	1,857	16,708	52,359	6,041	1,110	827
2010	705	1,633	20,137	36,654	6,868	898	863
2011	525	994	10,706	20,629	1,920	238	220
2012	580	707	8,956	7,206	561	142	129
2013	752	587					

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

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

Table 4(0). Summary of statistics for the model (Scenario 0(7ac)).

Parameter counts

Fixed growth parameters	9
Fixed recruitment parameters	2
Fixed length-weight relationship parameters	6
Fixed mortality parameters	4
Fixed survey catchability parameter	1
Fixed high grading parameters	8
Total number of fixed parameters	30
Free growth parameters	8
Initial abundance (1968)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	46
Female recruitment deviations	46
Natural and fishing mortality parameters	4
Survey catchability parameters	2
Pot male fishing mortality deviations	47
Bycatch mortality from the Tanner crab fishery	6
Pot female bycatch fishing mortality deviations	25
Trawl bycatch fishing mortality deviations	39
Initial (1968) length composition deviations	36
Free selectivity parameters	28
Effective sample size parameters	10
Total number of free parameters	301
Total number of fixed and free parameters	331

Negative log likelihood components (see the table at the beginning)

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

43

Table 4(1). Summary of statistics for the model (Scenario 1).

Parameter counts

Fixed growth parameters	9
Fixed recruitment parameters	2
Fixed length-weight relationship parameters	6
Fixed mortality parameters	4
Fixed survey catchability parameter	1
Fixed high grading parameters	8
Total number of fixed parameters	30
Free growth parameters	6
Initial abundance (1975)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	39
Female recruitment deviations	39
Natural and fishing mortality parameters	4
Pot male fishing mortality deviations	40
Bycatch mortality from the Tanner crab fishery	6
Pot female bycatch fishing mortality deviations	25
Trawl bycatch fishing mortality deviations	39
Initial (1975) length compositions	35
Free selectivity parameters	28
Total number of free parameters	265
Total number of fixed and free parameters	295

Negative log likelihood components (see the table at the beginning)

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(4). Summary of statistics for the model (Scenario 4).

Parameter counts

Fixed growth parameters	9
Fixed recruitment parameters	2
Fixed length-weight relationship parameters	6
Fixed mortality parameters	4
Fixed survey catchability parameter	2
Fixed high grading parameters	8
Total number of fixed parameters	31
Free growth parameters	6
Initial abundance (1975)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	39
Female recruitment deviations	39
Natural and fishing mortality parameters	4
Pot male fishing mortality deviations	40
Bycatch mortality from the Tanner crab fishery	6
Pot female bycatch fishing mortality deviations	25
Trawl bycatch fishing mortality deviations	39
Initial (1975) length compositions	35
Free selectivity parameters	32
Total number of free parameters	269
Total number of fixed and free parameters	300

Negative log likelihood components (see the table at the beginning)

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

45

Table 5(0). Summary of model parameter estimates (scenario 0(7ac)) 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).

	Recruits				F for Directed Pot Fishery				F for Trawl	
Year	Females	S. dev.	Males	S.dev.	Males	S.dev.	Females	S.dev.	Est.	S.dev.
Mean	16.264	0.019	16.264	0.019	-1.792	0.034	0.010	0.001	-5.151	0.062
1968					1.828	0.071				
1969	-0.029	0.107	0.737	0.074	1.829	0.100				
1970	-0.040	0.080	1.047	0.078	1.507	0.109				
1971	-0.246	0.163	1.682	0.061	1.058	0.109				
1972	-0.325	0.092	0.740	0.093	1.126	0.104				
1973	0.083	0.077	1.387	0.050	0.884	0.095				
1974	0.361	0.060	1.557	0.049	1.062	0.081				
1975	-0.382	0.190	2.129	0.041	0.909	0.065				
1976	0.619	0.144	0.929	0.088	0.982	0.059			0.224	0.105
1977	0.429	0.116	0.483	0.106	1.042	0.055			0.751	0.104
1978	0.103	0.112	0.835	0.082	1.163	0.050			0.709	0.103
1979	0.090	0.102	1.046	0.076	1.260	0.049			0.669	0.103
1980	0.224	0.111	1.292	0.077	2.199	0.024			0.748	0.103
1981	-0.149	0.045	0.669	0.086	2.199	0.008			0.311	0.104
1982	-0.049	0.071	2.136	0.041	0.319	0.044			2.023	0.105
1983	0.314	0.060	1.177	0.050	-10.522	0.819			1.957	0.105
1984	0.135	0.148	1.009	0.043	0.908	0.059			3.005	0.104
1985	0.387	0.053	-0.849	0.097	1.057	0.068			2.008	0.105
1986	-0.148	0.123	0.413	0.040	1.377	0.062			0.899	0.104
1987	0.248	0.152	-0.445	0.063	0.891	0.056			0.298	0.104
1988	0.088	0.145	-1.168	0.095	-0.061	0.050			1.397	0.102
1989	-0.027	0.064	-1.033	0.081	0.040	0.048			0.043	0.102
1990	-0.204	0.099	0.036	0.042	0.641	0.044	2.128	0.104	0.244	0.102
1991	-0.349	0.330	-0.445	0.054	0.566	0.046	0.023	0.104	0.452	0.103
1992	-0.283	0.094	-2.161	0.167	0.024	0.046	2.335	0.104	0.581	0.103
1993	-0.087	0.321	-0.618	0.053	0.719	0.047	2.173	0.104	0.995	0.102
1994	0.034	0.037	-2.304	0.177	-4.332	0.049	1.444	0.131	-0.390	0.103
1995	-0.397	0.216	0.947	0.031	-4.596	0.047	1.499	0.136	-0.220	0.103
1996	-0.461	0.345	-0.990	0.112	-0.121	0.044	-3.667	0.152	-0.380	0.102
1997	-0.226	0.109	-1.935	0.177	-0.044	0.044	-0.955	0.105	-0.736	0.103
1998	0.050	0.058	-0.484	0.061	0.707	0.045	2.075	0.103	-0.010	0.101
1999	0.131	0.127	0.308	0.040	0.242	0.045	-2.031	0.108	0.114	0.102
2000	0.775	0.154	-0.742	0.082	-0.048	0.044	-0.318	0.104	-0.461	0.102
2001	0.175	0.052	-1.184	0.123	-0.081	0.044	1.108	0.103	-0.167	0.102
2002	-0.003	0.192	0.822	0.037	0.076	0.044	-2.271	0.109	-0.435	0.102
2003	-0.013	0.136	-0.763	0.122	0.562	0.044	1.150	0.103	-0.320	0.101
2004	0.341	0.060	-0.211	0.082	0.386	0.044	0.425	0.103	-0.629	0.102
2005	-0.742	0.156	0.706	0.047	0.783	0.045	0.953	0.103	-0.308	0.102
2006	-0.172	0.161	0.153	0.062	0.462	0.046	-1.437	0.104	-0.769	0.102
2007	0.114	0.160	-0.612	0.096	0.741	0.047	-0.156	0.103	-0.597	0.102
2008	0.153	0.150	-0.977	0.103	0.896	0.050	-0.521	0.104	-0.312	0.103
2009	-0.067	0.117	-1.007	0.098	0.689	0.053	-0.832	0.105	-0.731	0.104
2010	-0.051	0.110	-0.521	0.075	0.600	0.057	-0.336	0.106	-0.894	0.105
2011	0.148	0.158	-0.339	0.073	-0.177	0.058	-1.151	0.107	-1.100	0.106
2012	-0.226	0.279	-0.808	0.108	-0.329	0.060	-1.635	0.109	-1.450	0.108
2013	-0.029	0.107	-1.212	0.169						

Table 5(0) (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 0(7ac)). 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.

						Dev. From 1968 Obs. Length comp.		
Parameter	Value	St.dev.	Parameter	Value	St.dev.	Length	Dev.	St.dev.
Mm80-84	0.514	0.015	log_srv_L50, m, 70-72	4.572	0.039	68	-0.007	0.003
Mf80-84	0.815	0.019	srv_slope, f, 70-72	0.129	0.012	73	-0.004	0.003
Mf76-79,85-93	0.065	0.005	log_srv_L50, f, 70-72	4.378	0.016	78	0.001	0.003
log_betal, females	0.172	0.053	log_srv_L50, m, 73-81	4.378	0.018	83	0.003	0.003
log_betal, males	0.448	0.073	srv_slope, f, 73-81	0.069	0.004	88	0.004	0.004
log_betar, females	-0.634	0.057	log_srv_L50, f, 73-81	4.422	0.017	93	0.003	0.004
log_betar, males	-0.565	0.042	log_srv_L50, m, 82-13	4.504	0.009	98	0.004	0.004
Q, females, 70-72	0.208	0.021	srv_slope, f, 82-13	0.054	0.002	103	0.003	0.004
Q, males, 70-72	0.453	0.061	log_srv_L50, f, 82-13	4.537	0.013	108	-0.003	0.004
Bsfrf_CV	0.048	0.060	log_srv_L50, m, 68-69	4.523	0.024	113	-0.003	0.004
moltp_slope, 68-78	0.161	0.015	srv_slope, f, 68-69	0.058	0.007	118	0.000	0.004
moltp_slope, level 1	0.075	0.003	log_srv_L50, f, 68-69	4.592	0.033	123	-0.002	0.004
moltp_slope, level 2	0.089	0.004	TC_slope, females	0.334	0.122	128	-0.002	0.004
log_moltp_L50, 68-78	4.965	0.007	log_TC_L50, females	4.552	0.016	133	-0.003	0.004
log_moltp_L50, level 1	4.875	0.004	TC_slope, males	0.230	0.099	138	-0.004	0.003
log_moltp_L50, level 2	4.950	0.003	log_TC_L50, males	4.581	0.023	143	-0.001	0.003
log_N68	18.830	0.037	log_TC_F, males, 91	-4.299	0.079	148	0.001	0.003
log_avg_L50, 73-12	4.923	0.001	log_TC_F, males, 92	-5.433	0.080	153	0.002	0.003
log_avg_L50, 68-72	4.865	0.006	log_TC_F, males, 93	-6.678	0.082	158	0.001	0.003
ret_fish_slope, 73-12	0.494	0.024	log_TC_F, females, 91	-2.960	0.085	163	0.010	0.001
ret_fish_slope, 68-72	0.443	0.120	log_TC_F, females, 92	-4.131	0.084	68	-0.007	0.003
pot disc.males, φ	-0.274	0.010	log_TC_F, females, 93	-4.734	0.083	73	-0.010	0.001
pot disc.males, κ	0.003	0.000				78	-0.009	0.003
pot disc.males, γ	-0.014	0.000				83	-0.005	0.003
sel_62.5mm, 68-72	1.415	0.002				88	-0.002	0.004
pot disc.fema., slope	0.319	0.106				93	0.002	0.005
log_pot disc.fema., L50	4.409	0.007				98	-0.002	0.005
trawl disc slope	0.053	0.003				103	-0.003	0.005
log_trawl disc L50	5.105	0.054				108	0.000	0.005
						113	0.001	0.005
						118	0.003	0.005
						123	0.004	0.006
						128	0.004	0.006
						133	0.006	0.006
						138	0.009	0.005
						143	0.010	0.001

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).

	Recruits				F for Directed Pot Fishery				F for Trawl	
Year	Females	S. dev.	Males	S.dev.	Males	S.dev.	Females	S.dev.	Est.	S.dev.
Mean	15.963	0.021	15.963	0.021	-2.017	0.033	0.011	0.001	-5.177	0.065
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	0.100				
1976	-0.413	0.304	0.764	0.129	1.145	0.071			0.199	0.107
1977	0.682	0.132	0.702	0.093	1.174	0.060			0.727	0.105
1978	0.574	0.112	0.906	0.078	1.407	0.053			0.721	0.104
1979	0.281	0.110	1.082	0.074	1.663	0.047			0.745	0.104
1980	0.287	0.105	1.289	0.073	2.425	0.012			0.768	0.104
1981	0.441	0.116	0.647	0.093	2.425	0.007			0.338	0.104
1982	-0.112	0.049	2.250	0.043	0.530	0.046			2.063	0.106
1983	0.003	0.073	1.373	0.050	-10.158	0.658			1.943	0.105
1984	0.358	0.063	1.247	0.044	0.956	0.056			2.930	0.104
1985	0.152	0.159	-0.590	0.102	1.028	0.063			1.869	0.105
1986	0.442	0.058	0.632	0.045	1.480	0.059			0.807	0.105
1987	-0.106	0.135	-0.266	0.071	1.083	0.054			0.245	0.104
1988	0.342	0.165	-1.022	0.107	0.181	0.049			1.378	0.102
1989	0.070	0.143	-0.755	0.082	0.310	0.046			0.058	0.102
1990	-0.076	0.068	0.311	0.045	0.918	0.042	2.087	0.104	0.286	0.102
1991	-0.244	0.100	-0.125	0.054	0.890	0.044	-0.063	0.104	0.524	0.103
1992	-0.662	0.388	-1.798	0.159	0.372	0.045	2.239	0.104	0.684	0.103
1993	-0.253	0.096	-0.343	0.054	1.018	0.047	2.140	0.104	1.045	0.102
1994	-0.151	0.393	-2.123	0.184	-4.116	0.047	1.497	0.131	-0.397	0.104
1995	0.034	0.039	1.190	0.035	-4.446	0.044	1.611	0.135	-0.279	0.103
1996	-0.644	0.237	-0.600	0.107	0.100	0.042	-3.672	0.151	-0.397	0.103
1997	-0.810	0.386	-1.439	0.156	0.210	0.042	-0.961	0.105	-0.722	0.103
1998	-0.209	0.115	-0.250	0.067	0.907	0.043	2.135	0.103	-0.040	0.102
1999	0.021	0.060	0.574	0.042	0.464	0.042	-2.002	0.108	0.099	0.102
2000	-0.037	0.133	-0.369	0.079	0.099	0.041	-0.230	0.103	-0.535	0.102
2001	0.782	0.163	-0.947	0.128	0.125	0.041	1.148	0.103	-0.198	0.102
2002	0.239	0.056	0.974	0.041	0.233	0.041	-2.184	0.109	-0.501	0.102
2003	0.010	0.210	-0.584	0.127	0.756	0.041	1.186	0.103	-0.354	0.102
2004	-0.067	0.139	0.051	0.081	0.621	0.041	0.415	0.102	-0.636	0.102
2005	0.378	0.062	0.880	0.048	1.048	0.042	0.940	0.103	-0.289	0.102
2006	-0.785	0.177	0.286	0.067	0.777	0.043	-1.512	0.104	-0.725	0.102
2007	-0.301	0.160	-0.279	0.085	1.108	0.044	-0.262	0.103	-0.528	0.102
2008	0.058	0.165	-0.748	0.103	1.206	0.048	-0.563	0.104	-0.284	0.103
2009	0.106	0.158	-0.796	0.101	0.921	0.051	-0.792	0.105	-0.740	0.104
2010	-0.116	0.120	-0.278	0.075	0.792	0.055	-0.254	0.105	-0.932	0.106
2011	-0.026	0.117	-0.204	0.077	0.127	0.058	-1.181	0.107	-1.075	0.107
2012	0.129	0.167	-0.650	0.111	0.033	0.060	-1.722	0.110	-1.376	0.108
2013	-0.377	0.315	-0.992	0.167						

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.

Parameter	Value	St.dev.	Limits	Initial length composition 1975 Length	Value	St.dev.	Limits
Mm80-84	0.473	0.016	0.184, 1.0	68	1.224	0.095	-5, 5
Mf80-84	0.801	0.020	0.276, 1.5	73	1.265	0.086	-5, 5
Mf76-79,85-93	0.072	0.006	0.0, 0.082	78	0.483	0.111	-5, 5
log_betal, females	0.163	0.054	-0.67, 1.32	83	0.457	0.097	-5, 5
log_betal, males	0.528	0.084	-0.67, 1.32	88	0.416	0.090	-5, 5
log_betar, females	-0.709	0.064	-1.14, 0.5	93	0.107	0.102	-5, 5
log_betar, males	-0.644	0.048	-1.14, 0.5	98	0.133	0.099	-5, 5
Bsfrf_CV	0.148	0.112	0.00, 0.40	103	-0.099	0.114	-5, 5
moltp_slope, 75-78	0.137	0.021	0.01, 0.207	108	-0.043	0.114	-5, 5
moltp_slope, 79-13	0.101	0.004	0.01, 0.207	113	0.072	0.112	-5, 5
log_moltp_L50, 75-78	4.964	0.011	4.47, 5.62	118	-0.079	0.130	-5, 5
log_moltp_L50, 79-13	4.943	0.003	4.47, 5.62	123	-0.093	0.139	-5, 5
log_N75	20.048	0.031	15.0, 21.0	128	-0.079	0.148	-5, 5
log_avg_L50_ret	4.921	0.002	4.78, 5.05	133	-0.129	0.161	-5, 5
ret_fish_slope	0.529	0.032	0.05, 0.70	138	-0.216	0.145	-5, 5
pot disc.males, φ	-0.329	0.015	-0.40, 0.00	143	-0.315	0.146	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.470	0.156	-5, 5
pot disc.males, γ	-0.015	0.001	-0.025, 0.0	153	-0.828	0.190	-5, 5
pot disc.fema., slope	0.583	0.204	0.05, 0.69	158	-1.319	0.255	-5, 5
log_pot disc.fema., L50	4.385	0.009	4.24, 4.61	163	-1.345	0.268	-5, 5
trawl disc slope	0.056	0.003	0.01, 0.20	68	1.655	0.096	-5, 5
log_trawl disc L50	5.039	0.045	4.40, 5.20	73	1.585	0.095	-5, 5
log_srv_L50, m, 75-81	4.325	0.011	4.09, 5.54	78	1.403	0.094	-5, 5
srv_slope, f, 75-81	0.067	0.004	0.01, 0.33	83	1.158	0.097	-5, 5
log_srv_L50, f, 75-81	4.442	0.018	4.09, 4.70	88	1.156	0.087	-5, 5
log_srv_L50, m, 82-12	4.480	0.008	4.09, 5.10	93	0.764	0.100	-5, 5
srv_slope, f, 82-12	0.058	0.002	0.01, 0.30	98	0.483	0.114	-5, 5
log_srv_L50, f, 82-12	4.524	0.012	4.09, 4.90	103	0.403	0.116	-5, 5
TC_slope, females	0.290	0.122	0.02, 0.40	108	0.206	0.129	-5, 5
log_TC_L50, females	4.557	0.019	4.24, 4.90	113	0.026	0.144	-5, 5
TC_slope, males	0.177	0.066	0.05, 0.90	118	-0.490	0.210	-5, 5
log_TC_L50, males	4.606	0.029	4.25, 5.14	123	-0.684	0.256	-5, 5
log_TC_F, males, 91	-4.150	0.083	-7.0, 1.0	128	-1.103	0.379	-5, 5
log_TC_F, males, 92	-5.277	0.086	-7.0, 1.0	133	-1.878	0.758	-5, 5
log_TC_F, males, 93	-6.567	0.088	-7.0, 1.0	138	-2.349	1.260	-5, 5
log_TC_F, females, 91	-2.874	0.087	-7.0, 1.0	143	NA	NA	
log_TC_F, females, 92	-4.025	0.088	-7.0, 1.0				
log_TC_F, females, 93	-4.620	0.087	-7.0, 1.0				

Table 5(4). Summary of model parameter estimates (scenario 4) 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).

	Recruits				F for Directed Pot Fishery				F for Trawl	
Year	Females	S. dev.	Males	S.dev.	Males	S.dev.	Females	S.dev.	Est.	S.dev.
Mean	15.967	0.021	15.967	0.021	-2.021	0.033	0.011	0.001	-5.182	0.065
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					1.122	0.100				
1976	-0.413	0.305	0.759	0.130	1.148	0.070			0.201	0.107
1977	0.683	0.132	0.698	0.093	1.178	0.060			0.729	0.105
1978	0.575	0.112	0.902	0.078	1.410	0.053			0.723	0.104
1979	0.281	0.110	1.079	0.074	1.665	0.047			0.747	0.104
1980	0.288	0.105	1.287	0.073	2.425	0.011			0.769	0.104
1981	0.440	0.117	0.645	0.093	2.425	0.007			0.339	0.104
1982	-0.113	0.048	2.248	0.043	0.532	0.046			2.065	0.106
1983	0.002	0.073	1.369	0.050	-10.147	0.653			1.946	0.105
1984	0.359	0.062	1.243	0.044	0.962	0.056			2.935	0.104
1985	0.151	0.159	-0.596	0.102	1.036	0.063			1.874	0.105
1986	0.442	0.058	0.627	0.045	1.487	0.059			0.811	0.105
1987	-0.105	0.135	-0.272	0.071	1.089	0.054			0.249	0.104
1988	0.342	0.166	-1.028	0.107	0.187	0.049			1.382	0.102
1989	0.067	0.144	-0.760	0.082	0.315	0.046			0.062	0.102
1990	-0.076	0.068	0.307	0.045	0.922	0.042	2.084	0.104	0.290	0.102
1991	-0.244	0.100	-0.130	0.054	0.895	0.044	-0.066	0.104	0.528	0.103
1992	-0.662	0.387	-1.803	0.159	0.377	0.045	2.236	0.104	0.688	0.103
1993	-0.256	0.096	-0.347	0.054	1.023	0.047	2.138	0.104	1.049	0.102
1994	-0.155	0.393	-2.128	0.184	-4.112	0.047	1.495	0.131	-0.393	0.104
1995	0.032	0.039	1.187	0.035	-4.442	0.044	1.609	0.135	-0.276	0.103
1996	-0.646	0.237	-0.605	0.107	0.103	0.042	-3.674	0.151	-0.394	0.103
1997	-0.817	0.386	-1.444	0.156	0.213	0.042	-0.963	0.105	-0.719	0.103
1998	-0.213	0.116	-0.252	0.067	0.910	0.043	2.133	0.103	-0.037	0.102
1999	0.020	0.060	0.573	0.042	0.466	0.042	-2.003	0.108	0.102	0.102
2000	-0.037	0.133	-0.370	0.079	0.101	0.041	-0.231	0.103	-0.533	0.102
2001	0.779	0.163	-0.947	0.128	0.126	0.041	1.147	0.103	-0.196	0.102
2002	0.242	0.056	0.975	0.041	0.233	0.041	-2.186	0.109	-0.500	0.102
2003	0.017	0.210	-0.584	0.127	0.756	0.040	1.184	0.103	-0.353	0.102
2004	-0.067	0.139	0.047	0.081	0.620	0.041	0.413	0.102	-0.636	0.102
2005	0.365	0.061	0.897	0.047	1.045	0.042	0.939	0.103	-0.291	0.102
2006	-0.701	0.164	0.289	0.066	0.772	0.042	-1.512	0.104	-0.728	0.102
2007	-0.336	0.157	-0.264	0.084	1.101	0.044	-0.263	0.103	-0.532	0.102
2008	0.029	0.164	-0.741	0.103	1.198	0.048	-0.563	0.104	-0.291	0.103
2009	0.118	0.156	-0.783	0.101	0.908	0.051	-0.788	0.105	-0.750	0.104
2010	-0.120	0.120	-0.267	0.075	0.775	0.055	-0.246	0.105	-0.944	0.106
2011	-0.026	0.117	-0.192	0.077	0.107	0.057	-1.171	0.107	-1.089	0.107
2012	0.129	0.167	-0.638	0.111	0.012	0.060	-1.711	0.110	-1.391	0.108
2013	-0.374	0.315	-0.982	0.167						

Table 5(4) (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 4). 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.

Parameter	Value	St.dev.	Limits	Initial length composition 1975 Length	Value	St.dev.	Limits
Mm80-84	0.475	0.016	0.184, 1.00	68	1.225	0.095	-5, 5
Mf80-84	0.802	0.020	0.276, 1.50	73	1.266	0.087	-5, 5
Mf76-79,85-93	0.073	0.006	0.0, 0.082	78	0.484	0.111	-5, 5
log_betal, females	0.171	0.054	-0.67, 1.32	83	0.457	0.097	-5, 5
log_betal, males	0.531	0.084	-0.67, 1.32	88	0.416	0.090	-5, 5
log_betar, females	-0.707	0.064	-1.14, 0.50	93	0.107	0.102	-5, 5
log_betar, males	-0.646	0.048	-1.14, 0.50	98	0.133	0.099	-5, 5
Bsfrf_CV	0.066	0.067	0.00, 0.40	103	-0.100	0.114	-5, 5
moltp_slope, 75-79	0.137	0.021	0.01, 0.168	108	-0.044	0.114	-5, 5
moltp_slope, 80-12	0.100	0.004	0.01, 0.168	113	0.071	0.112	-5, 5
log_moltp_L50, 75-79	4.964	0.011	4.47, 5.52	118	-0.080	0.130	-5, 5
log_moltp_L50, 80-12	4.943	0.003	4.47, 5.52	123	-0.094	0.139	-5, 5
log_N75	20.049	0.031	15.0, 21.00	128	-0.080	0.148	-5, 5
log_avg_L50_ret	4.921	0.002	4.78, 5.05	133	-0.130	0.161	-5, 5
ret_fish_slope	0.530	0.032	0.05, 0.70	138	-0.218	0.145	-5, 5
pot disc.males, φ	-0.329	0.015	-0.40, 0.00	143	-0.317	0.146	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.471	0.156	-5, 5
pot disc.males, γ	-0.015	0.001	-0.025, 0.0	153	-0.829	0.190	-5, 5
pot disc.fema., slope	0.577	0.203	0.05, 0.69	158	-1.321	0.255	-5, 5
log_pot disc.fema., L50	4.386	0.009	4.24, 4.61	163	-1.347	0.268	-5, 5
trawl disc slope	0.056	0.003	0.01, 0.20	68	1.658	0.096	-5, 5
log_trawl disc L50	5.037	0.044	4.40, 5.20	73	1.588	0.095	-5, 5
log_srv_L50, m, bsfrf	4.387	0.045	3.59, 5.49	78	1.405	0.094	-5, 5
srv_slope, f, bsfrf	0.013	0.006	0.01, 0.435	83	1.159	0.097	-5, 5
log_srv_L50, f, bsfrf	5.166	0.478	4.09, 5.54	88	1.156	0.088	-5, 5
log_srv_L50, m, 75-81	4.326	0.011	4.09, 5.54	93	0.764	0.100	-5, 5
srv_slope, f, 75-81	0.067	0.004	0.01, 0.33	98	0.484	0.114	-5, 5
log_srv_L50, f, 75-81	4.443	0.018	4.09, 4.70	103	0.403	0.116	-5, 5
log_srv_L50, m, 82-12	4.482	0.008	4.09, 5.10	108	0.206	0.129	-5, 5
srv_slope, f, 82-12	0.058	0.002	0.01, 0.30	113	0.027	0.144	-5, 5
log_srv_L50, f, 82-12	4.525	0.012	4.09, 4.90	118	-0.490	0.210	-5, 5
TC_slope, females	0.290	0.122	0.02, 0.40	123	-0.683	0.256	-5, 5
log_TC_L50, females	4.558	0.019	4.24, 4.90	128	-1.102	0.378	-5, 5
TC_slope, males	0.177	0.066	0.05, 0.90	133	-1.877	0.757	-5, 5
log_TC_L50, males	4.606	0.029	4.25, 5.14	138	-2.349	1.259	-5, 5
log_TC_F, males, 91	-4.148	0.083	-7.0, 1.00	143	NA	NA	
log_TC_F, males, 92	-5.275	0.086	-7.0, 1.00				
log_TC_F, males, 93	-6.565	0.088	-7.0, 1.00				
log_TC_F, females, 91	-2.871	0.087	-7.0, 1.00				
log_TC_F, females, 92	-4.022	0.088	-7.0, 1.00				
log_TC_F, females, 93	-4.617	0.087	-7.0, 1.00				

Table 6(0). Annual abundance estimates (million crabs), mature male biomass (MMB, 1000 t), and total survey biomass estimates (1000 t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 0(7ac)) from 1968-2013. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm CL.

	Males				Females	Total	Total Survey Biomass	
Year (t)	Mature (>119mm)	Legal (>134mm)	MMB (>119mm)	MMB SD	Mature (>89mm)	Recruits	Model Est. (>64mm)	Area-swept (>64mm)
1968	13.267	8.504	14.532	1.201	51.409		84.654	89.427
1969	13.134	6.066	14.100	1.458	54.058	46.580	85.209	94.054
1970	17.310	6.974	20.848	2.278	58.126	65.022	38.010	46.251
1971	19.647	9.957	27.704	2.890	64.128	122.043	45.588	
1972	24.471	12.646	34.281	3.248	77.090	43.234	56.665	53.060
1973	31.665	15.556	47.076	3.776	93.586	79.785	189.742	174.815
1974	45.651	21.668	64.924	4.102	99.052	114.576	222.424	206.370
1975	51.076	29.431	76.796	4.104	106.485	236.936	265.354	219.344
1976	54.224	32.942	80.797	3.731	135.471	49.321	305.065	301.530
1977	62.035	34.400	89.896	3.254	164.433	53.608	323.270	391.066
1978	77.387	39.563	107.501	2.912	156.636	67.665	324.933	349.495
1979	77.119	47.532	104.415	2.927	140.734	69.461	310.436	264.389
1980	56.704	35.830	31.904	1.073	129.894	88.267	271.038	243.299
1981	18.875	9.354	11.673	0.448	56.003	50.871	114.186	122.497
1982	9.392	3.557	10.019	0.359	26.090	182.292	62.615	141.612
1983	7.709	3.133	9.367	0.322	17.446	73.314	52.057	49.322
1984	7.110	2.906	6.827	0.301	17.677	75.198	47.960	134.594
1985	8.178	2.300	11.033	0.440	14.337	10.625	36.751	34.285
1986	13.796	5.137	17.671	0.669	20.188	43.255	49.208	47.901
1987	17.115	7.767	24.830	0.827	24.365	13.810	56.580	69.759
1988	17.852	10.279	31.013	0.916	29.871	8.212	61.721	54.224
1989	19.783	12.156	35.593	0.964	28.037	8.617	65.976	61.835
1990	20.322	13.480	34.217	0.983	24.589	23.681	67.091	56.892
1991	16.888	12.465	29.663	0.963	22.731	13.472	62.030	87.572
1992	13.695	10.417	27.493	0.924	22.684	2.275	56.488	37.671
1993	13.582	8.951	23.116	0.850	20.273	10.945	53.084	51.022
1994	12.839	7.611	26.976	0.833	16.931	2.215	46.405	32.357
1995	13.205	8.815	28.738	0.796	16.403	60.717	51.840	38.656
1996	13.573	10.115	27.811	0.774	22.141	7.189	59.943	44.338
1997	12.900	9.513	26.525	0.756	32.155	2.725	64.915	84.836
1998	16.617	8.730	27.376	0.773	30.081	12.832	66.811	84.572
1999	18.730	10.471	32.904	0.869	26.463	32.304	67.256	64.609
2000	16.395	10.874	31.010	0.832	28.665	11.794	67.495	69.314
2001	15.548	11.234	30.815	0.829	32.710	11.238	70.849	52.816
2002	16.487	10.289	30.970	0.813	32.669	57.696	74.164	69.327
2003	17.400	11.300	30.409	0.835	38.732	10.777	79.905	96.814
2004	15.754	10.912	28.930	0.836	46.827	18.621	82.940	96.297
2005	18.792	10.551	30.480	0.900	45.308	56.421	89.374	106.600
2006	19.553	11.561	33.661	1.006	49.884	19.909	93.564	95.743
2007	19.170	12.507	31.695	1.078	57.503	11.562	99.361	104.993
2008	20.046	10.837	30.882	1.164	53.752	9.238	97.459	124.971
2009	20.863	10.669	33.065	1.351	48.568	9.153	93.047	91.692
2010	19.860	11.309	32.398	1.485	44.059	13.302	88.554	81.527
2011	17.814	12.364	34.367	1.637	40.652	16.075	85.665	67.159
2012	16.189	12.438	33.789	1.705	38.862	11.145	84.571	61.106
2013	15.427	11.682	28.222	1.363	37.589	6.193	82.552	62.254

Table 6(1). Annual abundance estimates (million crabs), mature male biomass (MMB, 1000 t), and total survey biomass estimates (1000 t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 1) from 1975-2013. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm CL.

	Males				Females	Total	Total Survey Biomass	
Year (t)	Mature (>119mm)	Legal (>134mm)	MMB (>119mm)	MMB SD	Mature (>89mm)	Recruits	Model Est. (>64mm)	Area-swept (>64mm)
1975	55.447	29.673	82.466	5.229	89.701		254.552	219.344
1976	59.927	35.406	89.901	4.385	122.142	30.557	290.836	301.530
1977	61.539	37.279	91.848	3.674	151.687	51.420	301.873	391.066
1978	69.820	38.207	96.625	3.045	145.549	58.745	295.862	349.495
1979	67.820	41.066	85.203	2.558	129.657	58.684	274.486	264.389
1980	49.054	34.893	26.048	0.944	118.352	72.490	238.996	243.299
1981	15.517	8.887	9.138	0.404	51.434	41.762	99.489	122.497
1982	7.816	3.383	8.733	0.362	24.152	153.856	54.707	141.612
1983	6.824	3.207	8.889	0.349	15.828	67.654	47.389	49.322
1984	6.572	3.138	6.820	0.341	16.140	72.388	46.091	134.594
1985	8.443	2.669	11.949	0.511	13.621	10.270	37.455	34.285
1986	13.542	5.414	17.774	0.747	19.479	41.153	49.264	47.901
1987	16.502	7.720	24.047	0.905	23.326	12.461	55.828	69.759
1988	17.037	9.917	29.532	0.985	28.475	7.418	59.936	54.224
1989	18.598	11.564	33.169	1.022	26.436	8.337	63.082	61.835
1990	18.809	12.593	31.050	1.028	22.975	22.512	63.155	56.892
1991	15.279	11.354	25.934	0.998	20.992	13.478	57.635	87.572
1992	12.127	9.169	23.589	0.948	20.810	2.150	51.931	37.671
1993	12.657	8.274	20.976	0.913	18.515	10.791	50.097	51.022
1994	12.468	7.640	26.416	0.924	15.329	1.906	44.613	32.357
1995	12.876	9.438	29.118	0.895	15.011	57.250	50.781	38.656
1996	12.904	10.042	27.022	0.847	20.300	7.168	58.015	44.338
1997	12.083	9.091	25.024	0.806	29.888	2.933	62.395	84.836
1998	16.435	8.736	27.331	0.859	27.875	12.069	65.606	84.572
1999	18.053	10.351	31.866	0.942	24.425	30.729	65.156	64.609
2000	16.018	11.734	31.541	0.933	26.514	11.618	66.932	69.314
2001	14.867	11.183	30.153	0.898	30.362	10.574	69.222	52.816
2002	16.409	10.614	31.801	0.894	30.277	51.465	73.254	69.327
2003	17.032	11.345	30.251	0.888	35.745	9.599	77.578	96.814
2004	15.100	10.712	27.877	0.857	43.190	17.429	79.175	96.297
2005	17.206	10.054	27.725	0.874	41.657	50.764	83.830	106.600
2006	17.376	10.445	29.424	0.931	45.600	16.586	86.466	95.743
2007	16.853	10.932	26.627	0.969	52.491	11.271	90.899	104.993
2008	18.214	10.121	27.368	1.114	48.756	8.350	90.233	124.971
2009	19.029	10.719	30.456	1.333	43.966	8.160	86.706	91.692
2010	17.816	11.679	30.141	1.490	39.778	12.254	82.893	81.527
2011	15.181	11.147	29.898	1.560	36.604	13.786	77.975	67.159
2012	13.614	10.579	28.334	1.579	34.901	9.550	75.705	61.106
2013	13.000	9.716	24.465	1.282	33.588	5.350	73.092	62.254

Table 6(4). Annual abundance estimates (million crabs), mature male biomass (MMB, 1000 t), and total survey biomass estimates (1000 t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 4) from 1975-2013. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm CL.

	Males				Females	Total	Total Survey Biomass	
Year (t)	Mature (>119mm)	Legal (>134mm)	MMB (>119mm)	MMB SD	Mature (>89mm)	Recruits	Model Est. (>64mm)	Area-swept (>64mm)
1975	55.408	29.648	82.387	5.225	89.783		254.465	219.344
1976	59.896	35.392	89.842	4.382	122.321	30.516	290.827	301.530
1977	61.521	37.271	91.818	3.672	151.873	51.506	301.914	391.066
1978	69.830	38.211	96.645	3.045	145.703	58.869	295.928	349.495
1979	67.849	41.092	85.275	2.561	129.770	58.822	274.571	264.389
1980	49.089	34.934	26.105	0.945	118.433	72.679	239.106	243.299
1981	15.527	8.900	9.151	0.403	51.432	41.862	99.487	122.497
1982	7.814	3.385	8.727	0.361	24.137	154.219	54.593	141.612
1983	6.812	3.202	8.868	0.348	15.827	67.715	47.251	49.322
1984	6.557	3.130	6.793	0.340	16.122	72.499	45.936	134.594
1985	8.420	2.659	11.907	0.508	13.609	10.255	37.305	34.285
1986	13.510	5.397	17.712	0.744	19.457	41.173	49.093	47.901
1987	16.466	7.697	23.973	0.901	23.308	12.451	55.645	69.759
1988	17.003	9.890	29.459	0.981	28.442	7.411	59.752	54.224
1989	18.567	11.538	33.101	1.018	26.402	8.328	62.909	61.835
1990	18.780	12.568	30.989	1.024	22.936	22.526	62.994	56.892
1991	15.254	11.333	25.882	0.994	20.952	13.469	57.481	87.572
1992	12.107	9.150	23.545	0.944	20.768	2.149	51.785	37.671
1993	12.639	8.259	20.939	0.909	18.472	10.786	49.962	51.022
1994	12.453	7.627	26.383	0.921	15.290	1.901	44.493	32.357
1995	12.864	9.426	29.092	0.892	14.971	57.280	50.659	38.656
1996	12.895	10.032	27.005	0.845	20.270	7.161	57.885	44.338
1997	12.077	9.084	25.015	0.804	29.841	2.928	62.267	84.836
1998	16.434	8.732	27.333	0.857	27.840	12.089	65.499	84.572
1999	18.059	10.352	31.881	0.940	24.394	30.819	65.076	64.609
2000	16.029	11.740	31.570	0.932	26.496	11.660	66.875	69.314
2001	14.884	11.193	30.197	0.897	30.360	10.607	69.197	52.816
2002	16.440	10.629	31.872	0.894	30.293	51.865	73.281	69.327
2003	17.075	11.370	30.351	0.889	35.833	9.670	77.667	96.814
2004	15.154	10.747	28.003	0.858	43.369	17.446	79.333	96.297
2005	17.290	10.099	27.905	0.876	41.852	51.453	84.089	106.600
2006	17.482	10.511	29.656	0.935	45.834	17.186	86.881	95.743
2007	16.971	11.014	26.893	0.975	52.900	11.331	91.501	104.993
2008	18.425	10.220	27.776	1.128	49.315	8.322	91.011	124.971
2009	19.315	10.878	31.027	1.354	44.415	8.357	87.614	91.692
2010	18.125	11.892	30.809	1.514	40.150	12.434	83.894	81.527
2011	15.485	11.386	30.610	1.586	36.983	14.023	79.039	67.159
2012	13.904	10.820	29.054	1.605	35.284	9.713	76.809	61.106
2013	13.288	9.951	24.952	1.280	33.983	5.438	74.218	62.254

Table 7(0). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2013-2022. Parameter estimates with scenario 0 or 7ac are used for the projection.

Year	MMB	95% limits of MMB		Catch	95% limits of catch	
No directed fishery						
2013	36.467	33.260	39.496	0.000	0.000	0.000
2014	39.028	35.595	42.269	0.000	0.000	0.000
2015	40.848	37.255	44.241	0.000	0.000	0.000
2016	41.352	37.760	44.974	0.000	0.000	0.000
2017	43.146	37.635	53.583	0.000	0.000	0.000
2018	46.765	37.116	67.456	0.000	0.000	0.000
2019	51.019	36.261	78.341	0.000	0.000	0.000
2020	55.135	36.577	85.573	0.000	0.000	0.000
2021	58.888	36.808	91.696	0.000	0.000	0.000
2022	62.288	36.829	96.779	0.000	0.000	0.000
$F_{40\%}$						
2013	29.667	27.091	32.128	7.003	6.353	7.588
2014	27.084	25.061	29.215	5.871	5.020	6.475
2015	25.204	23.558	26.866	4.991	4.308	5.734
2016	23.270	21.772	24.840	4.262	3.739	4.838
2017	23.287	20.004	31.895	3.916	3.181	5.029
2018	25.177	18.354	40.852	4.041	2.674	6.234
2019	27.413	17.482	46.368	4.505	2.393	7.966
2020	29.216	17.320	50.291	5.023	2.210	9.076
2021	30.501	17.725	51.655	5.453	2.274	9.661
2022	31.435	17.879	52.373	5.762	2.282	10.098
$F_{35\%}$						
2013	28.290	26.086	30.603	8.418	7.386	9.155
2014	25.296	23.653	26.943	6.397	5.511	7.355
2015	23.354	22.001	24.666	5.213	4.586	5.857
2016	21.471	20.198	22.826	4.396	3.906	4.910
2017	21.504	18.380	29.645	4.077	3.282	5.585
2018	23.304	16.845	37.868	4.285	2.719	6.984
2019	25.332	16.131	43.023	4.853	2.457	8.893
2020	26.869	16.116	46.234	5.432	2.277	10.058
2021	27.882	16.509	47.093	5.886	2.359	10.844
2022	28.585	16.595	47.361	6.175	2.377	11.135

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 2013-2022. Parameter estimates with scenario 1 are used for the projection.

Year	MMB	95% limits of MMB		Catch	95% limits of catch	
No directed fishery						
2013	30.589	25.391	32.809	0.000	0.000	0.000
2014	33.359	27.690	35.780	0.000	0.000	0.000
2015	35.299	29.300	37.861	0.000	0.000	0.000
2016	36.002	29.712	38.645	0.000	0.000	0.000
2017	38.044	29.954	46.885	0.000	0.000	0.000
2018	41.928	28.502	58.166	0.000	0.000	0.000
2019	46.381	26.283	66.025	0.000	0.000	0.000
2020	50.638	25.540	73.511	0.000	0.000	0.000
2021	54.480	26.873	79.161	0.000	0.000	0.000
2022	57.932	28.630	85.630	0.000	0.000	0.000
$F_{40\%}$						
2013	25.280	21.628	26.885	5.441	3.857	6.071
2014	23.972	20.895	25.280	4.593	3.406	5.148
2015	22.783	20.090	23.902	4.103	3.134	4.541
2016	21.290	18.778	22.443	3.628	2.798	3.993
2017	21.596	17.400	28.541	3.441	2.492	4.516
2018	23.658	15.224	35.595	3.680	1.929	5.675
2019	25.928	13.409	40.321	4.218	1.456	6.992
2020	27.698	13.232	43.042	4.760	1.269	7.976
2021	28.931	14.864	45.318	5.182	1.433	8.517
2022	29.821	15.029	46.452	5.472	1.712	9.007
$F_{35\%}$						
2013	24.490	21.054	25.901	6.248	4.445	7.076
2014	22.828	20.015	23.963	5.010	3.760	5.557
2015	21.484	19.054	22.457	4.357	3.370	4.781
2016	19.955	17.689	20.947	3.792	2.957	4.158
2017	20.227	16.266	26.722	3.603	2.596	5.001
2018	22.174	14.177	33.260	3.909	1.983	6.269
2019	24.235	12.468	37.425	4.533	1.486	7.727
2020	25.757	12.381	39.931	5.123	1.304	8.770
2021	26.742	14.052	41.698	5.562	1.503	9.353
2022	27.427	14.054	42.902	5.831	1.784	9.778

Table 7(4). 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 2013-2022. Parameter estimates with scenario 1 are used for the projection.

Year	MMB	95% limits of MMB		Catch	95% limits of catch	
No directed fishery						
2013	31.321	28.507	33.978	0.000	0.000	0.000
2014	34.110	31.046	37.004	0.000	0.000	0.000
2015	36.059	32.819	39.118	0.000	0.000	0.000
2016	36.747	33.489	40.040	0.000	0.000	0.000
2017	38.754	33.583	48.693	0.000	0.000	0.000
2018	42.600	33.300	62.014	0.000	0.000	0.000
2019	47.017	32.882	72.705	0.000	0.000	0.000
2020	51.241	33.377	80.642	0.000	0.000	0.000
2021	55.053	33.750	86.096	0.000	0.000	0.000
2022	58.479	34.458	90.913	0.000	0.000	0.000
$F_{40\%}$						
2013	25.813	23.852	27.834	5.646	4.772	6.298
2014	24.390	22.765	26.003	4.749	4.085	5.455
2015	23.130	21.721	24.489	4.219	3.686	4.763
2016	21.582	20.233	22.961	3.717	3.280	4.175
2017	21.841	18.697	29.870	3.509	2.840	4.651
2018	23.871	17.294	38.308	3.733	2.397	5.945
2019	26.119	16.689	43.706	4.263	2.182	7.588
2020	27.876	16.674	47.663	4.801	2.092	8.671
2021	29.099	17.073	48.907	5.220	2.133	9.395
2022	29.982	17.477	50.225	5.507	2.208	9.633
$F_{35\%}$						
2013	24.980	23.161	26.720	6.497	5.480	7.437
2014	23.203	21.735	24.578	5.169	4.480	5.850
2015	21.794	20.533	22.959	4.472	3.936	4.990
2016	20.215	18.999	21.458	3.879	3.442	4.319
2017	20.444	17.455	28.008	3.671	2.940	5.142
2018	22.361	16.100	35.855	3.963	2.459	6.596
2019	24.404	15.586	41.141	4.579	2.241	8.378
2020	25.913	15.579	44.250	5.164	2.144	9.580
2021	26.890	16.047	45.384	5.600	2.211	10.305
2022	27.569	16.445	45.759	5.867	2.301	10.605

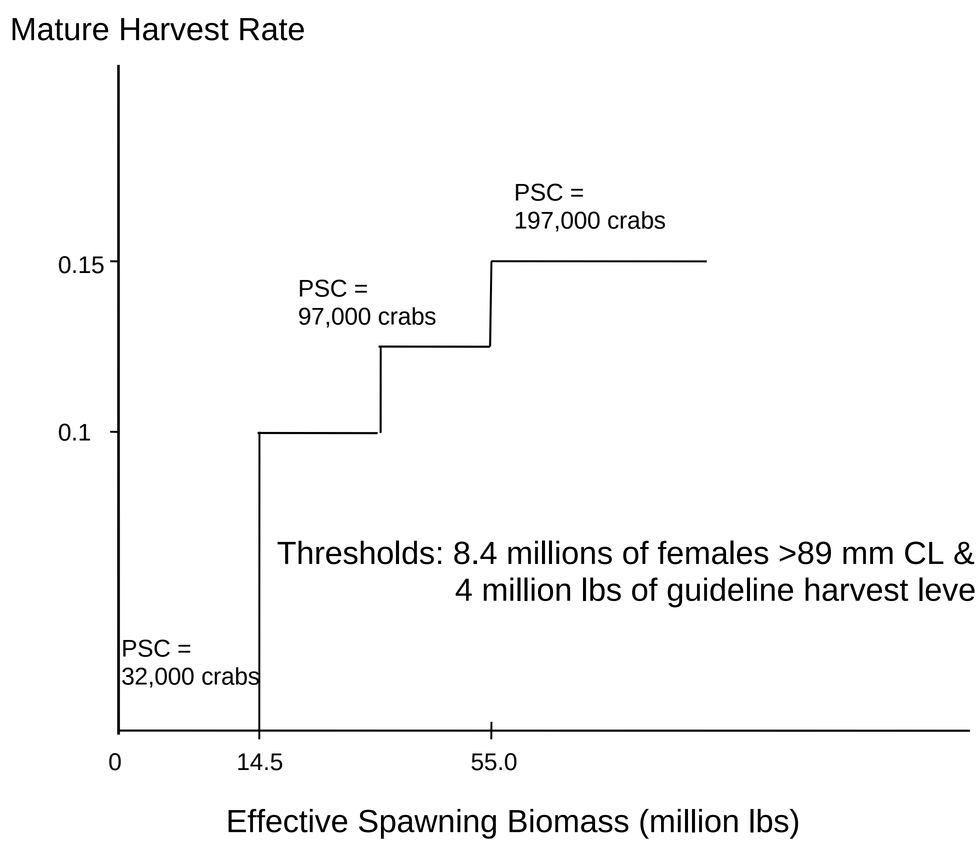

Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crabs) of Bristol Bay red king crabs in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates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

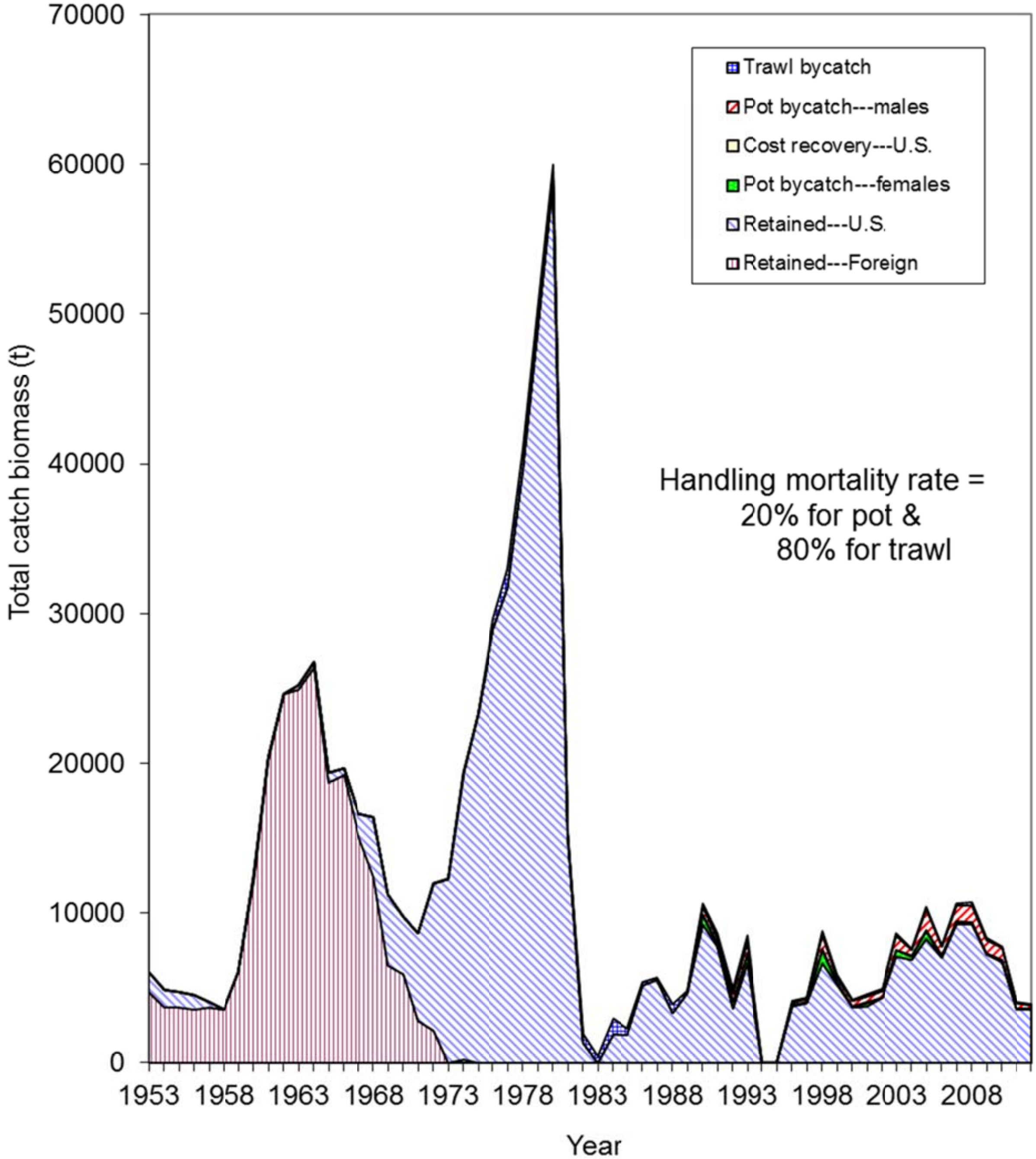

Figure 2. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2012. Handling mortality rates were assumed to be 0.2 for the directed pot fishery and 0.8 for the trawl fisheries.

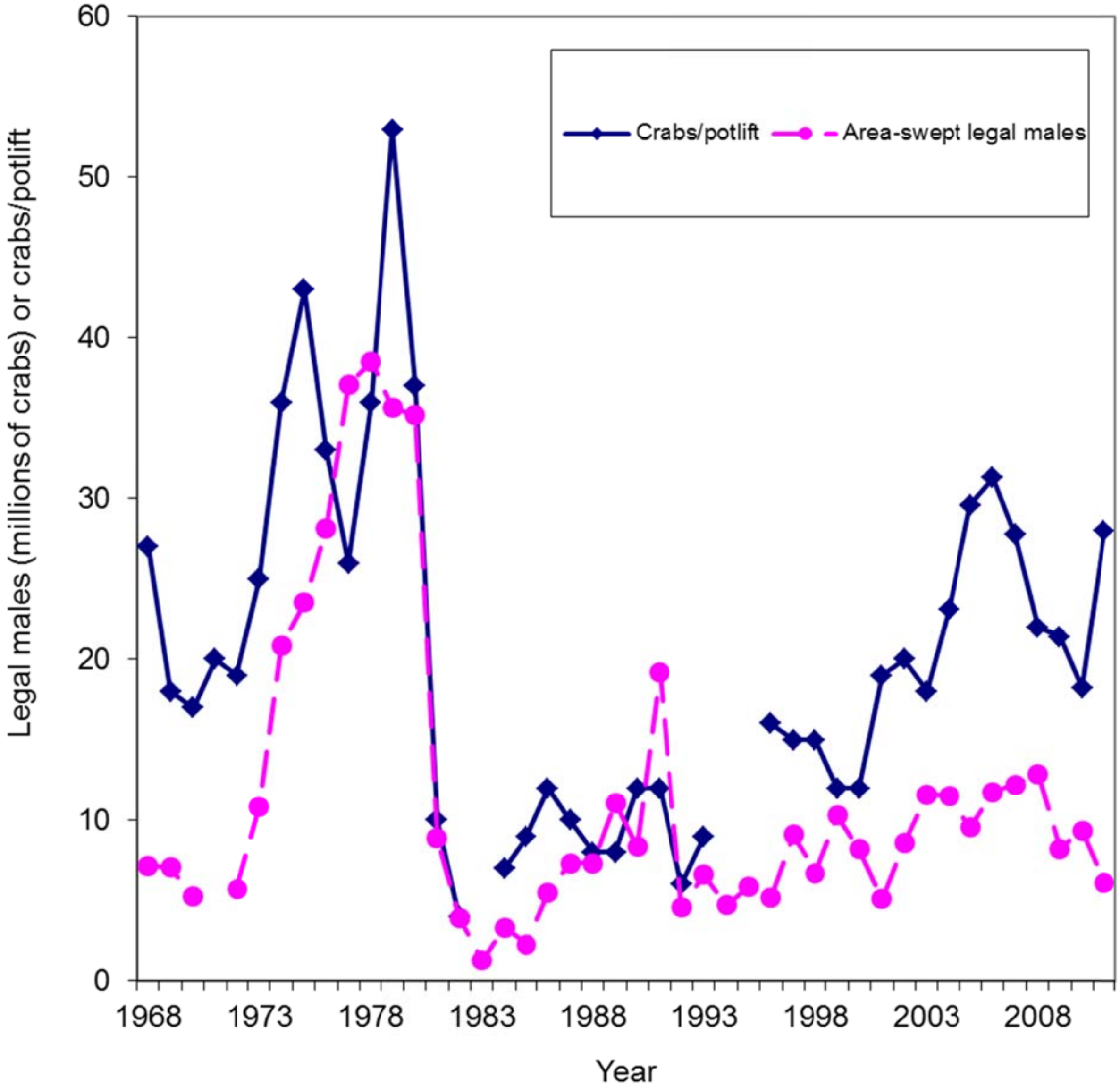

Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2011.

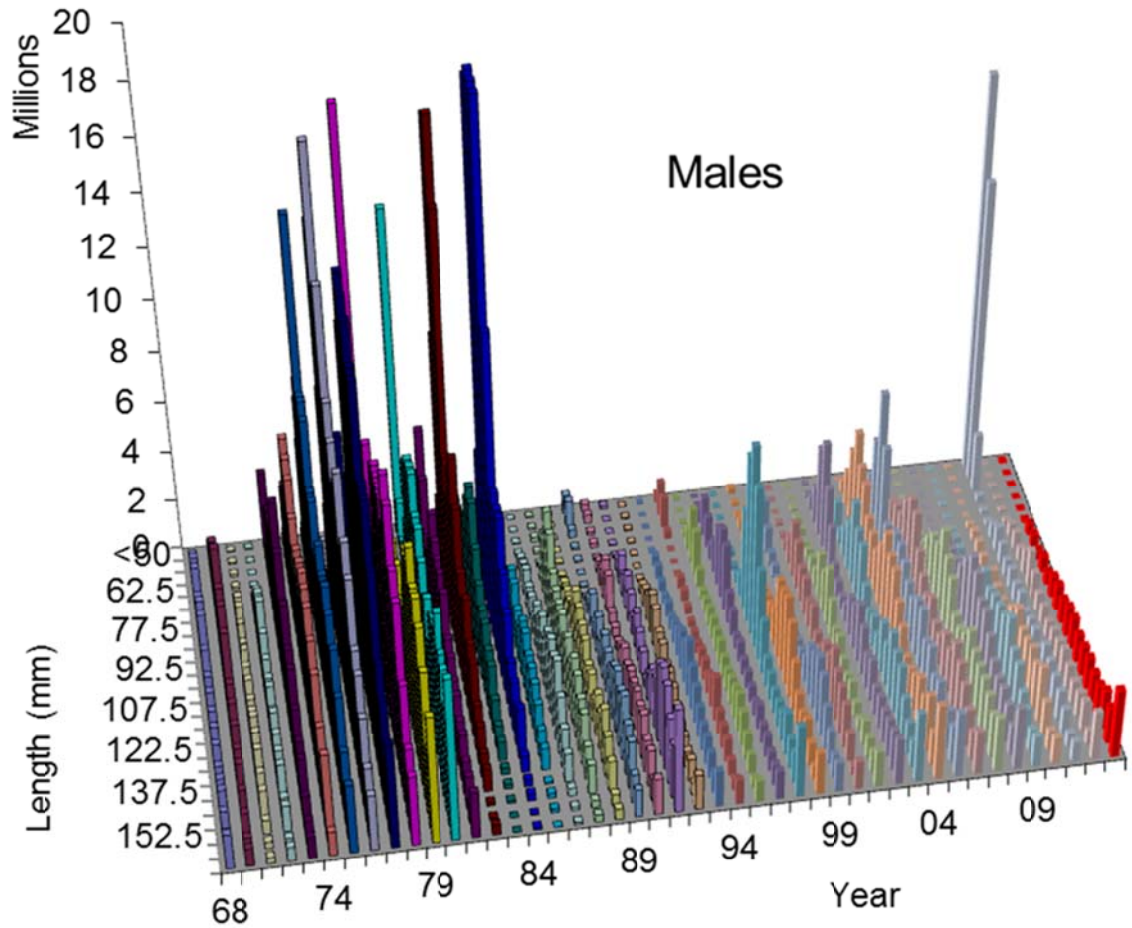

Figure 4. Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2013.

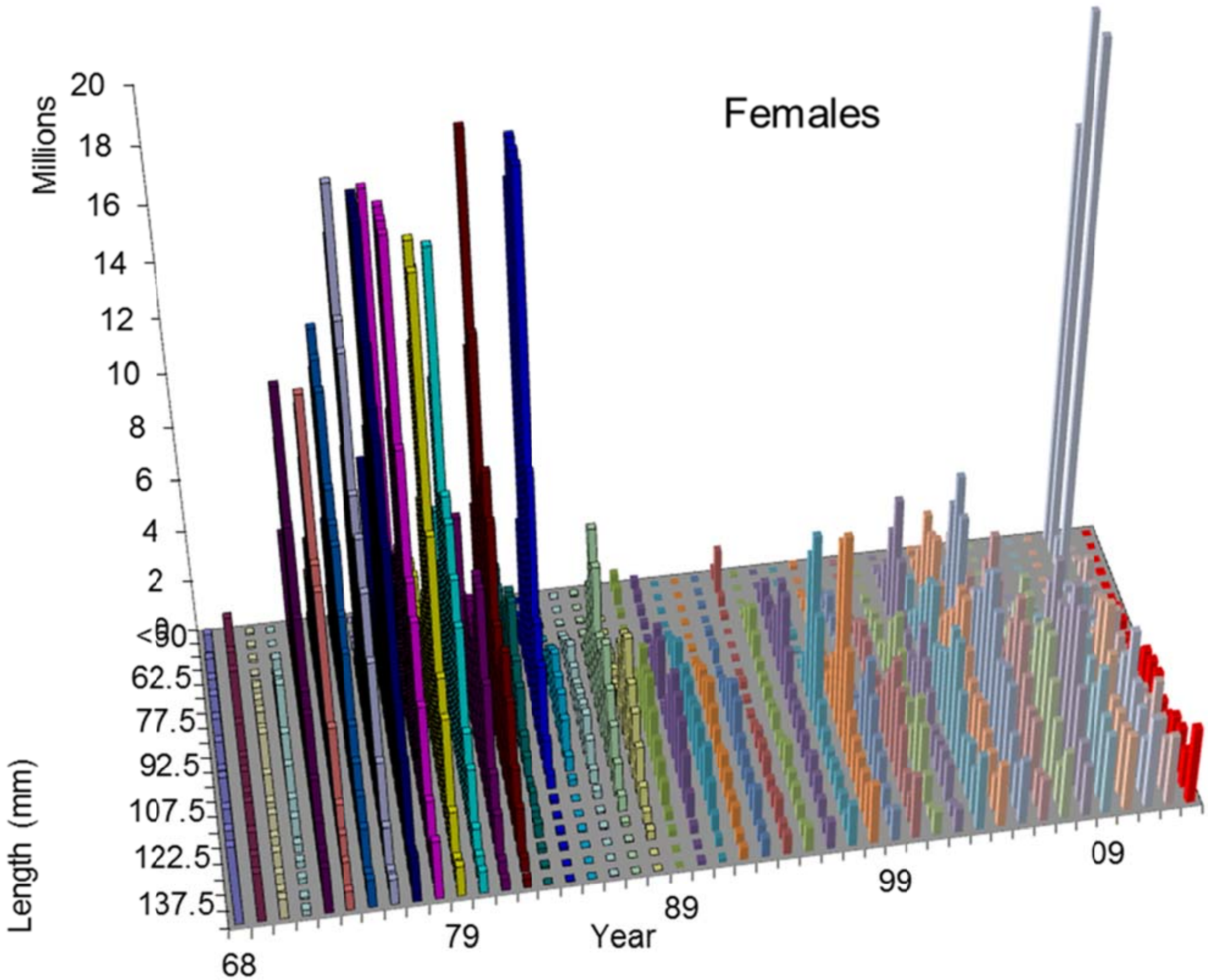

Figure 5. Survey abundances by length for female Bristol Bay red king crabs from 1968 to 2013.

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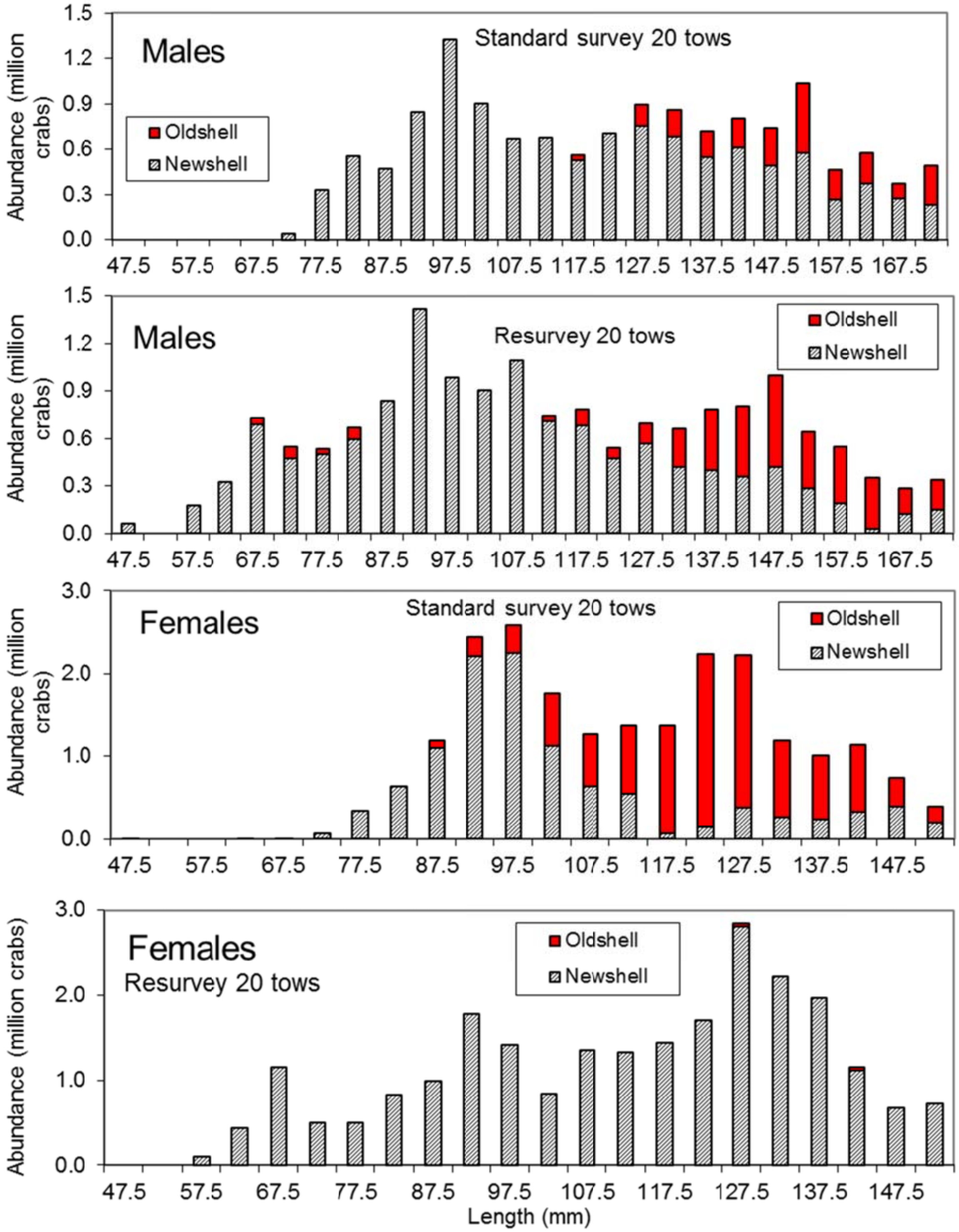
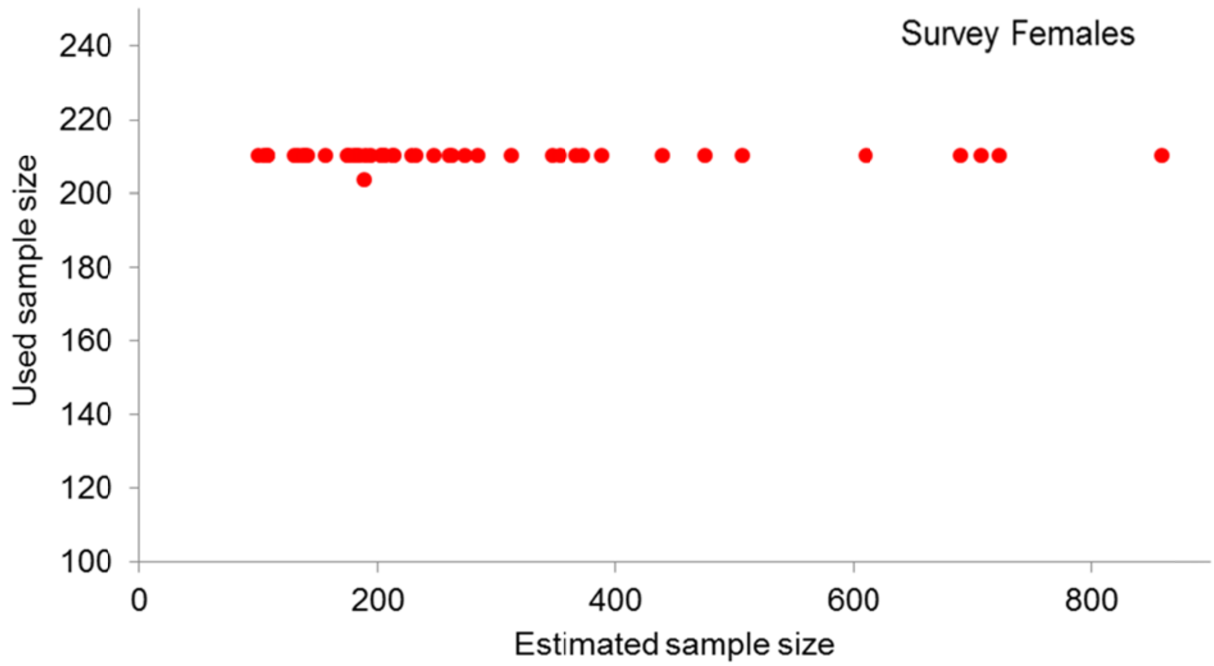


Figure 6. Comparison of area-swept estimates of abundance in 20 stations from the standard trawl survey and resurvey in 2012.



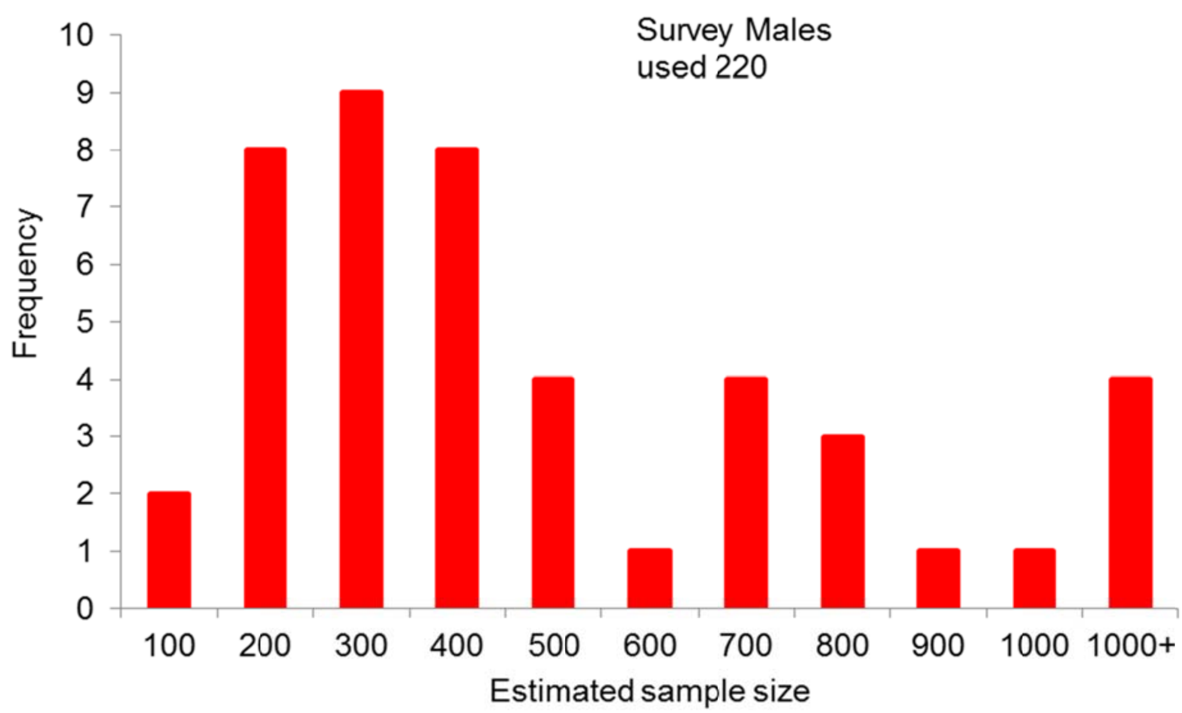
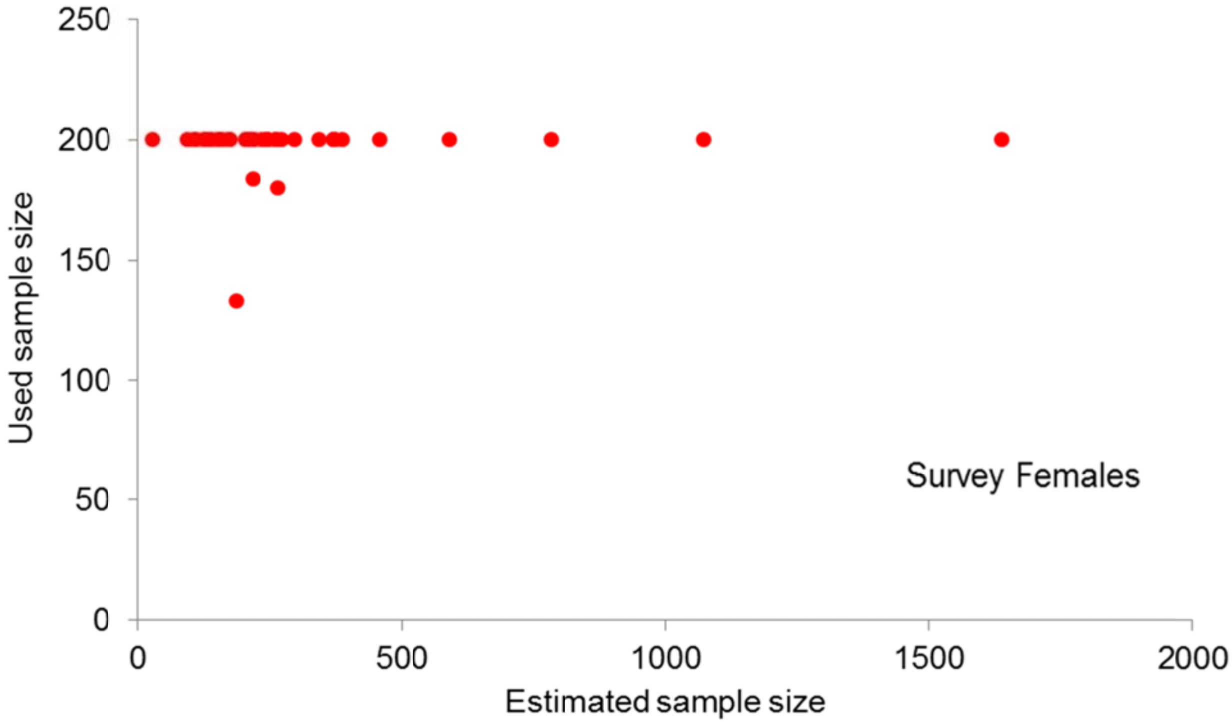


Figure 7a(0). Relationship between estimated effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (section 3(a)(5)(ii)) for length/sex composition data with scenario 0(7ac): trawl survey data.



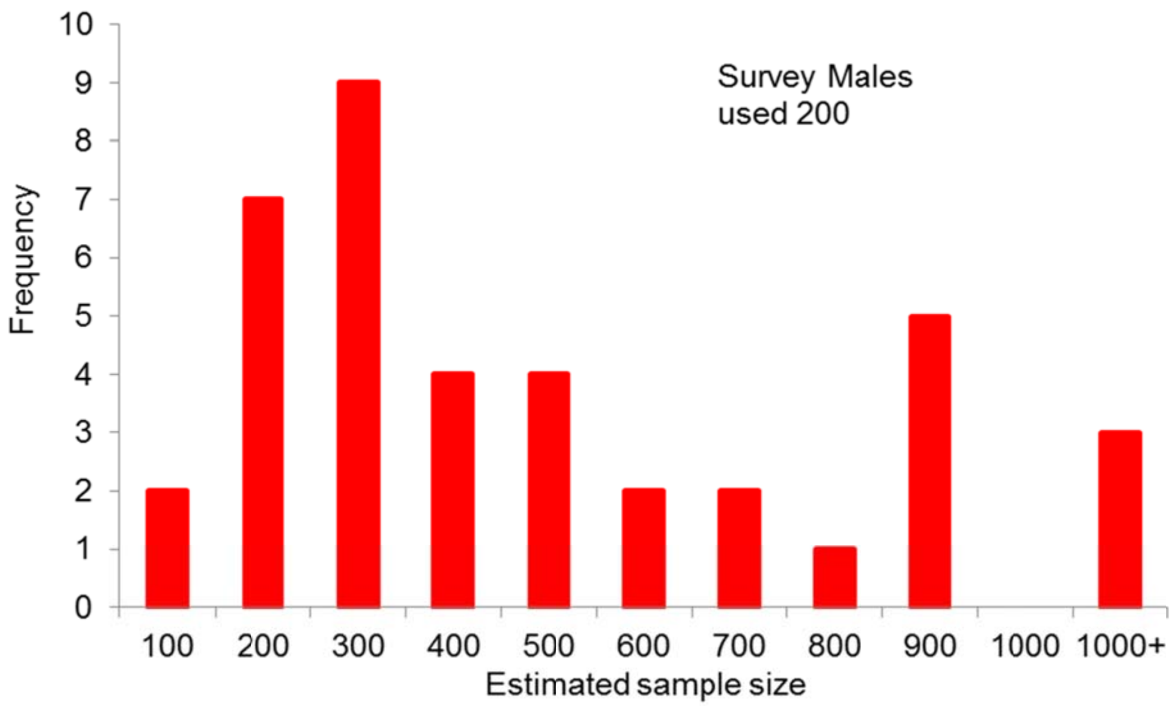


Figure 7b(1). Relationship between estimated effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (see effective sample sizes for scenario 1) for length/sex composition data with scenario 1: trawl survey data.

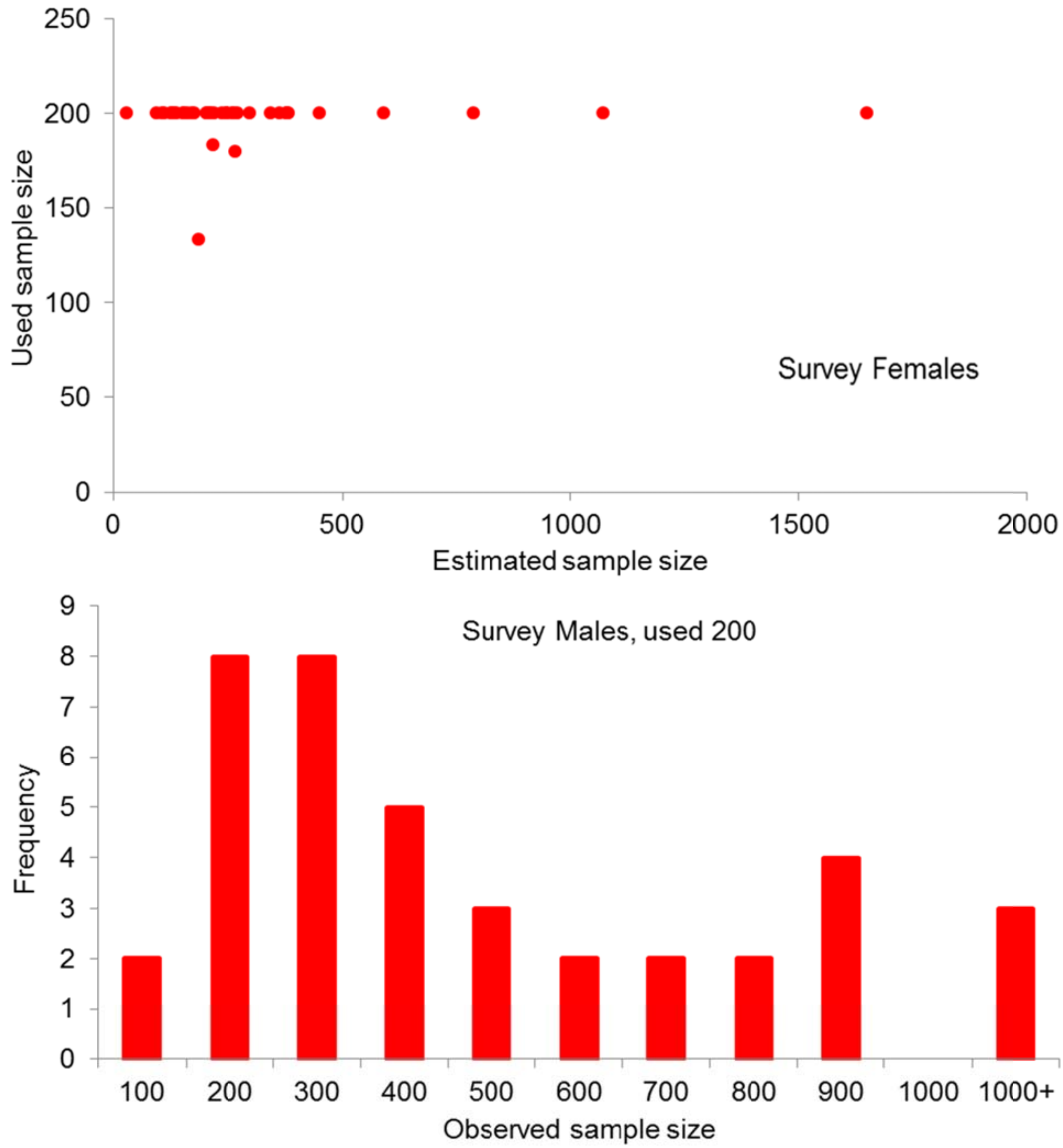


Figure 7b(4). Relationship between estimated effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (see effective sample sizes for scenario 4) for length/sex composition data with scenario 4: trawl survey data.

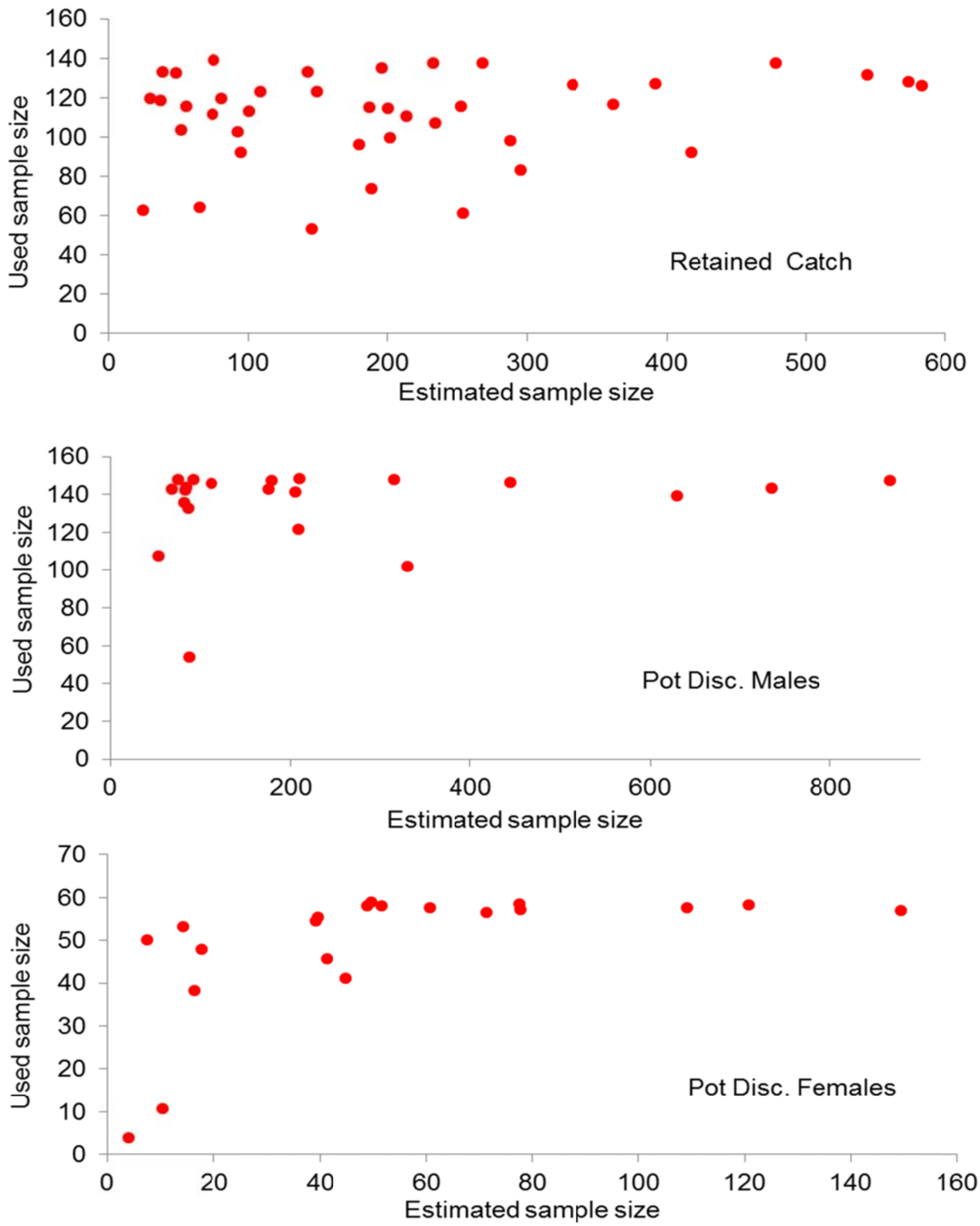


Figure 7b(0). Relationship between estimated effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (section 3(a)(5)(ii)) for length/sex composition data with scenario 0(7ac): directed pot fishery data.

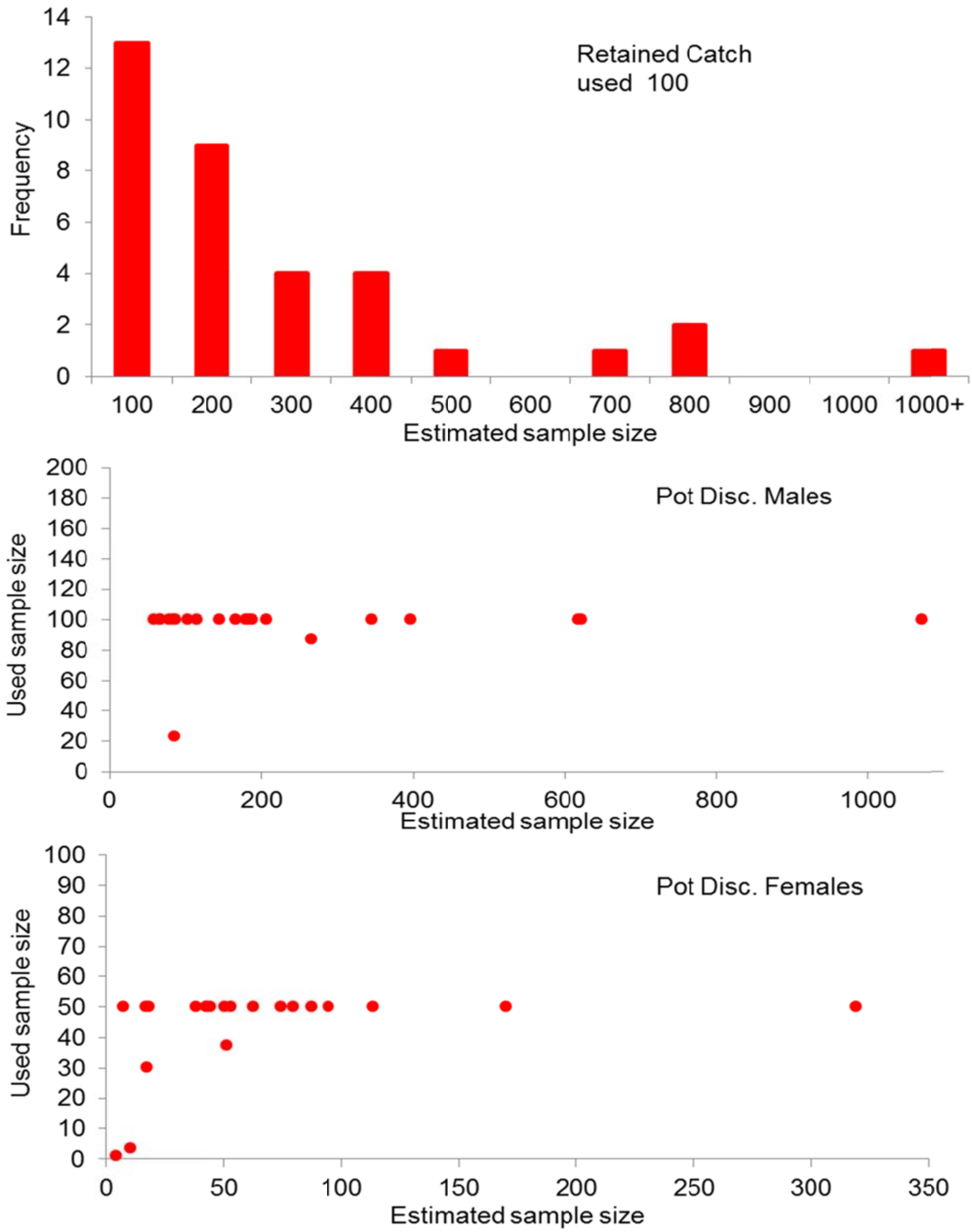


Figure 7b(1). Relationship between estimated effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (see effective sample sizes for scenario 1) for length/sex composition data with scenario 1: directed pot fishery data.

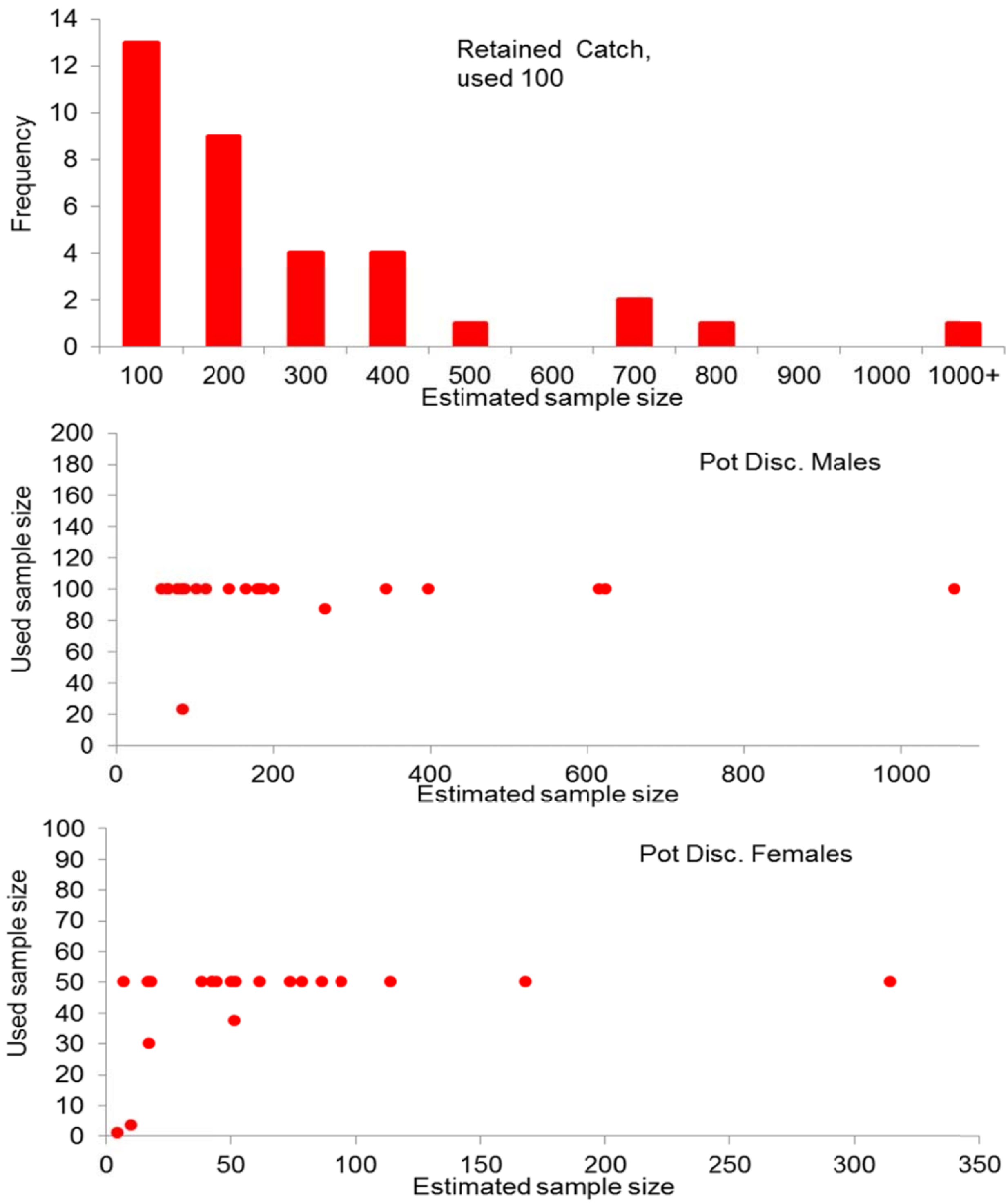


Figure 7b(4). Relationship between estimated effective sample sizes (section 3(a)(5)(i)) and used effective sample sizes (see effective sample sizes for scenario 4) for length/sex composition data with scenario 4: directed pot fishery data.

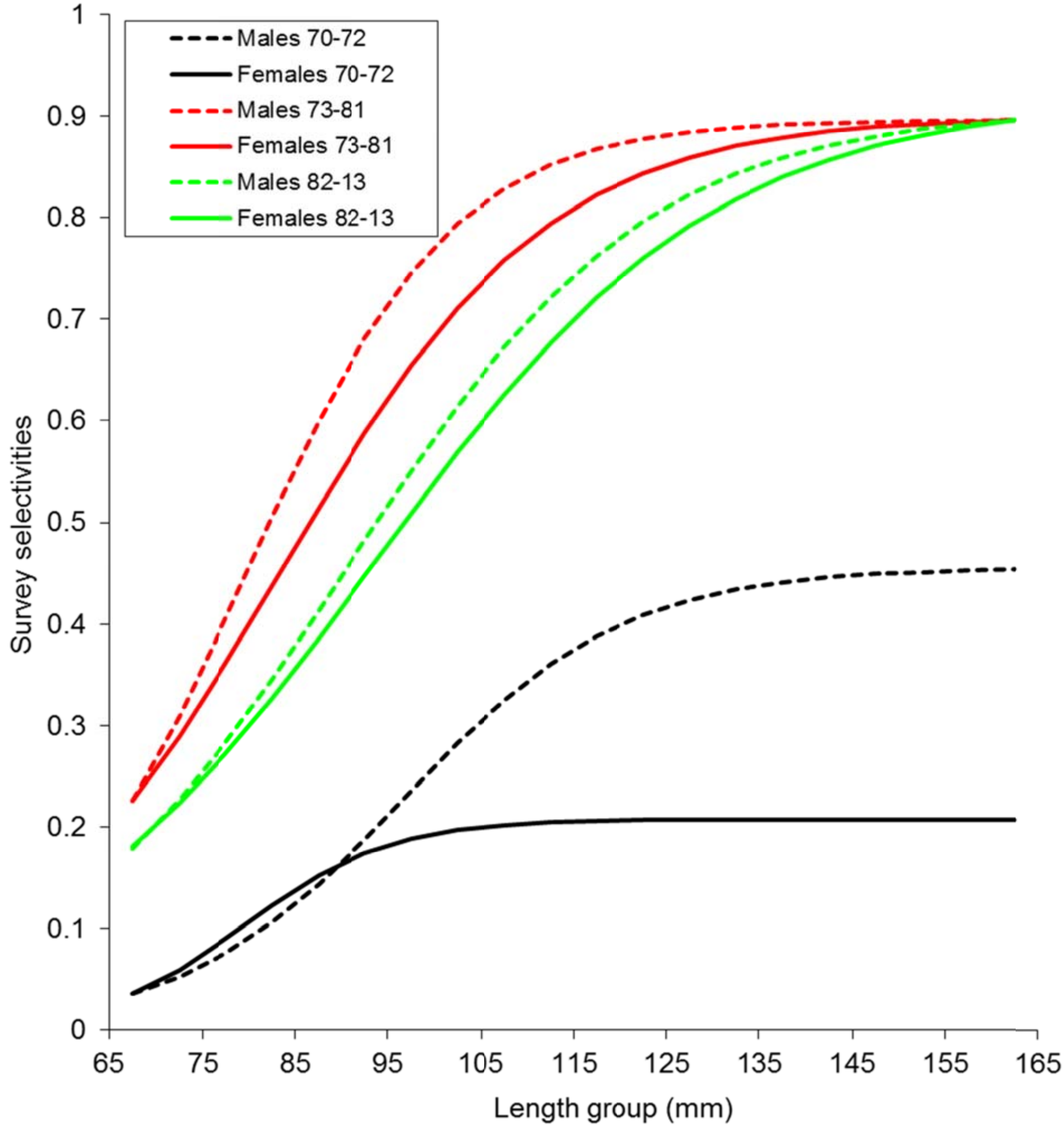


Figure 8a(0). Estimated trawl survey selectivities under scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

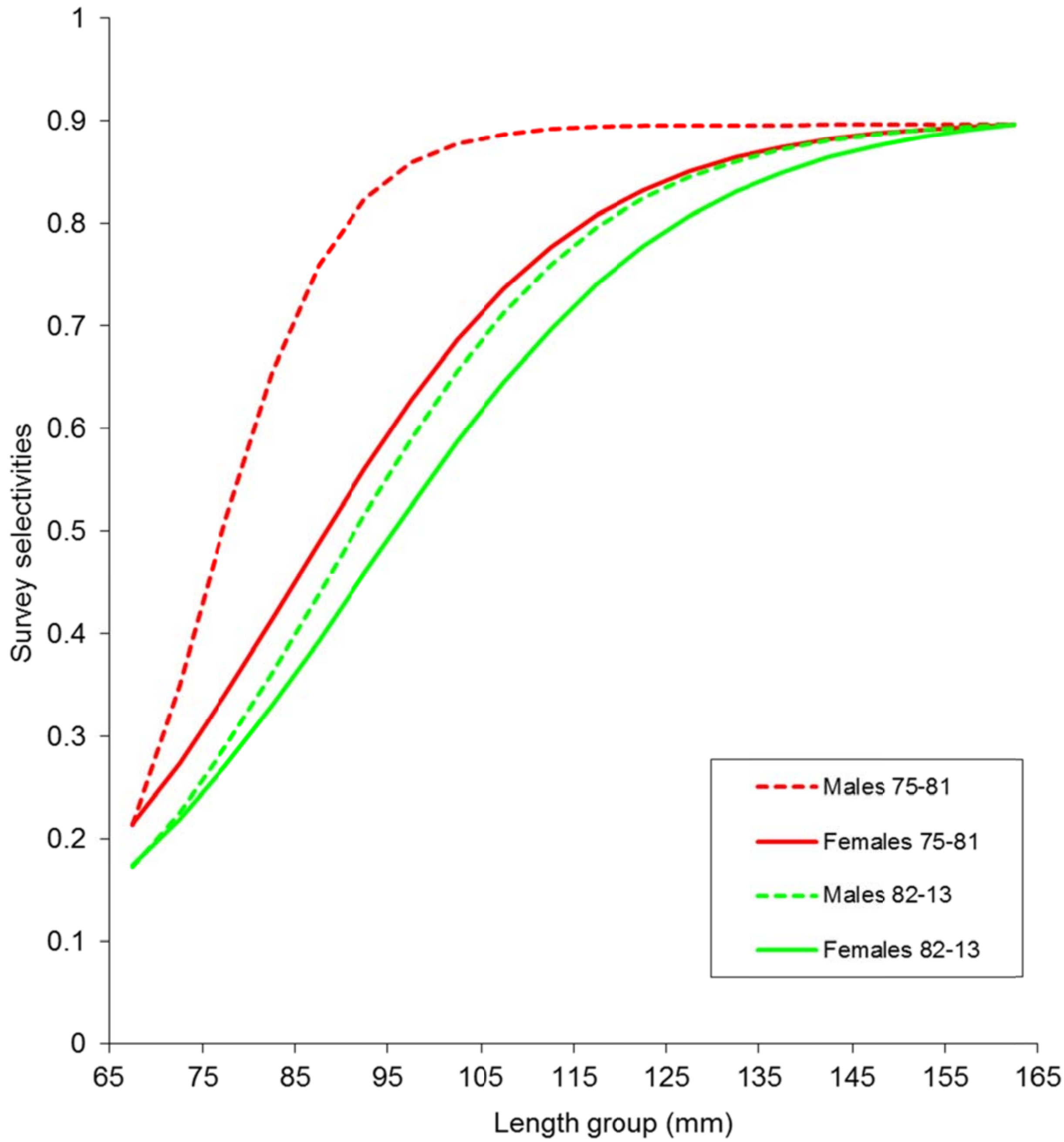


Figure 8a(1). Estimated trawl survey selectivities under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

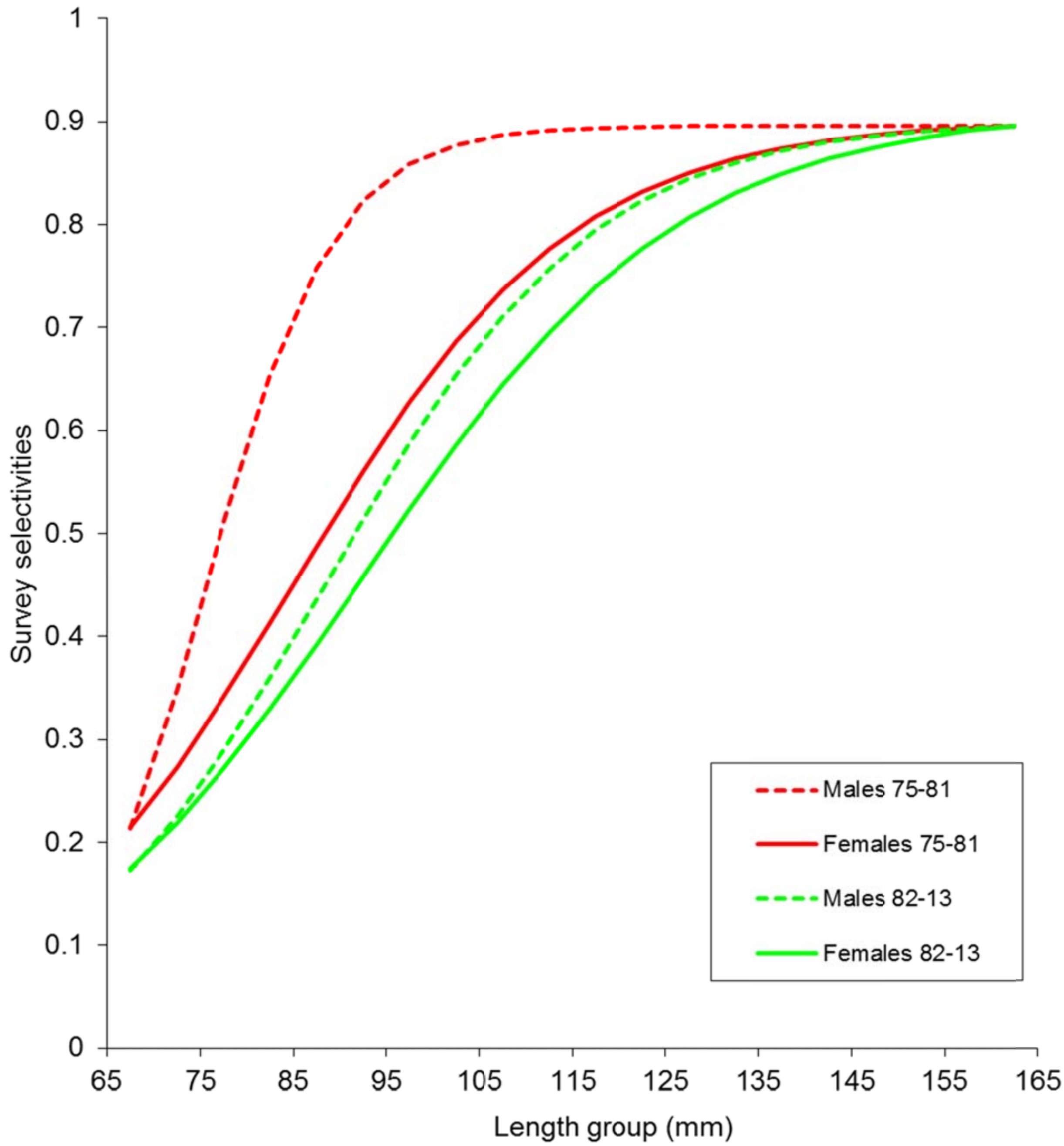
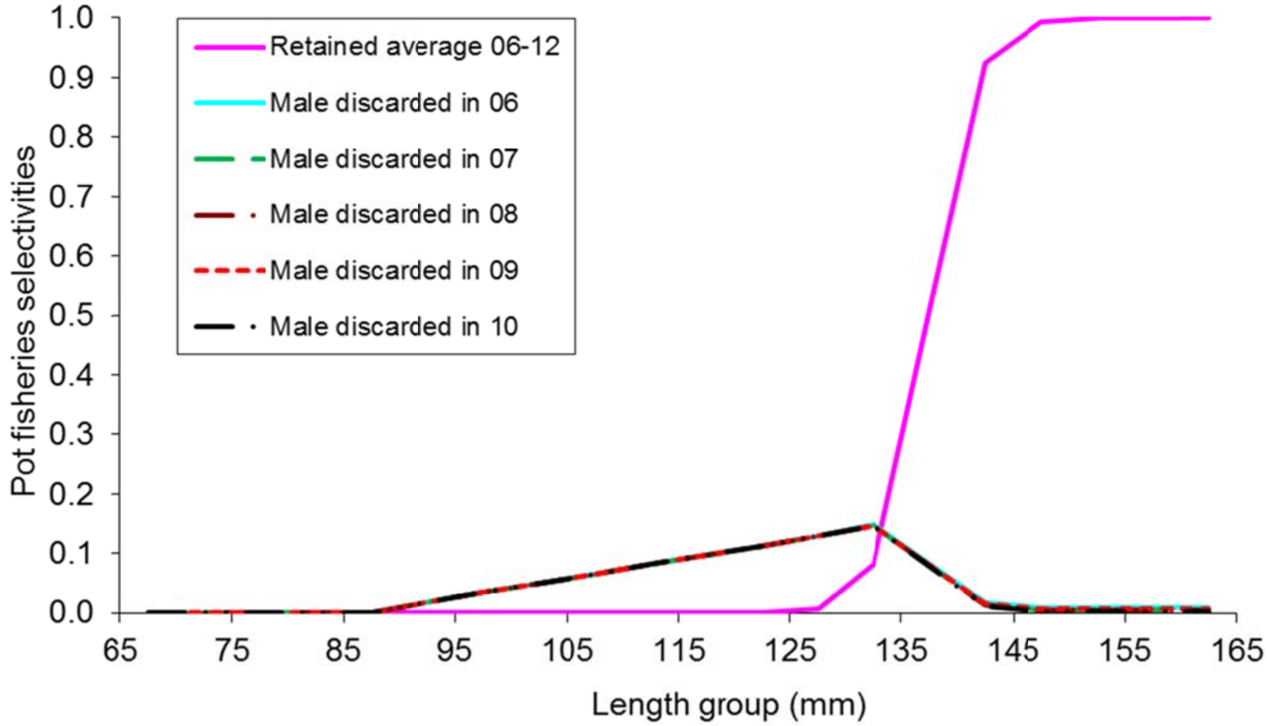


Figure 8a(4). Estimated trawl survey selectivities under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



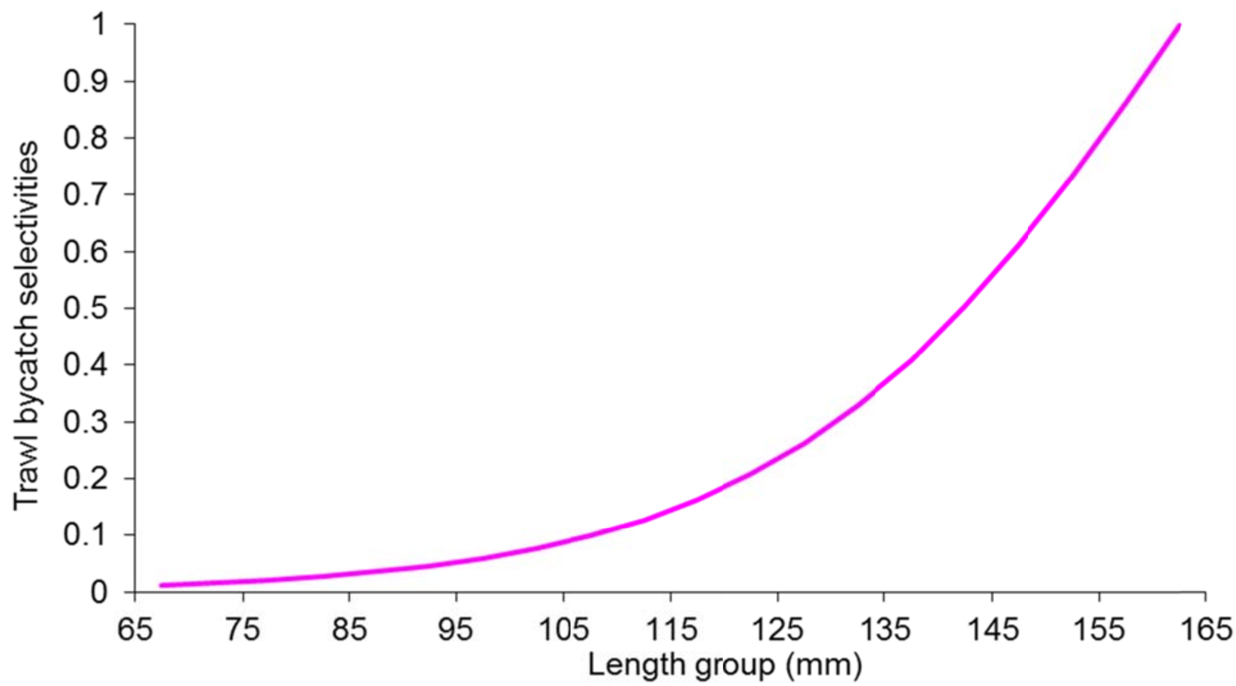


Figure 8b. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities under scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

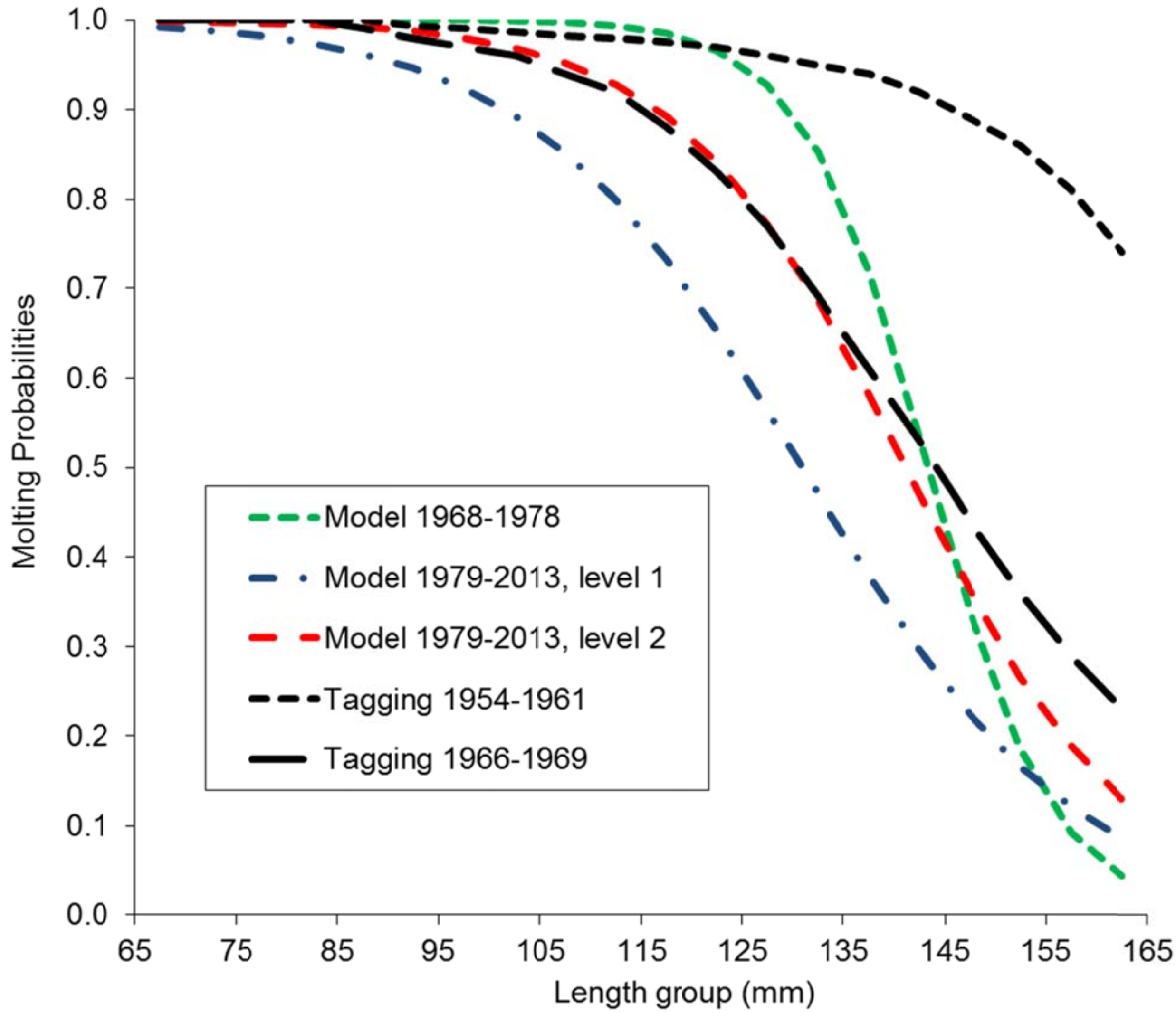


Figure 9(0). Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1968-2013 were estimated with a length-based model with pot handling mortality rate to be 0.2 under scenario 0(7ac).

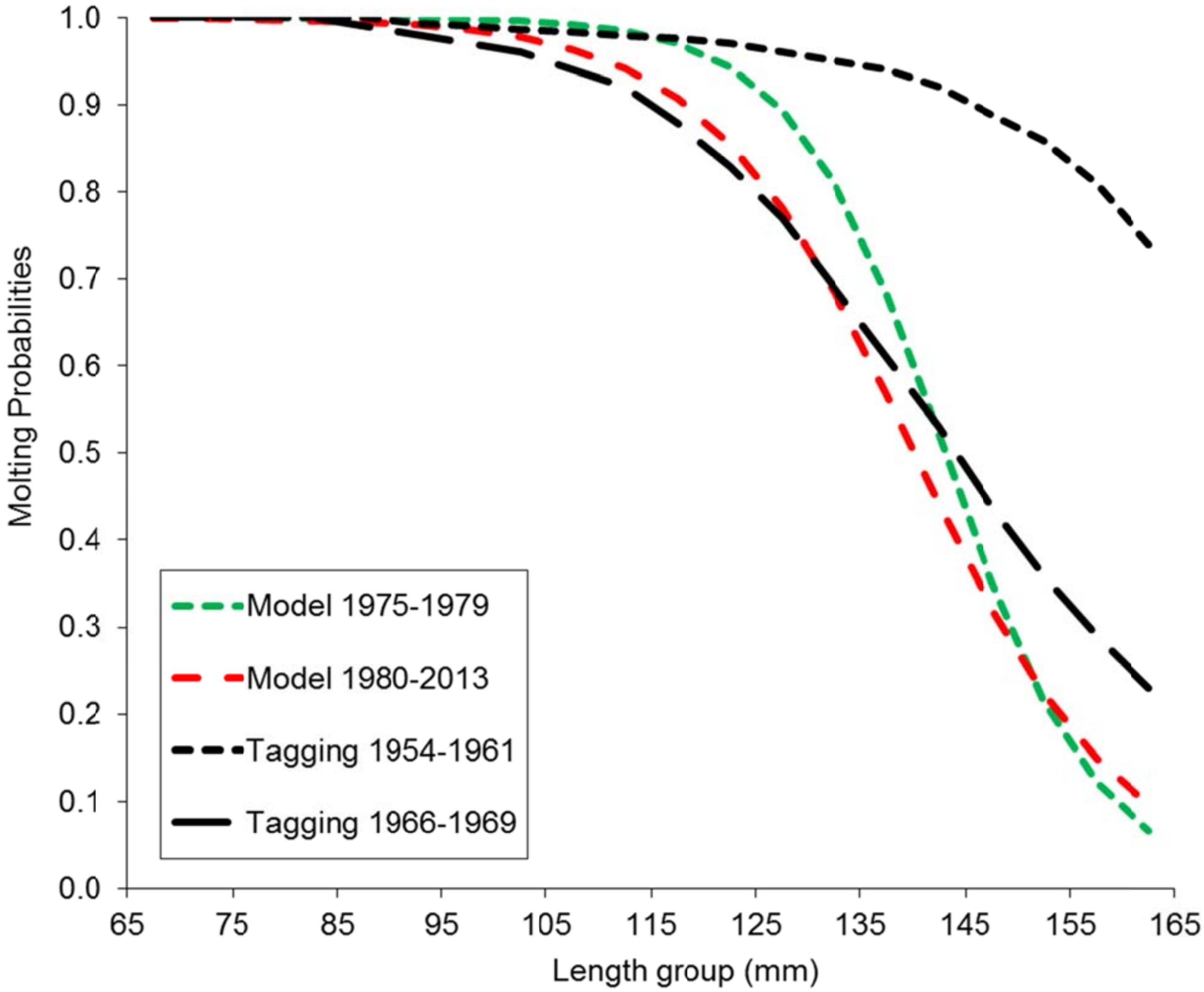


Figure 9(1). Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2013 were estimated with a length-based model with pot handling mortality rate to be 0.2 under scenario 1.

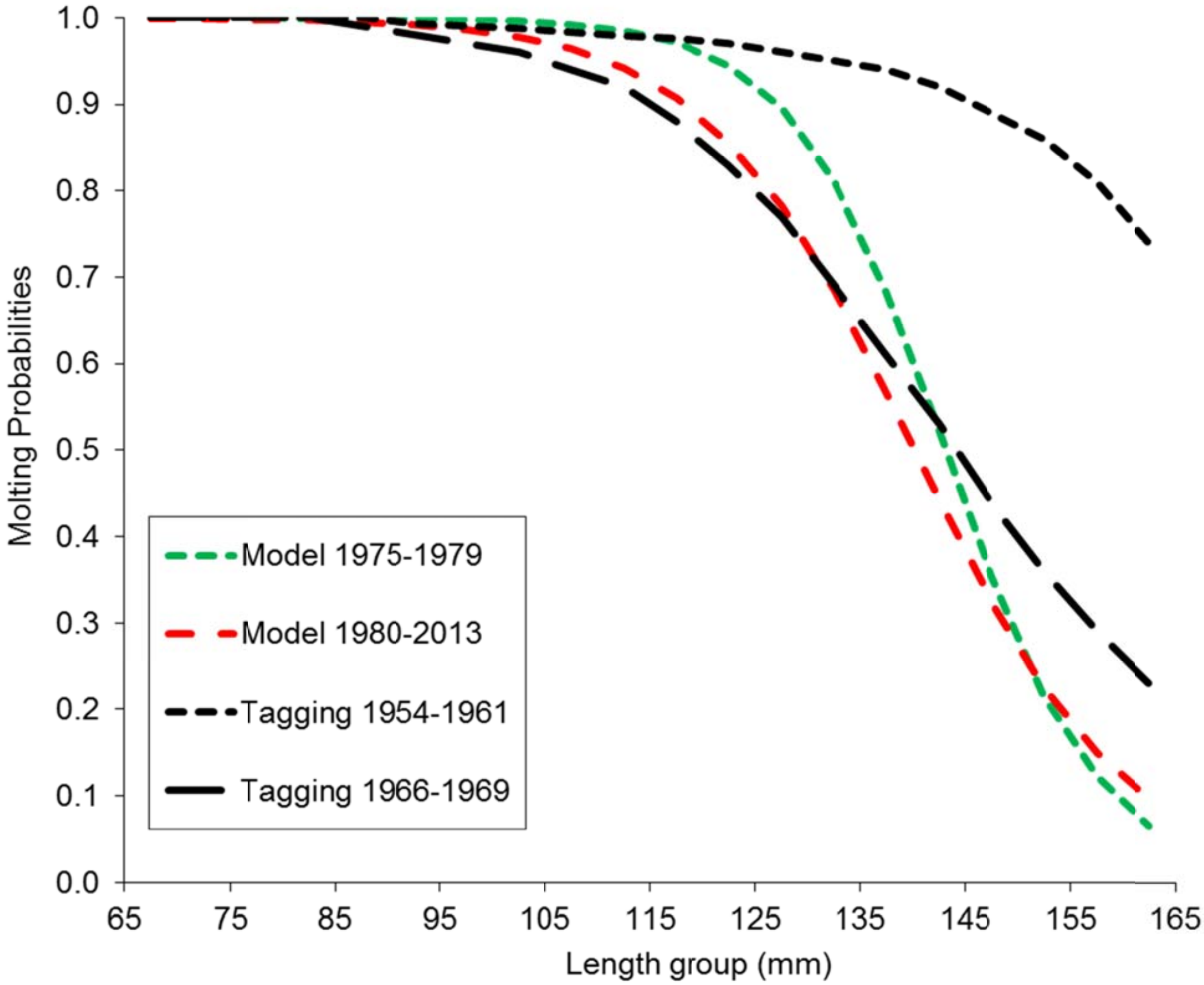


Figure 9(4). Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2013 were estimated with a length-based model with pot handling mortality rate to be 0.2 under scenario 4.

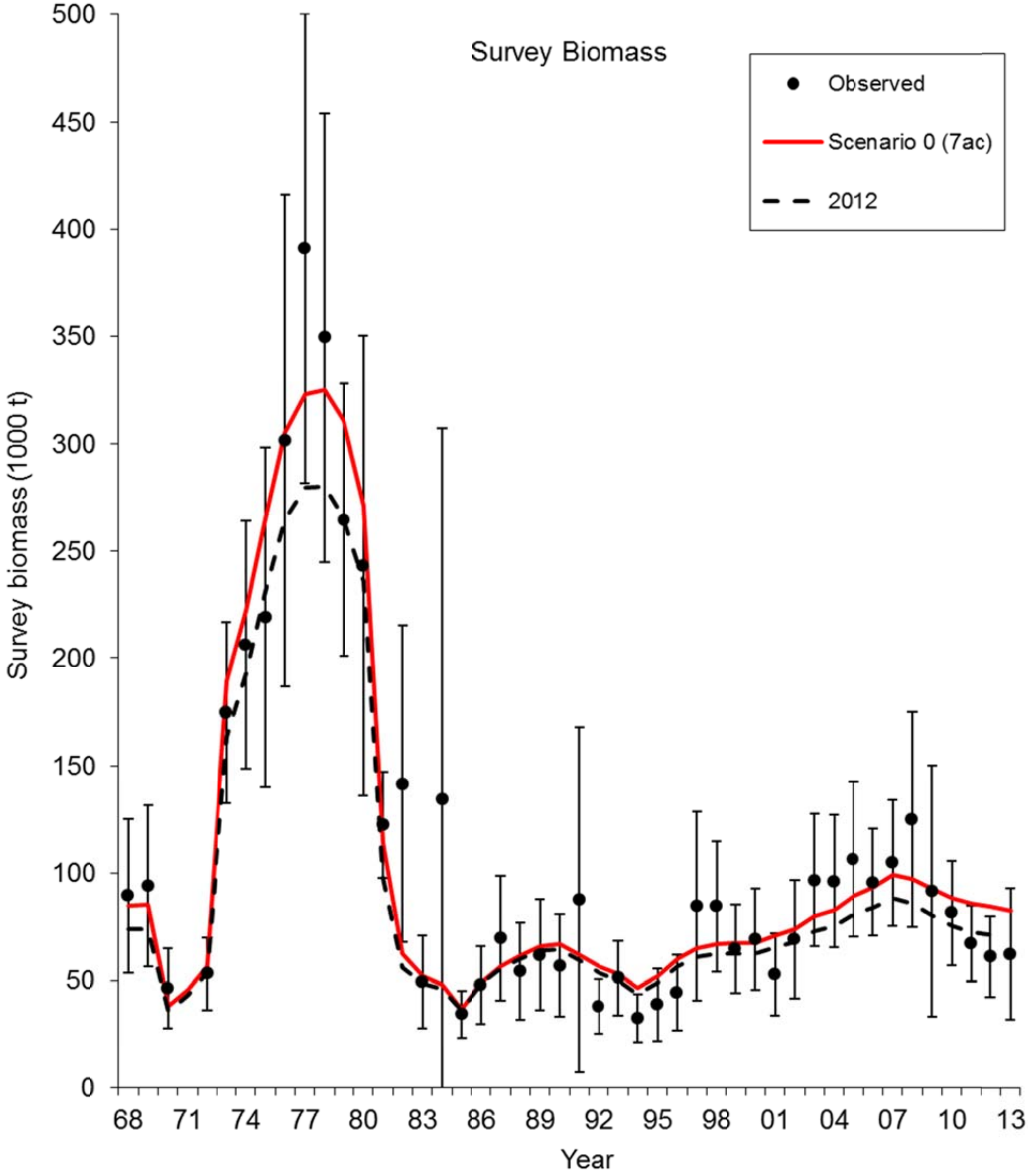


Figure 10a(0). Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2012 and 2013 under scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

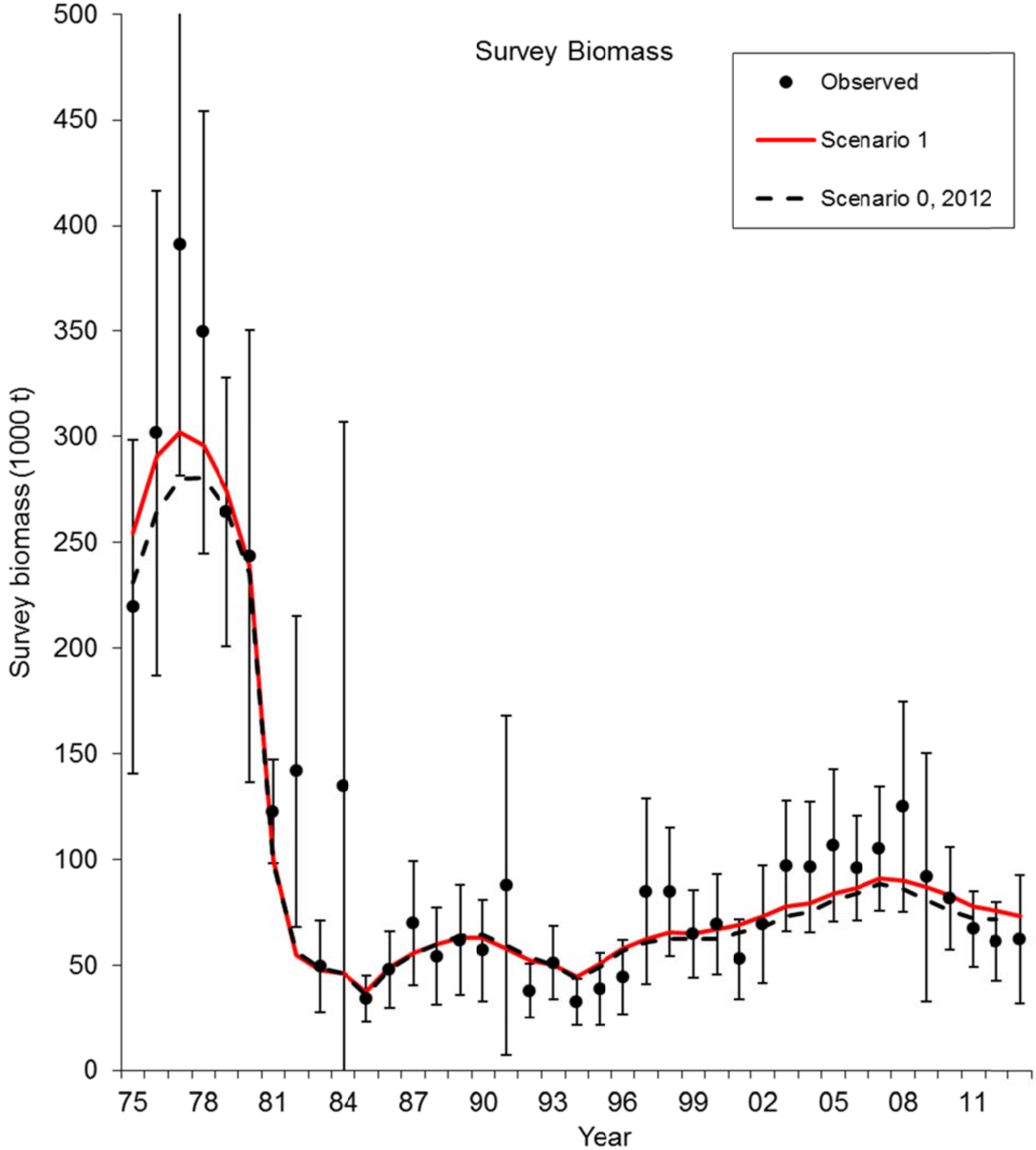


Figure 10a(1). Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2012 under scenario 0 and 2013 under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

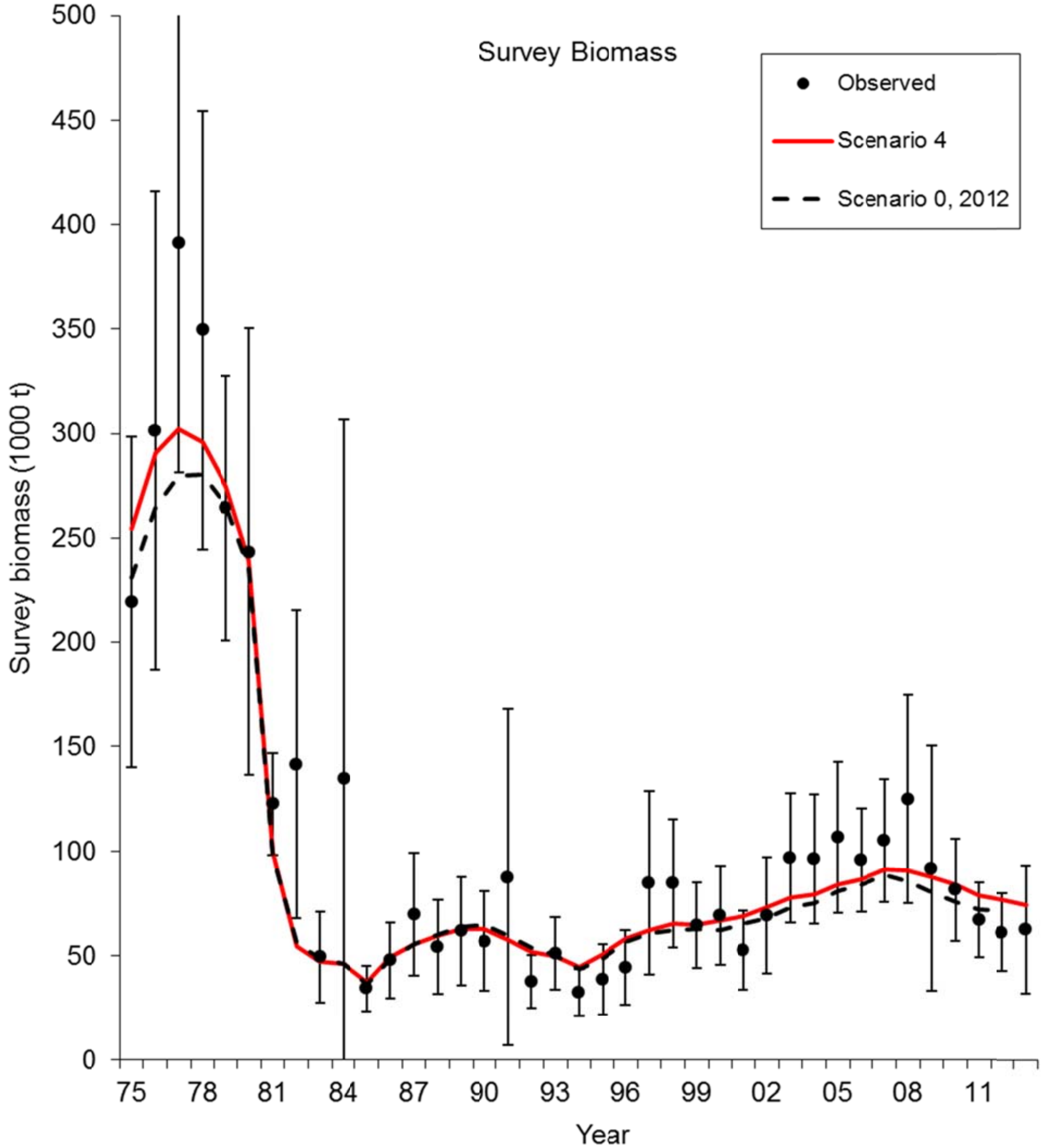


Figure 10a(4). Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2012 under scenario 0 and 2013 under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

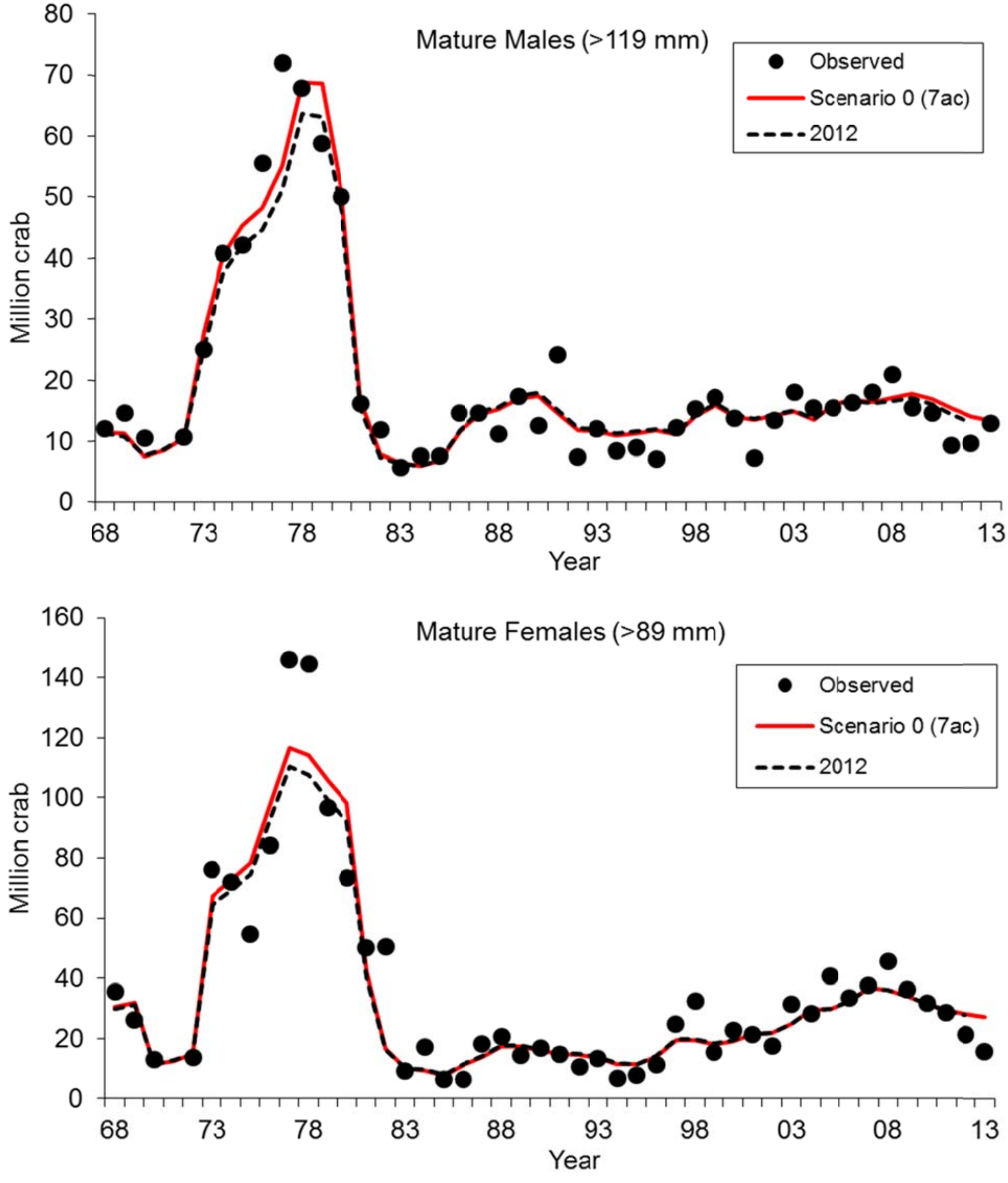


Figure 10b(0). Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2012 and 2013 under scenario 0 (7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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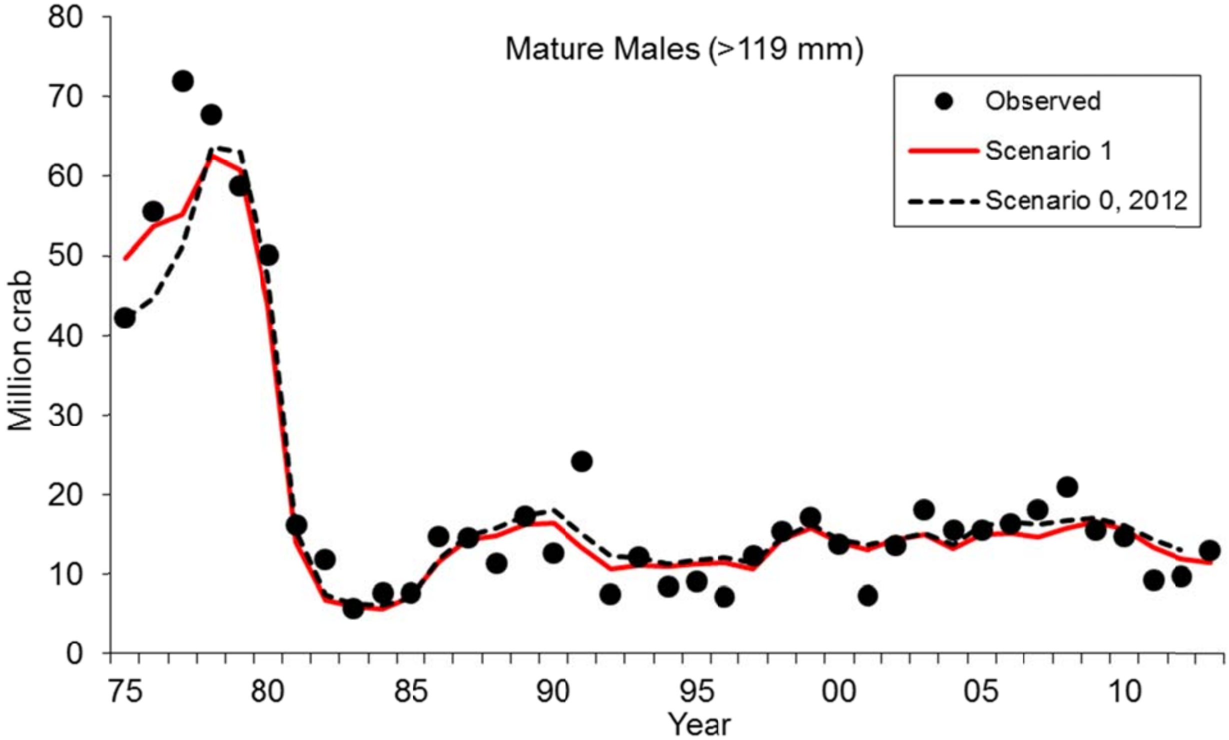


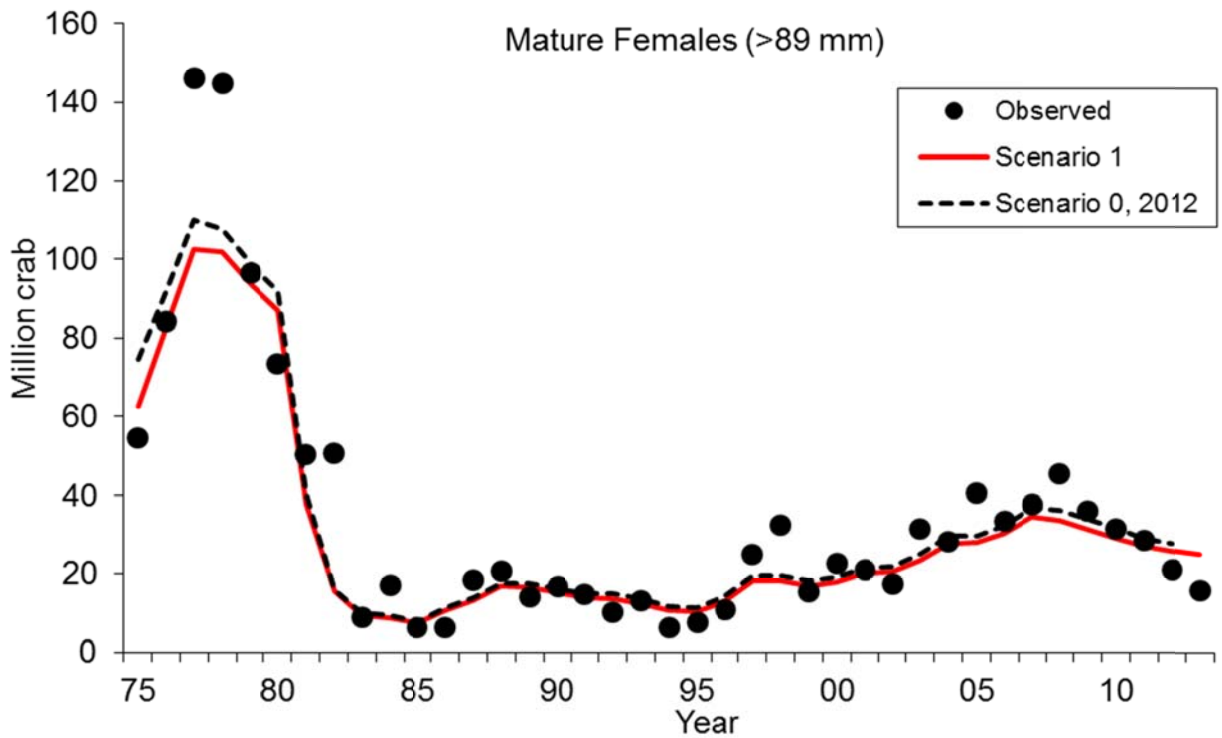


Figure 10b(1). Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2012 scenario 0 and 2013 under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

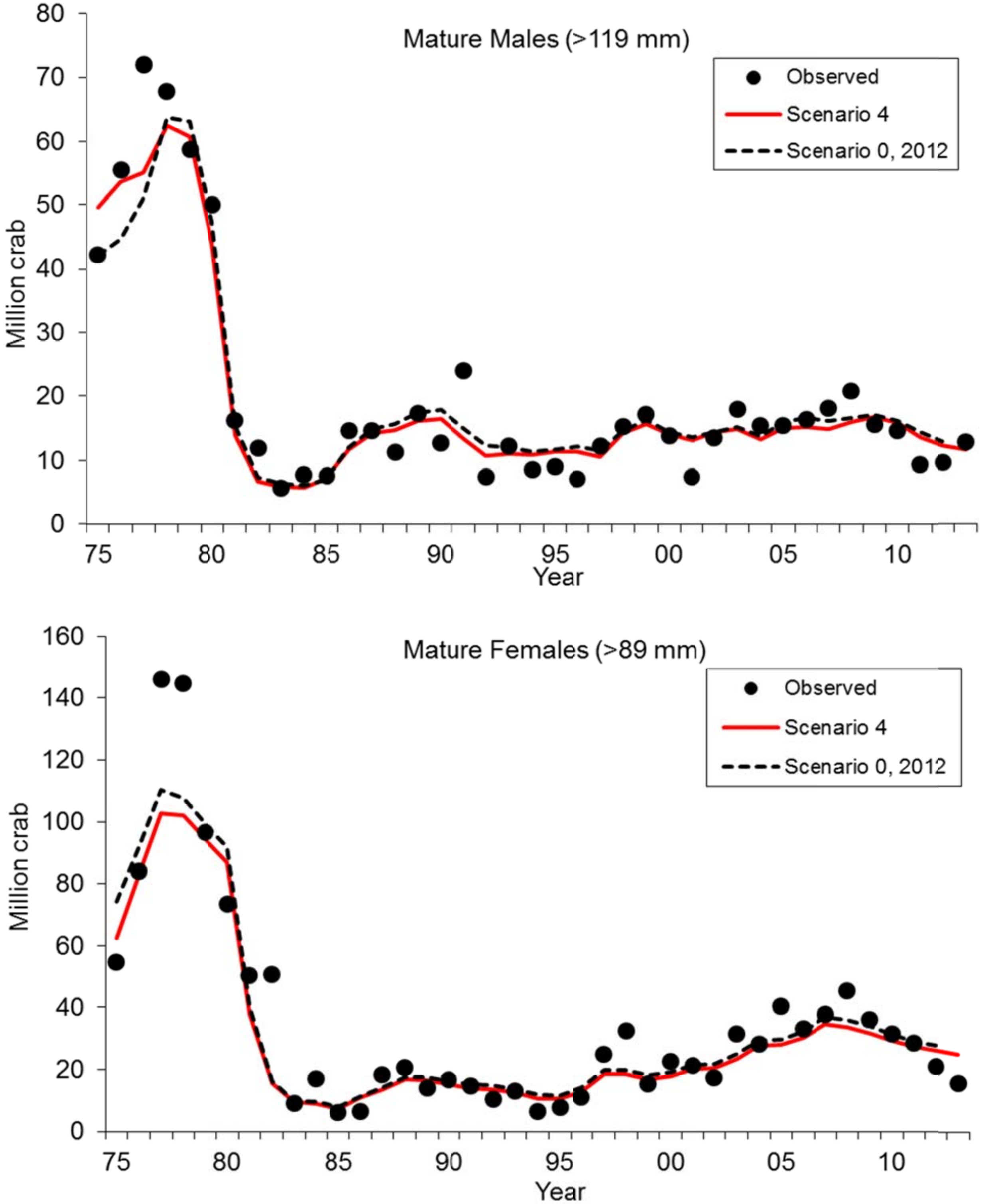


Figure 10b(4). Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2012 scenario 0 and 2013 under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

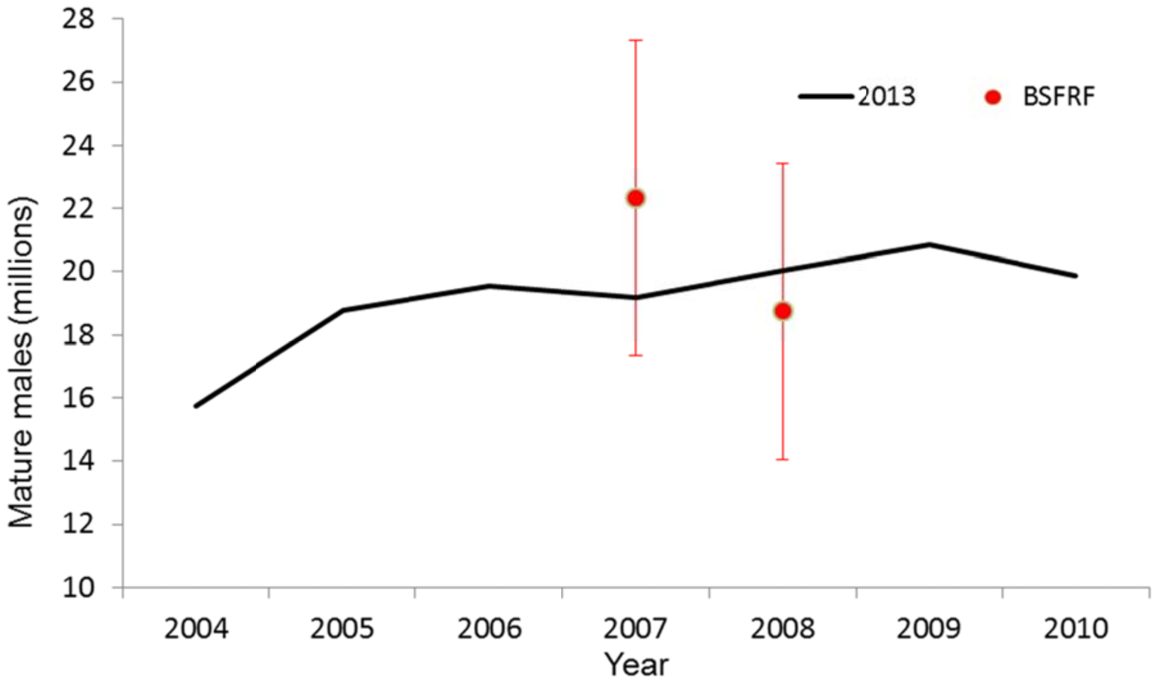


Figure 10c(0). Comparisons of total mature male abundance estimates by the BSFRF survey and the model for model estimates in 2013 (scenario 0(7ac)). The error bars are plus and minus 2 standard deviations.

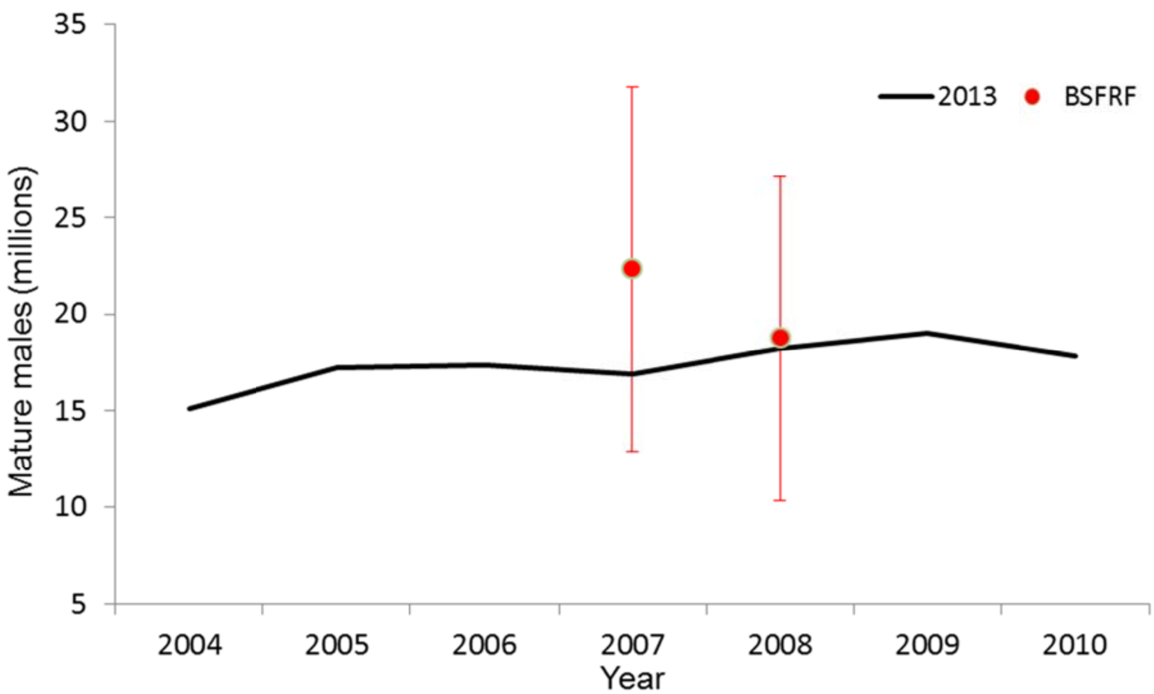


Figure 10c(1). Comparisons of total mature male abundance estimates by the BSFRF survey and the model for model estimates in 2013 (scenario 1). The error bars are plus and minus 2 standard deviations.

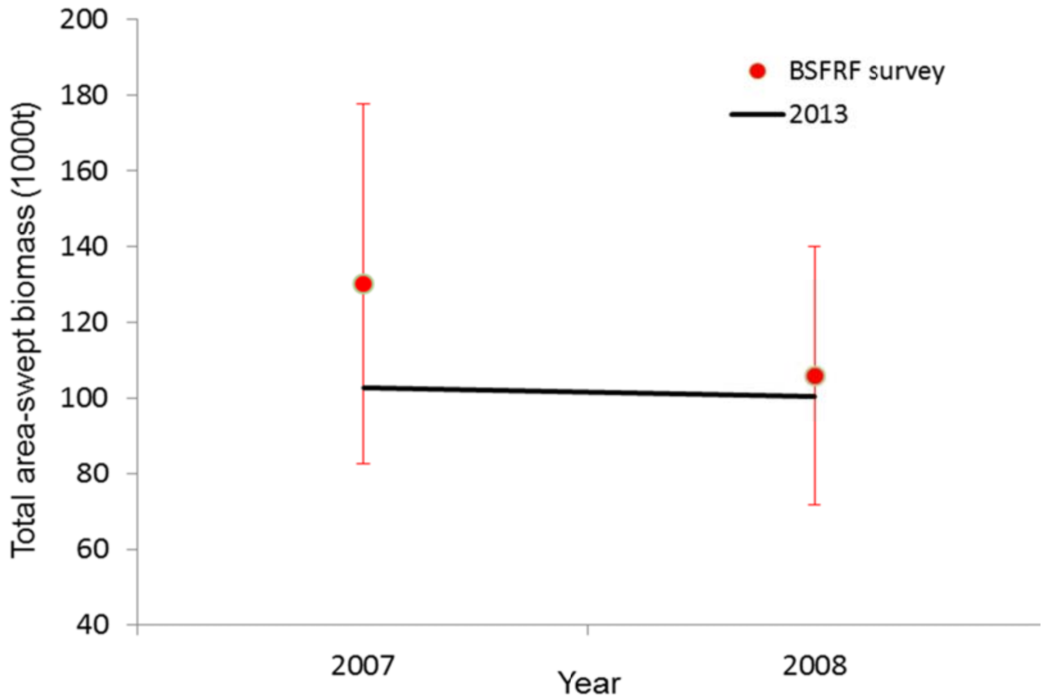


Figure 10c(4). Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2013 (scenario 4). The error bars are plus and minus 2 standard deviations.

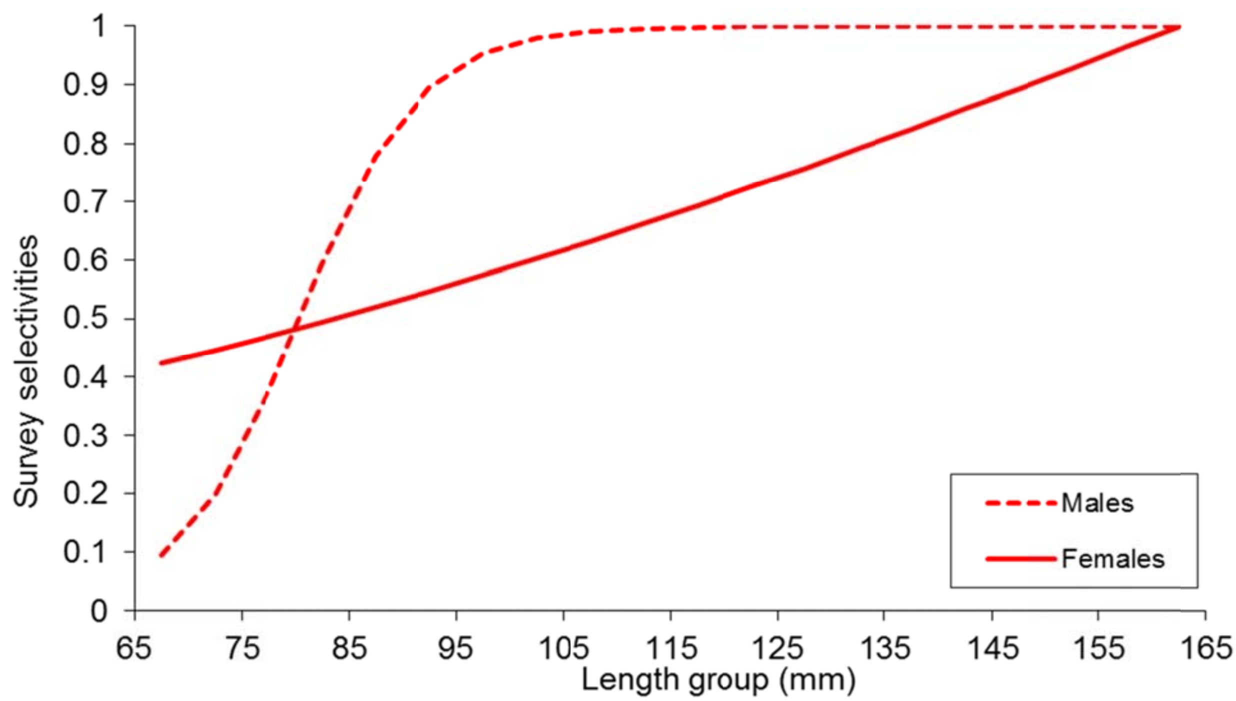
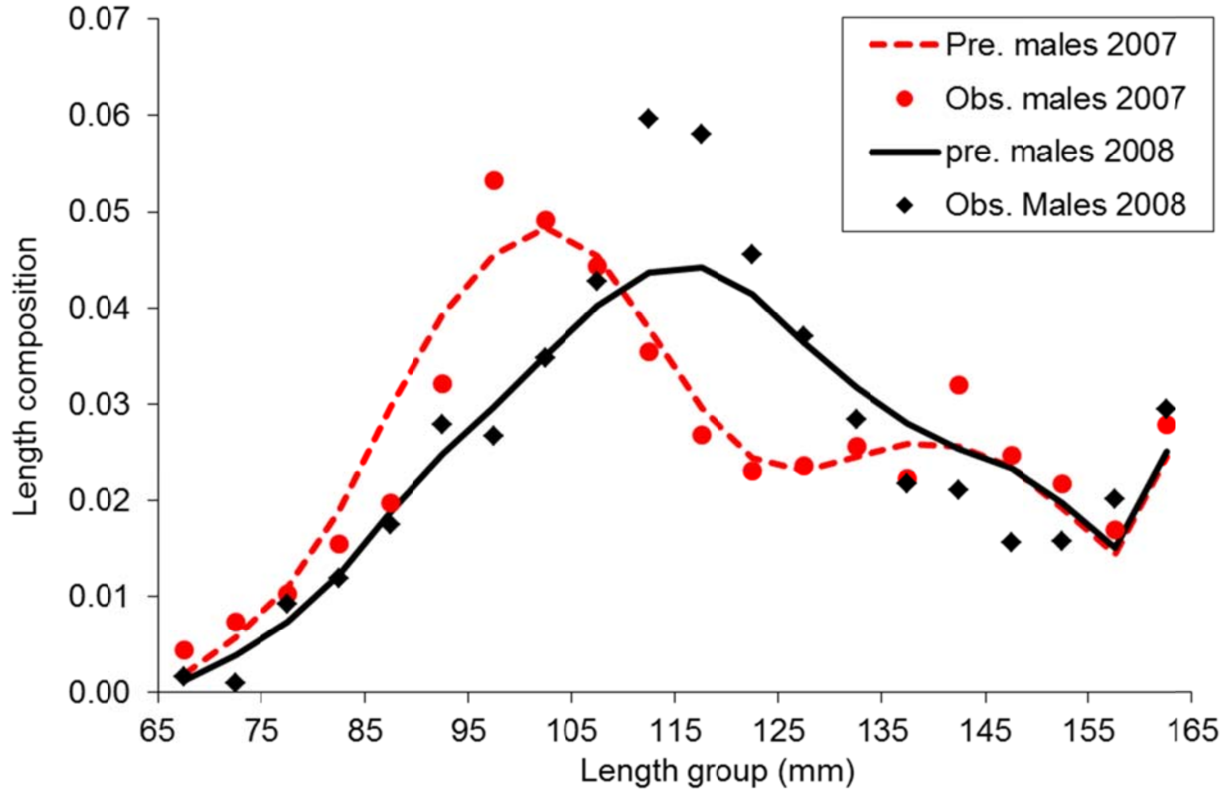


Figure 10c(4). Estimated BSFRF survey selectivities with scenario 4. The catchability is assumed to be 1.0.



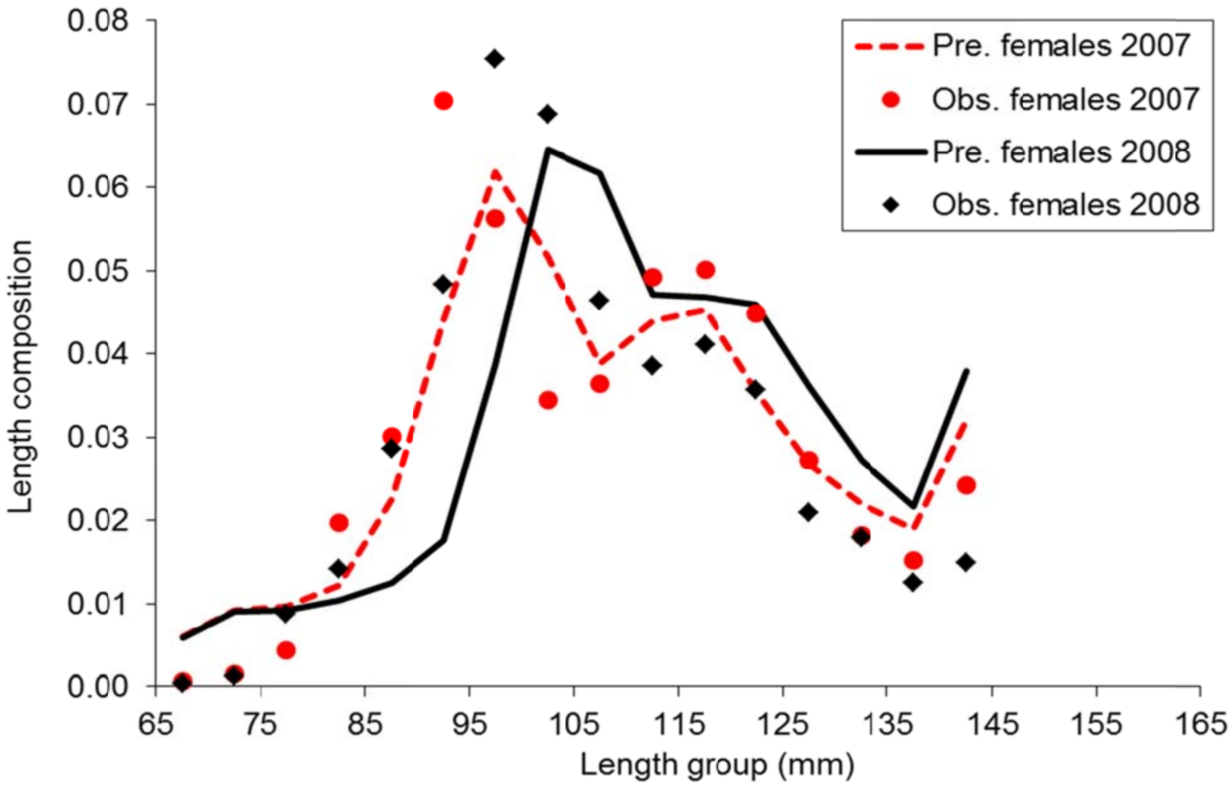


Figure 10c(4c). Comparisons of length compositions by the BSFRF survey and the model estimates in 2007 and 2008 with scenario 4.

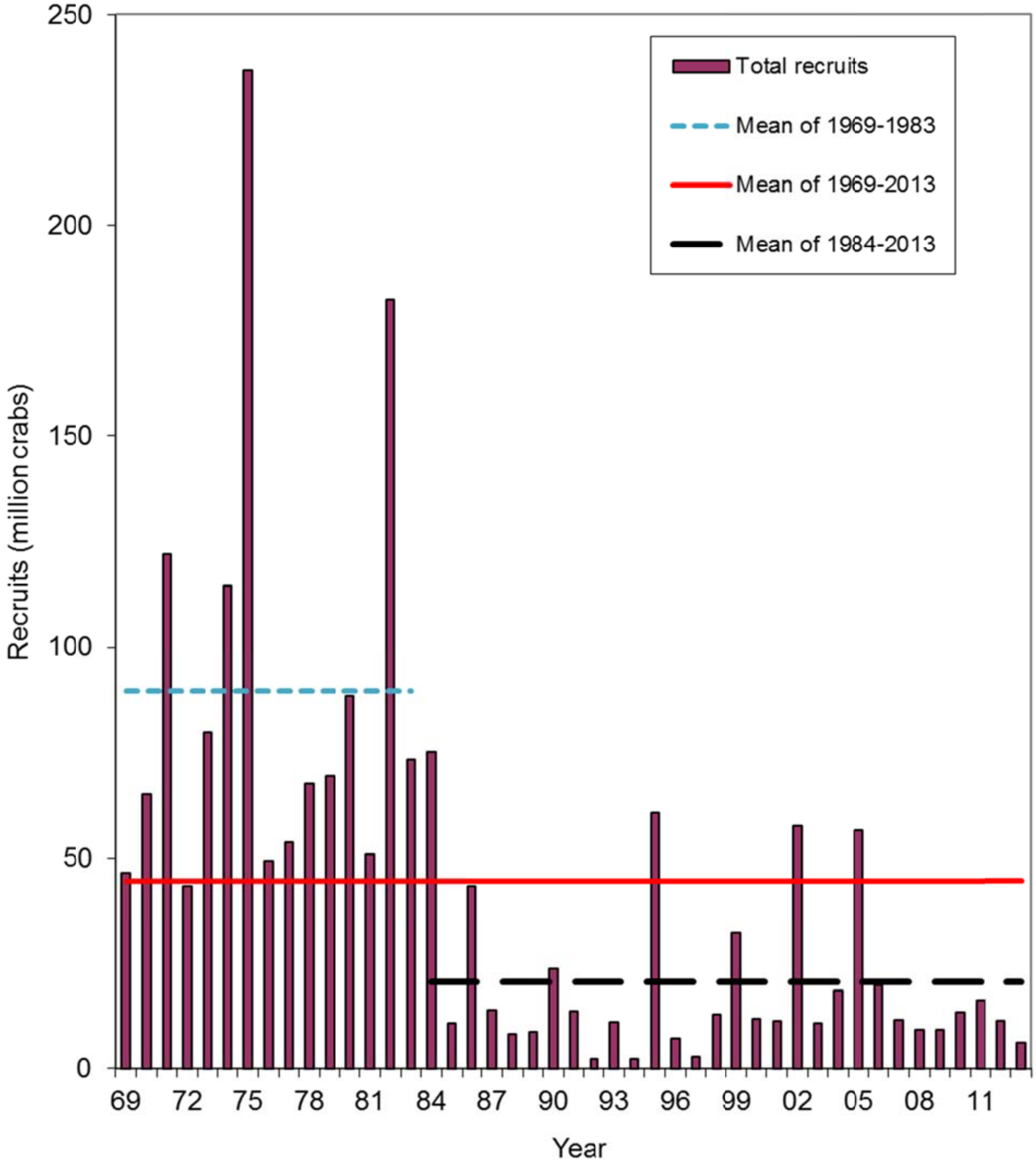


Figure 11(0). Estimated recruitment time series during 1969-2013 (occurred year) with scenario 0(7ac). Mean male recruits during 1984-2013 was used to estimate $B_{35\%}$.

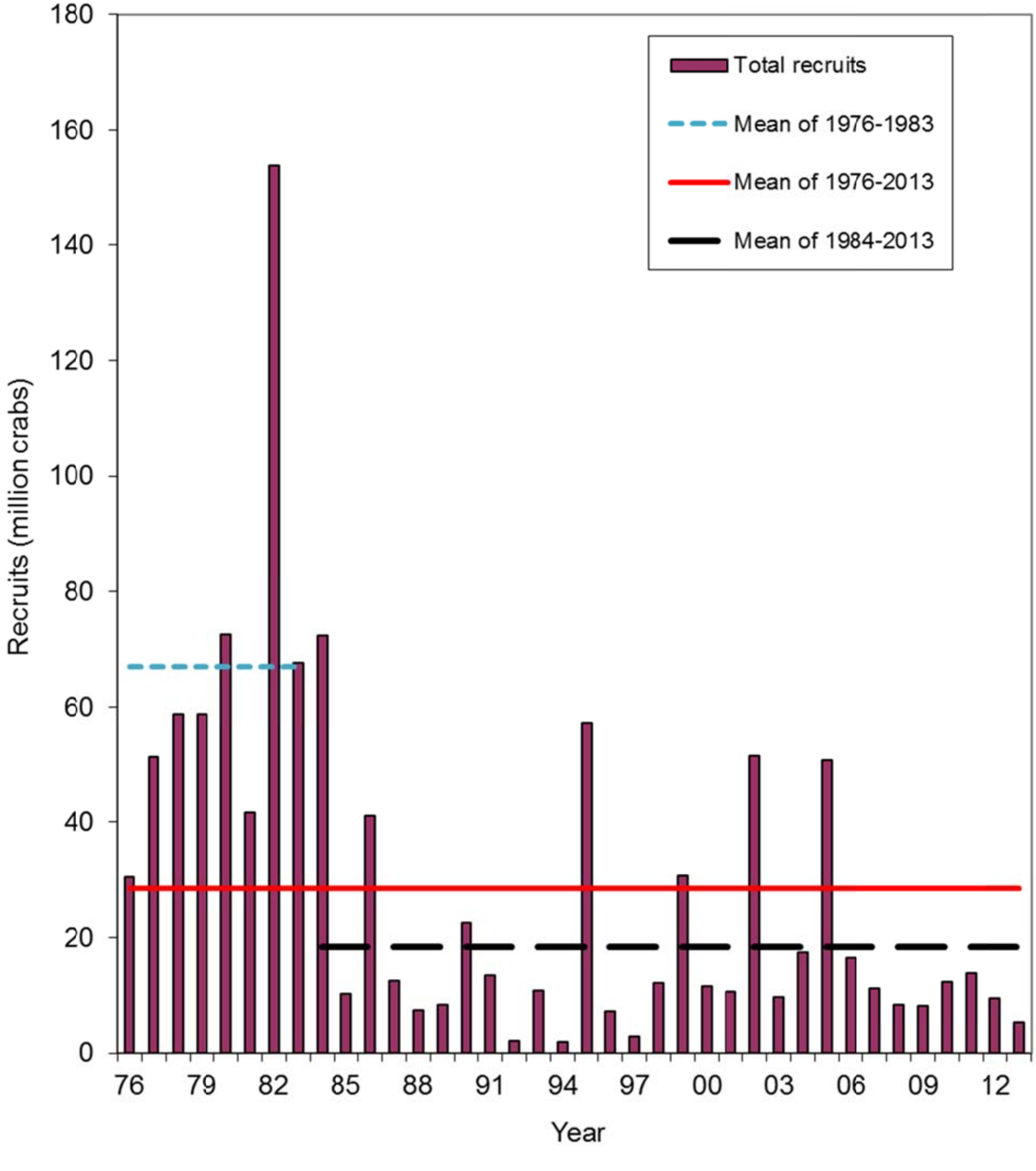


Figure 11(1). Estimated recruitment time series during 1976-2013 (occurred year) with scenario 1. Mean male recruits during 1984-2013 was used to estimate $B_{35\%}$.

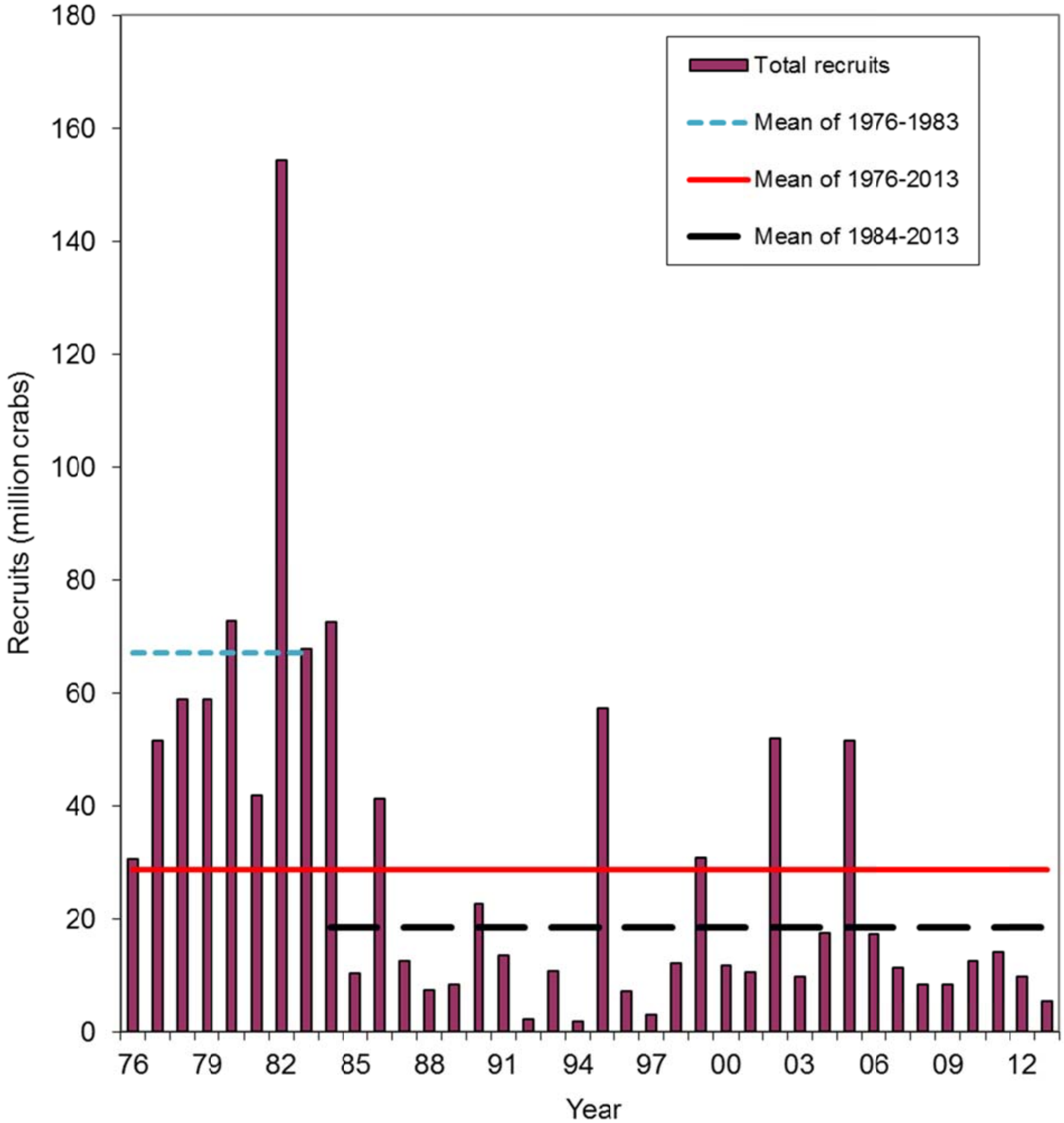


Figure 11(4). Estimated recruitment time series during 1976-2013 (occurred year) with scenario 4. Mean male recruits during 1984-2013 was used to estimate $B_{35\%}$.

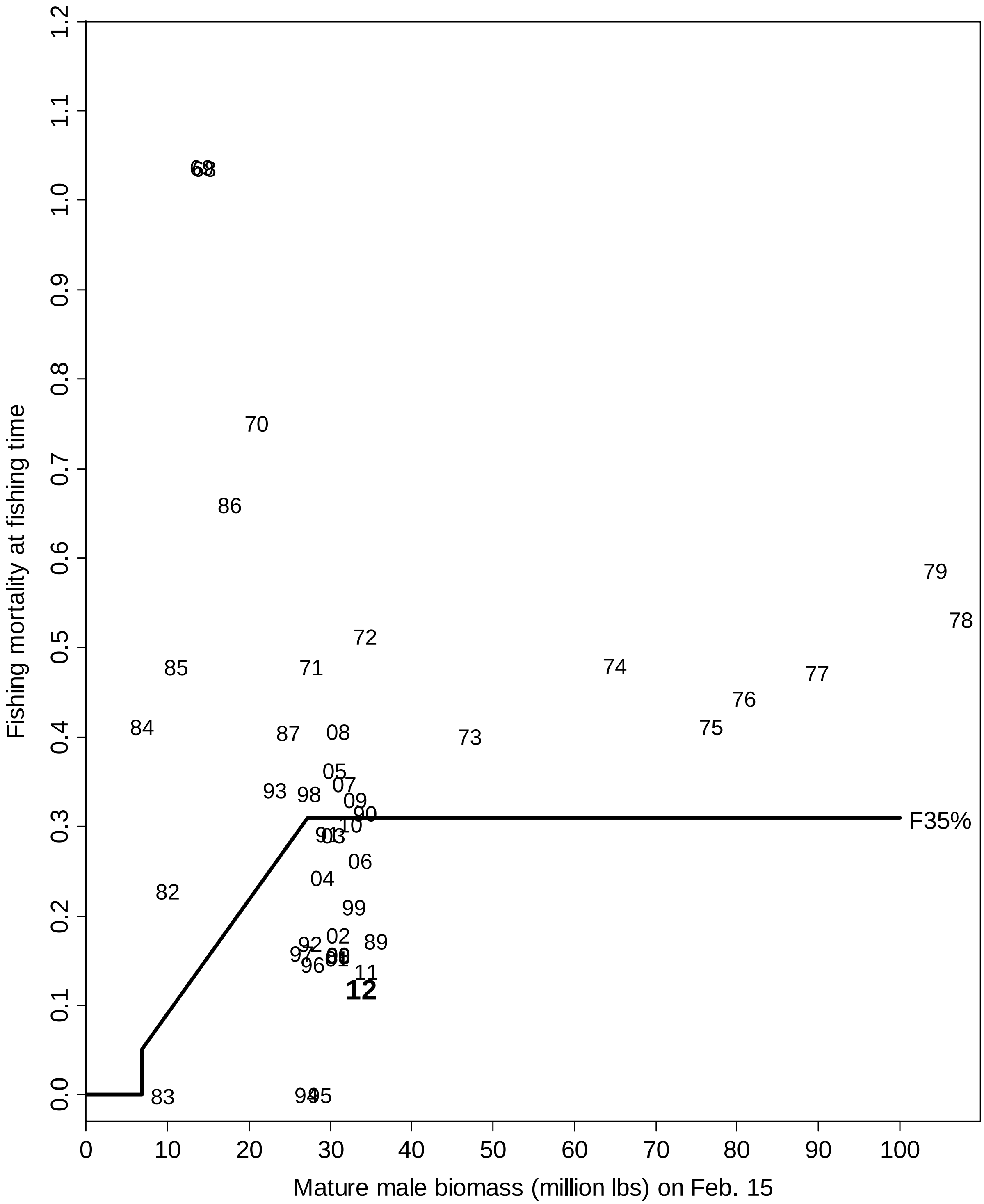


Figure 12(0). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1968-2012 under scenario 0(7ac). Average of recruitment from 1984 to 2013 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

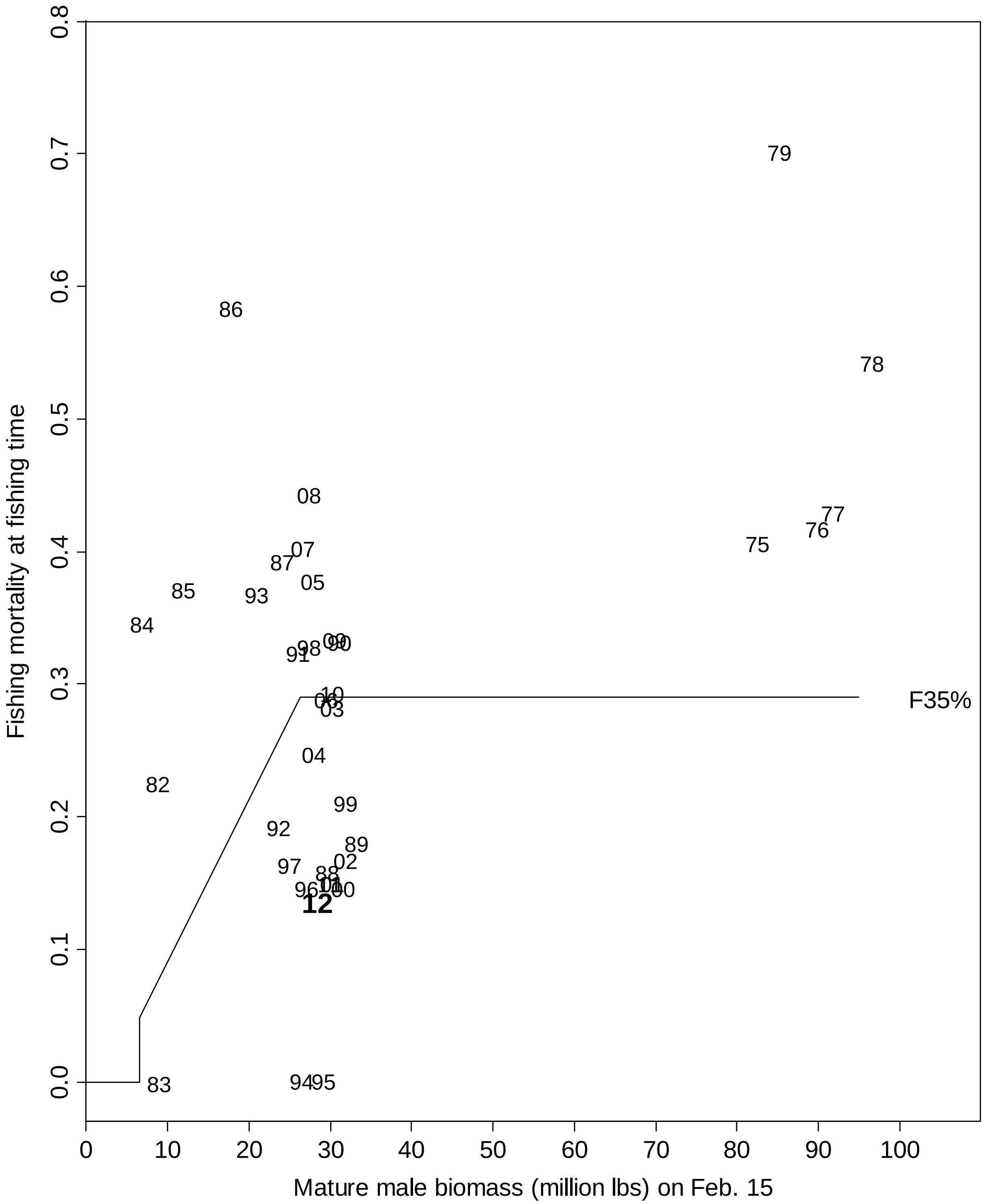


Figure 12(1). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2012 under scenario 1. Average of recruitment from 1984 to 2013 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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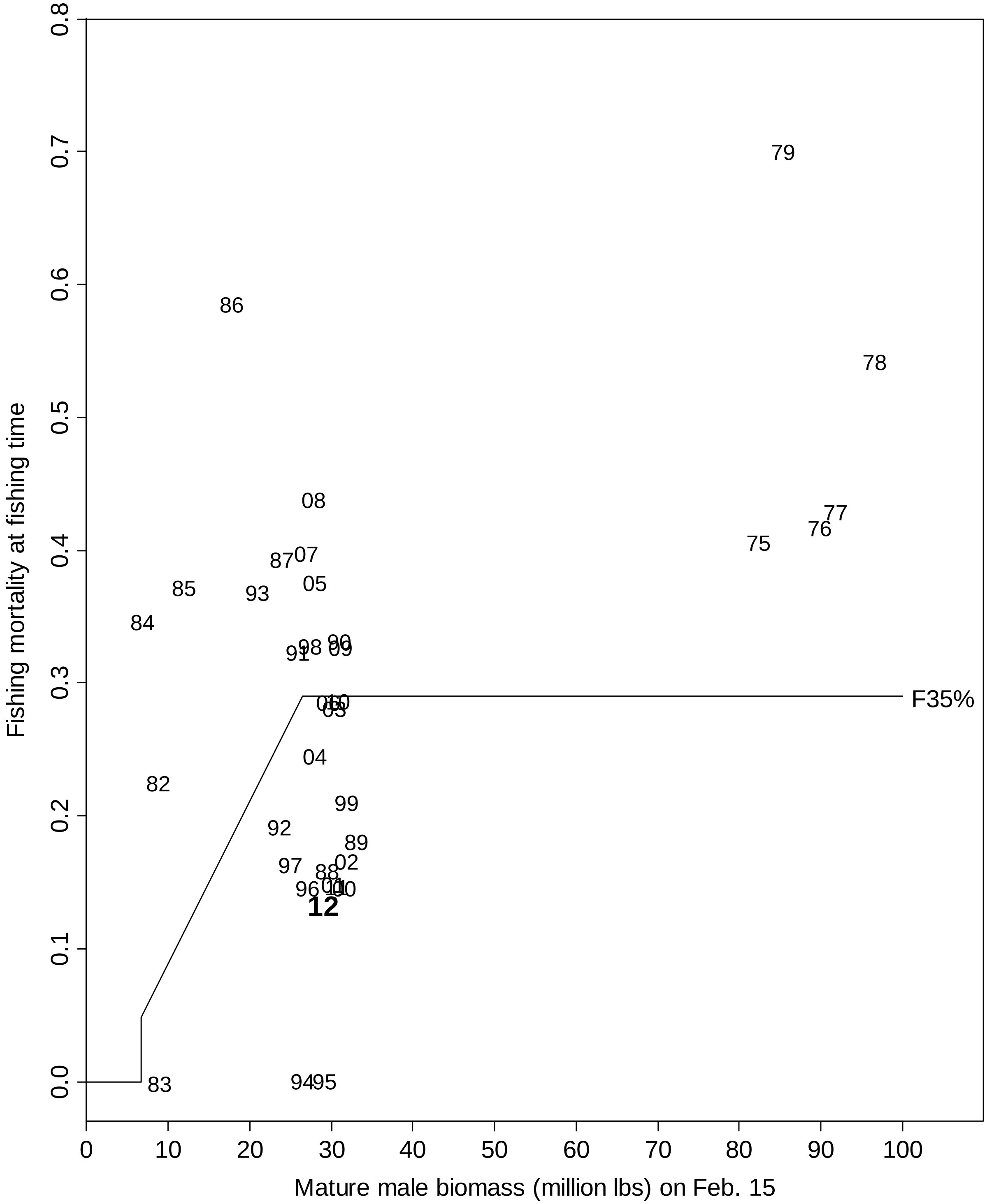

Figure 12(4). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2012 under scenario 4. Average of recruitment from 1984 to 2013 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

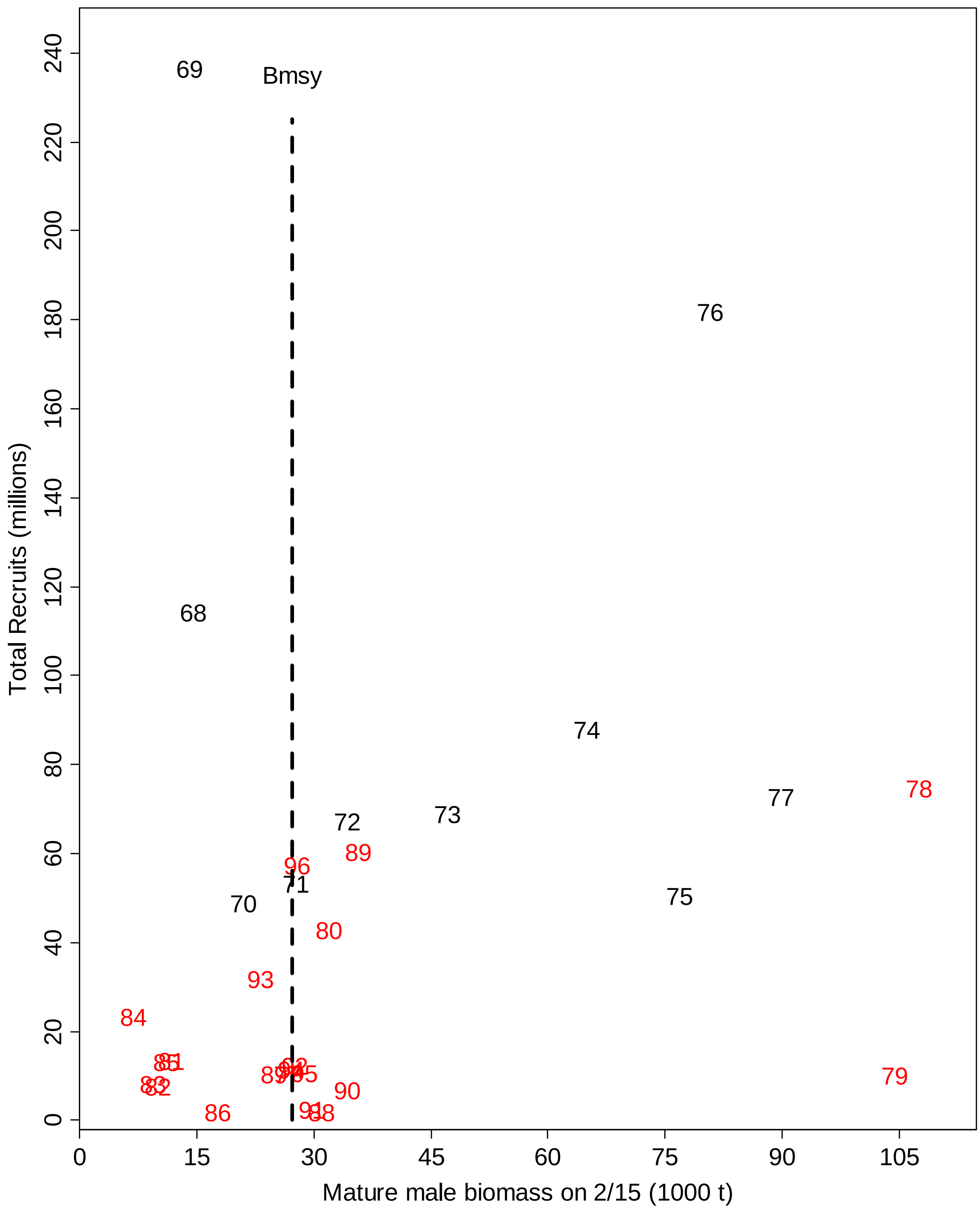

Figure 13a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 0(7ac). Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2013.

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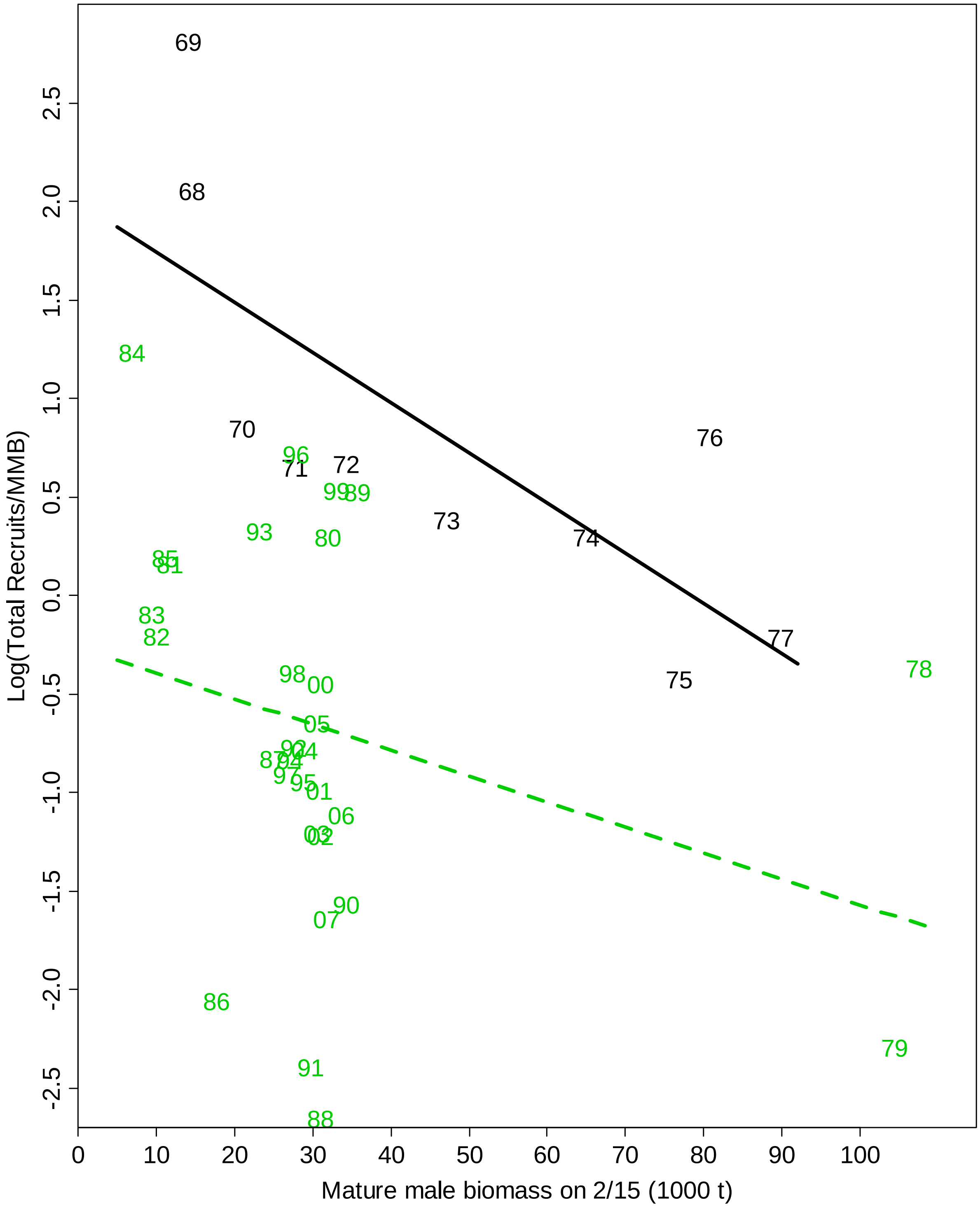


Figure 13b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 0(7ac). Numerical labels are years of mating, the solid line is the regression line for data of 1968-1977, and the dotted line is the regression line for data of 1978-2007.

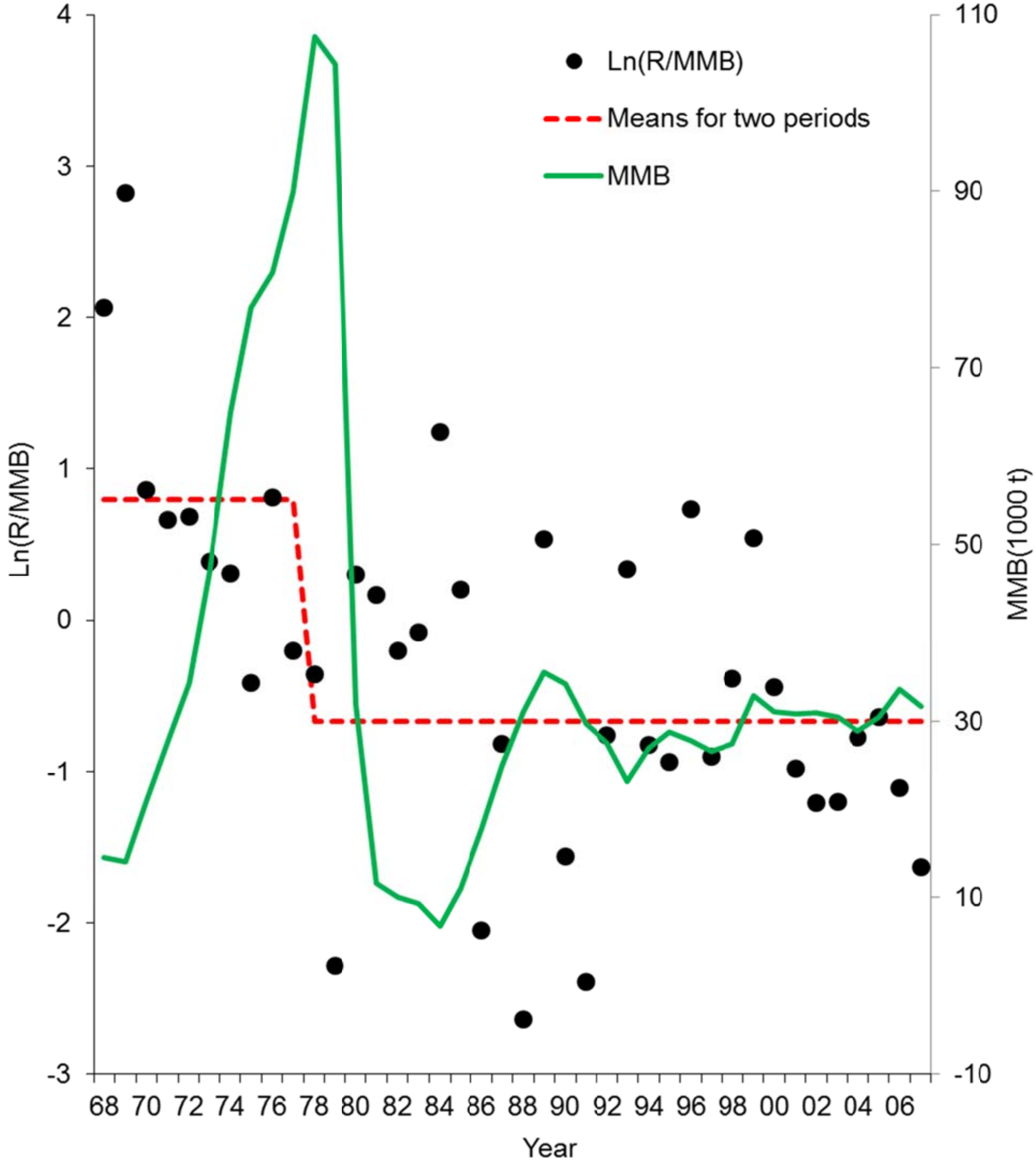


Figure 13c(0). Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 0(7ac). The dashed line is for the means of two periods: 1968-1977 and 1978-2007.

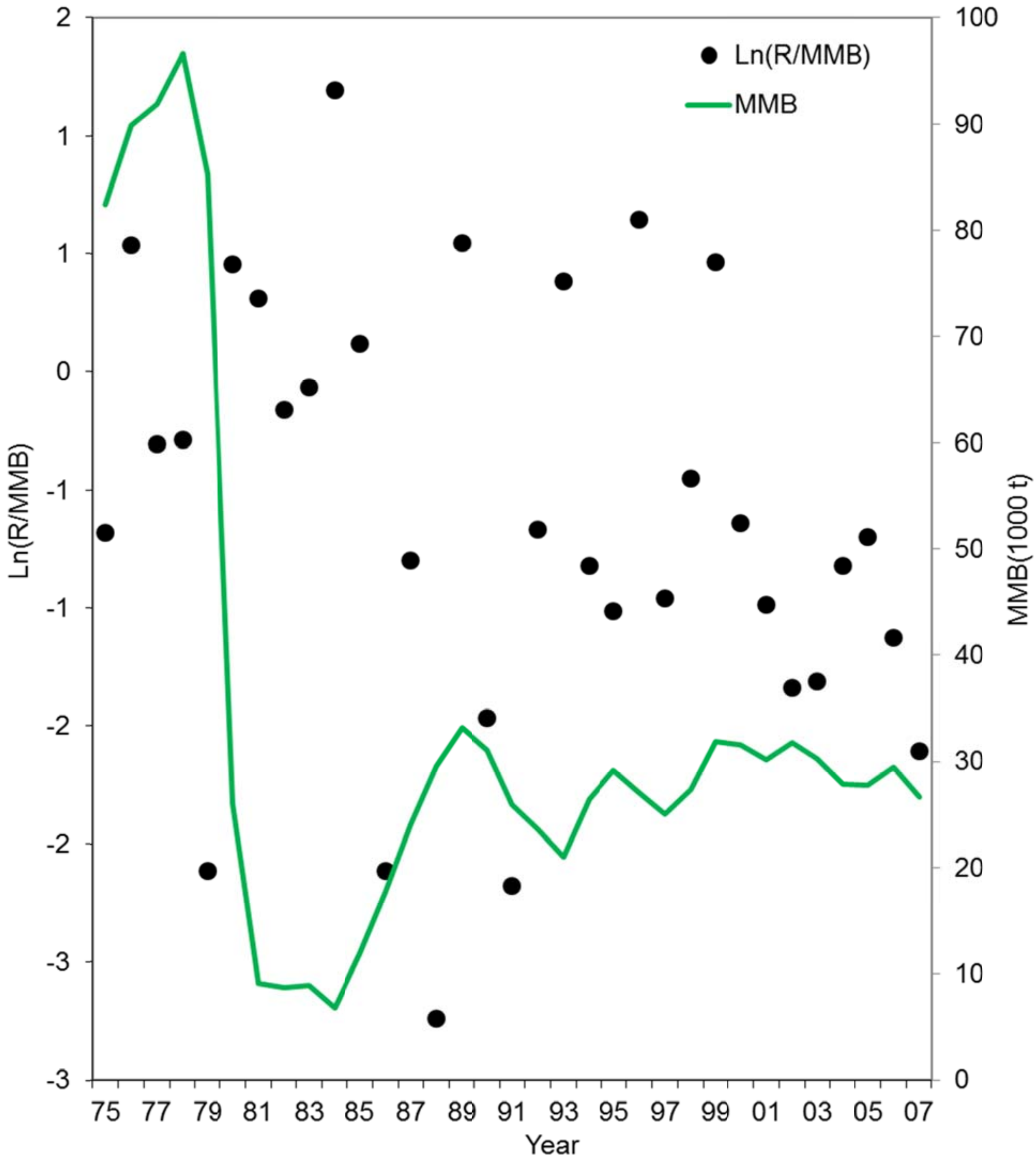


Figure 13c(1). Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 1.

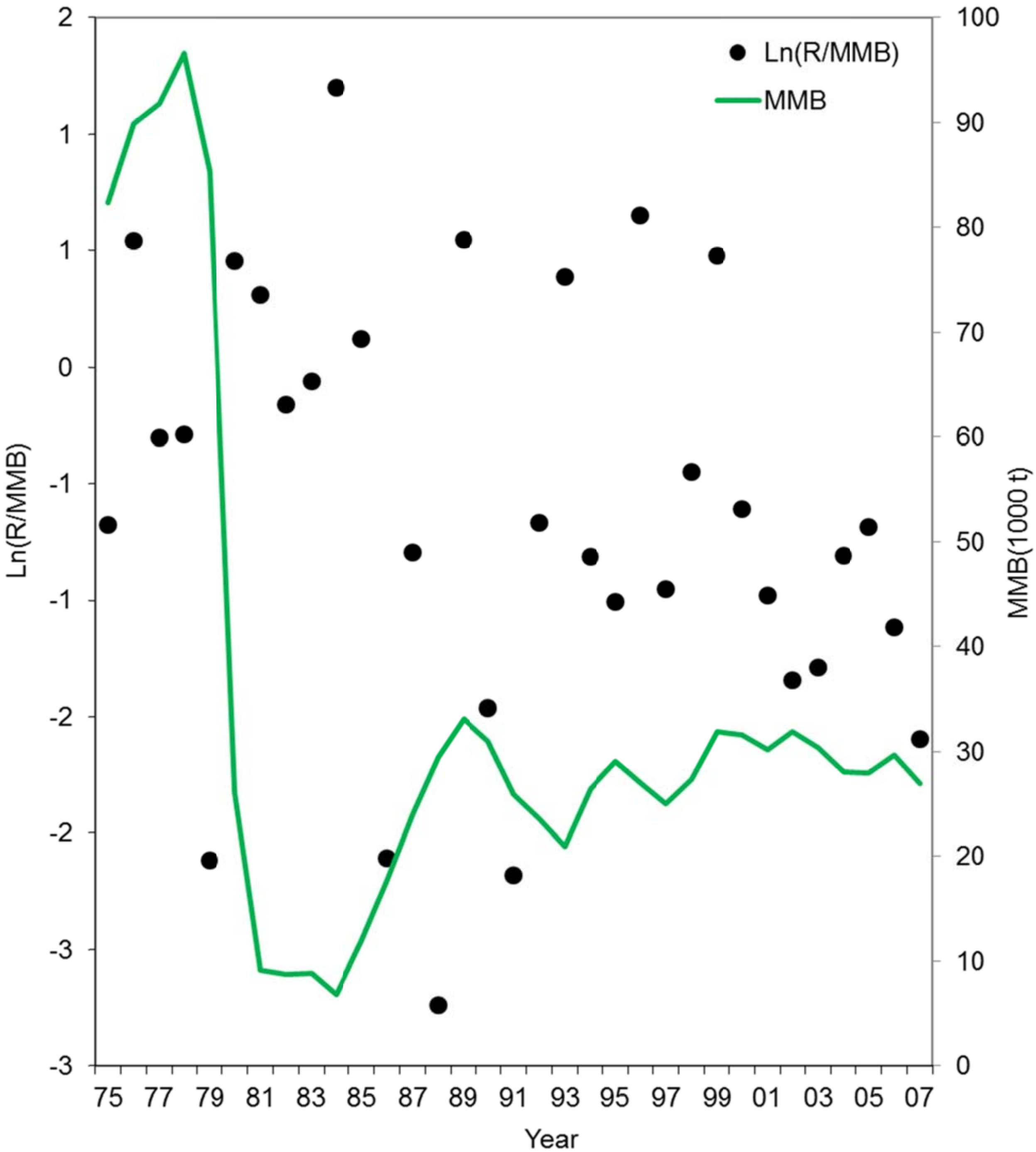


Figure 13c(4). Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 4.

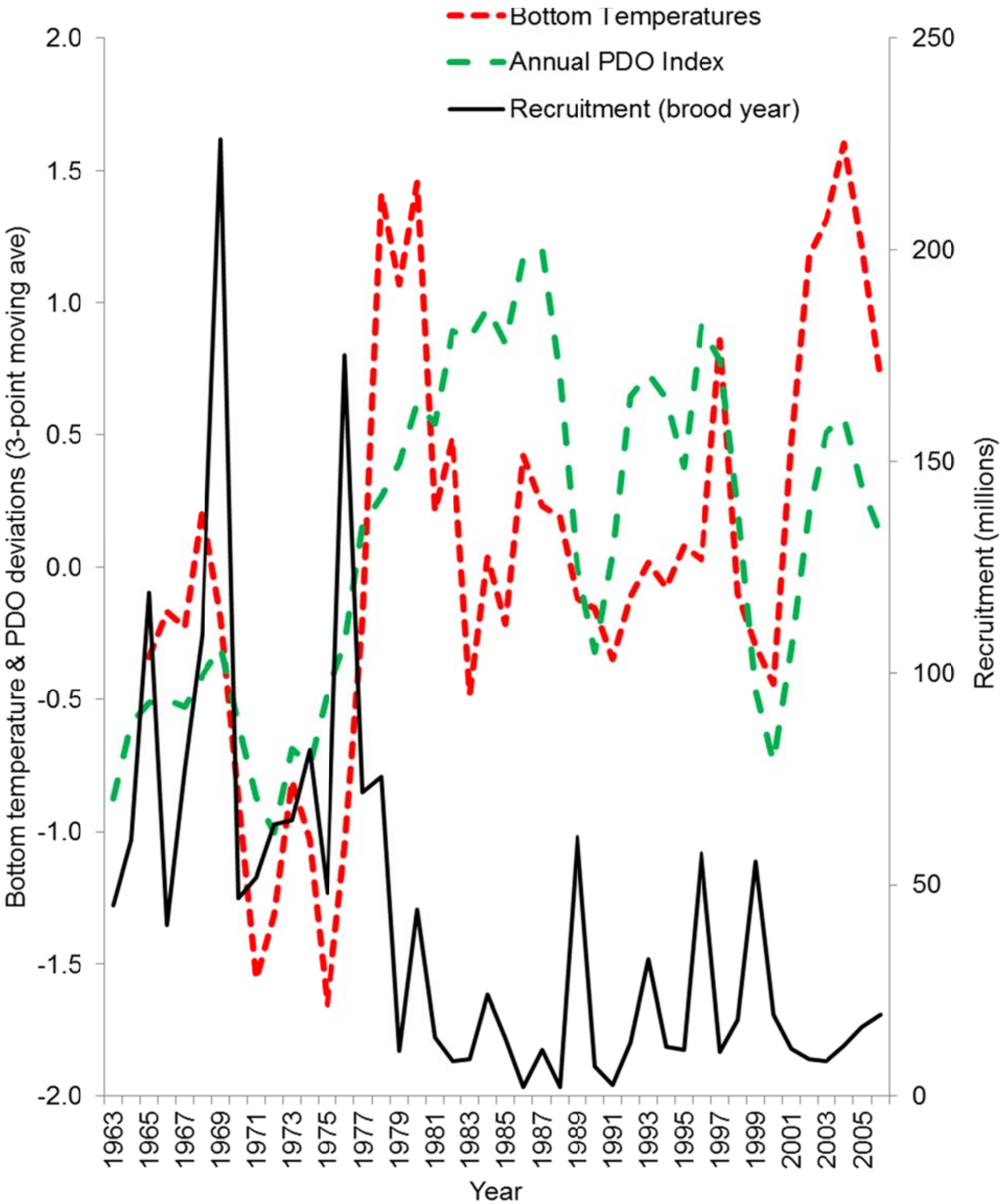


Figure 13d. Time series of recruitment in brood year, summer bottom temperatures in Bristol Bay and annual PDO index under scenario 0(7ac) (2012).

Figure 13e and Figure 13f are not shown here to reduce file size. Please see previous SAFE reports for these figures.

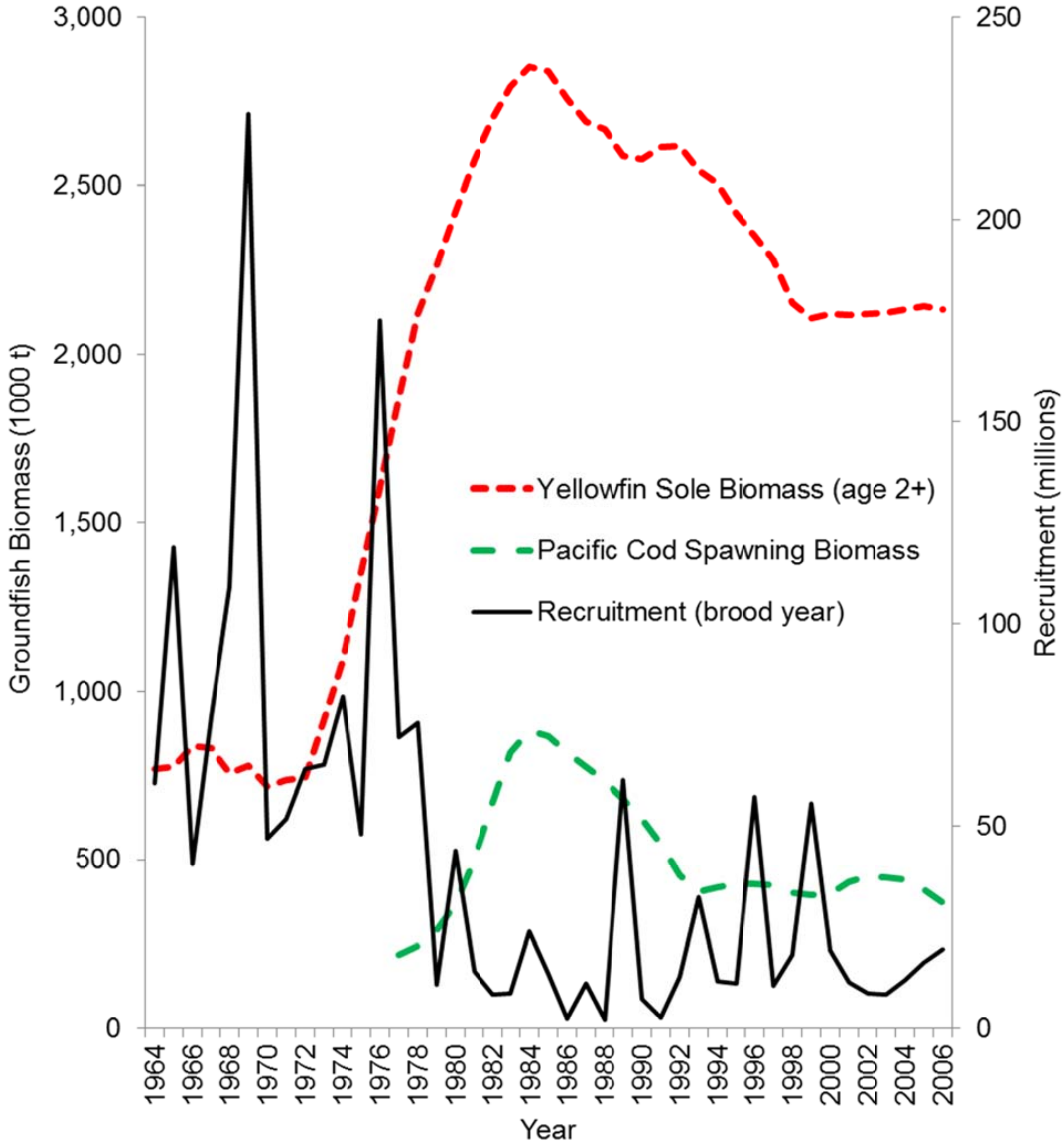
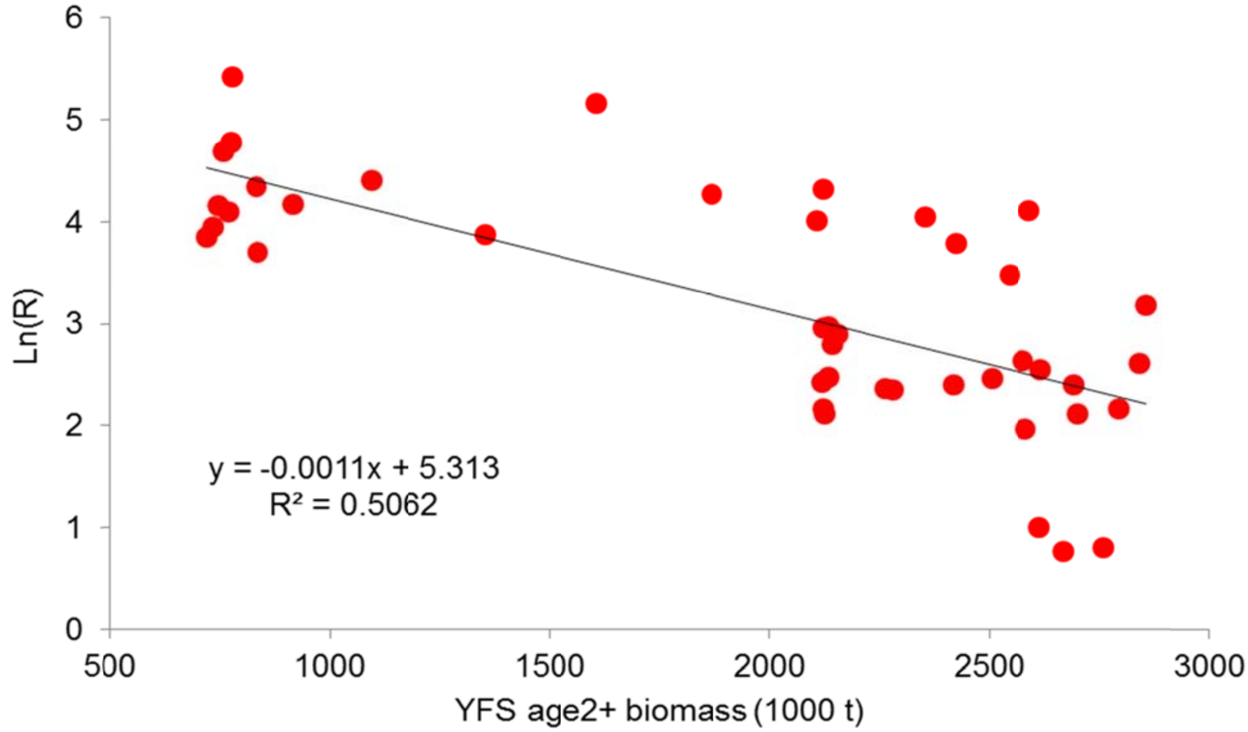


Figure 13g. Time series of recruitment in brood year, yellowfin sole biomass (age 2+) and Pacific cod spawning biomass under scenario 0(7ac) (2012). The groundfish biomass is from the Groundfish SAFE report. The Pacific cod biomass before 1977 was not available and should be less than the value in 1977.



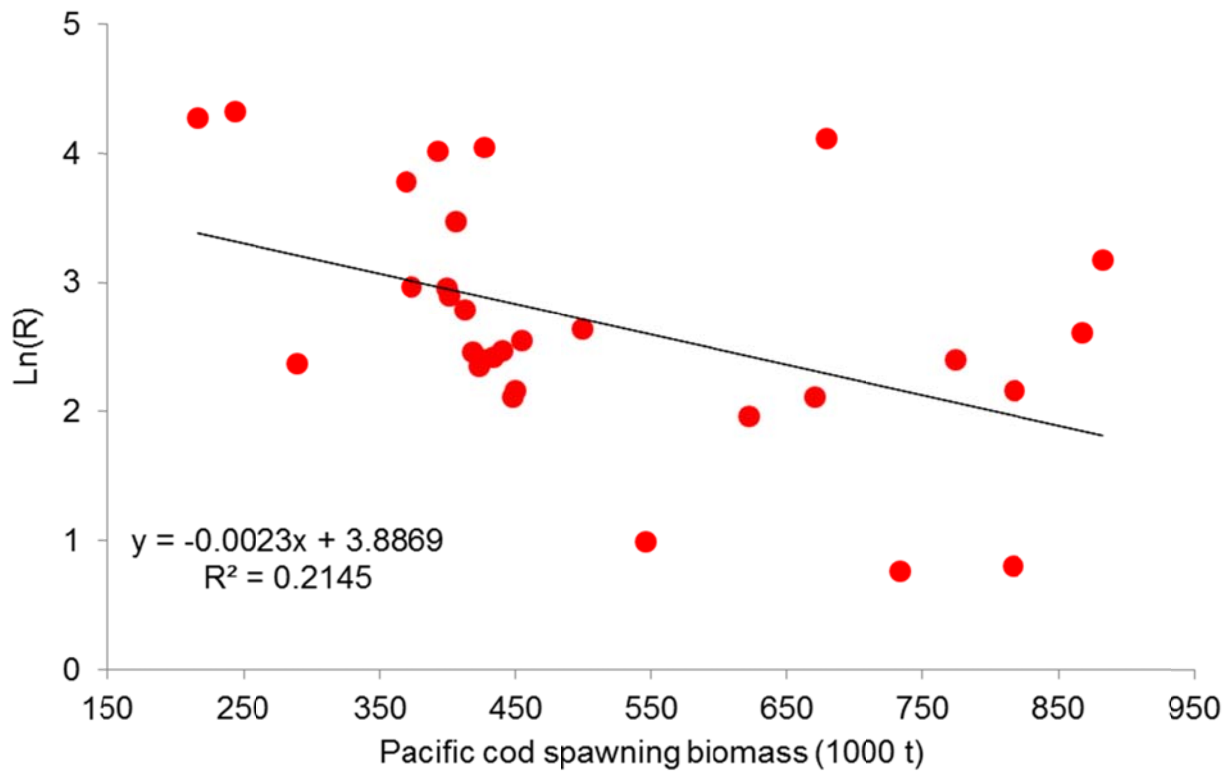


Figure 13h. Relationships between ln(recruitment) in brood year and yellowfin sole biomass (age 2+) and Pacific cod spawning biomass under scenario 0(7ac, 2012). The groundfish biomass is from the Groundfish SAFE report.

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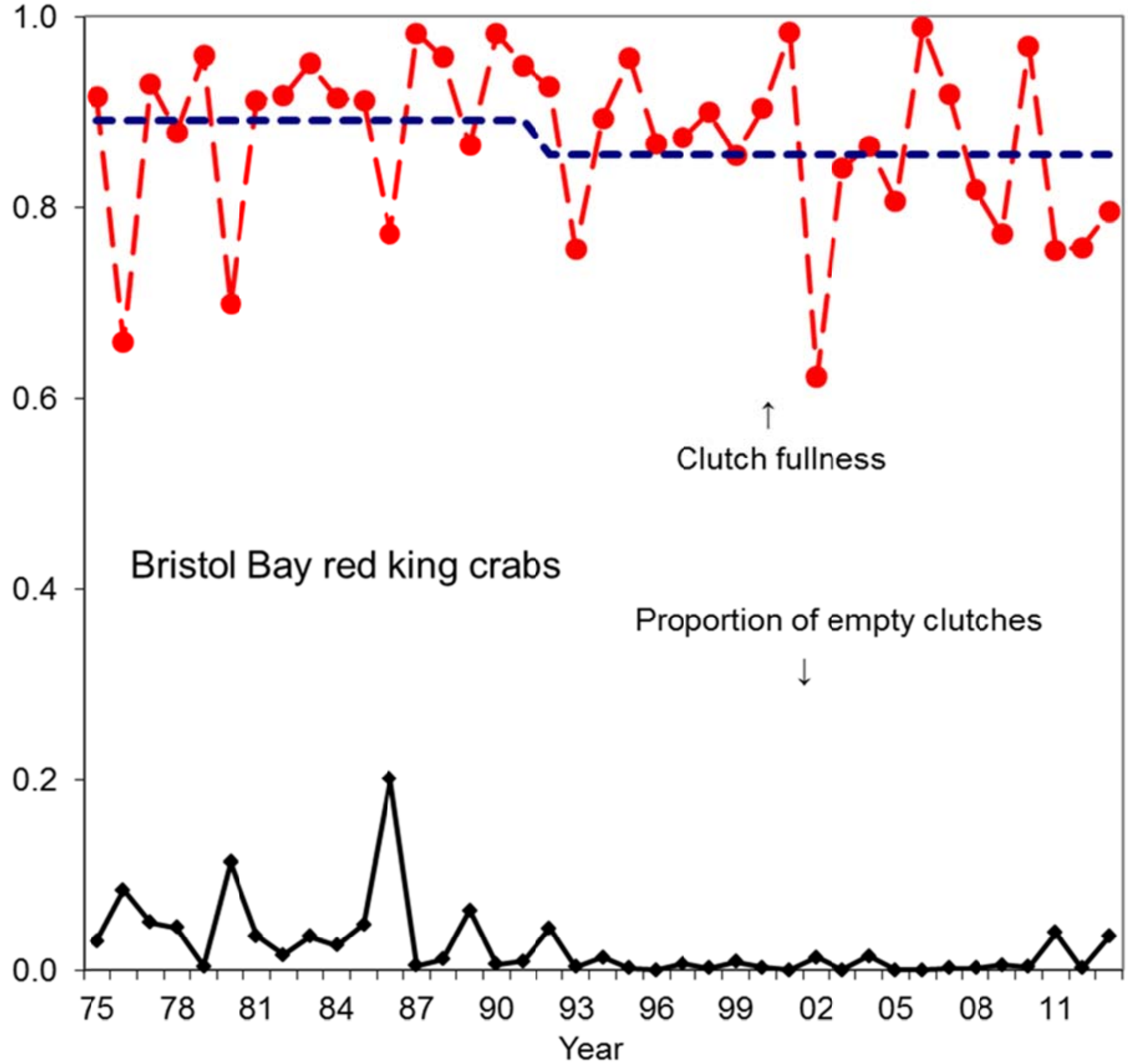


Figure 14. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crabs >89 mm CL from 1975 to 2013 from survey data. Oldshell females were excluded.

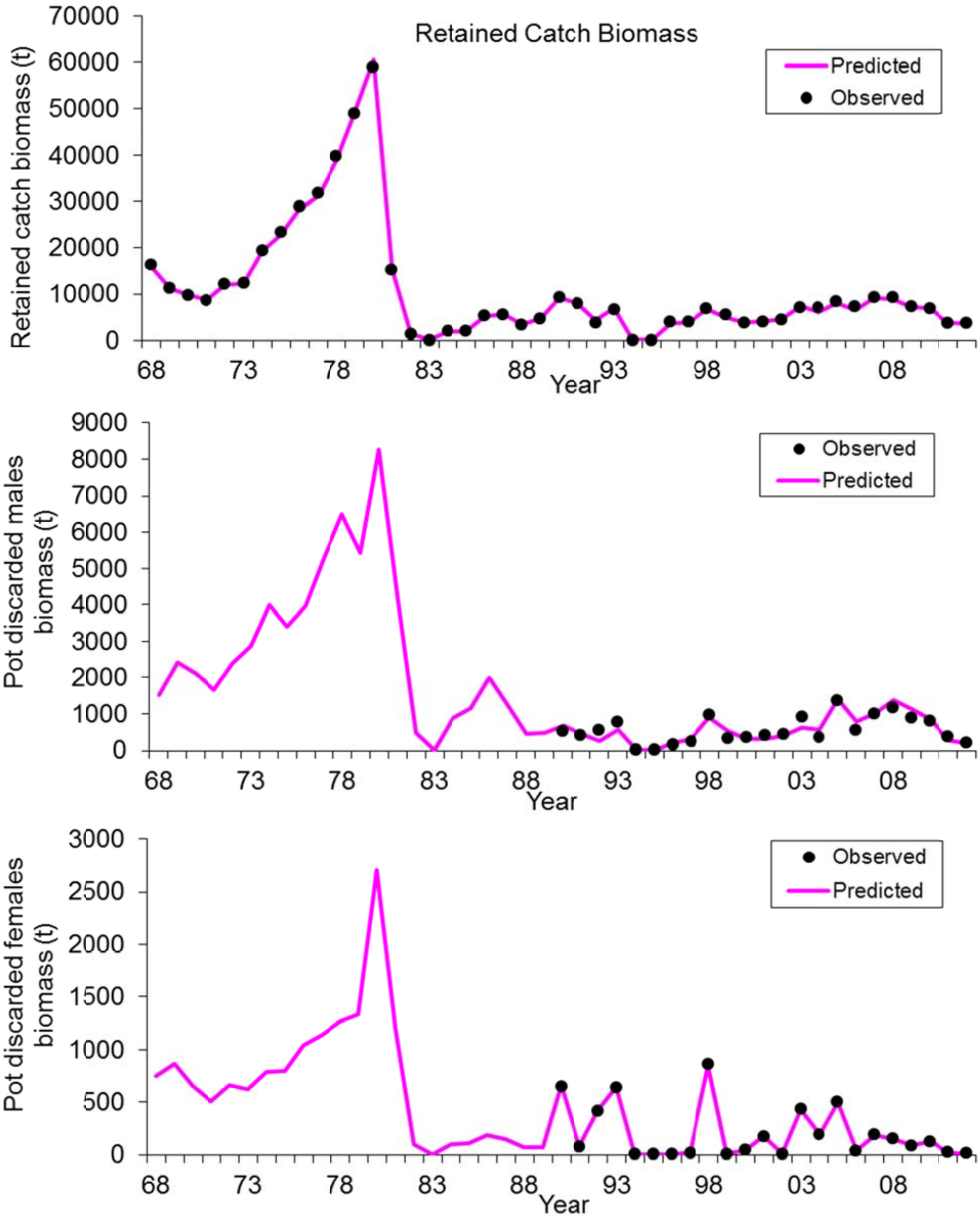


Figure 15a(0). Observed and predicted catch mortality biomass under scenario 0(7ac). Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

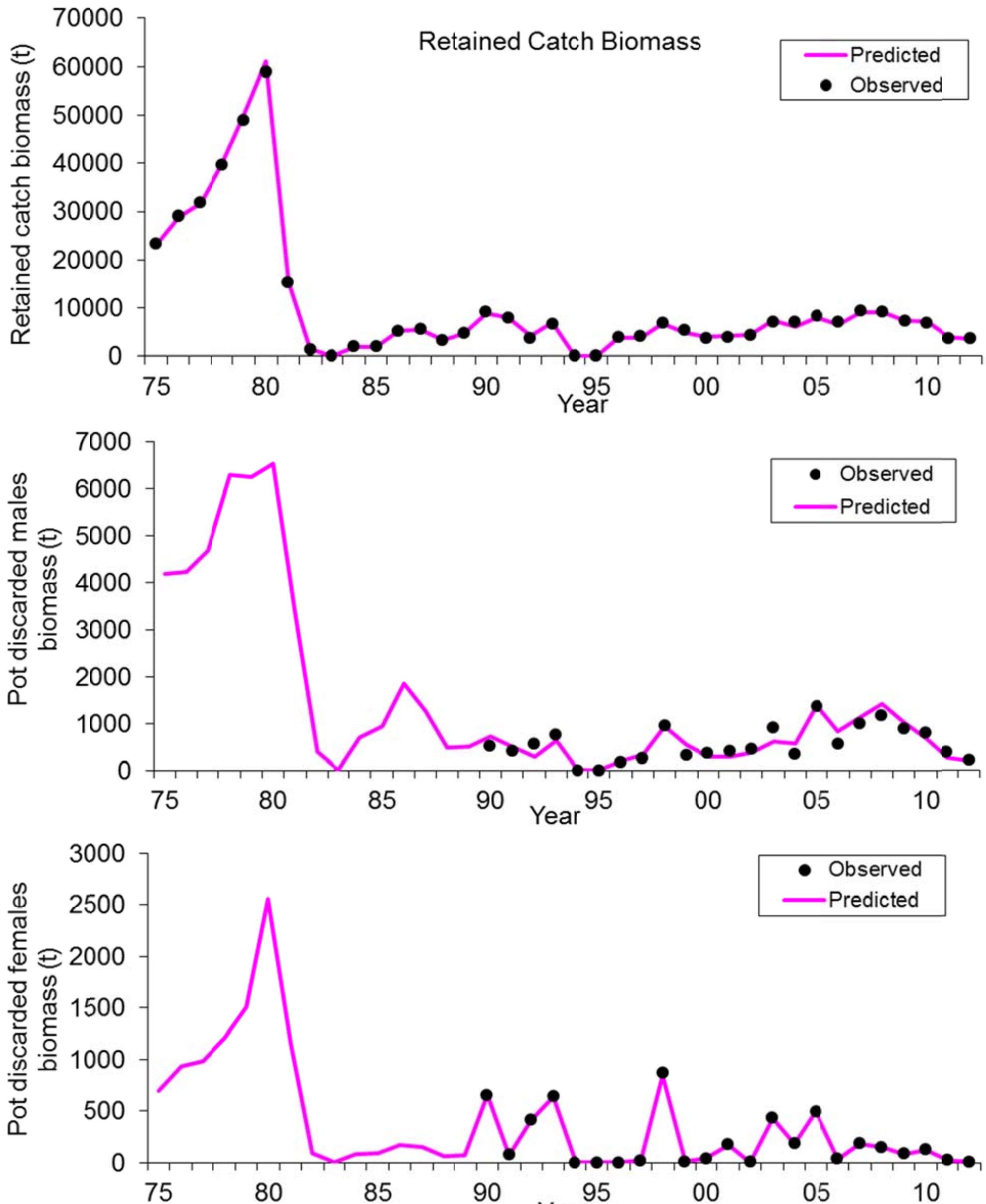
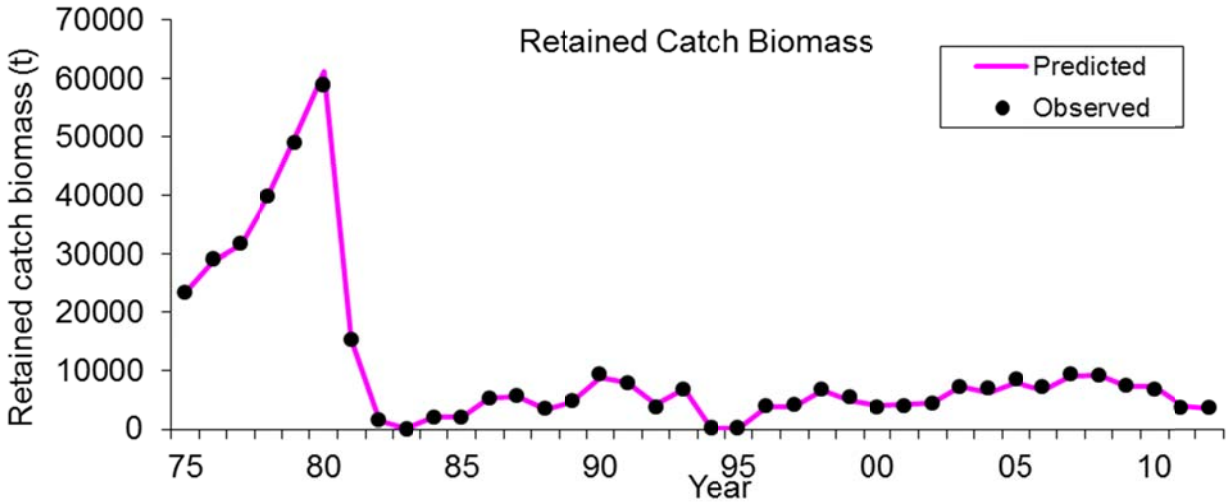
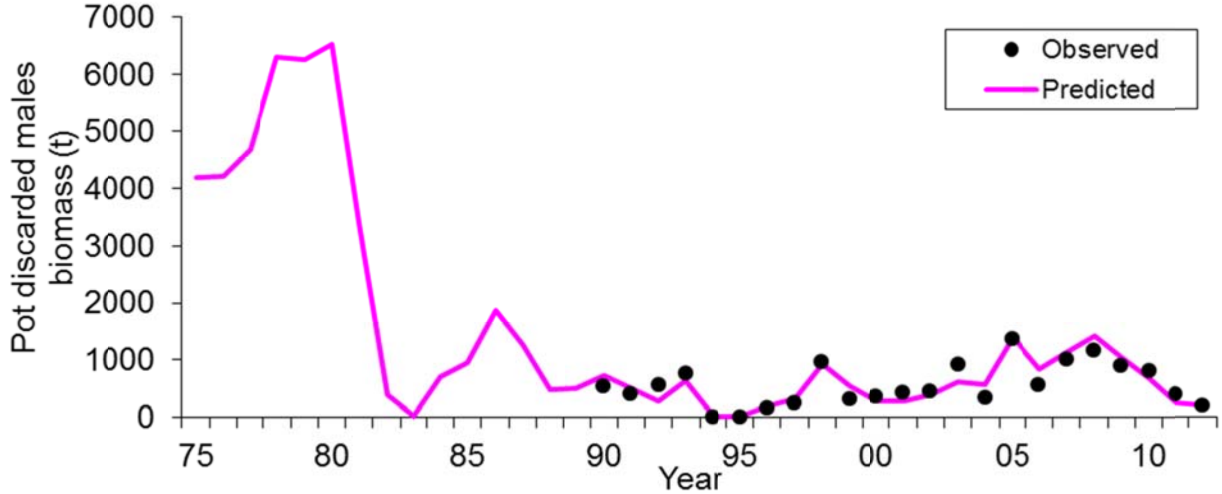


Figure 15a(1). Observed and predicted catch mortality biomass under scenario 1. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.





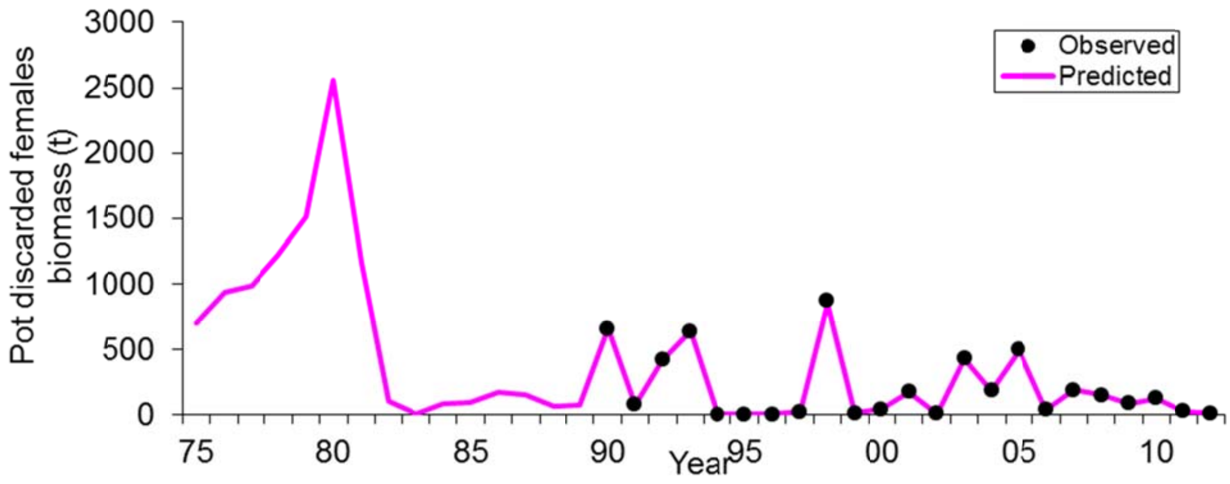


Figure 15a(4). Observed and predicted catch mortality biomass under scenario 4. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

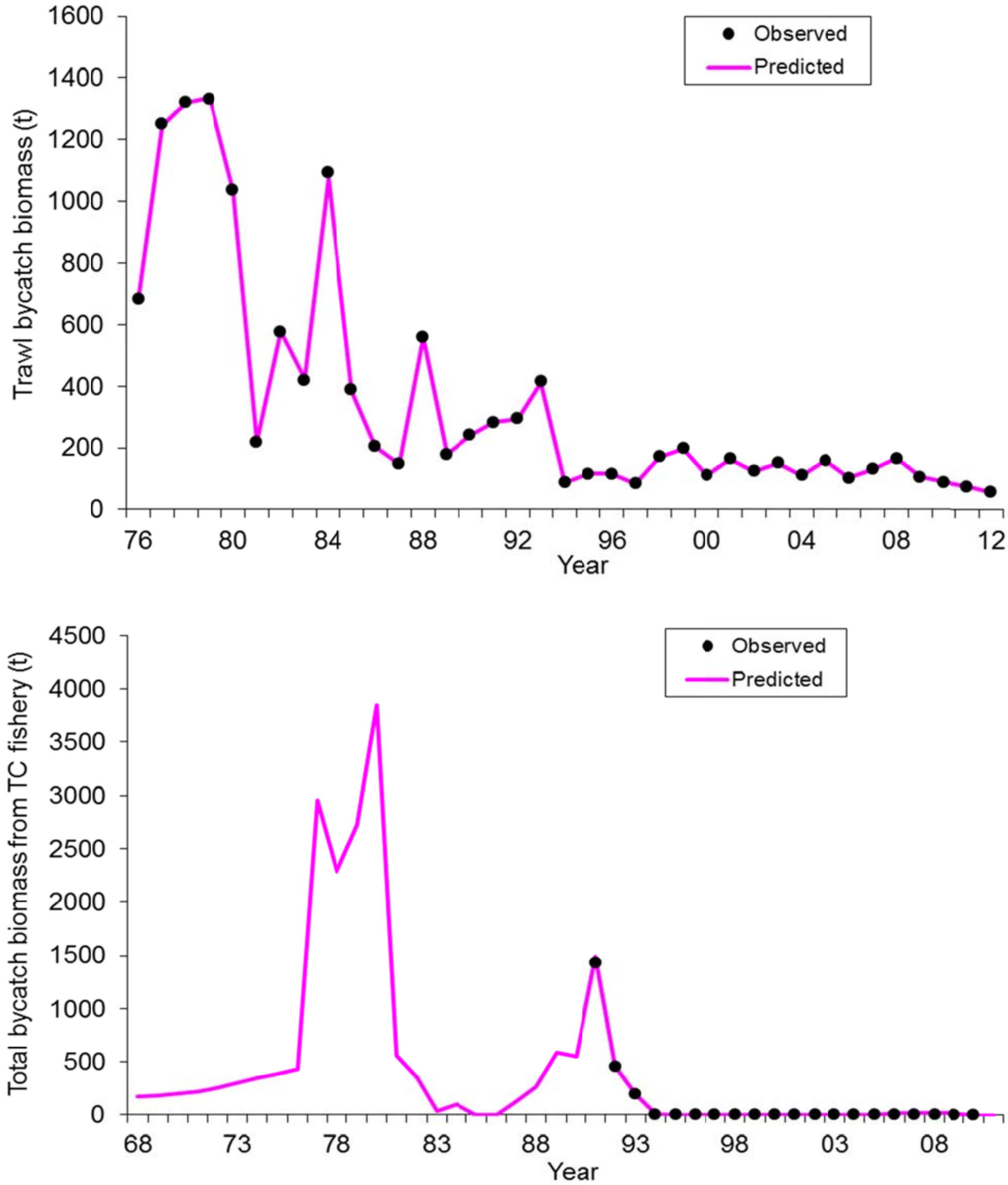


Figure 15b(0). Observed and predicted bycatch mortality biomass from trawl fisheries and Tanner crab fishery under scenario 0(7ac). Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl bycatch biomass was 0 before 1976.

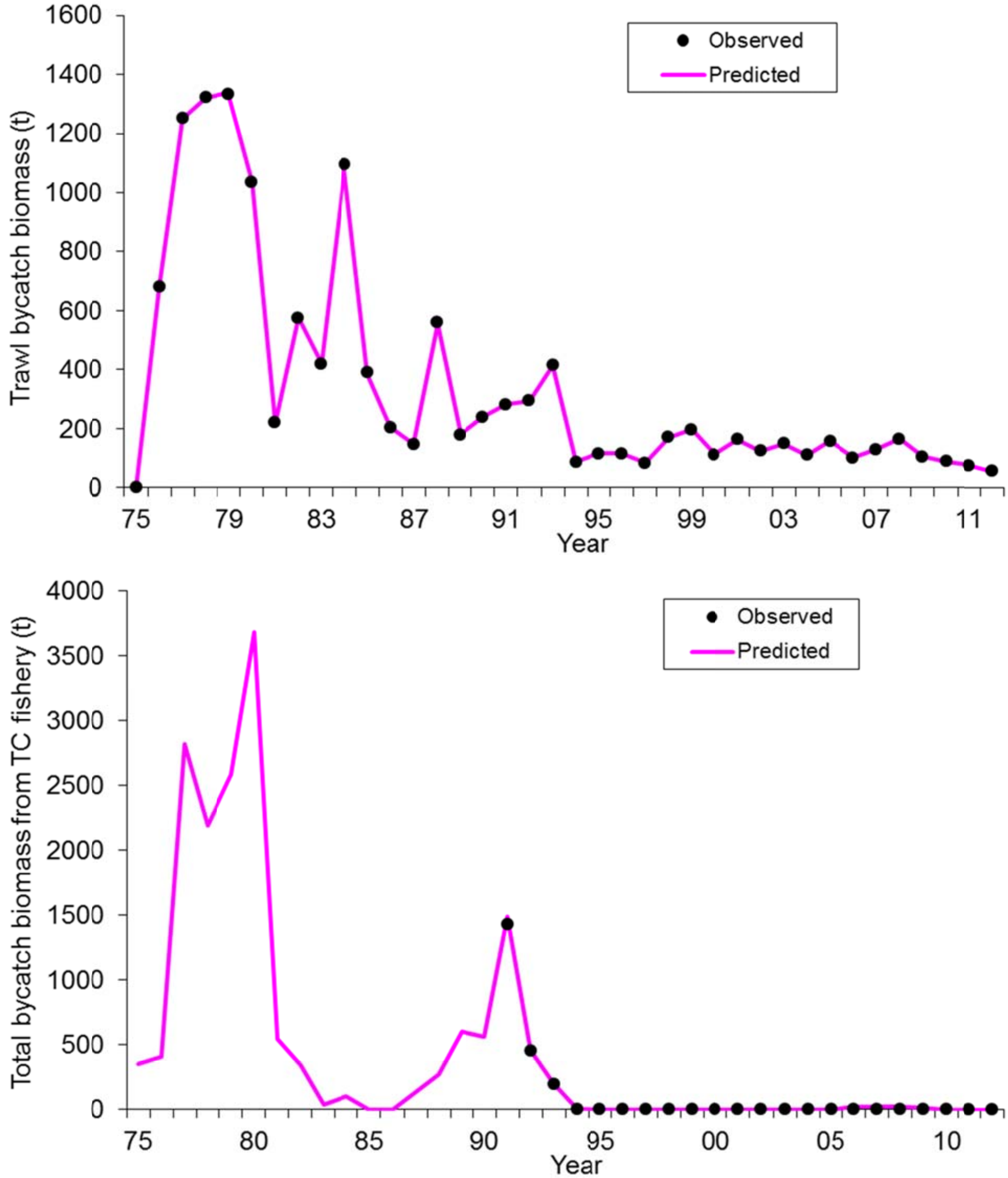
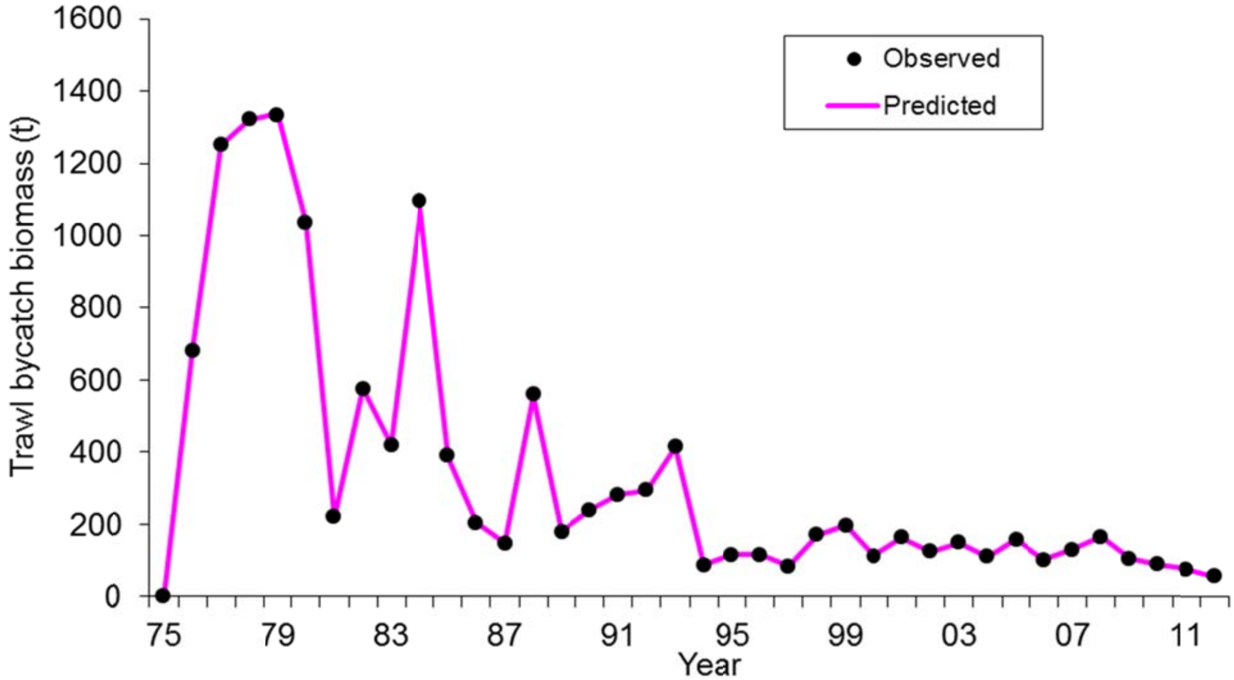


Figure 15b(1). Observed and predicted bycatch mortality biomass from trawl fisheries and Tanner crab fishery under scenario 1. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl bycatch biomass was 0 before 1976.



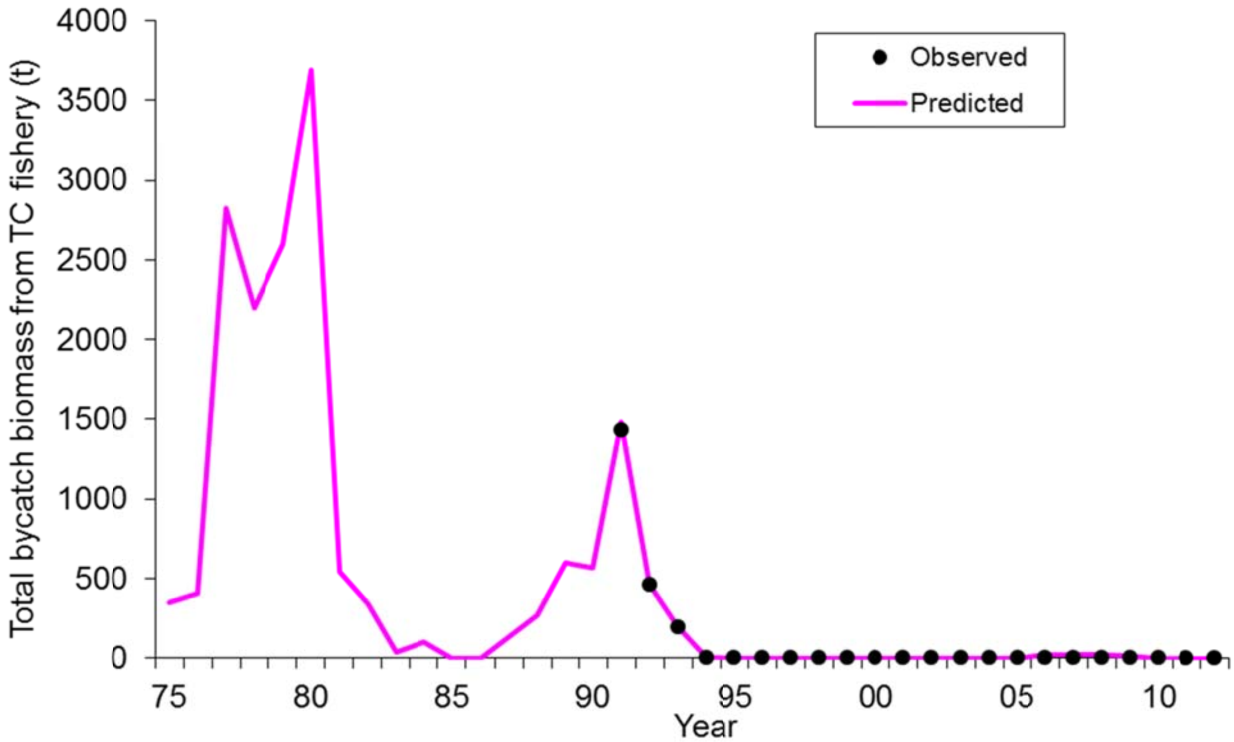


Figure 15b(4). Observed and predicted bycatch mortality biomass from trawl fisheries and Tanner crab fishery under scenario 4. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl bycatch biomass was 0 before 1976.

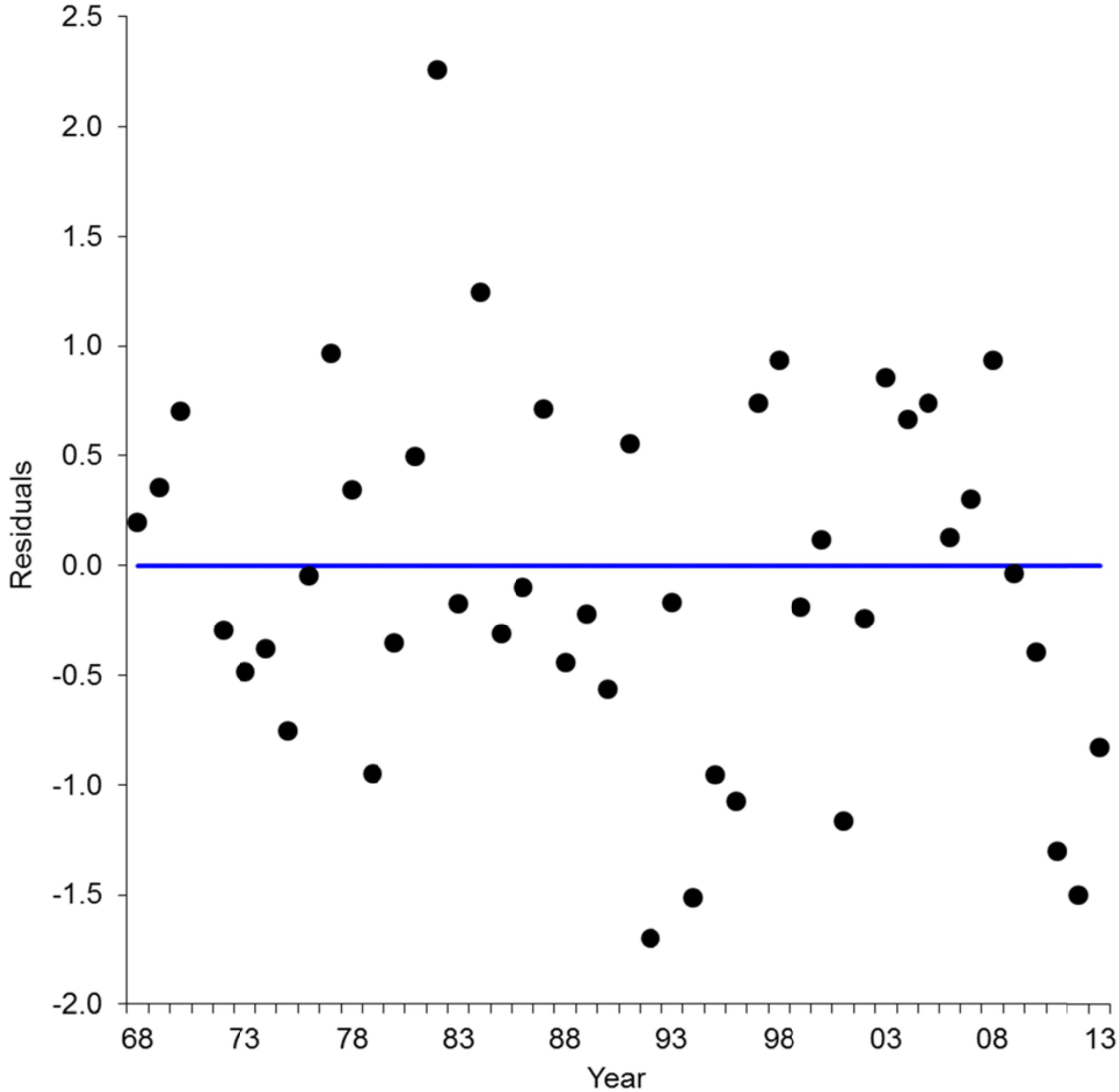


Figure 16(0). Standardized residuals of total survey biomass under scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

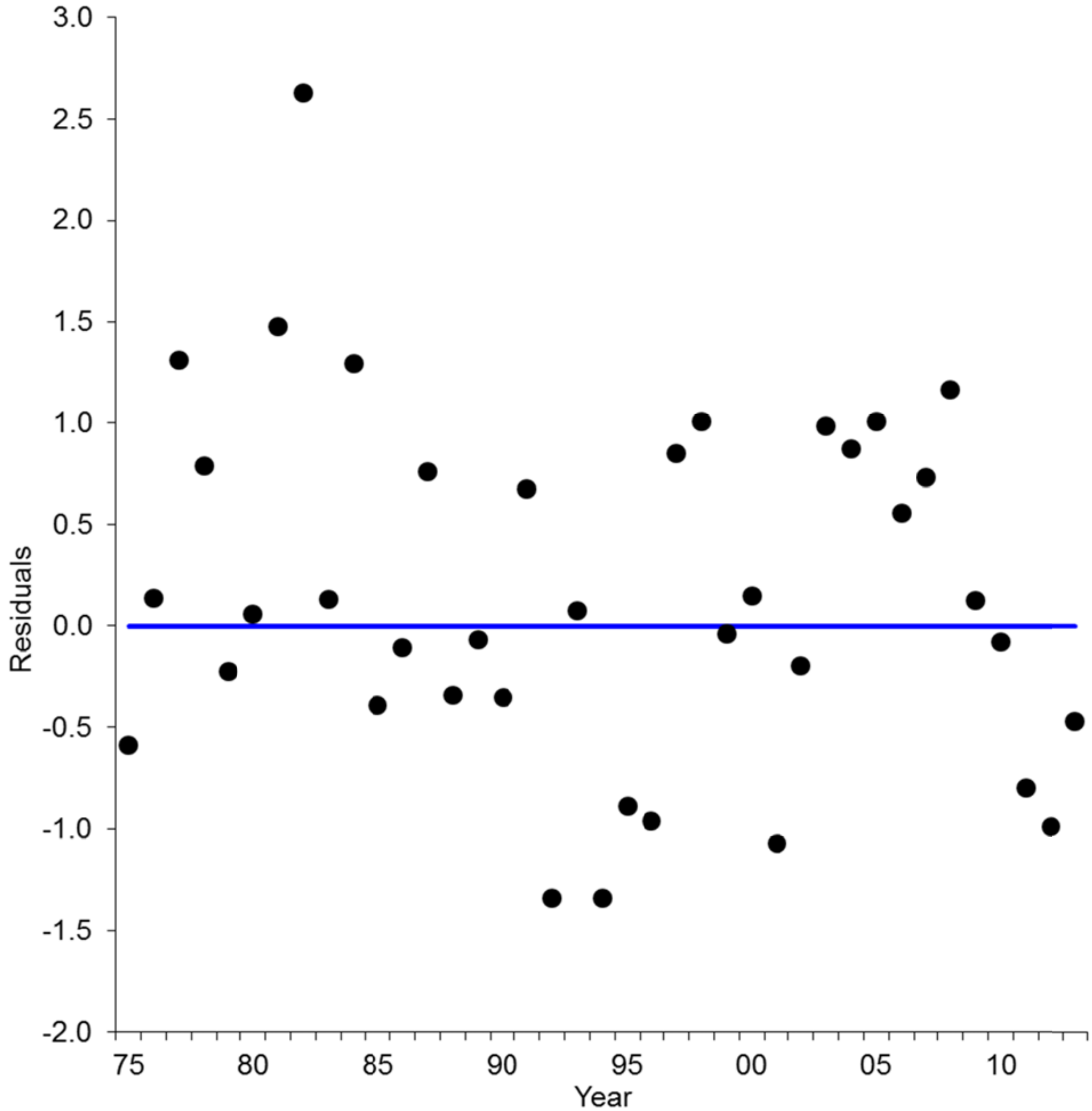


Figure 16(1). Standardized residuals of total survey biomass under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

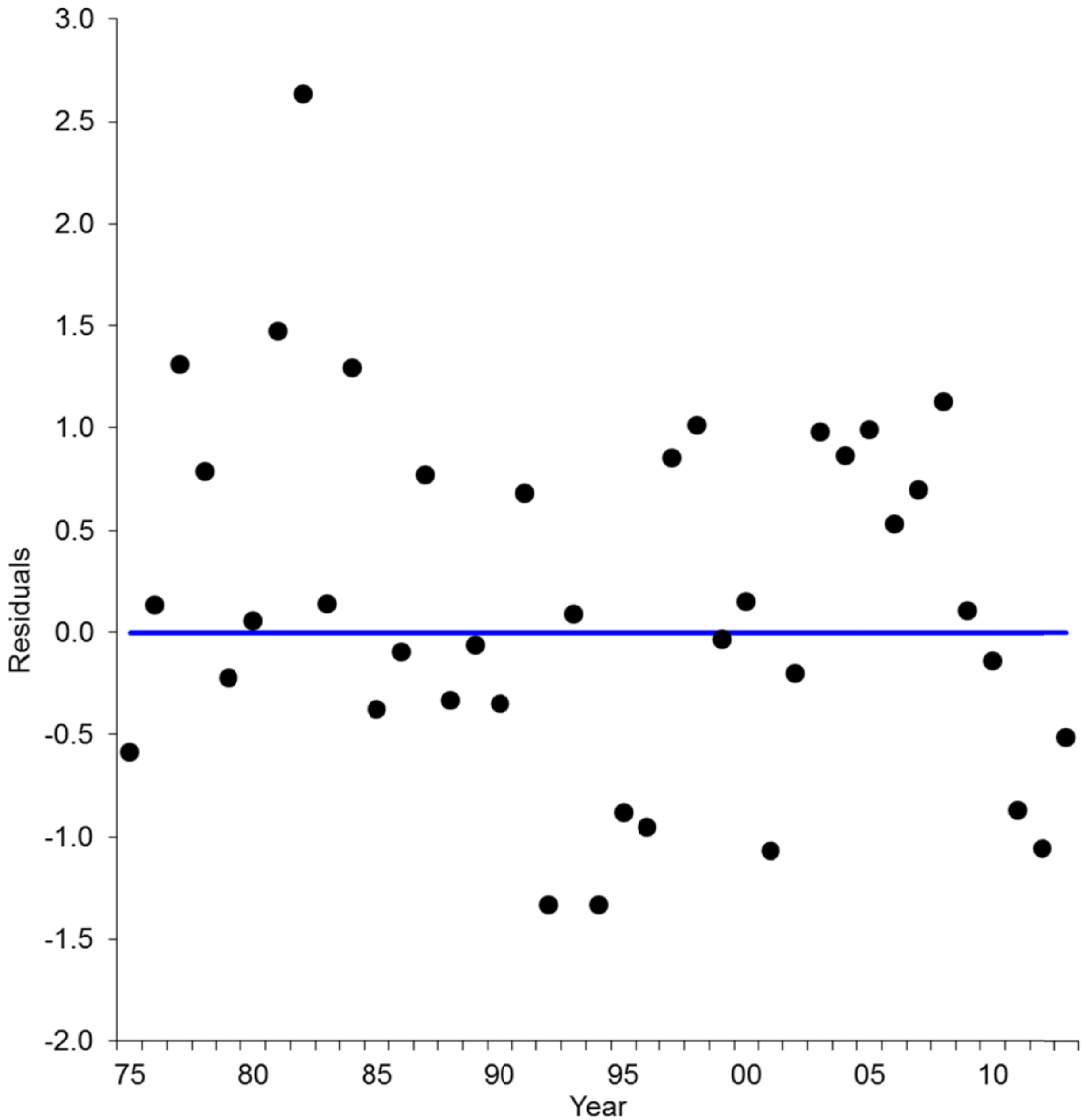


Figure 16(4). Standardized residuals of total survey biomass under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

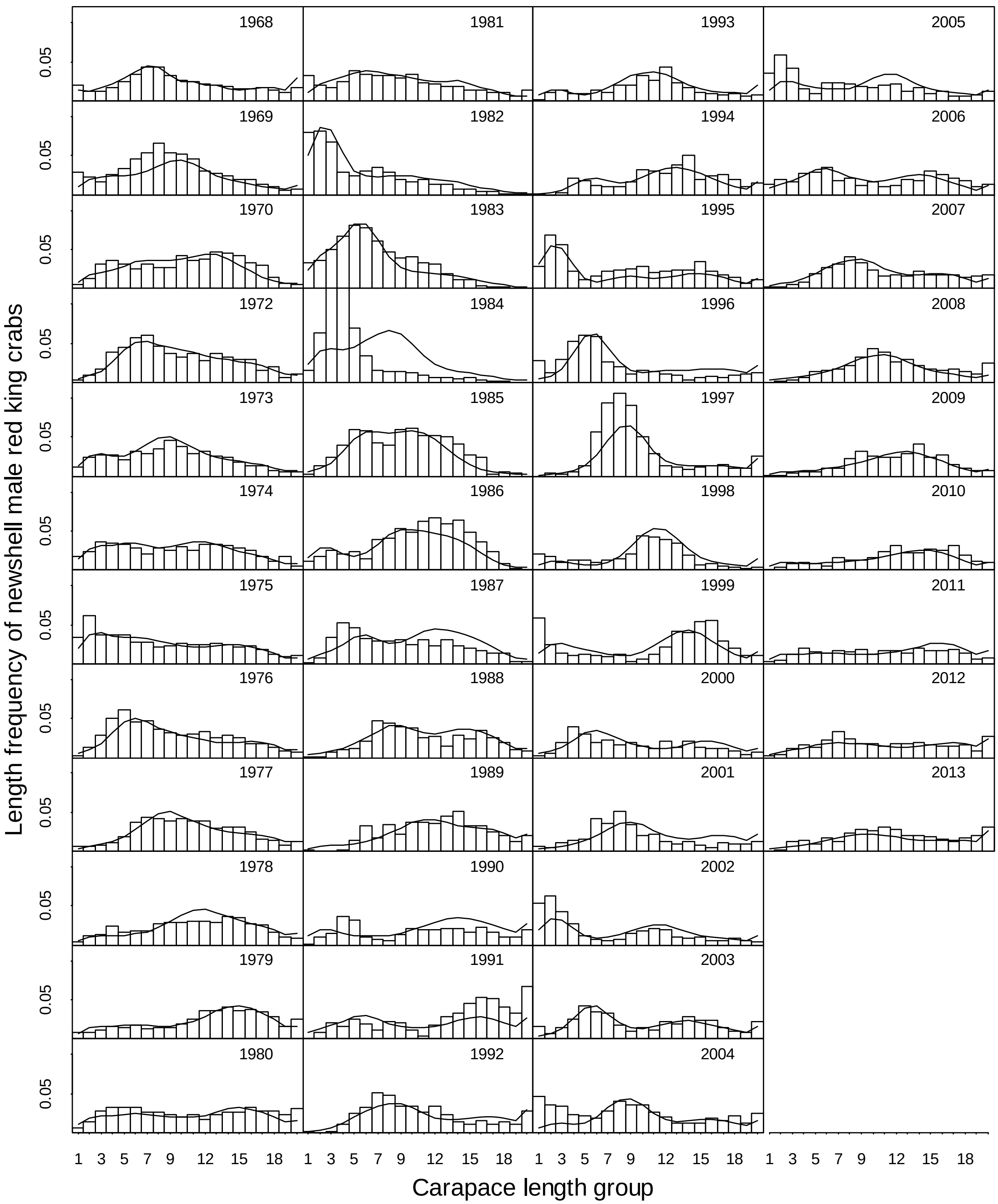


Figure 17(0). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay all-shell (before 1986) and newshell (1986-2013) male red king crabs by year under scenario 0 (7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, and the first length group is 67.5 mm.

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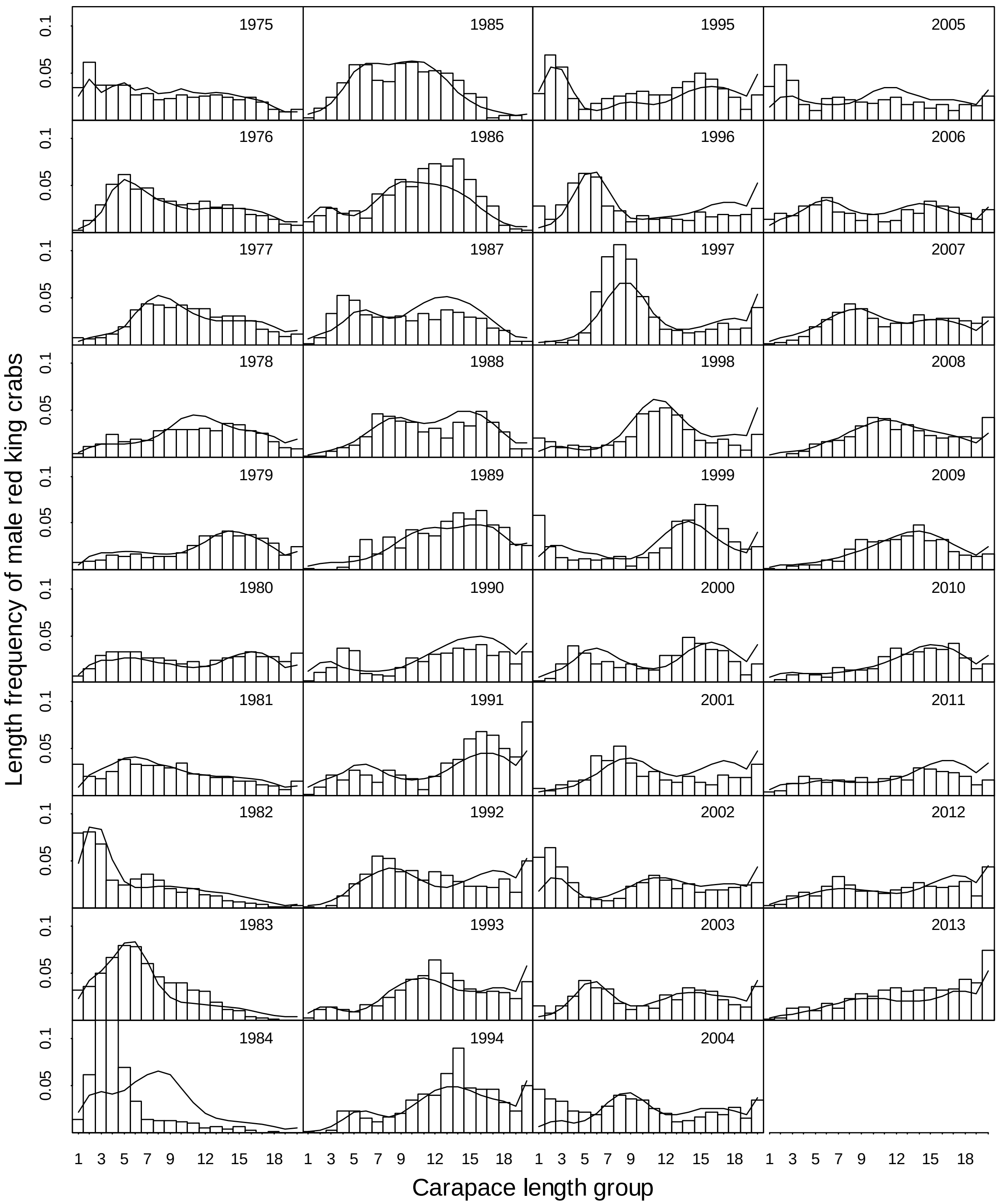

Figure 17(1). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crabs by year under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, and the first length group is 67.5 mm.

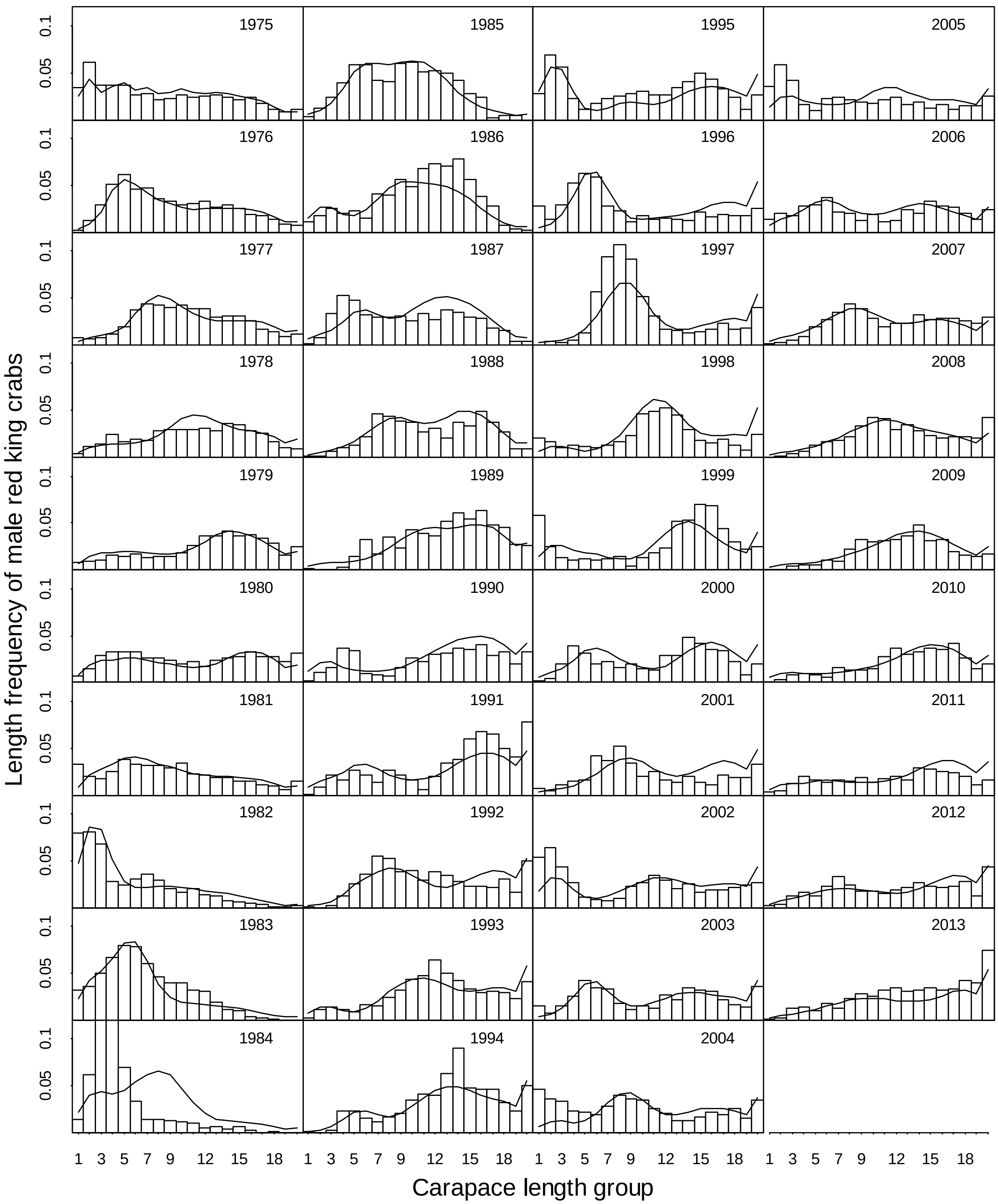

Figure 17(4). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crabs by year under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, and the first length group is 67.5 mm.

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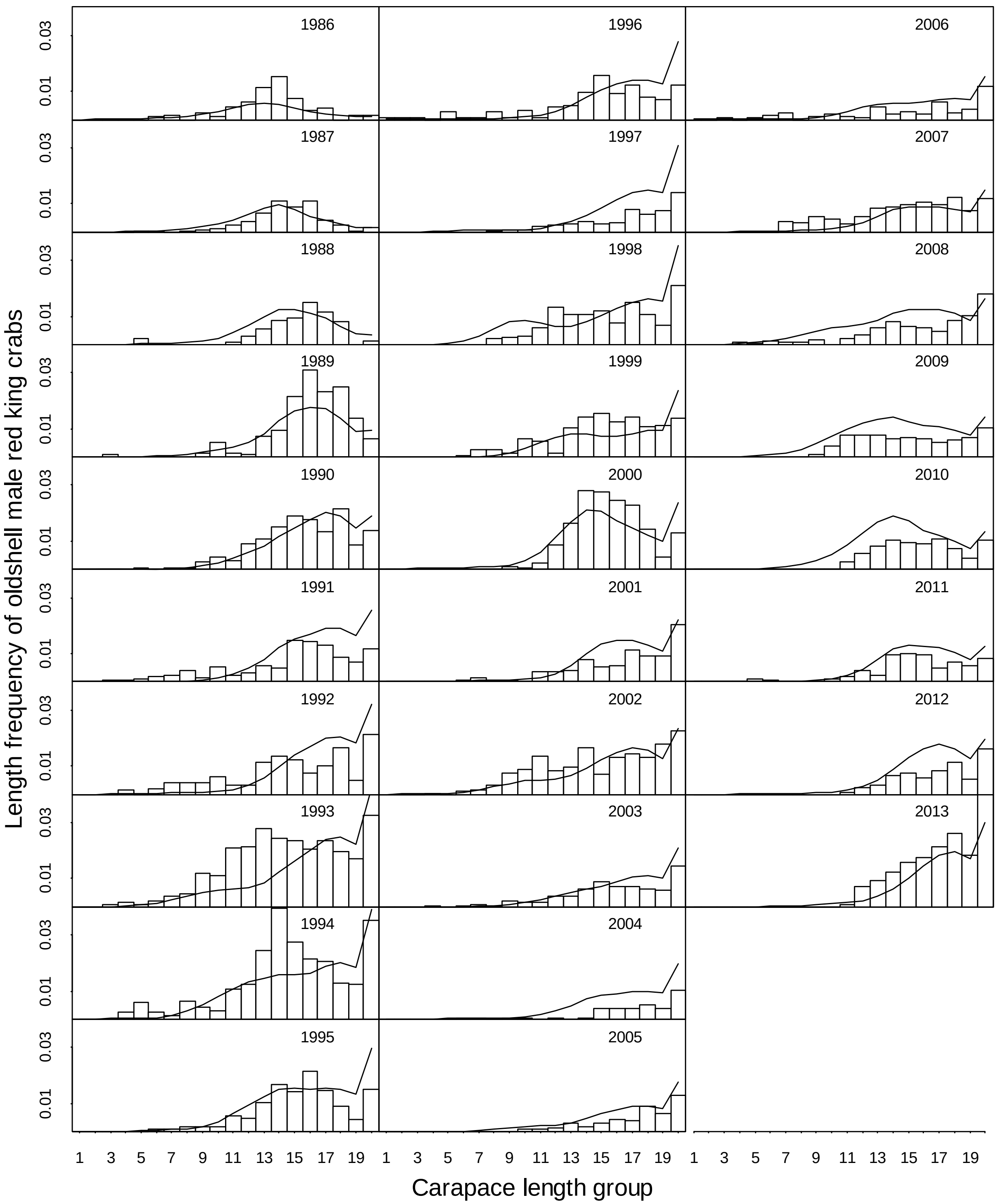

Figure 18. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay oldshell male red king crabs by year under scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

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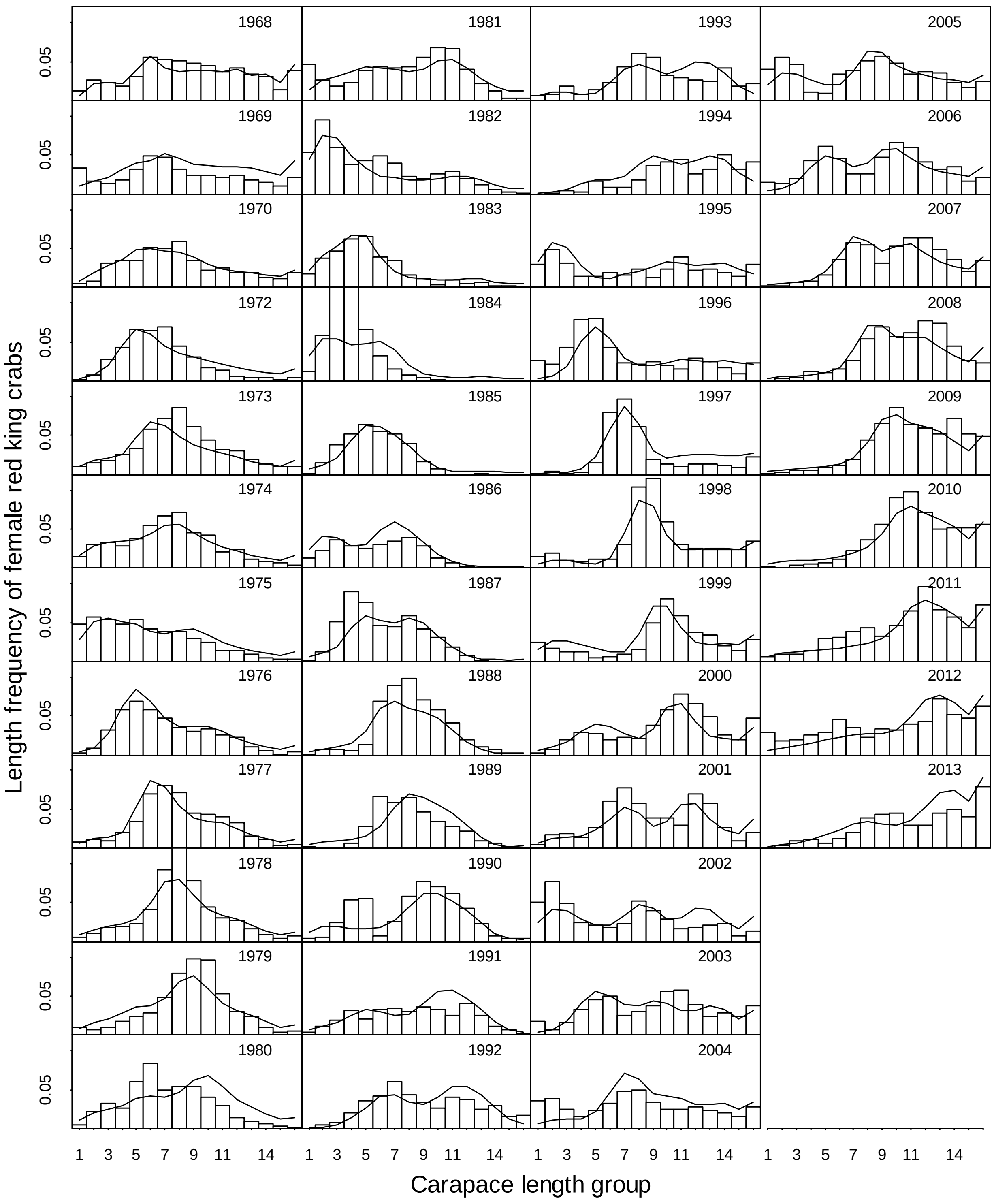

Figure 19(0). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year under scenario 0(7ac).Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

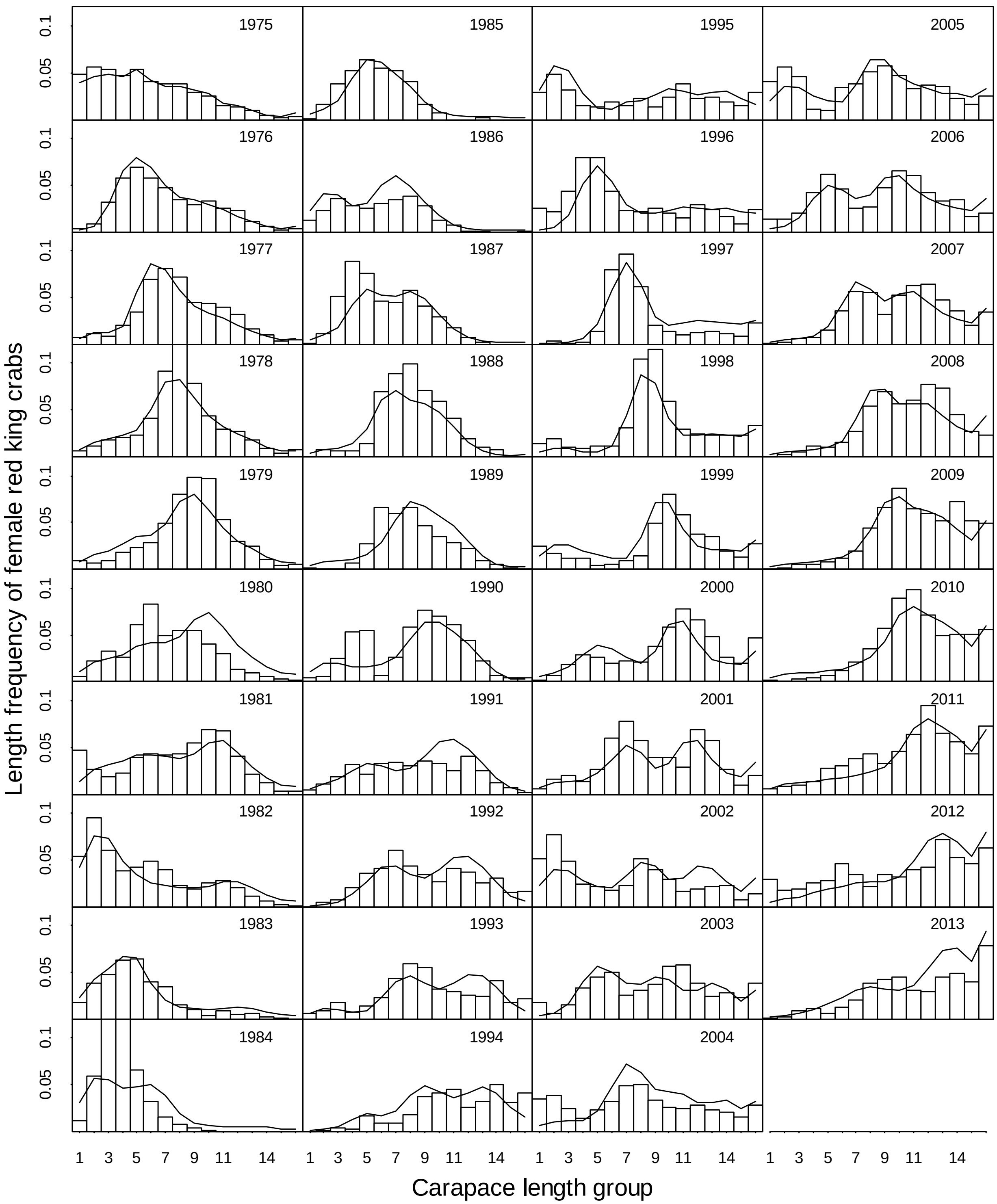

Figure 19(1). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

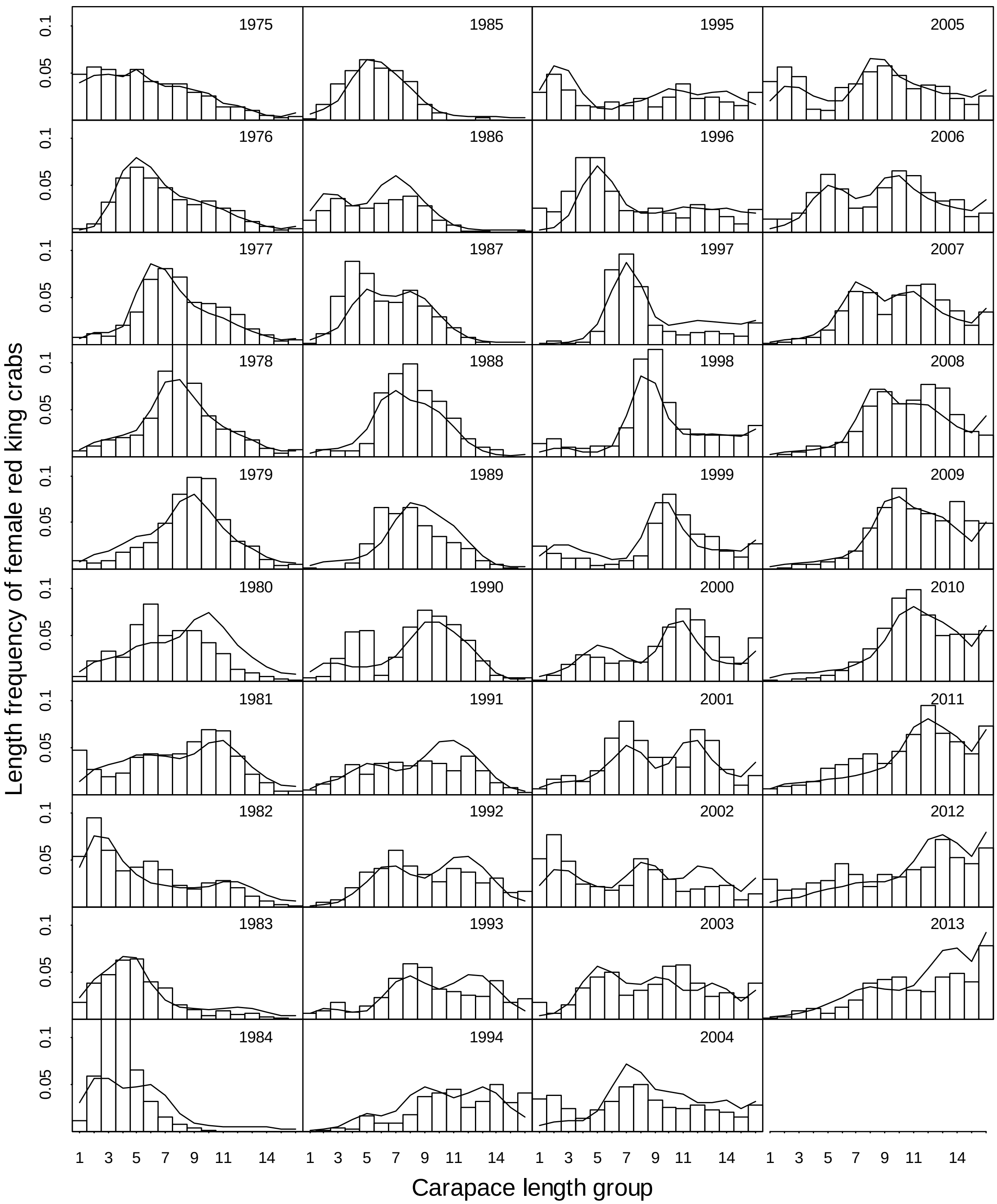

Figure 19(4). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

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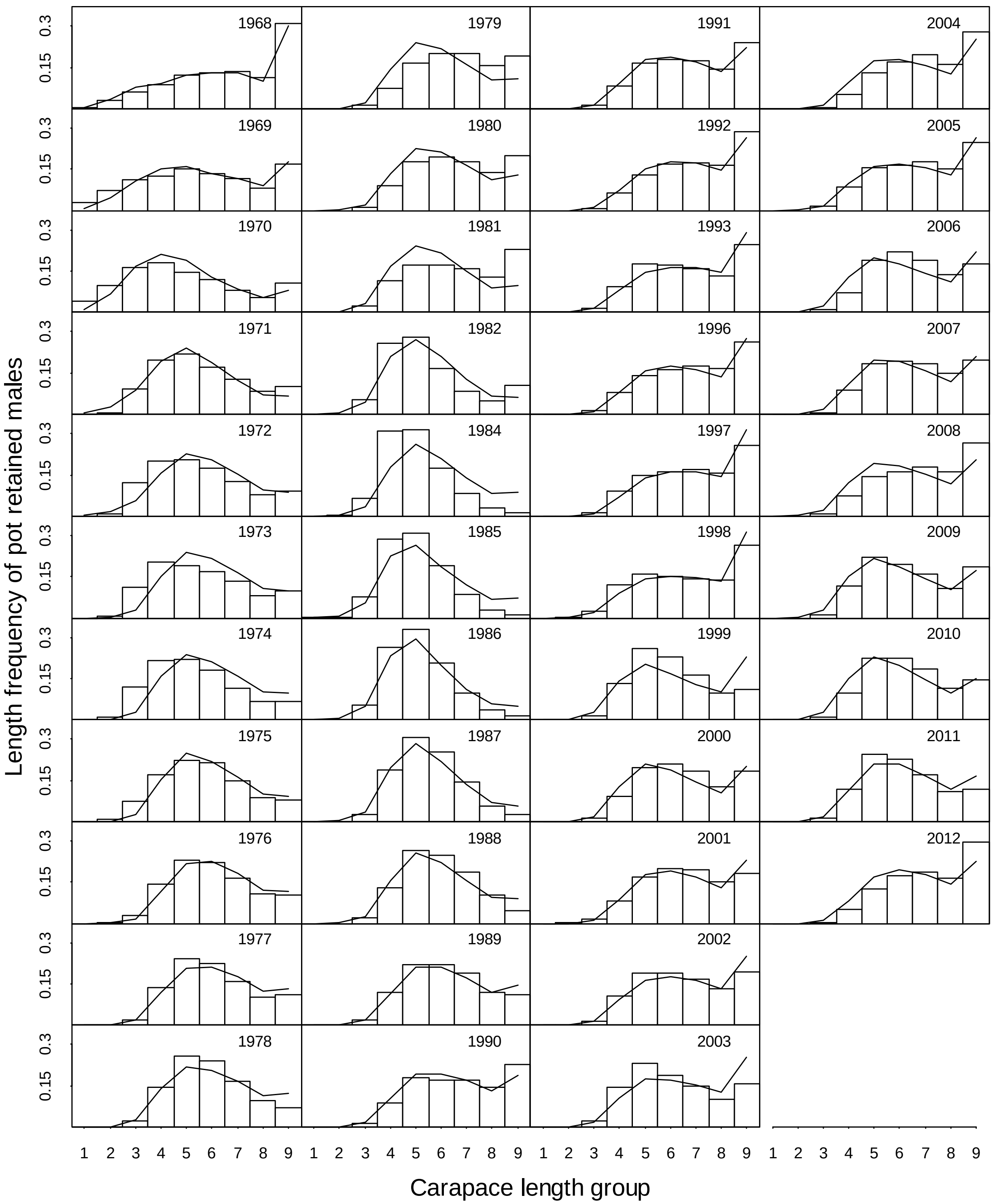

Figure 20(0). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 122.5 mm.

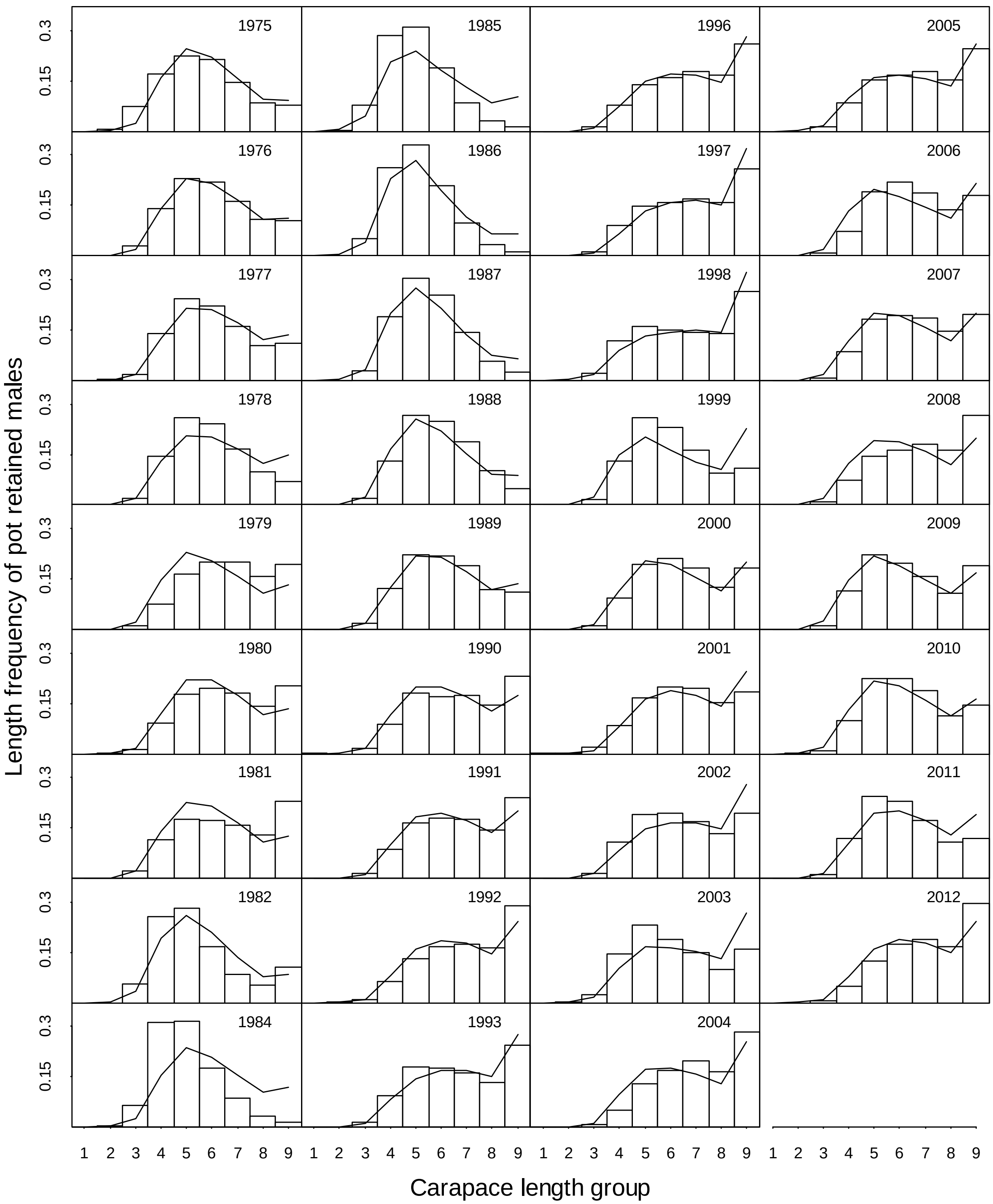

Figure 20(1). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 122.5 mm.

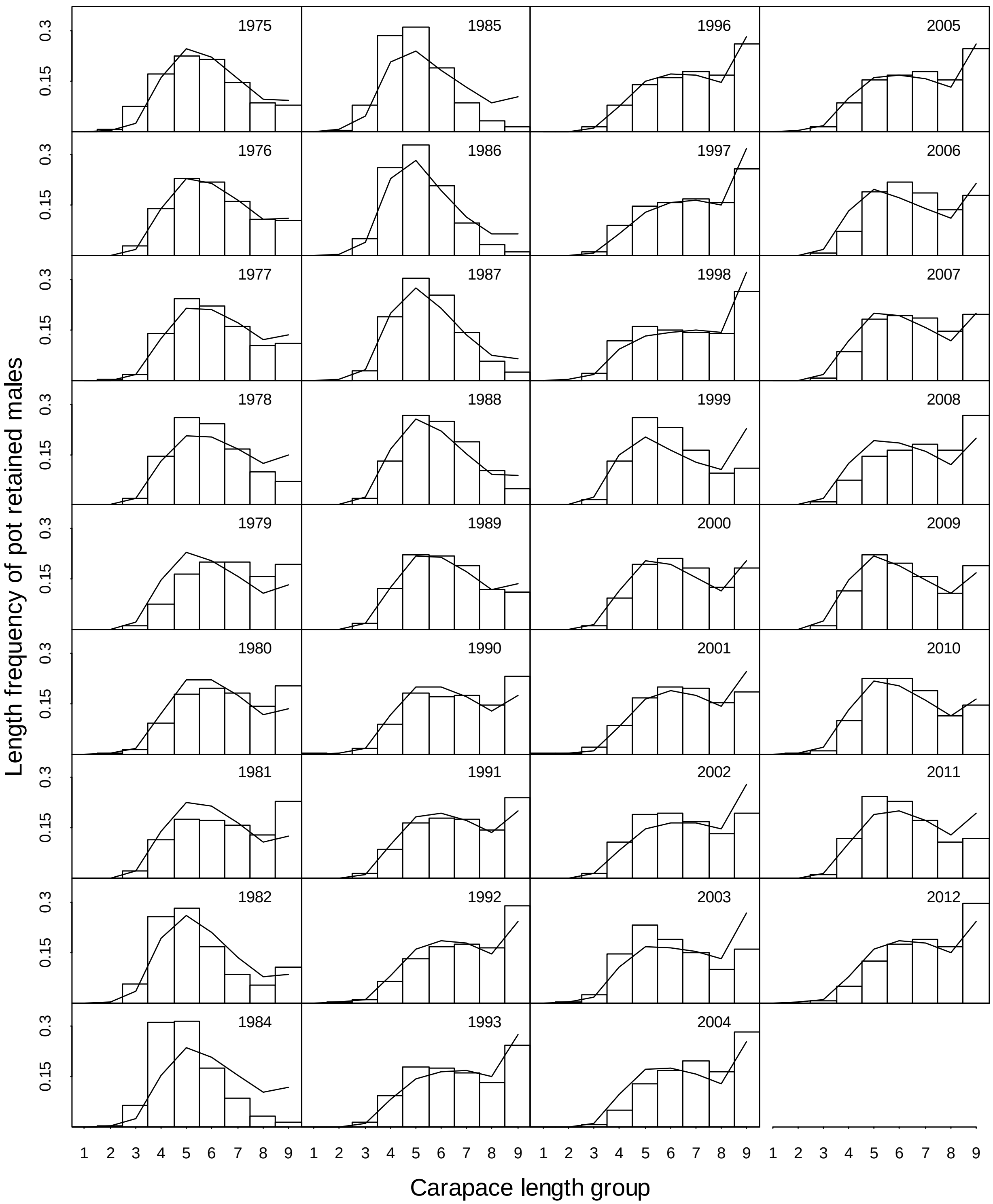

Figure 20(4). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 122.5 mm.

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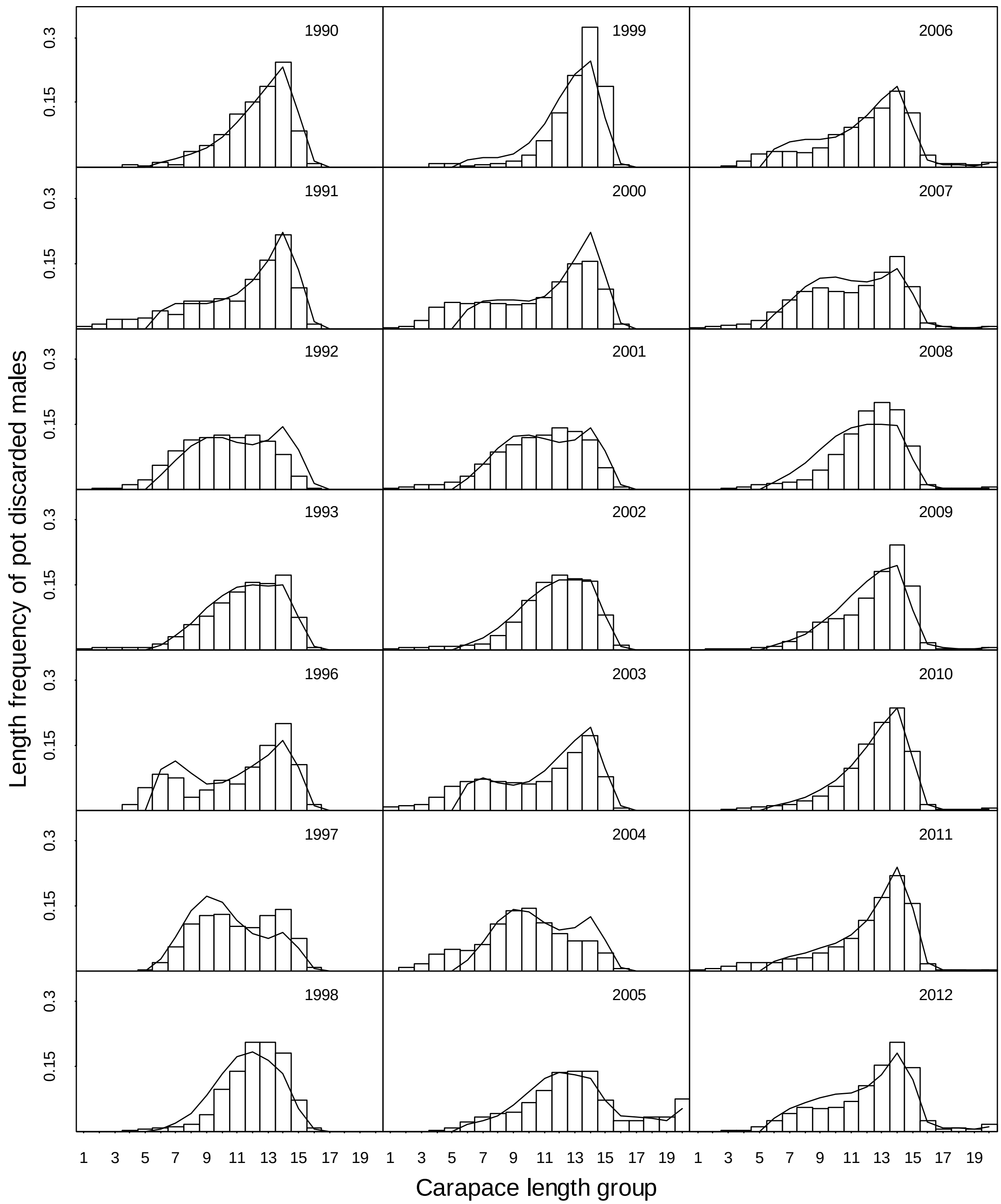

Figure 21(0). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

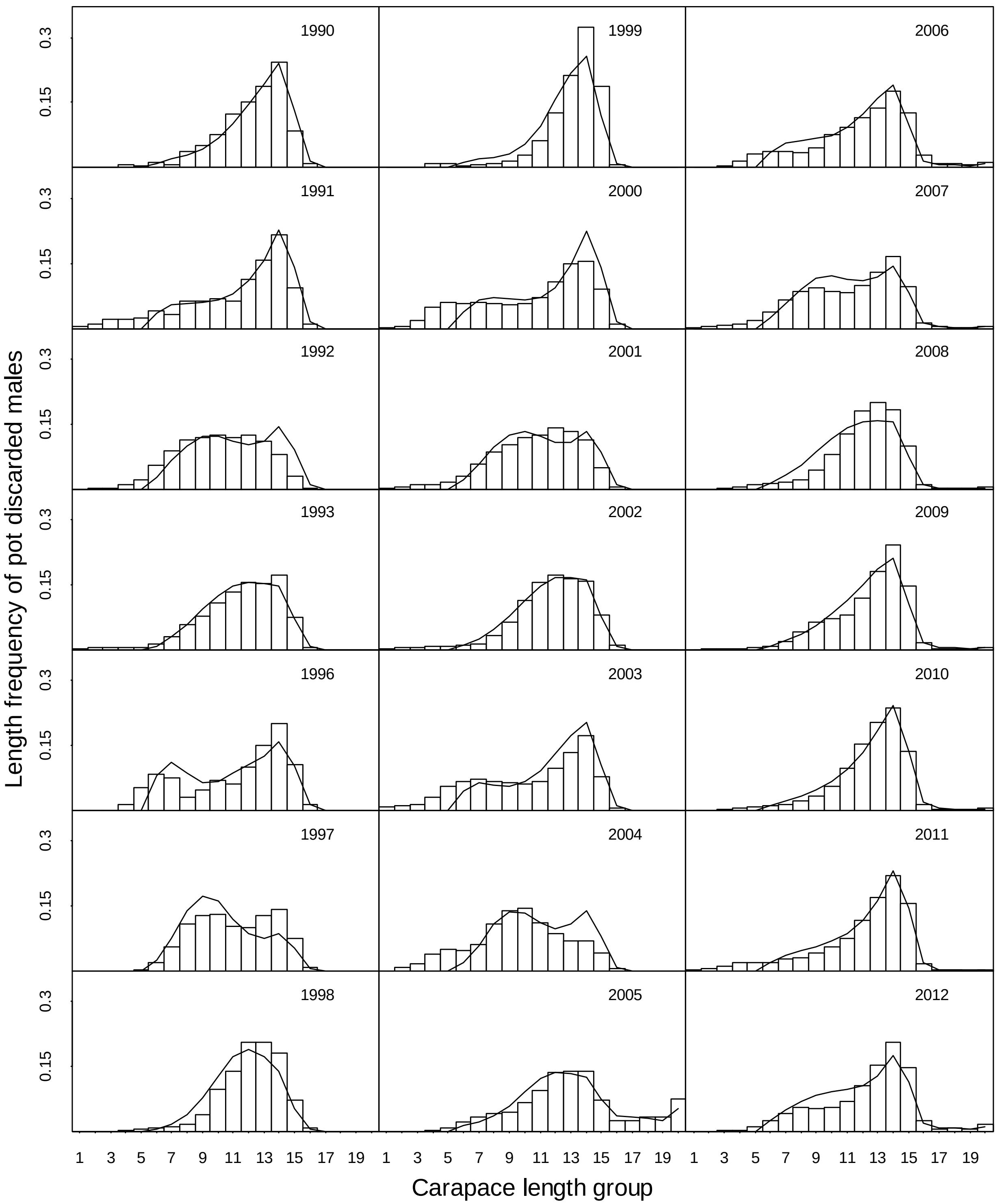

Figure 21(1). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

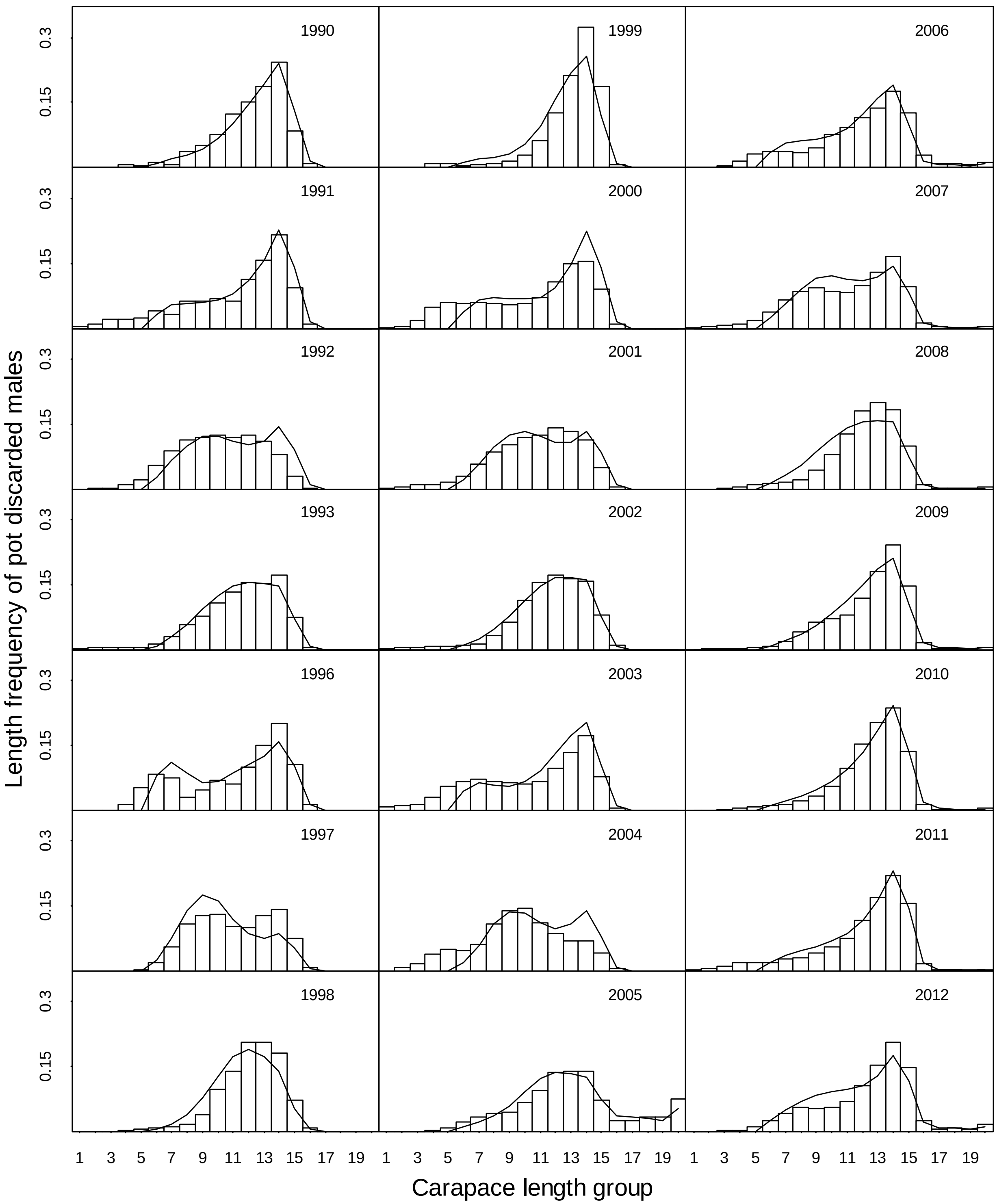

Figure 21(4). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

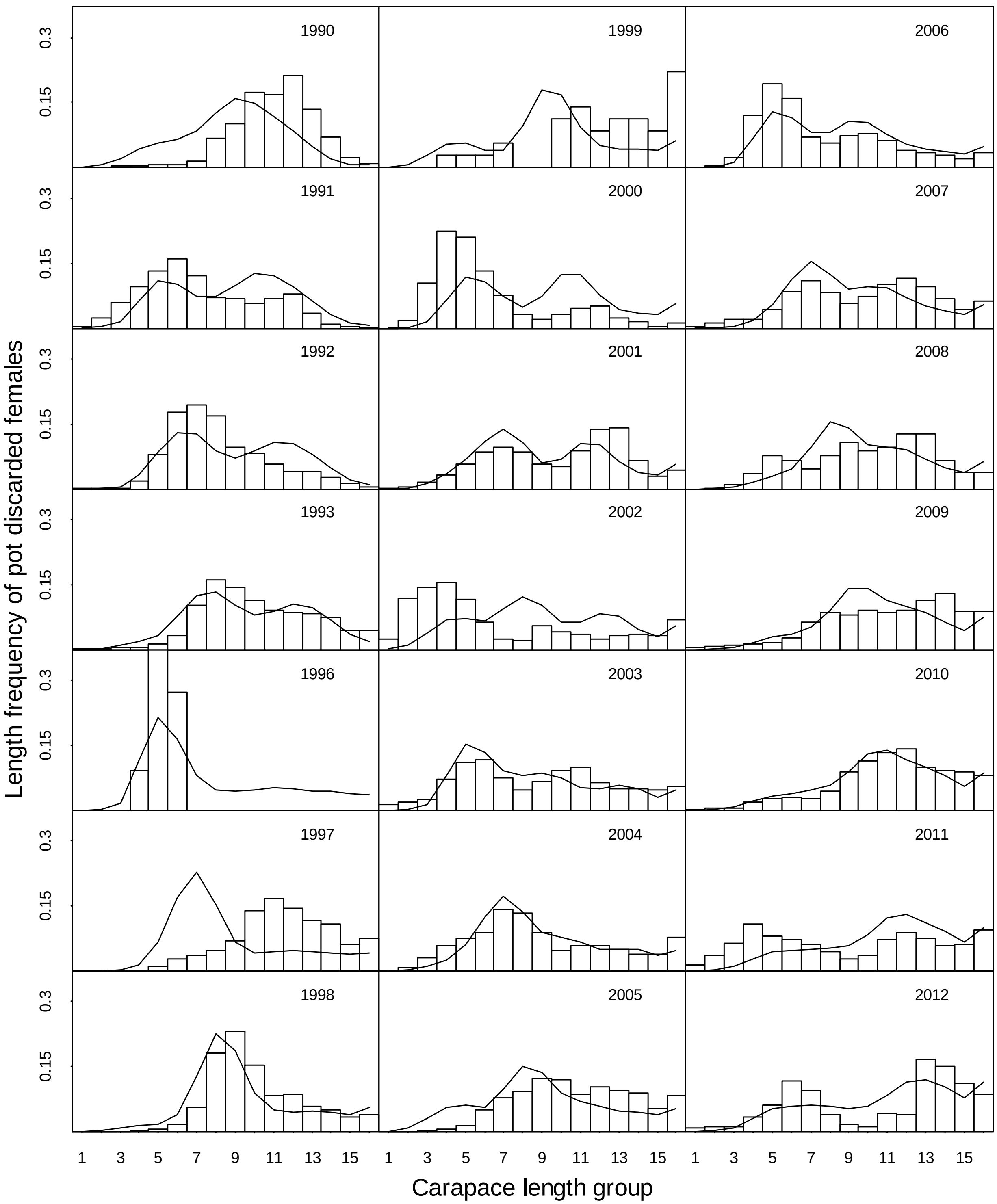

Figure 22(0). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery under scenario 0 (7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

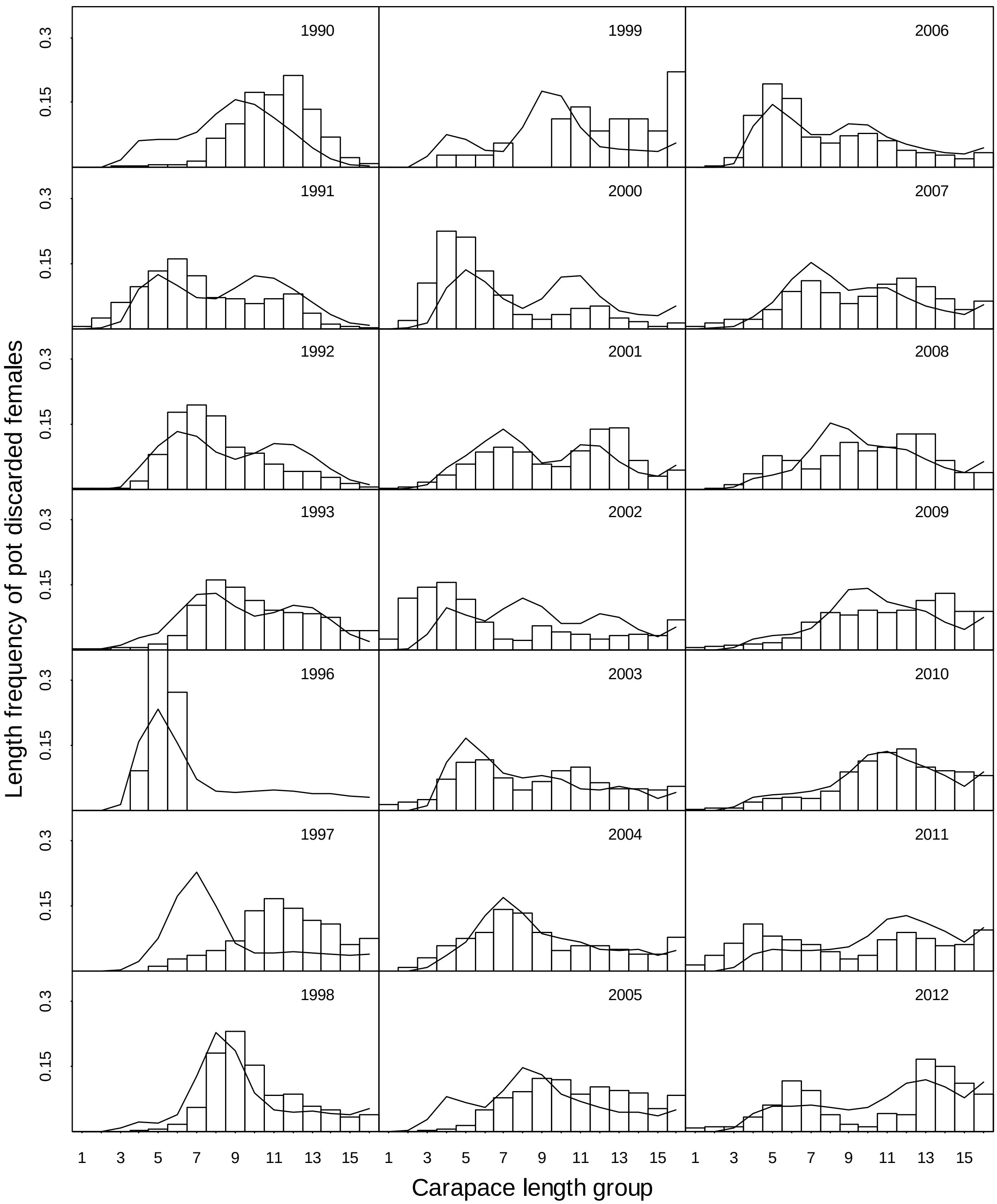

Figure 22(1). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

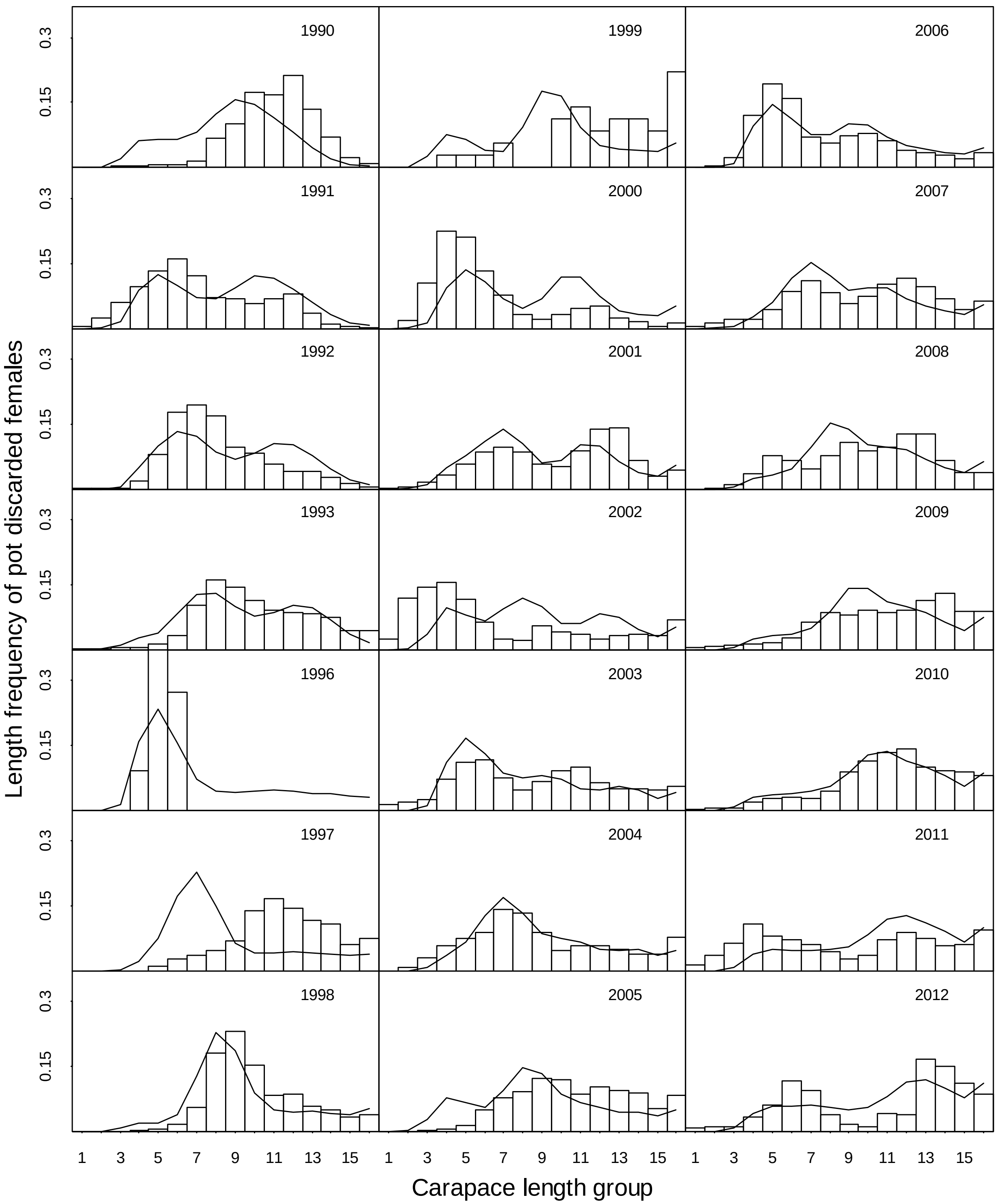

Figure 22(4). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

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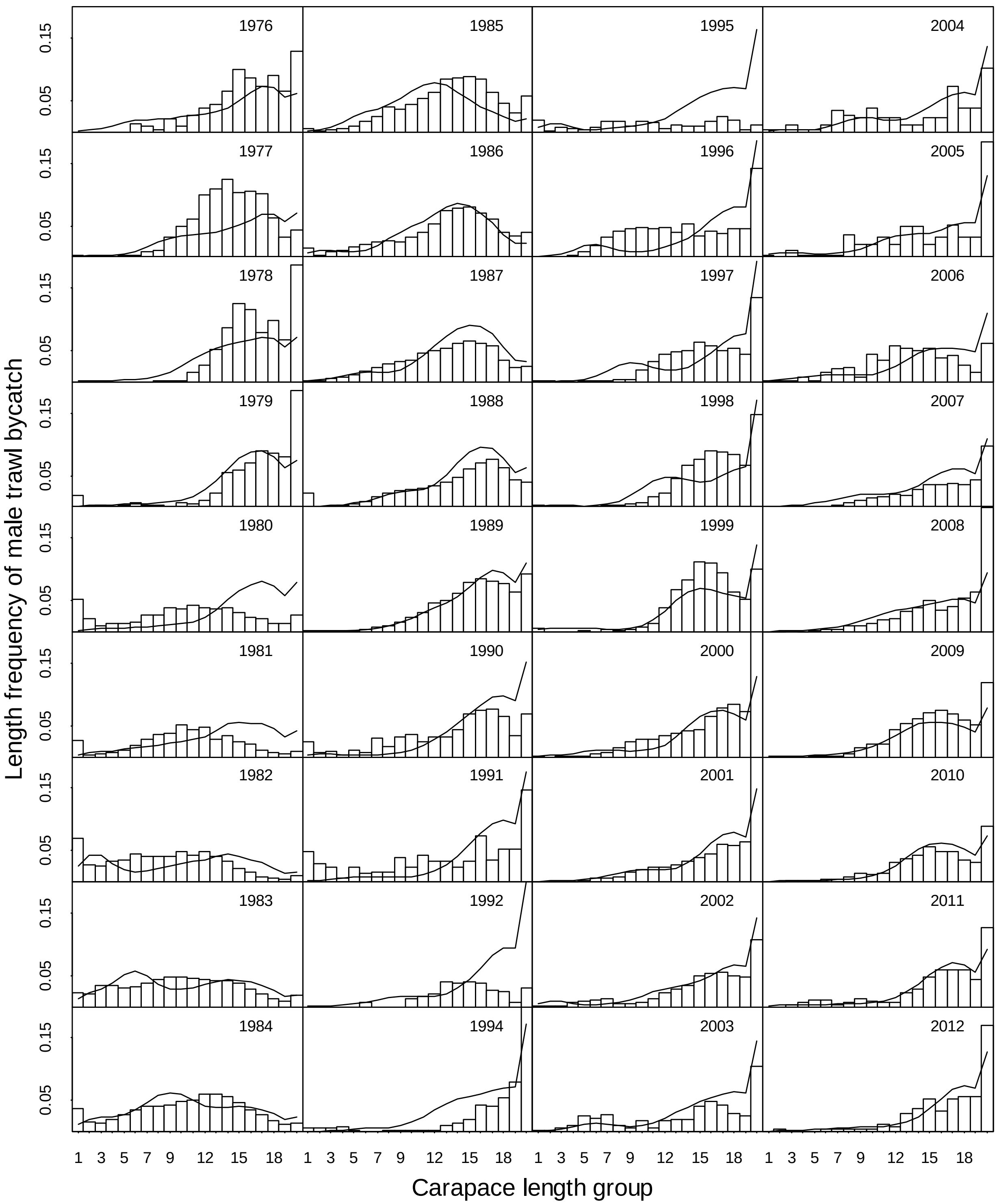

Figure 23(0). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries under scenario 0(7ac). Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

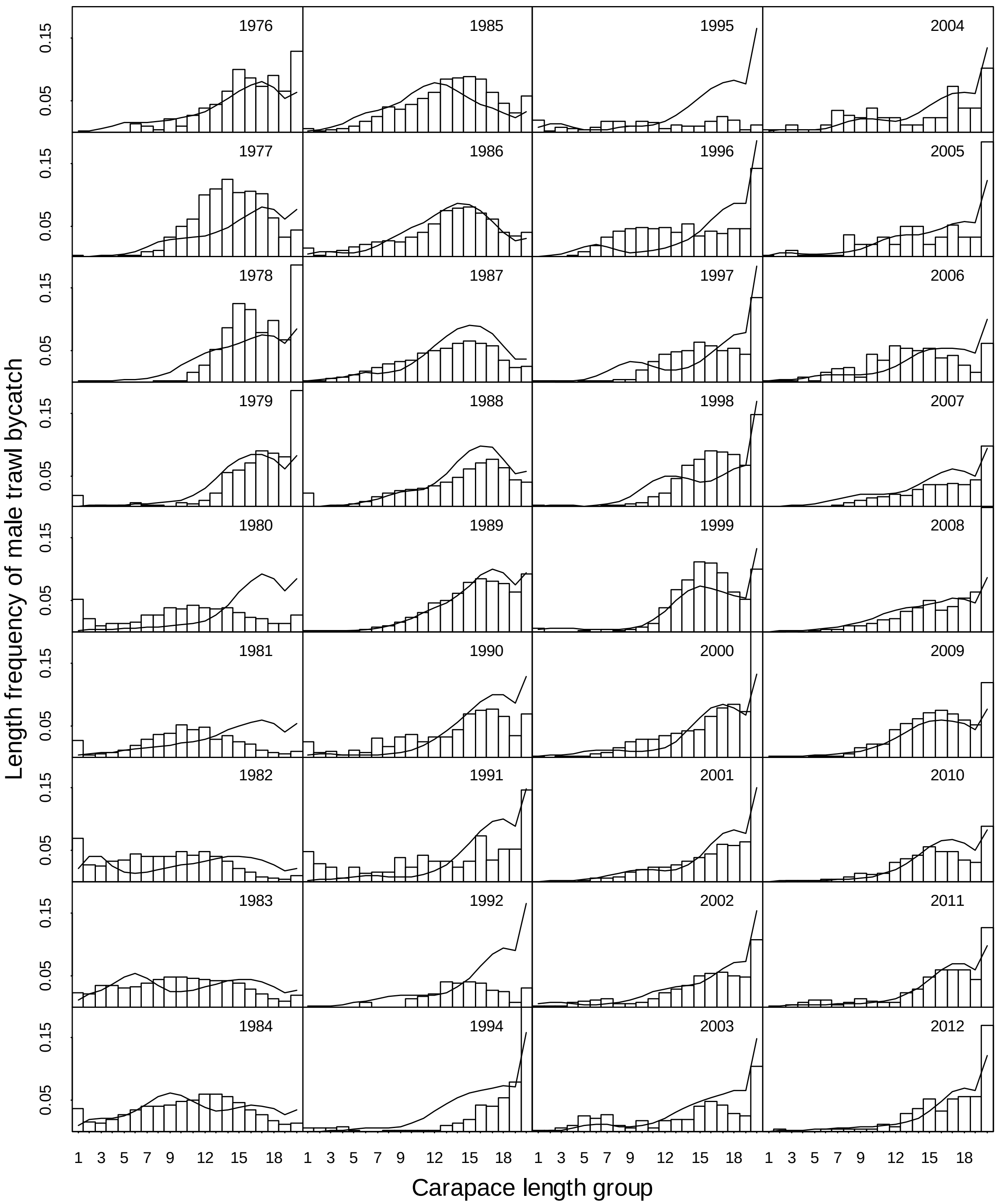

Figure 23(1). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries under scenario 1. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

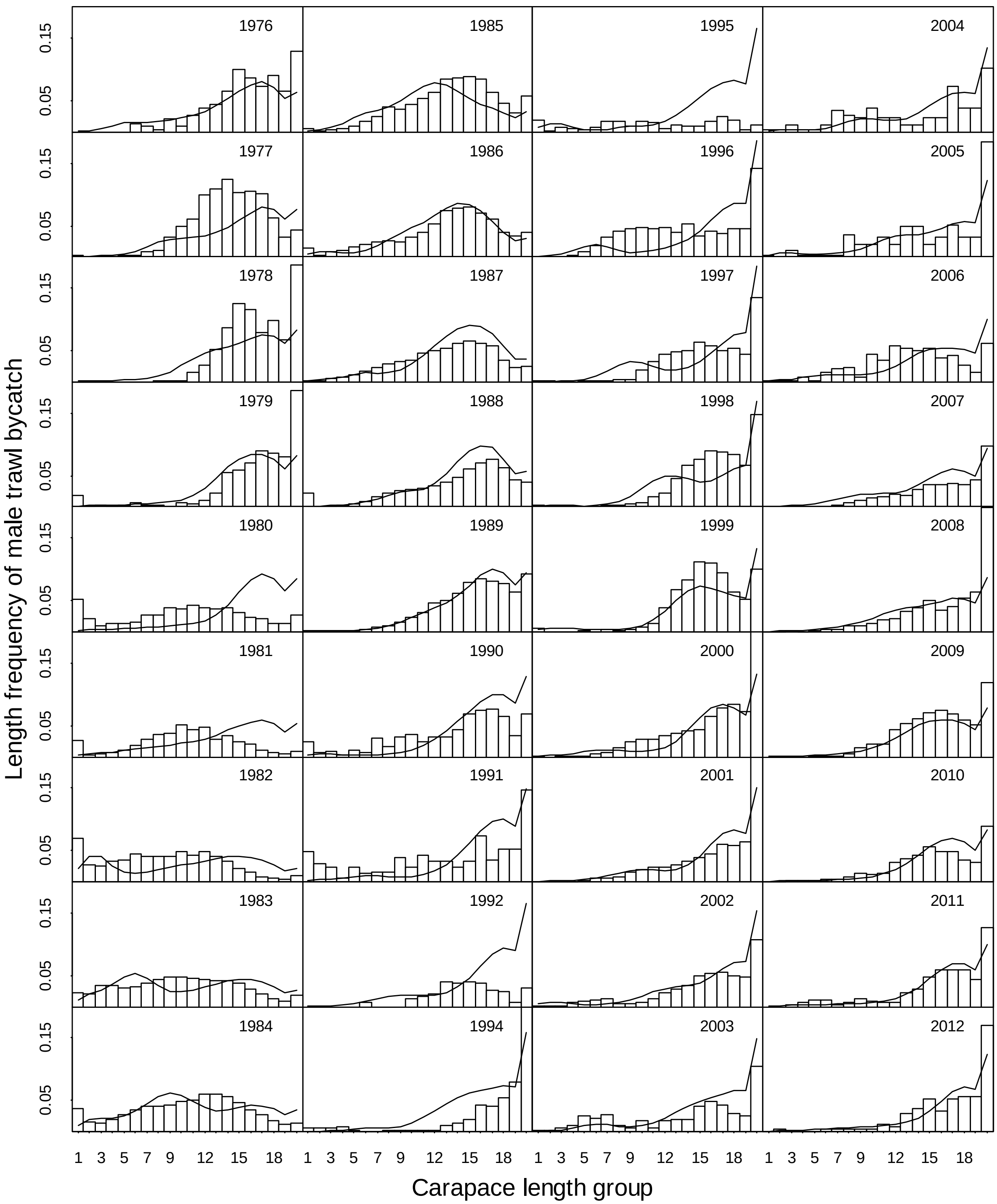

Figure 23(4). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries under scenario 4. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

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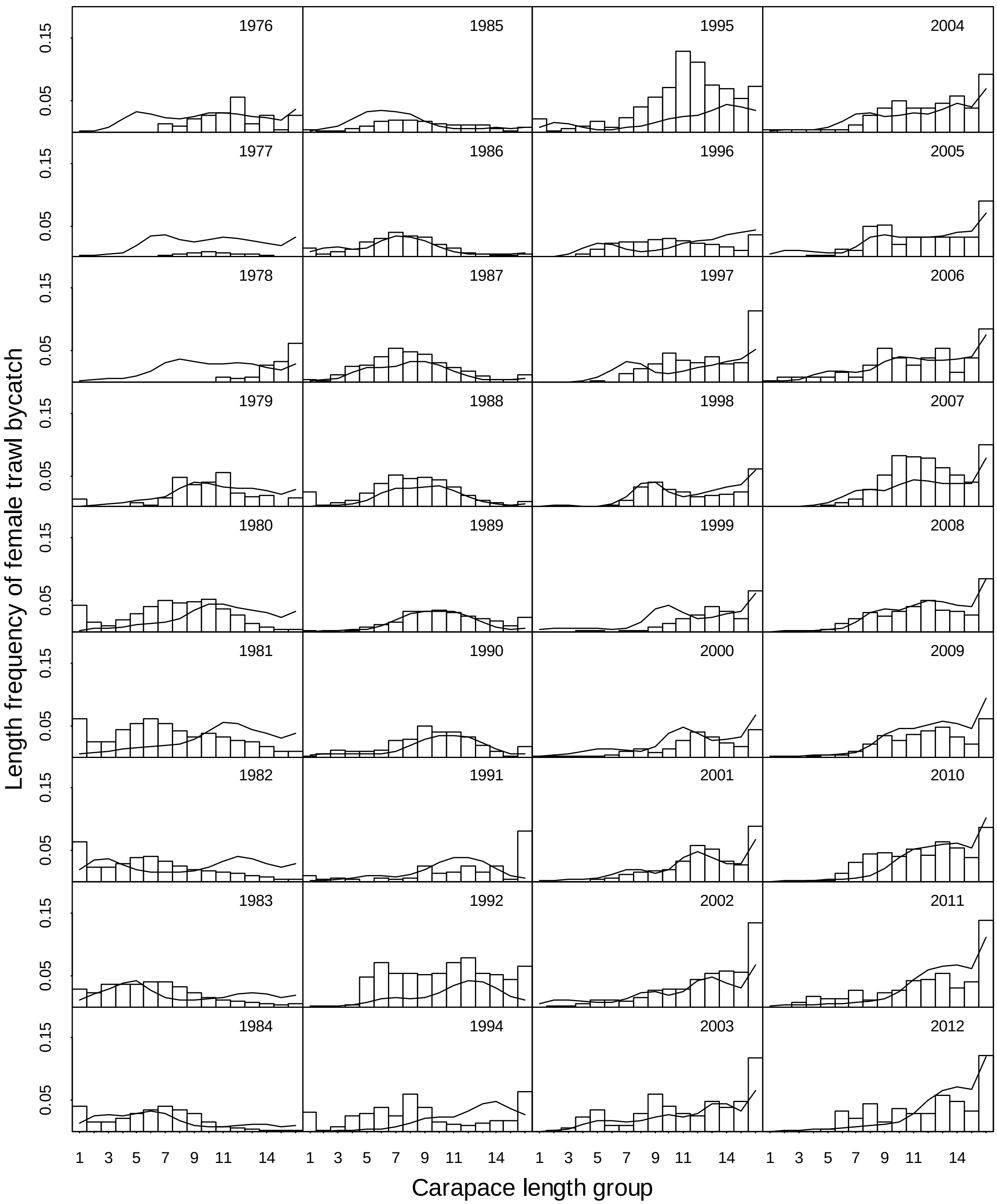

Figure 24(0). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries under scenario 0 (7ac). Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

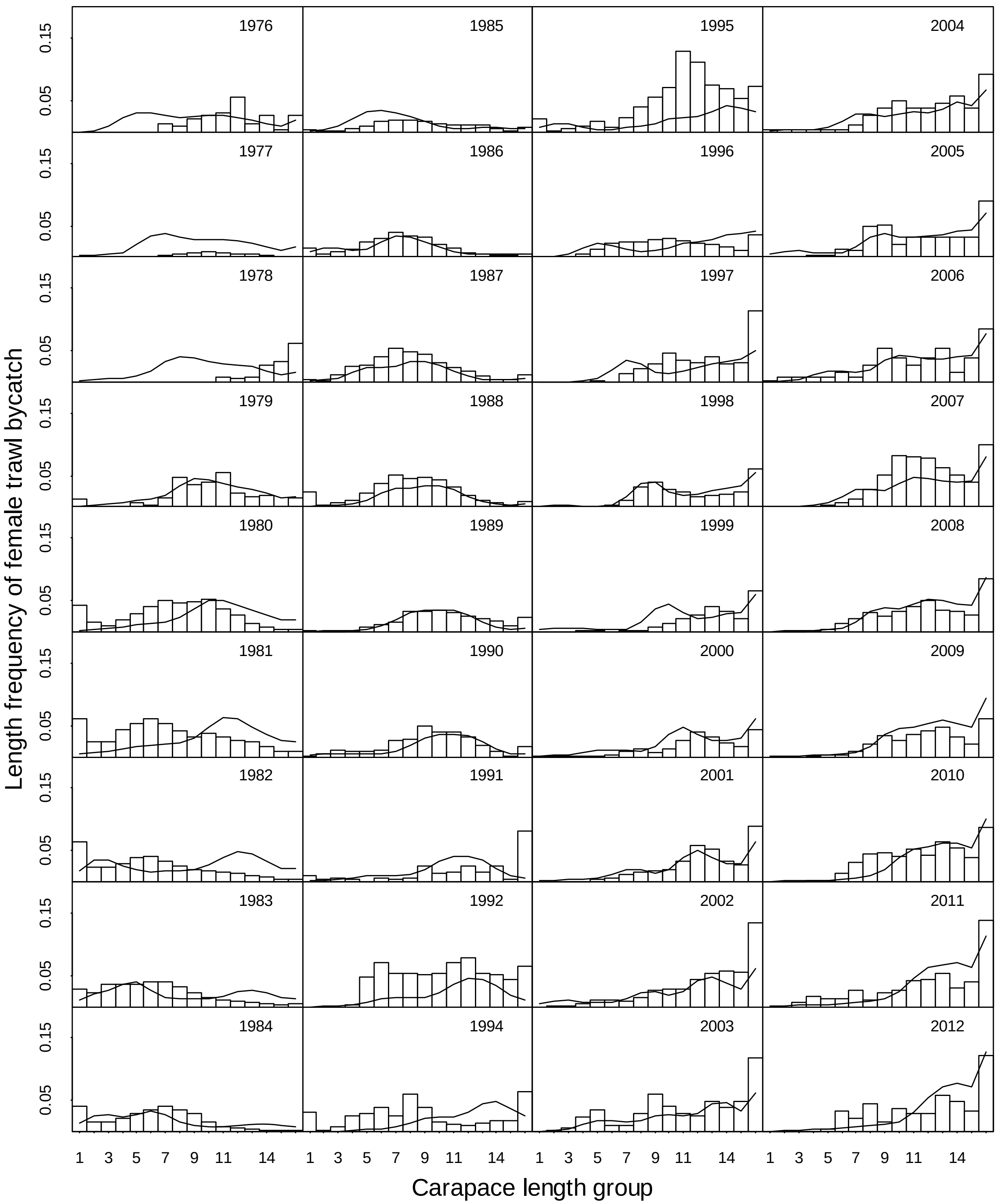

Figure 24(1). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries under scenario 1. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

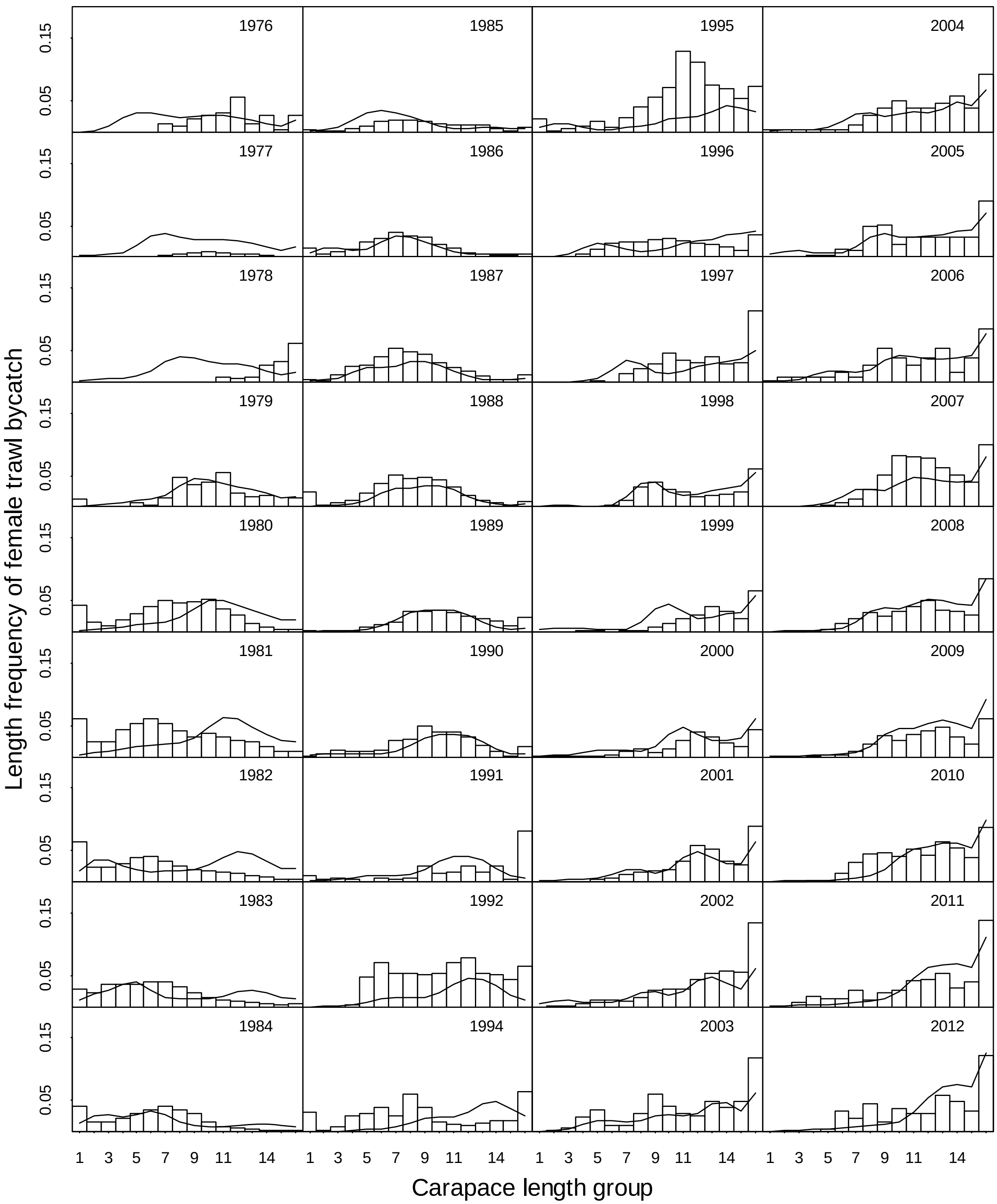

Figure 24(4). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries under scenario 4. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

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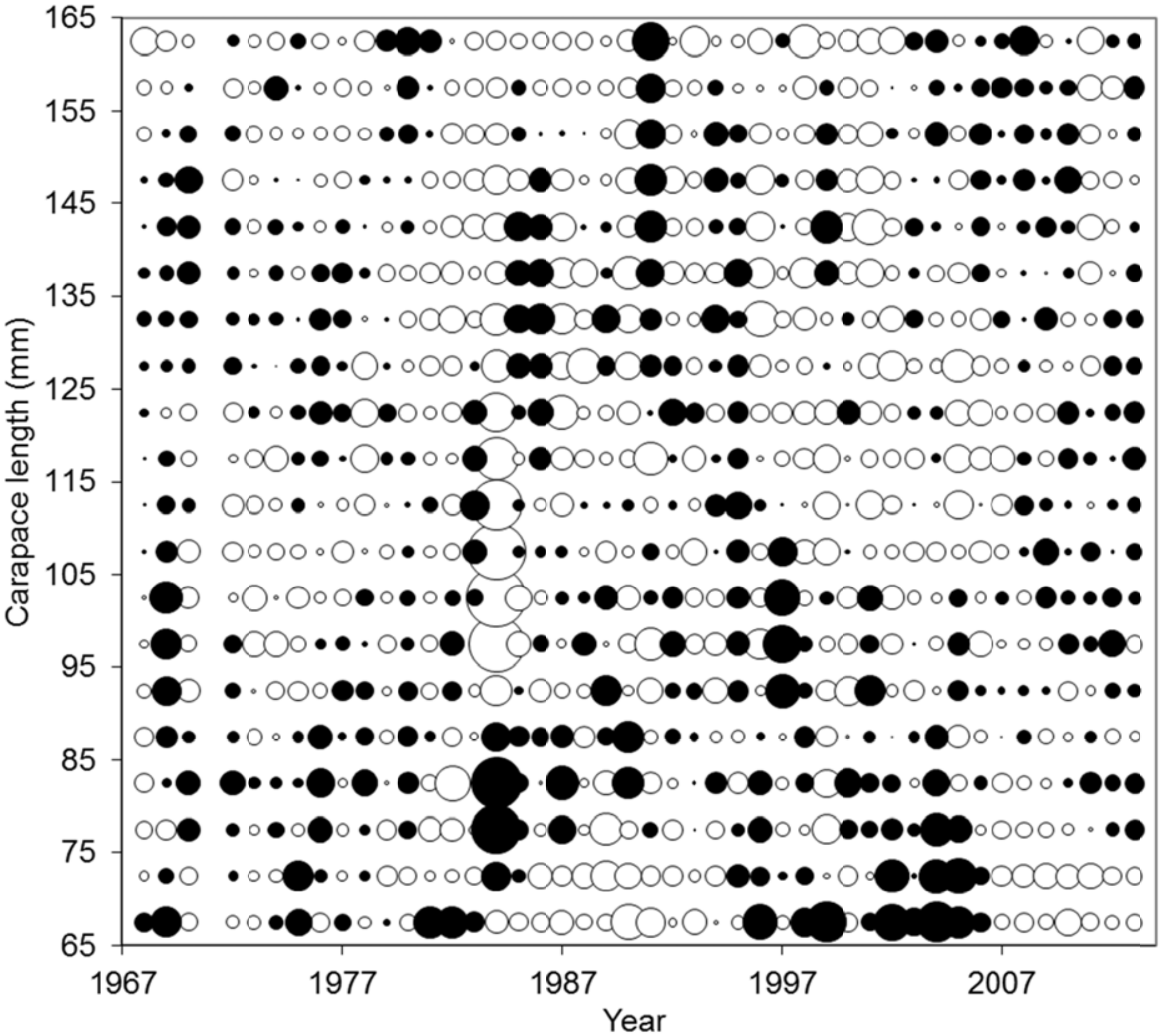

Figure 25(0). Standardized residuals of proportions of survey all-shell (1968-1985) and newshell (1986-2013) male red king crabs under scenario 0(7ac). Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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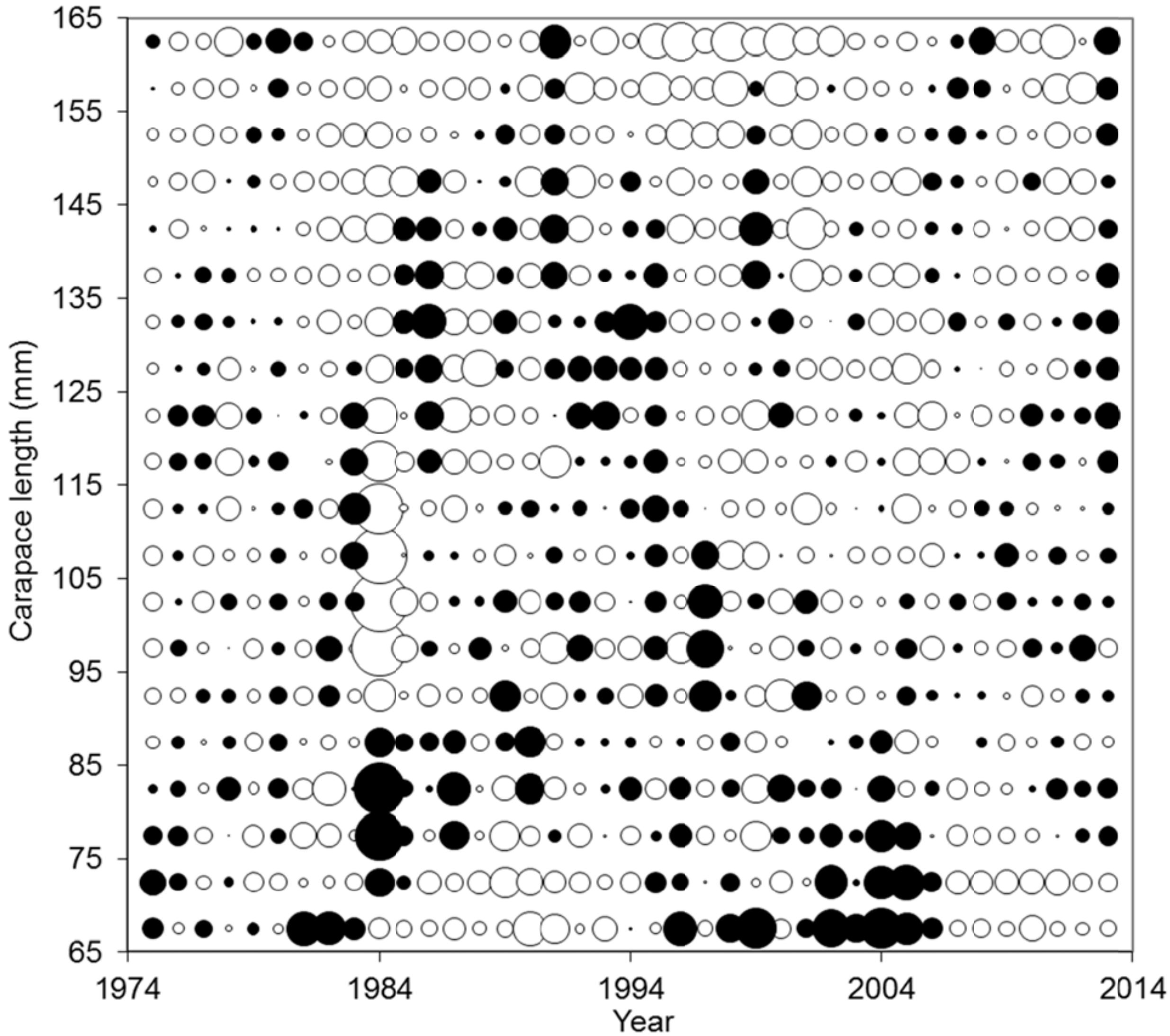


Figure 25(1). Standardized residuals of proportions of survey all-shell male red king crabs under scenario 1. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

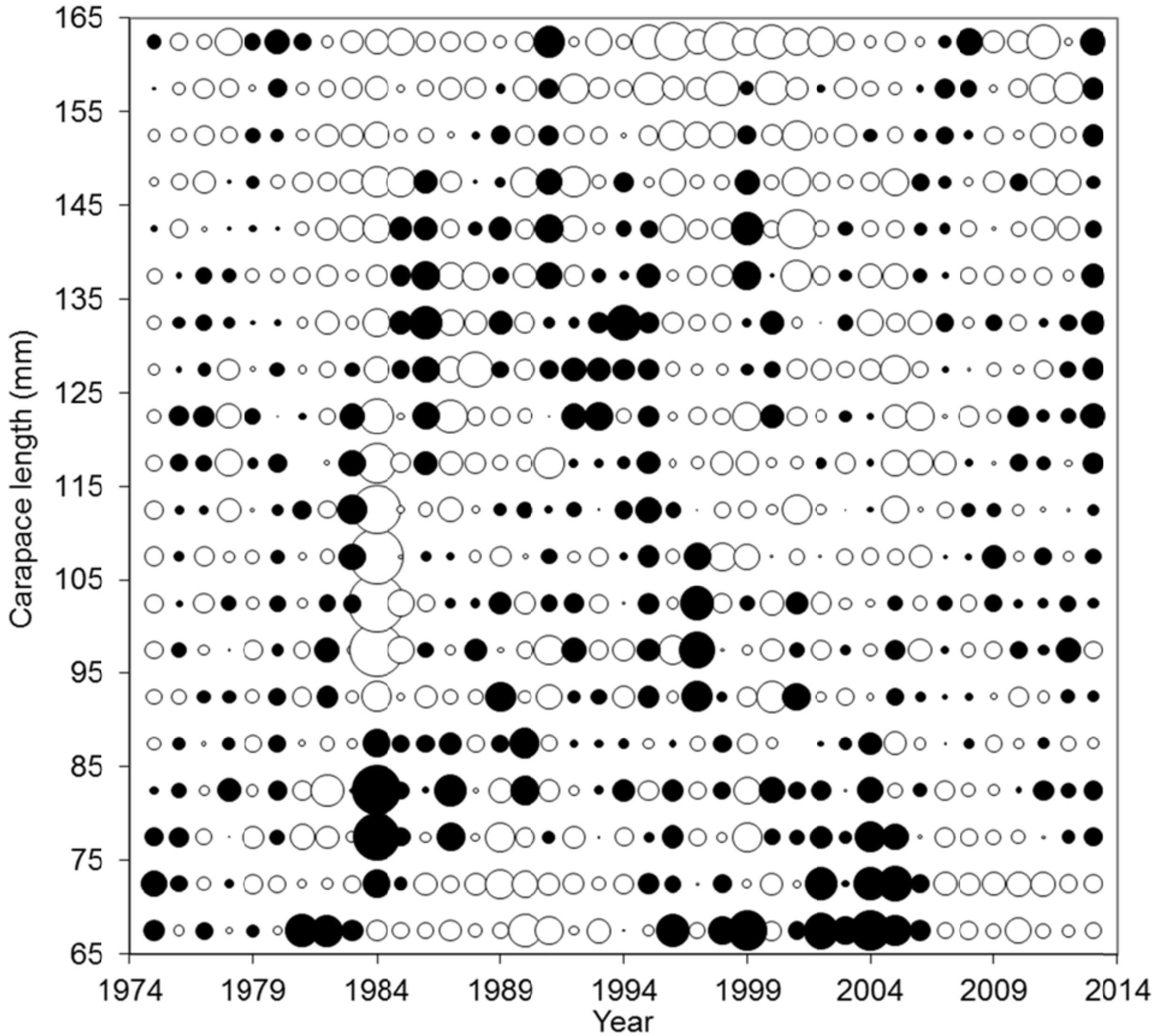


Figure 25(4). Standardized residuals of proportions of survey all-shell male red king crabs under scenario 4. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

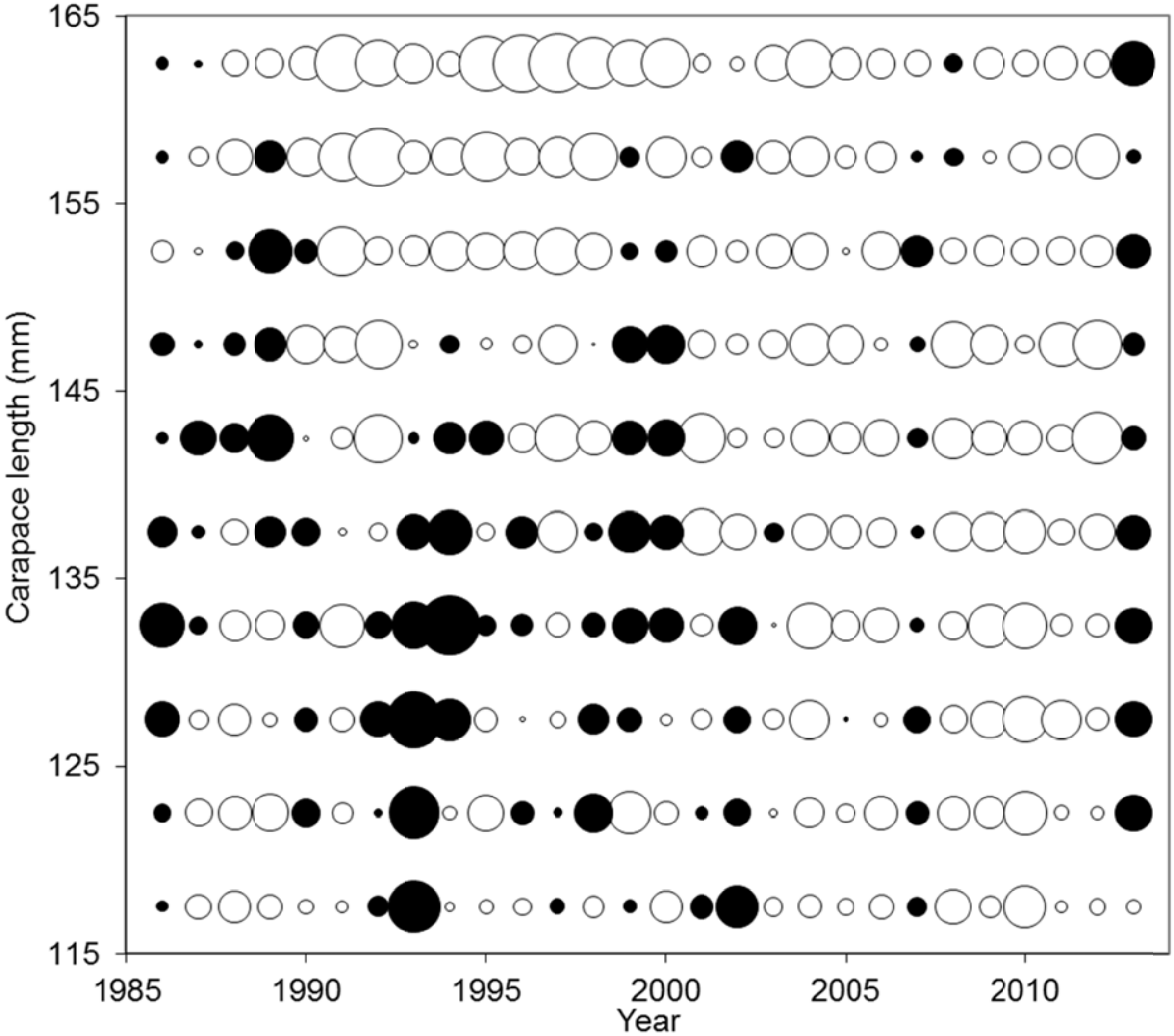


Figure 26. Standardized residuals of proportions of survey oldshell male red king crabs (1986-2013) under scenario 0(7ac). Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

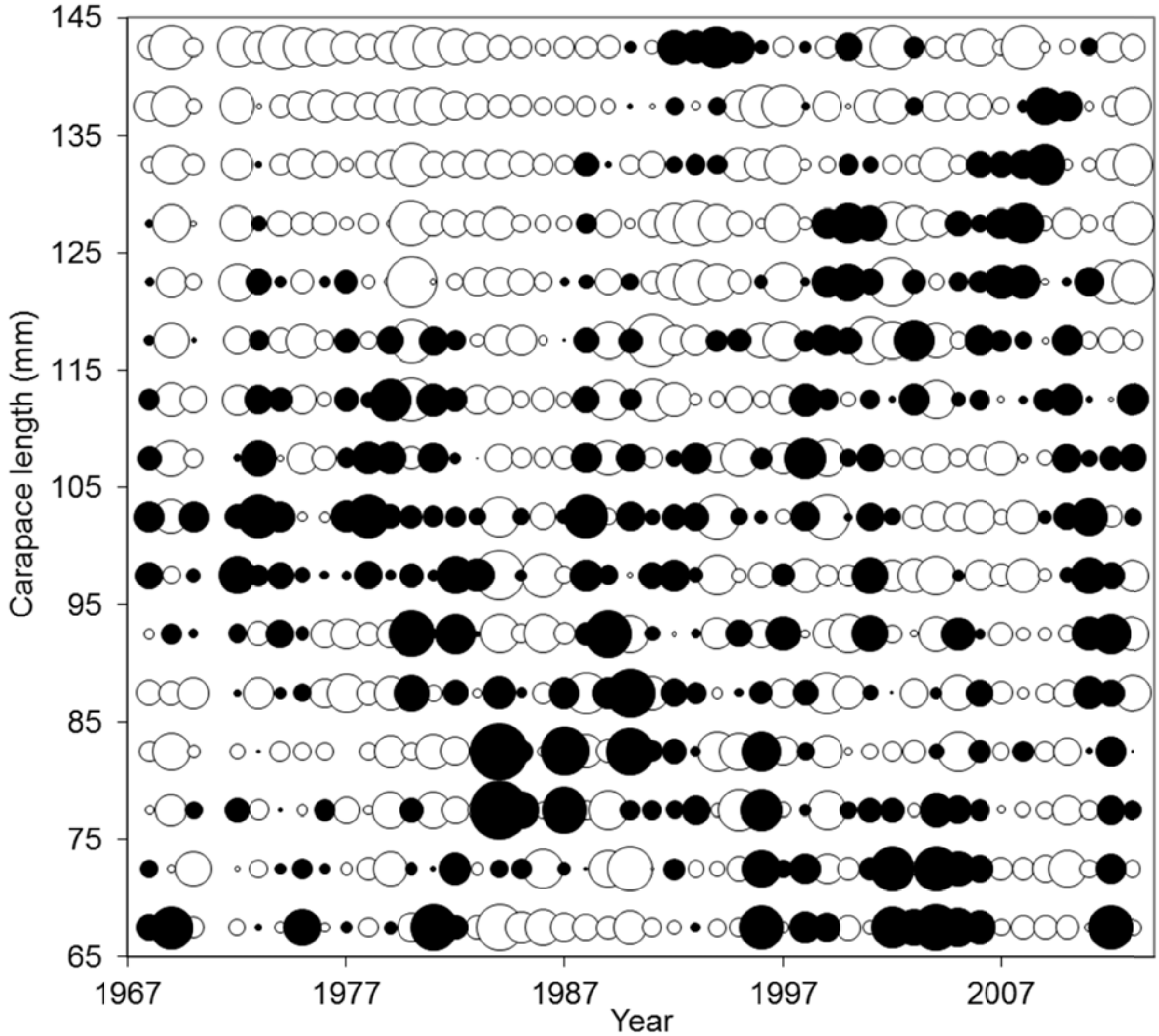


Figure 27(0). Standardized residuals of proportions of survey female red king crabs (1968-2013) under scenario 0(7ac). Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

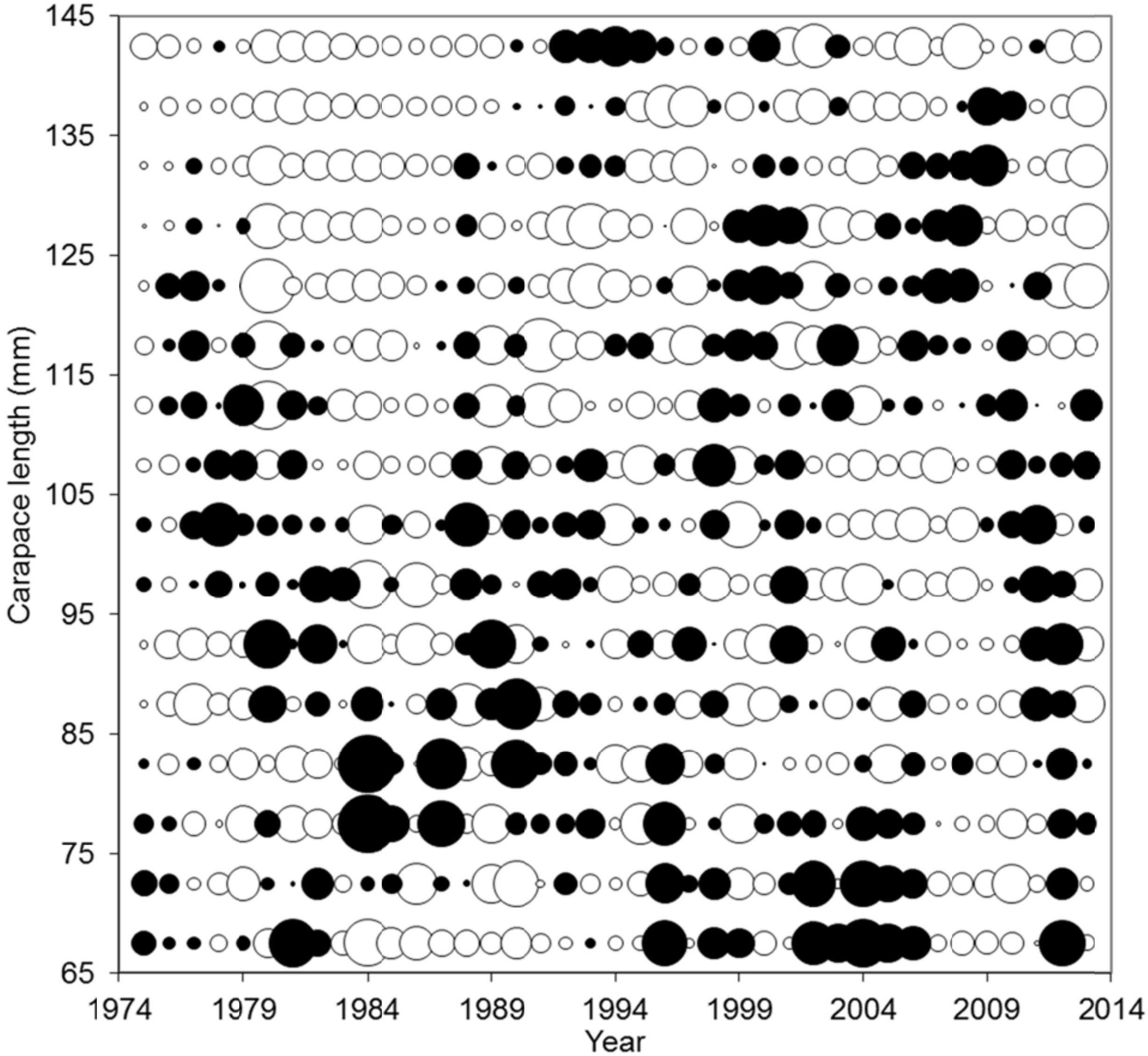


Figure 27(1). Standardized residuals of proportions of survey female red king crabs under scenario 1. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

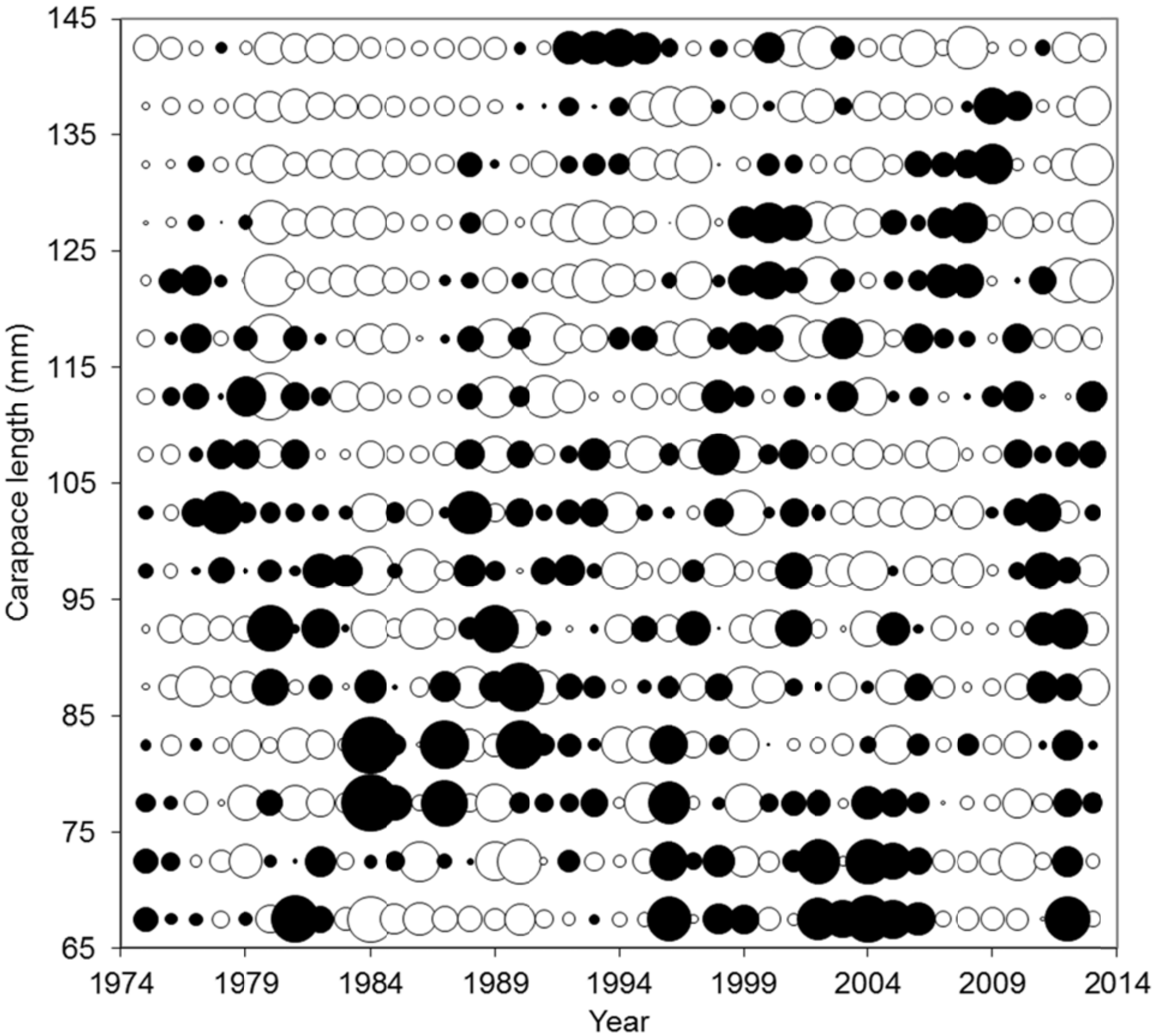
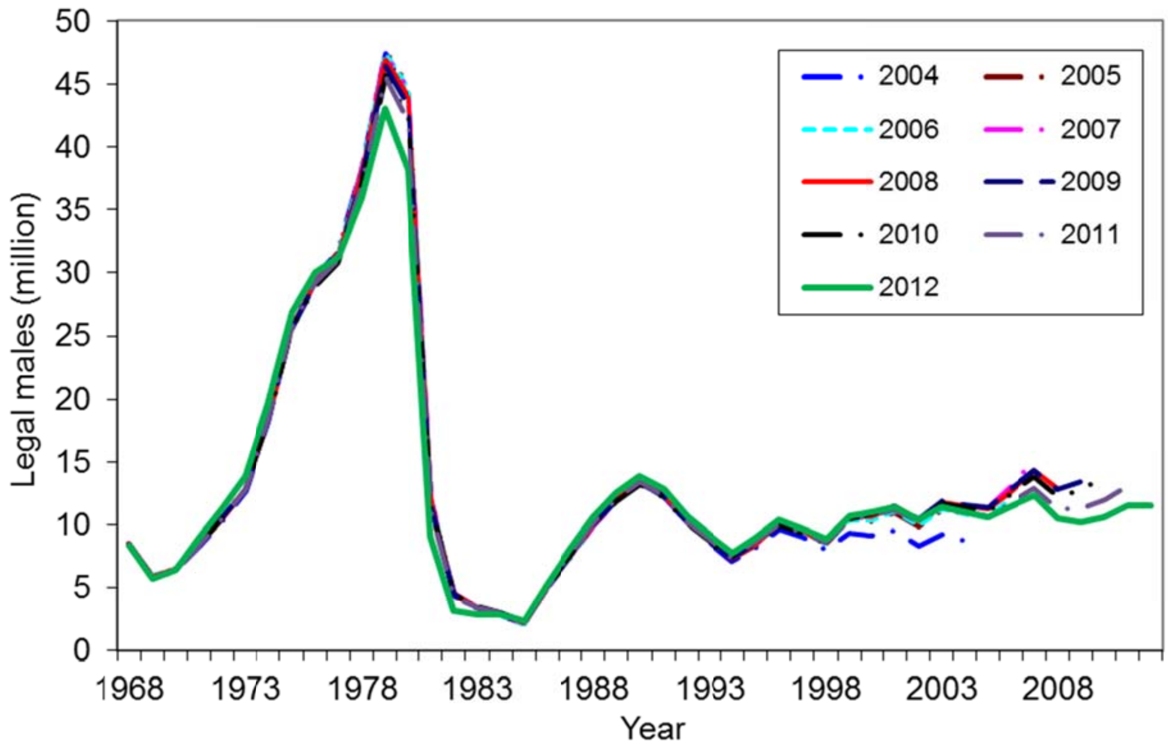


Figure 27(4). Standardized residuals of proportions of survey female red king crabs under scenario 4. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



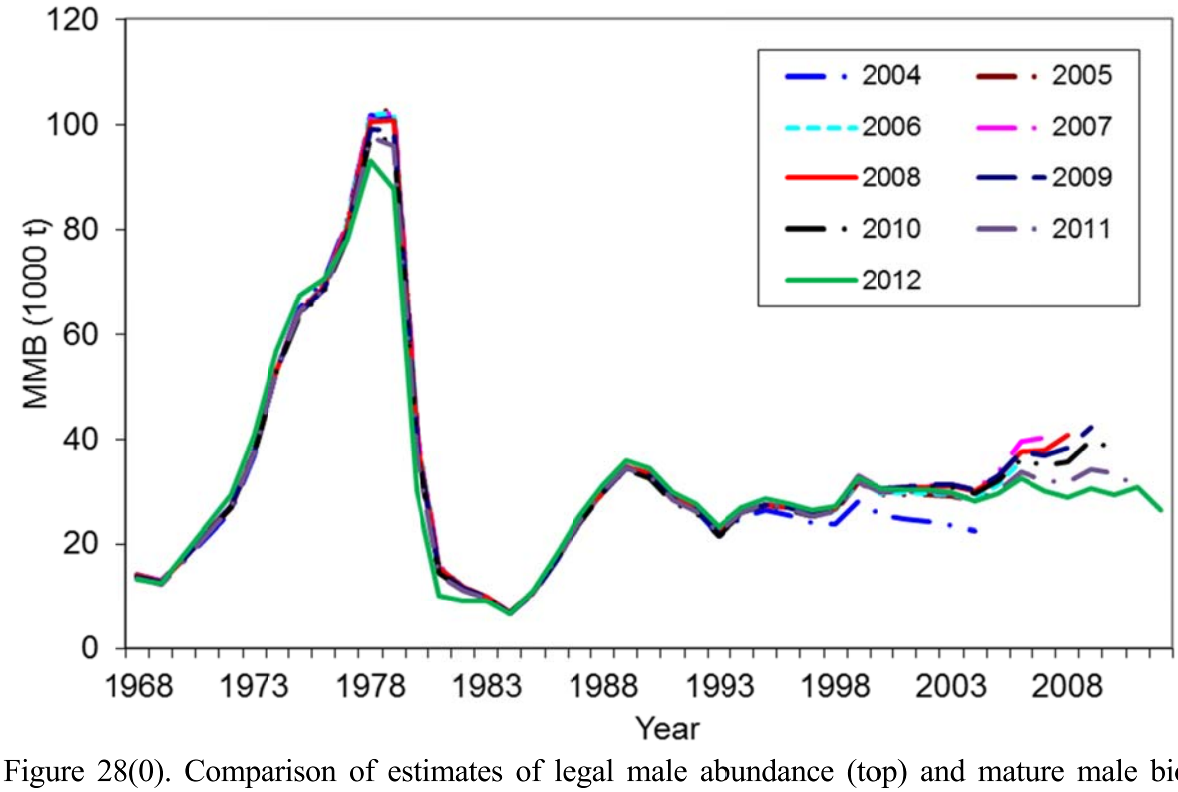


Figure 28(0). Comparison of estimates of legal male abundance (top) and mature male biomass (bottom) on Feb. 15 of Bristol Bay red king crab from 1968 to 2012 made with terminal years 2004-2012 with scenario 0(7ac). These are results of the 2012 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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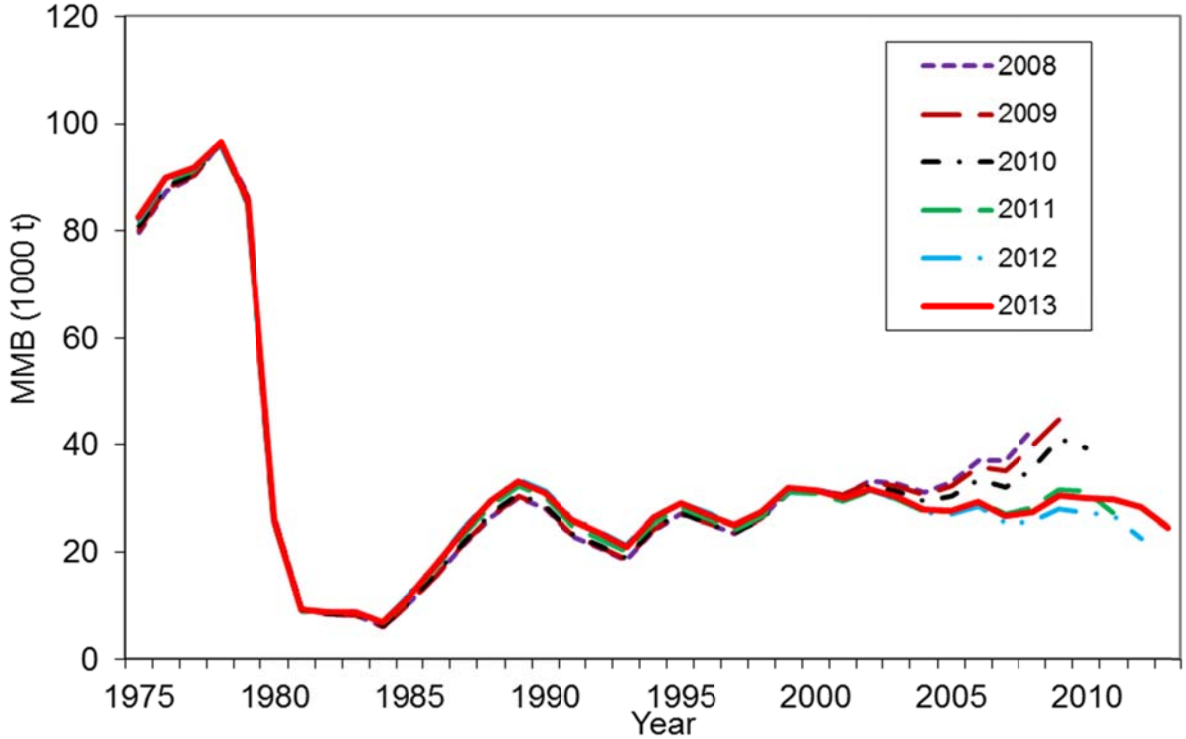


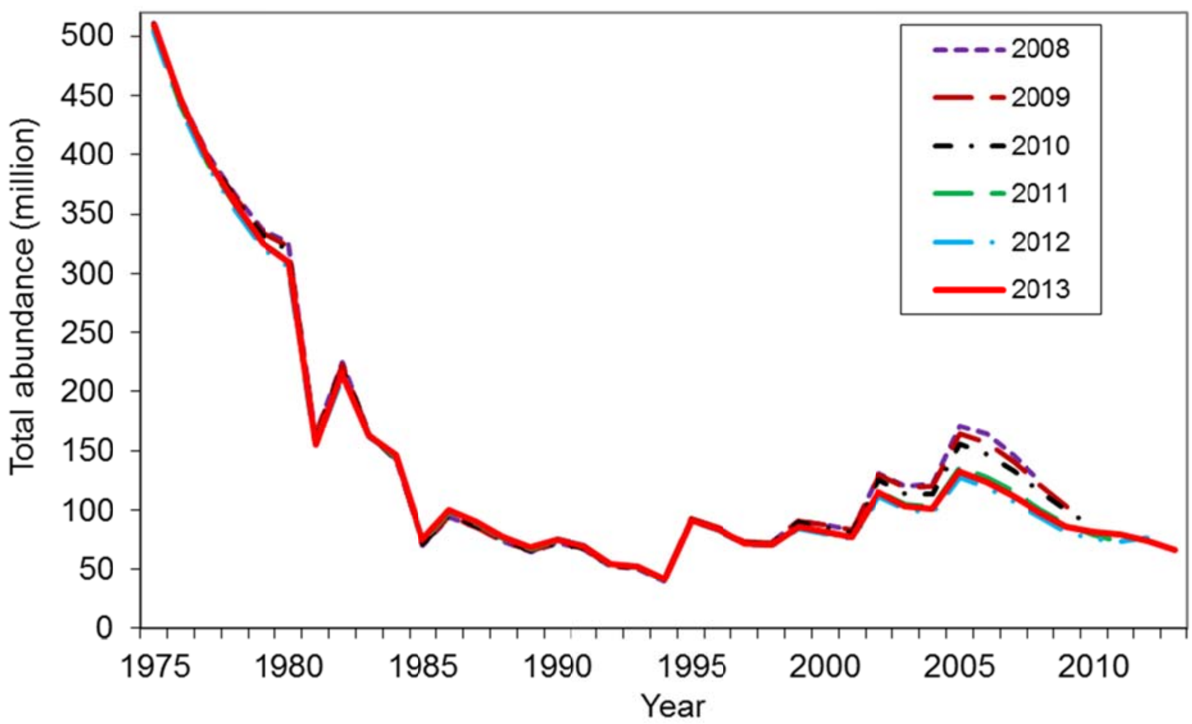
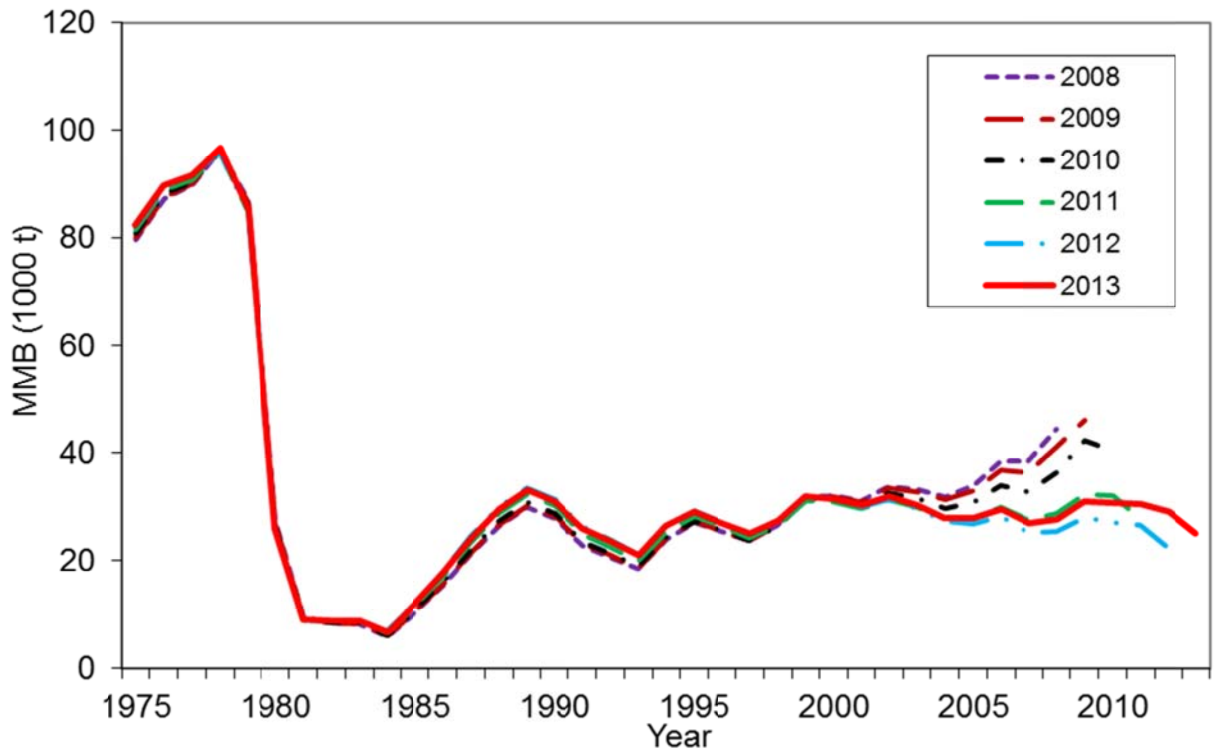


Figure 28(1). Comparison of estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2013 made with terminal years 2008-2013 with scenario 1. These are results of the 2013 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



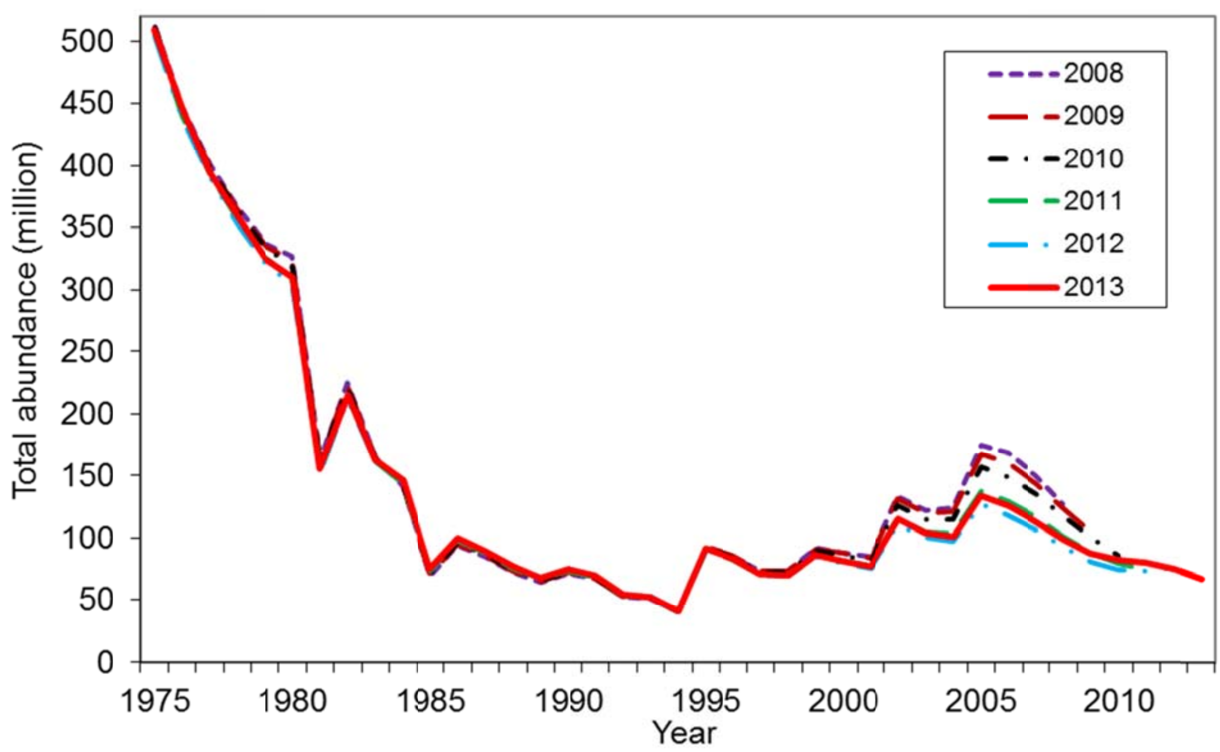


Figure 28(4). Comparison of estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2013 made with terminal years 2008-2013 with scenario 4. These are results of the 2013 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

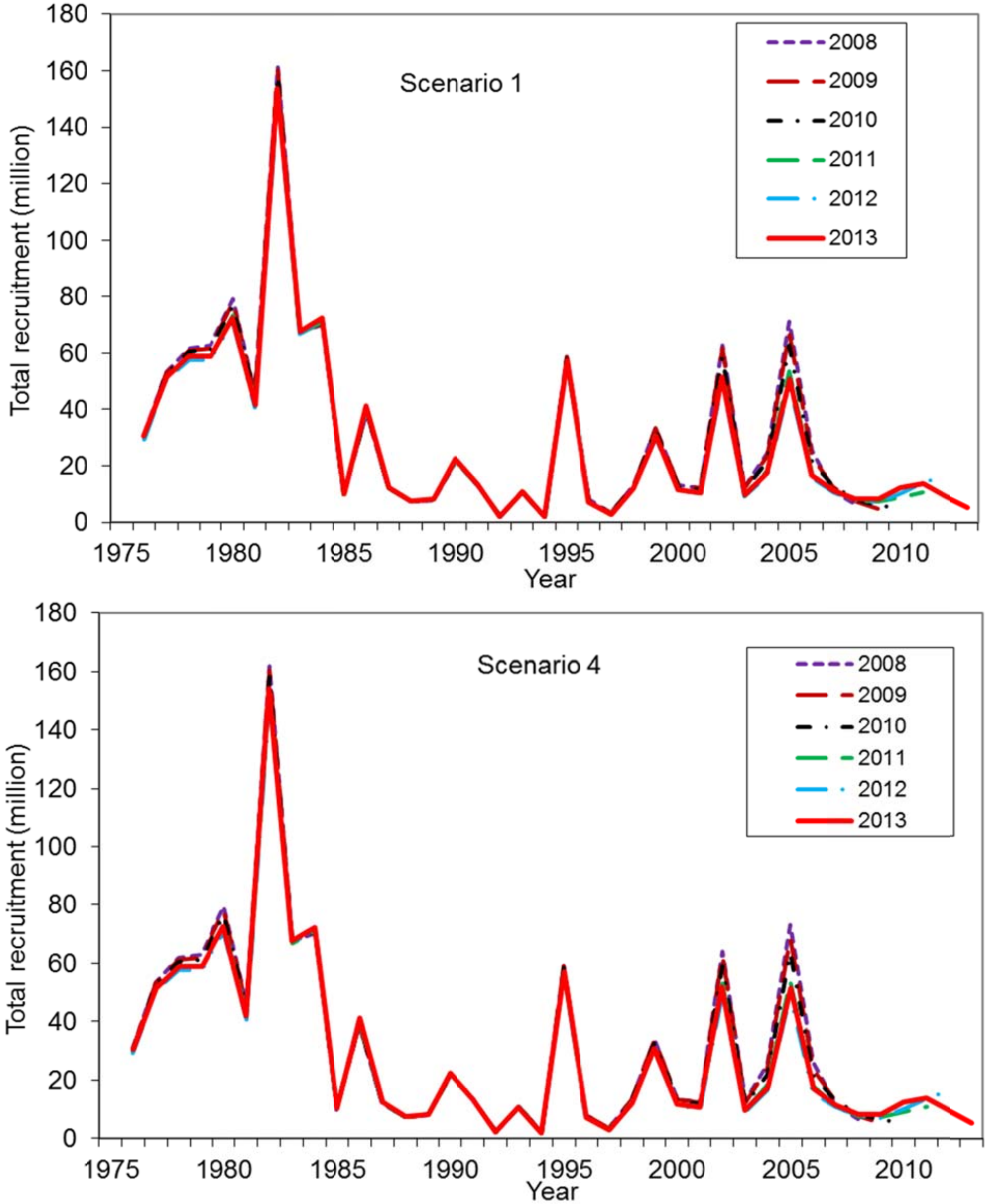


Figure 28(1&4). Comparison of estimates of total recruitment for scenario 1 (top) and scenario 4 (bottom) of Bristol Bay red king crab from 1976 to 2013 made with terminal years 2008-2013. These are results of the 2013 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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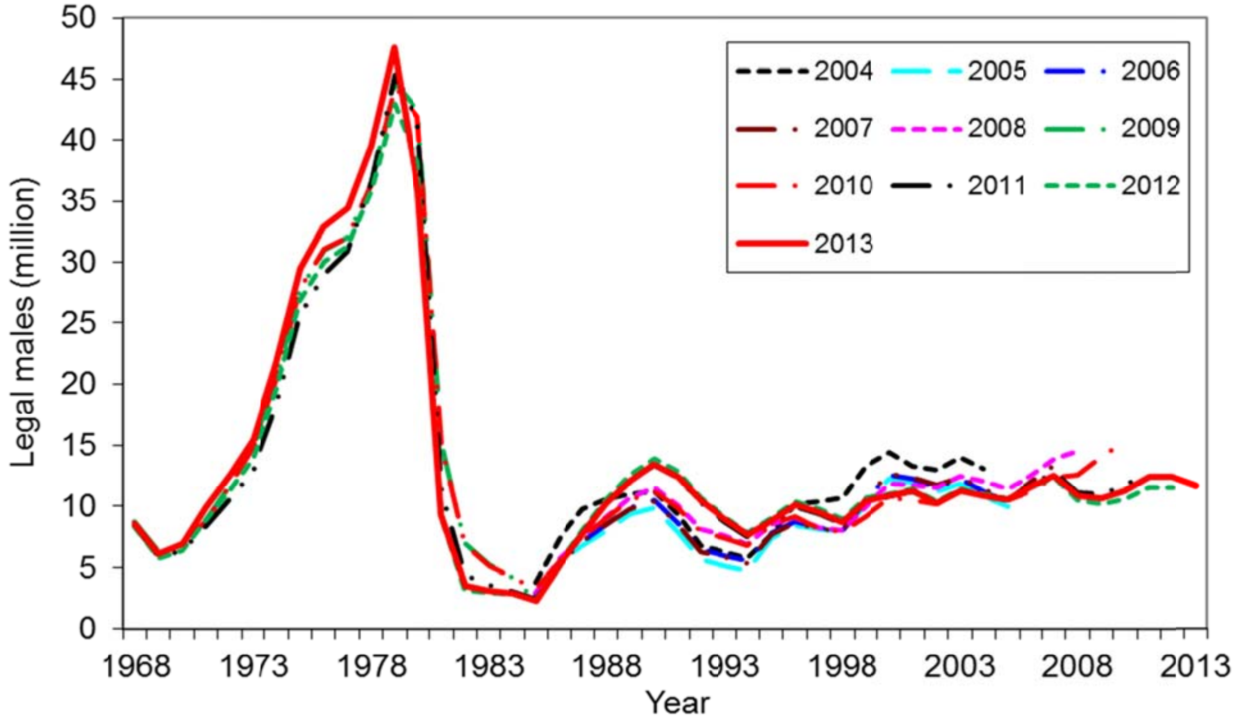

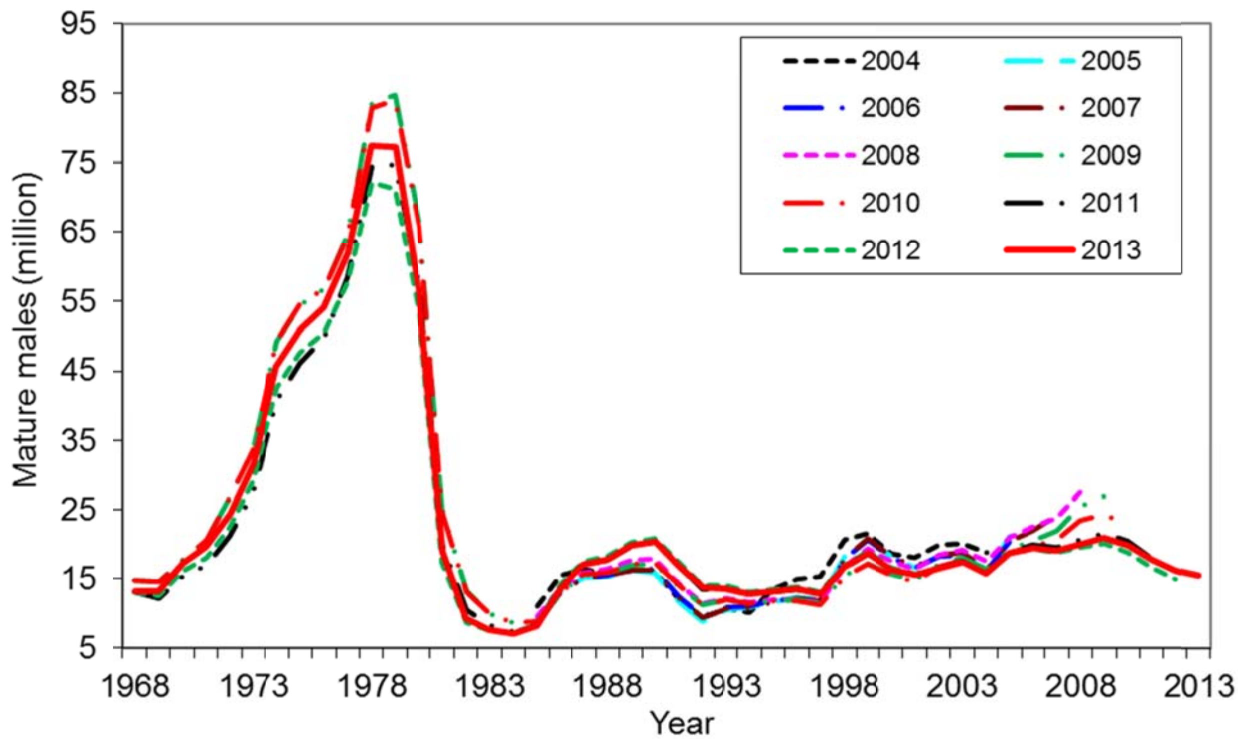

Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2013 made with terminal years 2004-2013 with scenario 0(7ac). These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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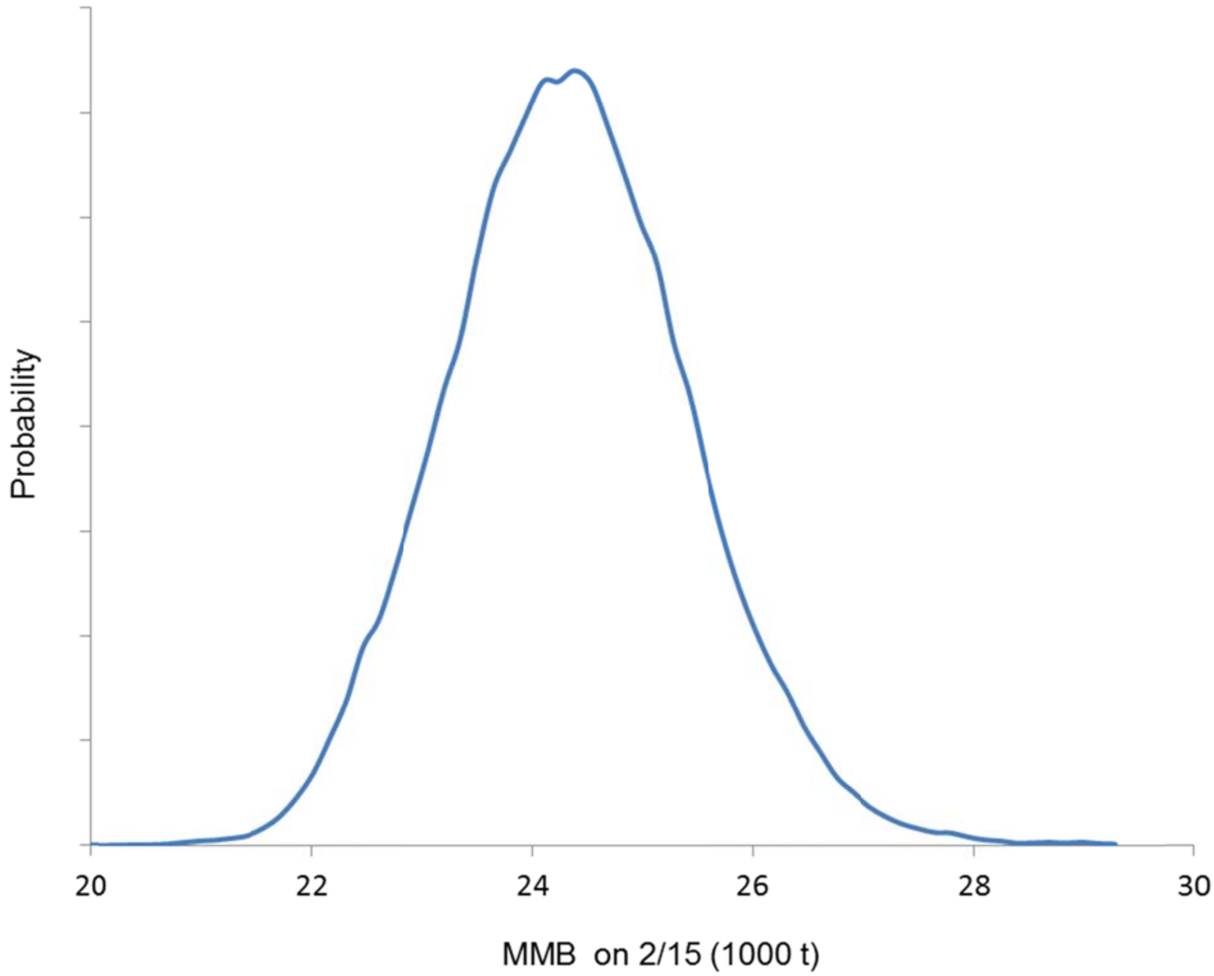

Figure 30(1). Probability of estimated mature male biomass on Feb. 15, 2014 with $F_{35\%}$ under scenario 1 with the mcmc approach . Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

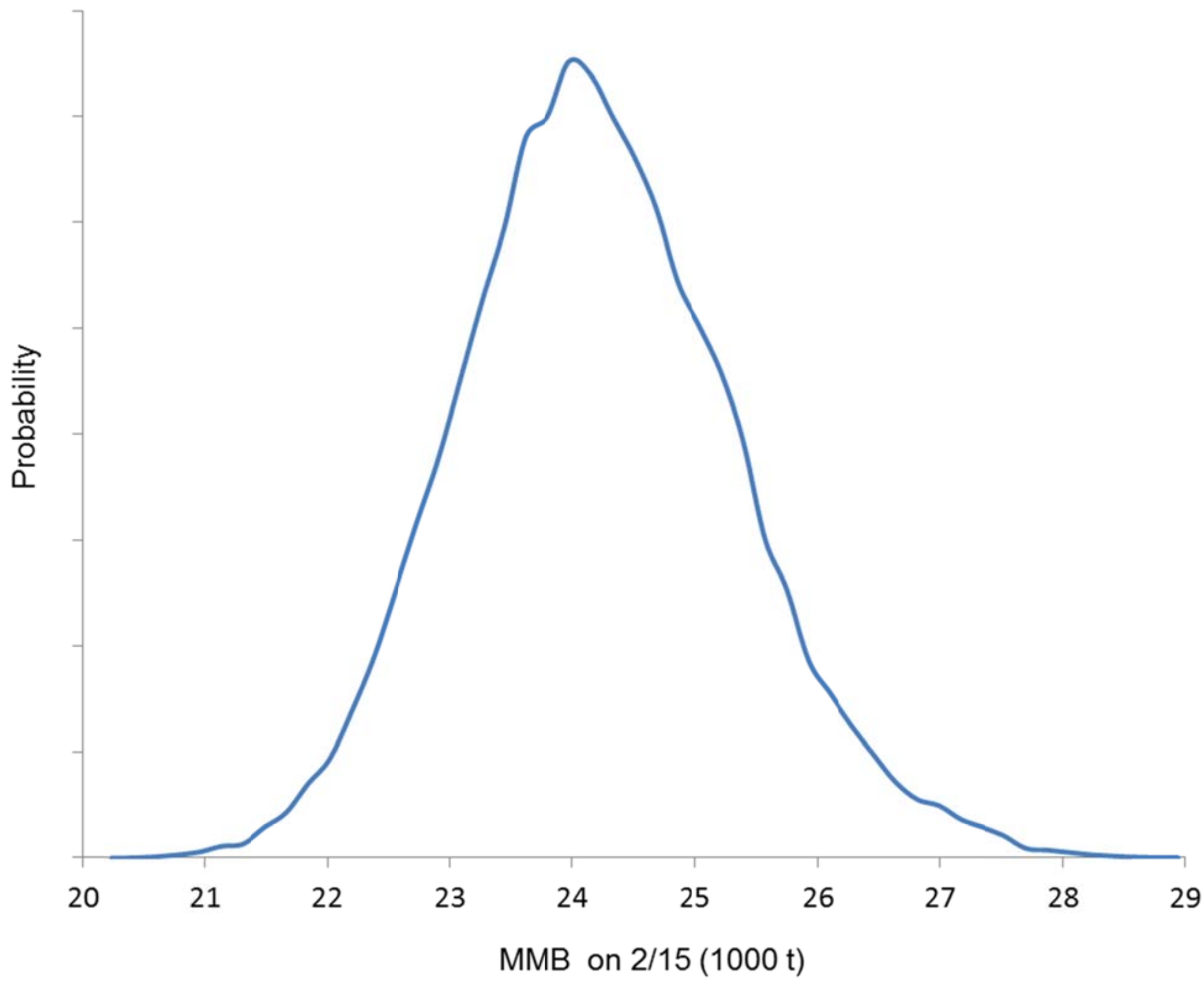

Figure 30(4). Probability of estimated mature male biomass on Feb. 15, 2014 with $F_{35\%}$ under scenario 4 with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

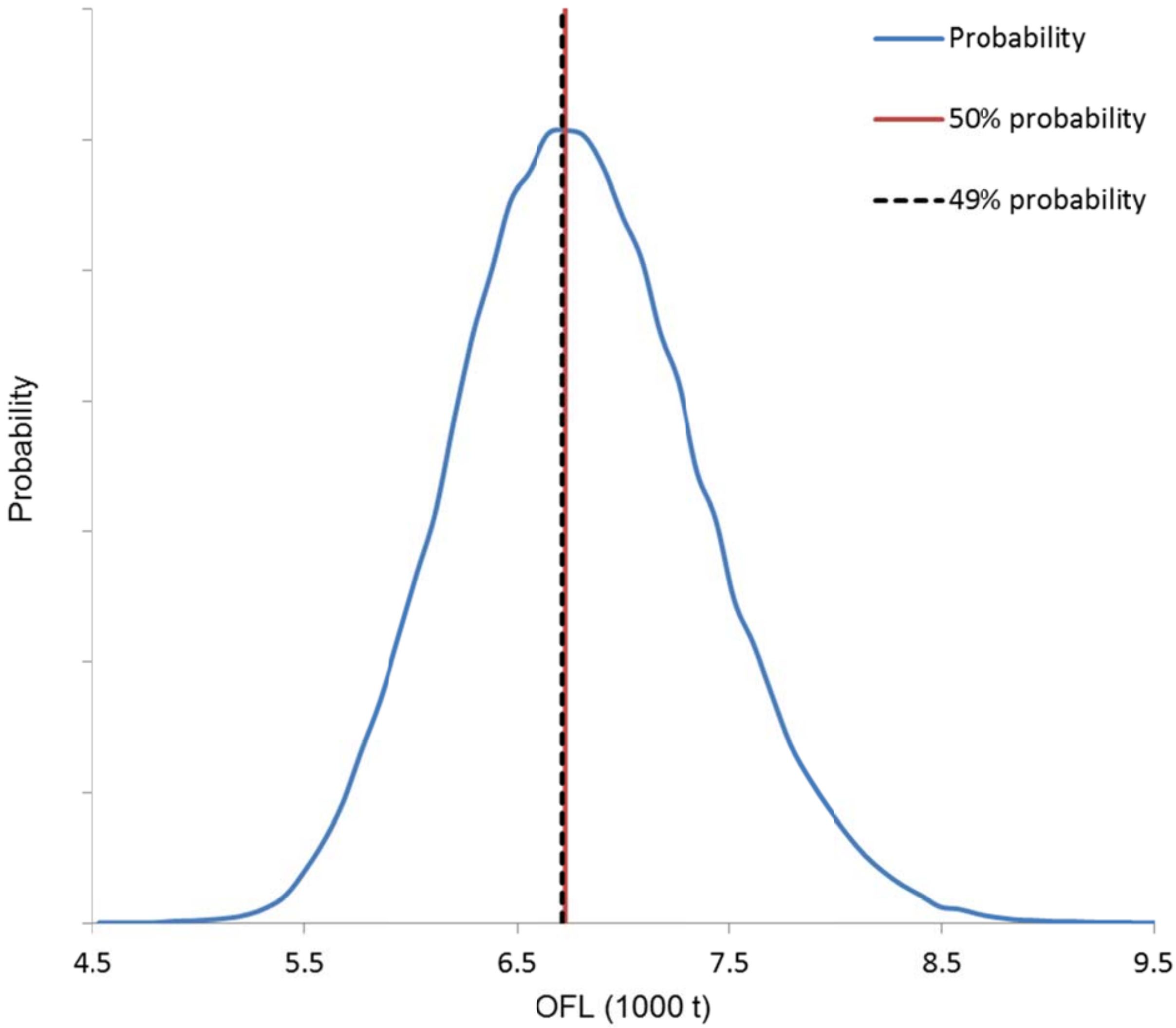

Figure 31(1). Probability of the 2013 estimated OFL with scenario 1 with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

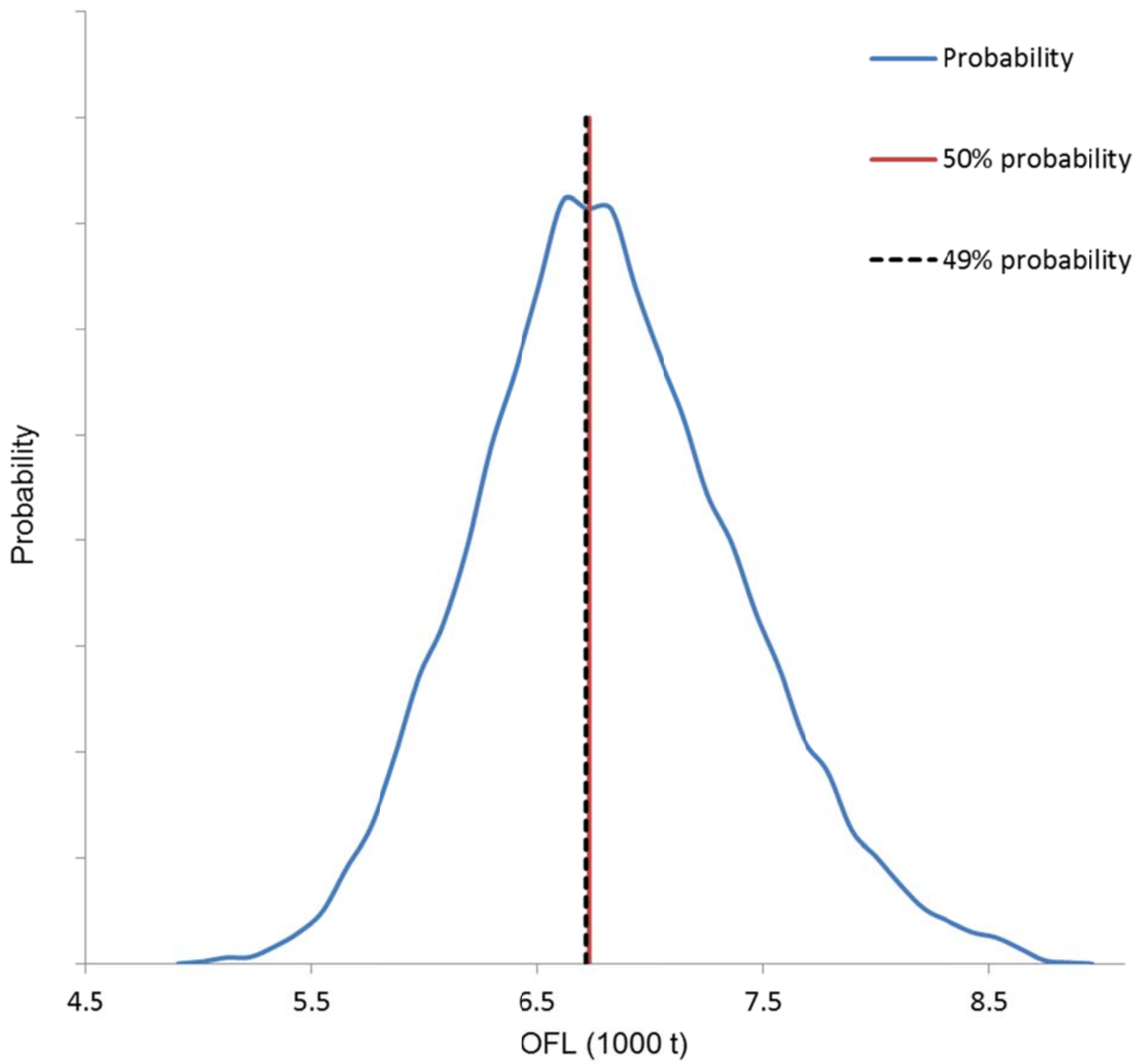

Figure 31(4). Probability of the 2013 estimated OFL with scenario 4 with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

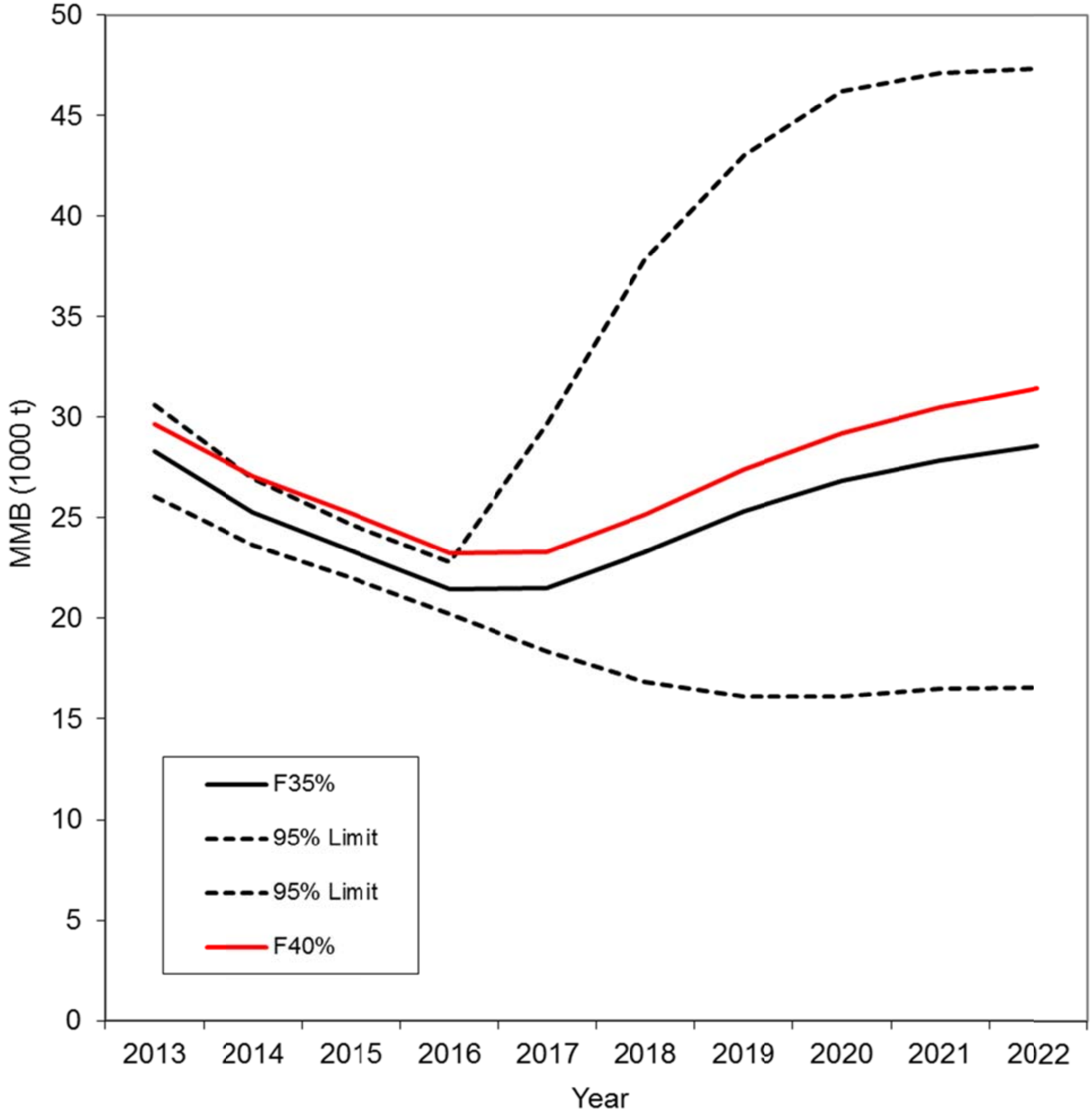

Figure 32(0). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2013-2122. Input parameter estimates are based on scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

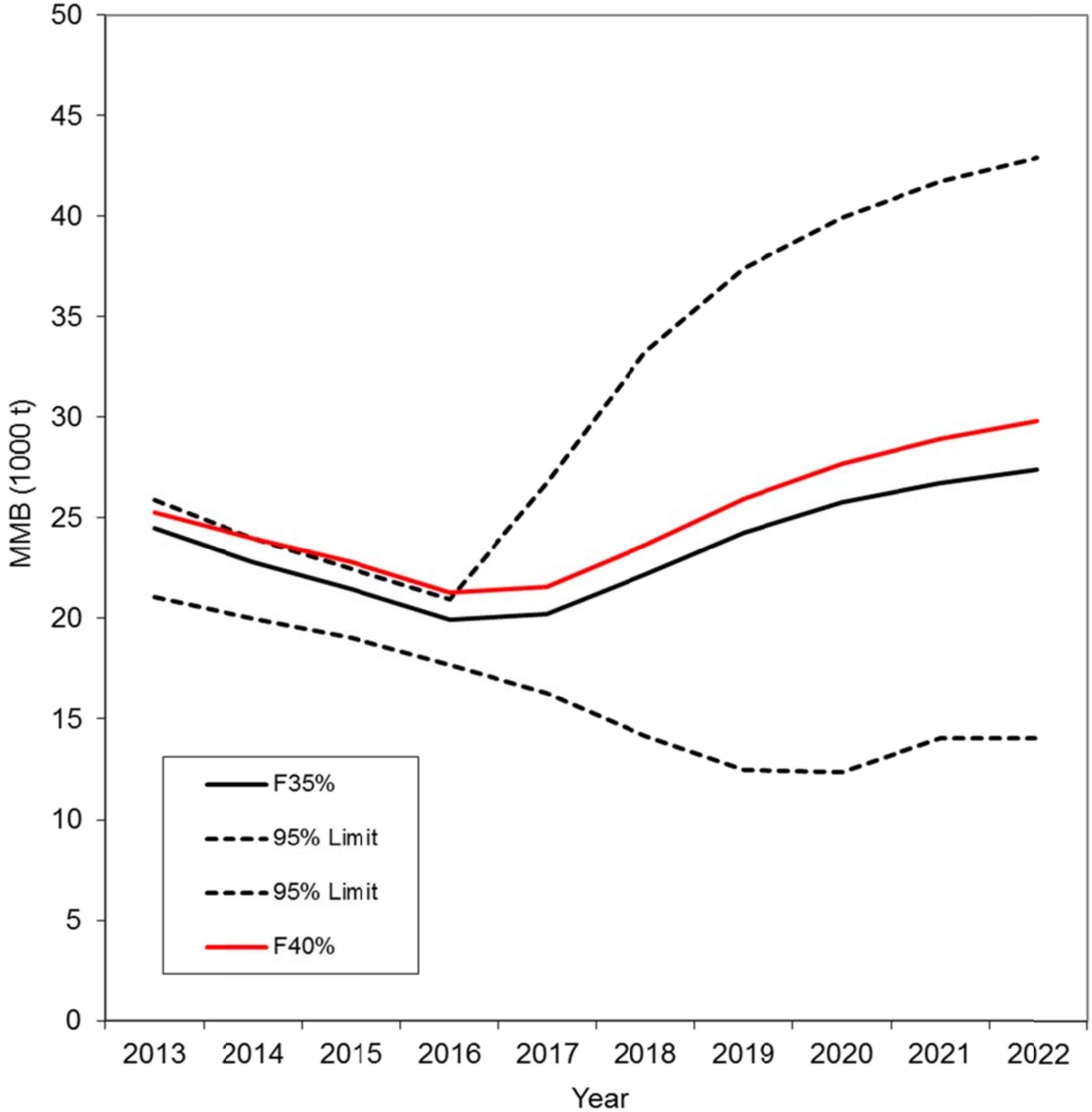

Figure 32(1). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2013-2122. Input parameter estimates are based on scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

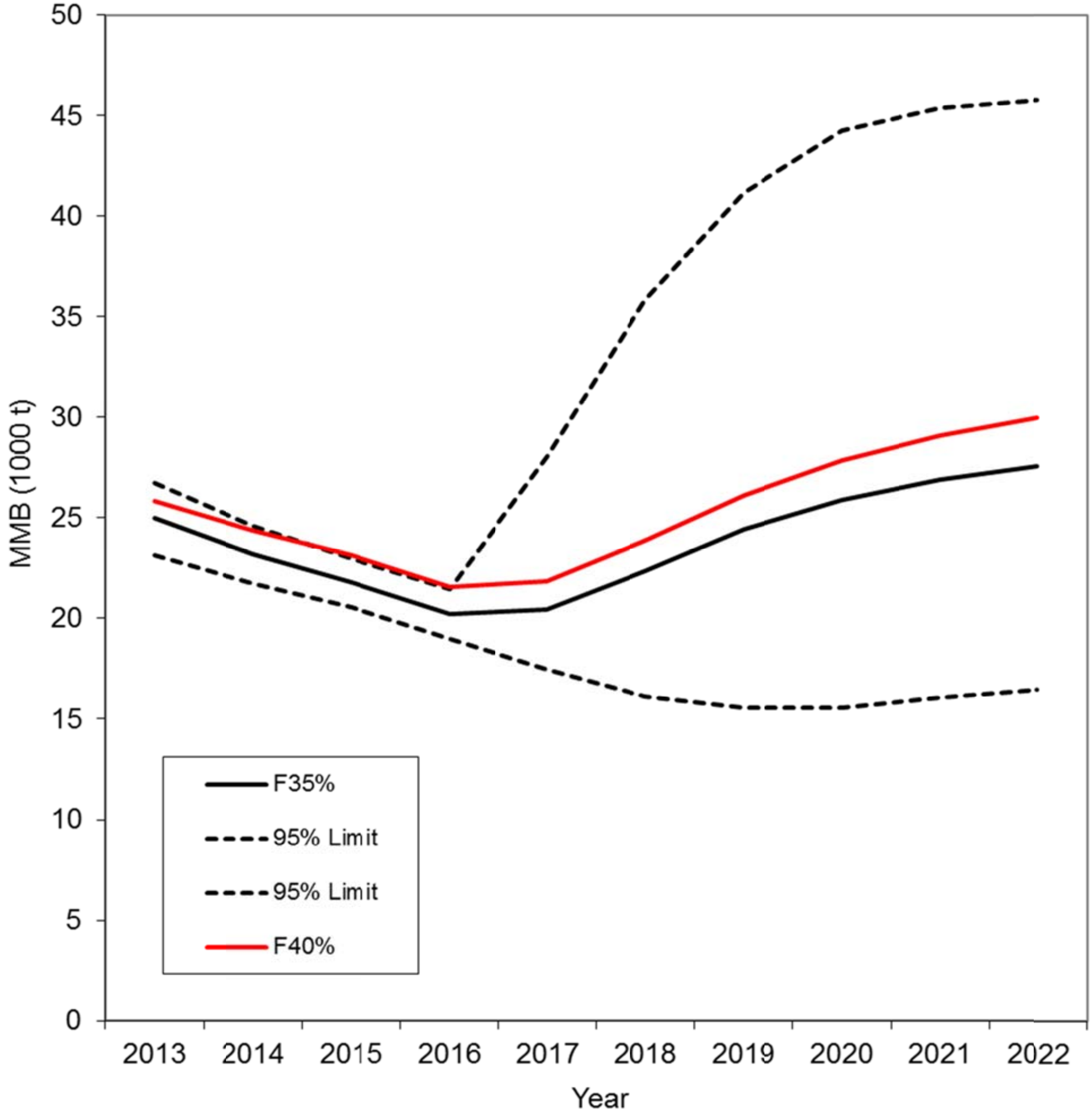

Figure 32(4). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2013-2122. Input parameter estimates are based on scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

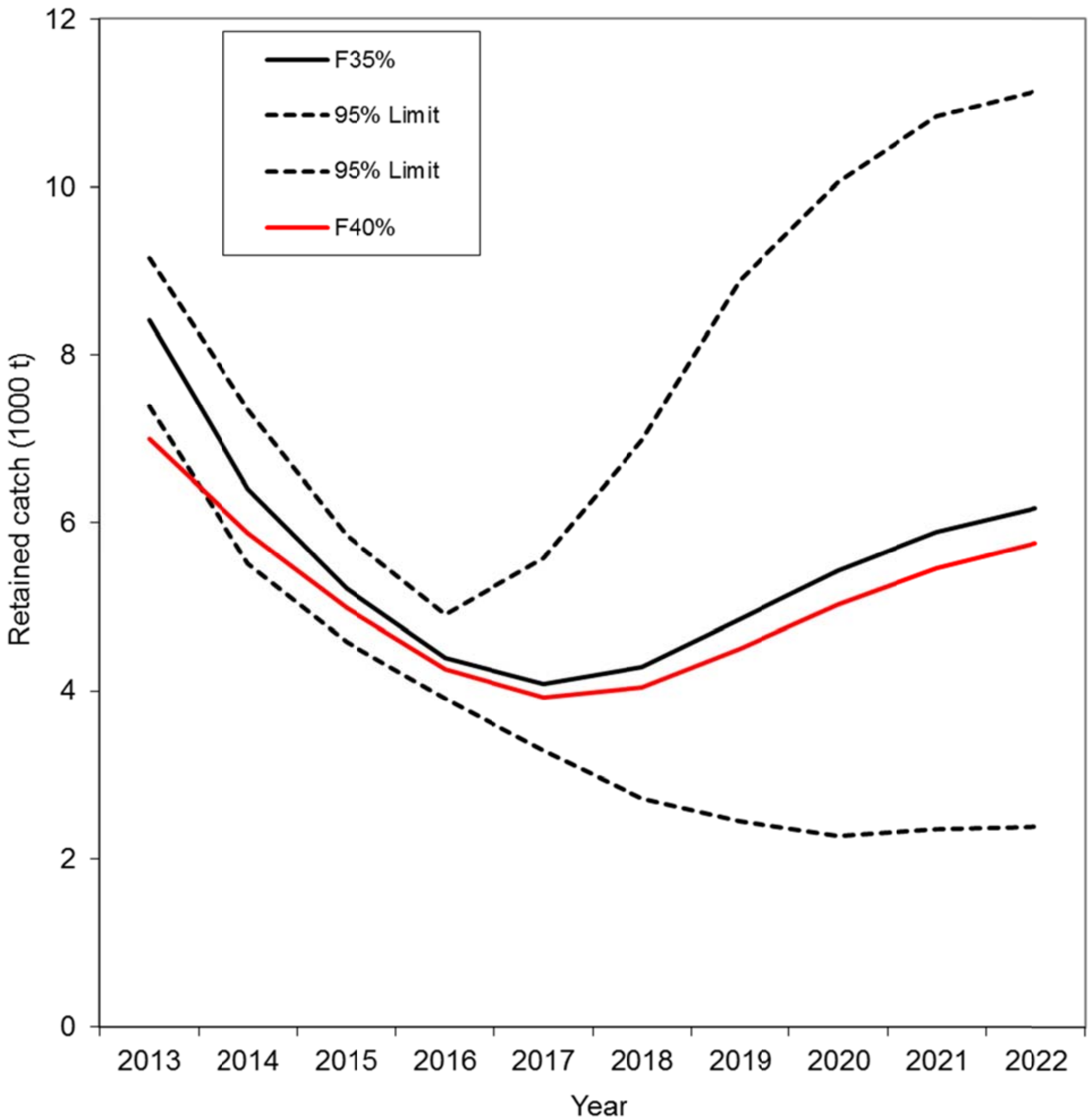

Figure 33(0). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2013-2122. Input parameter estimates are based on scenario 0(7ac). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

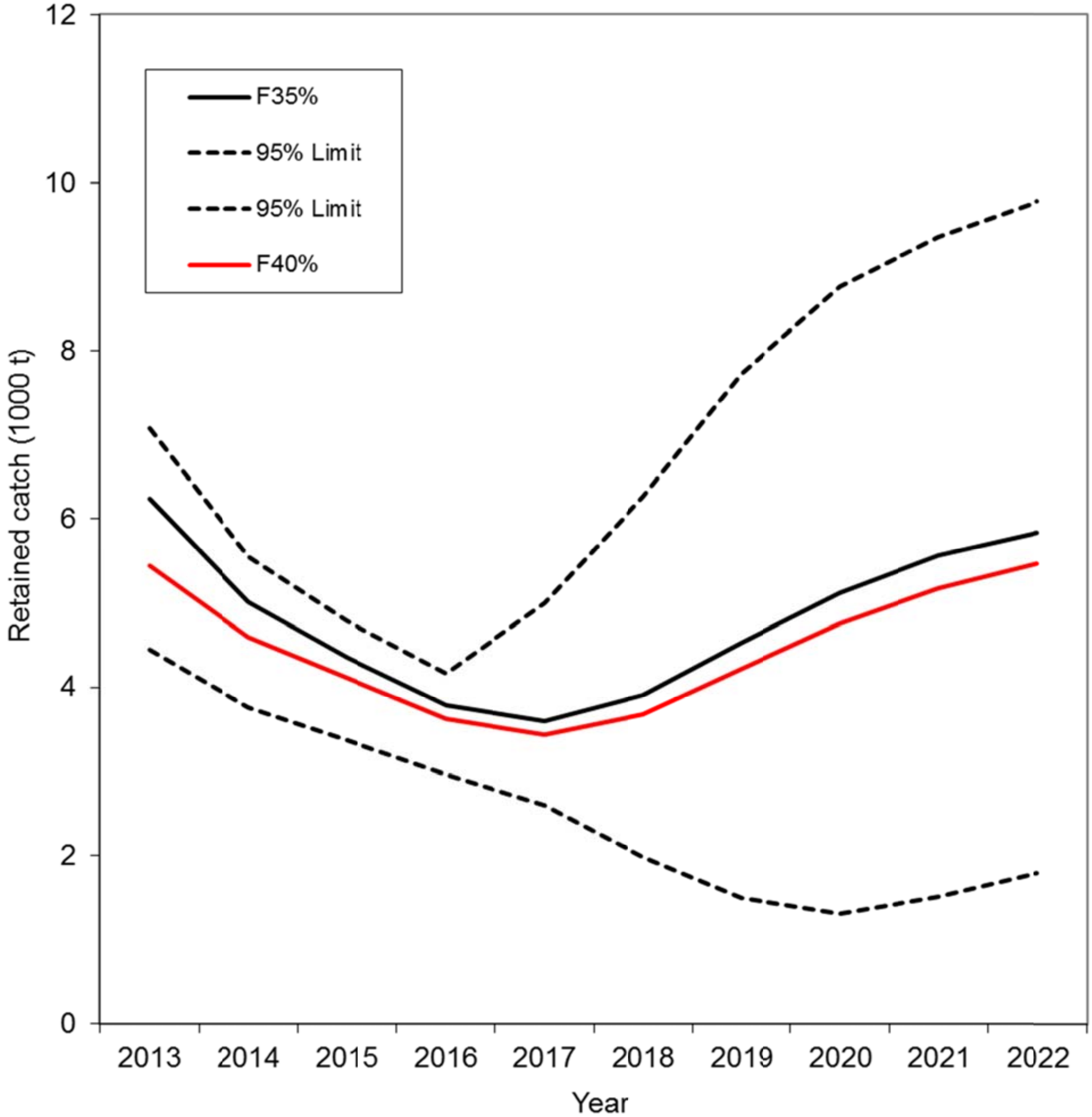

Figure 33(1). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2013-2122. Input parameter estimates are based on scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

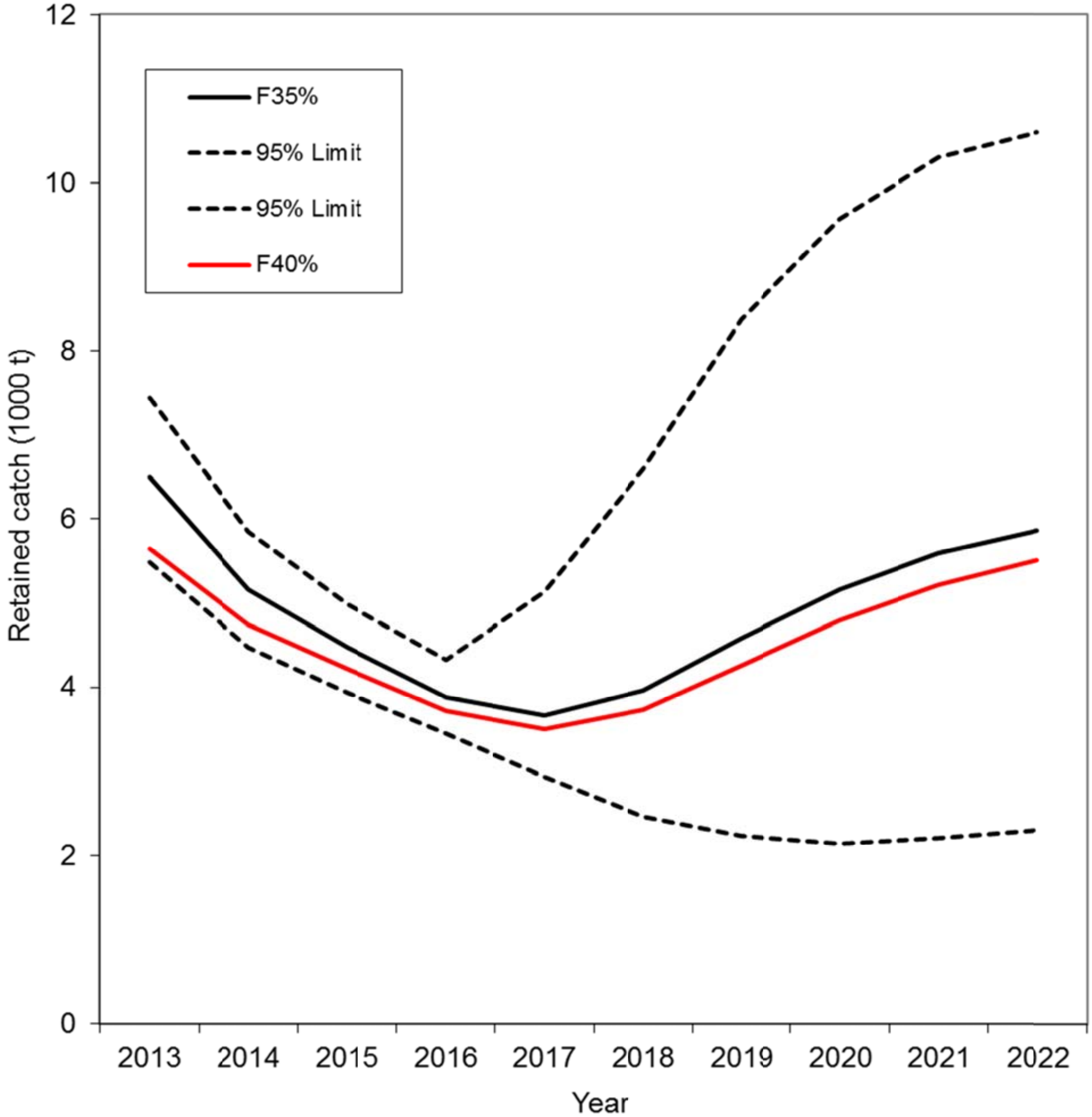

Figure 33(4). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2013-2122. Input parameter estimates are based on scenario 4. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

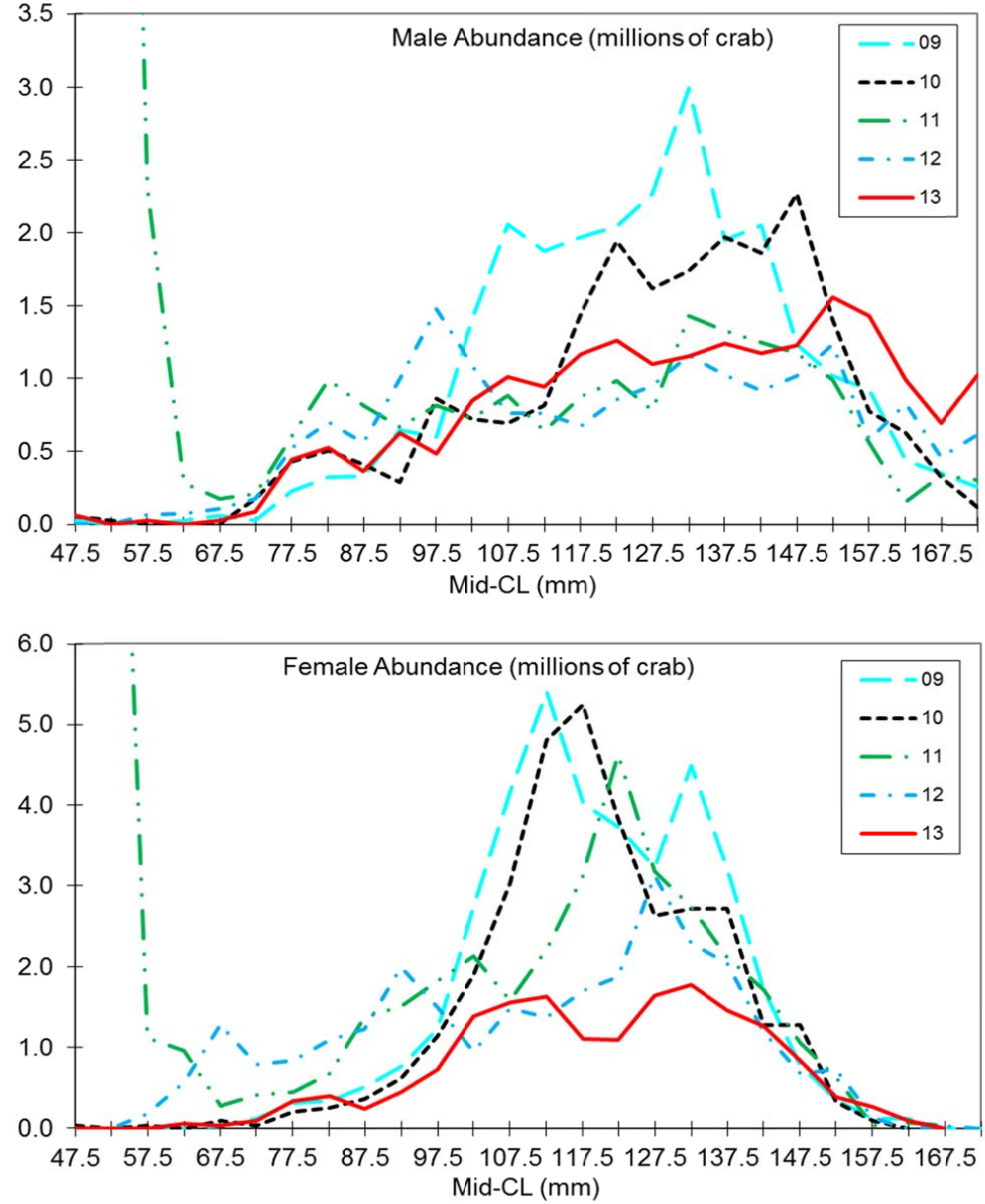

Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crabs in Bristol Bay from NMFS trawl surveys during 2009-2013. For purposes of these graphs, abundance estimates are based on area-swept methods.

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). Male 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:

$$N_{l+1,t+1} = \sum_{l'=1}^{l'=l+1} \{P_{l',l+1}[(N_{l',t}+O_{l',t})\,e^{-M_t} - (C_{l',t}+D_{l',t})\,e^{(y_t-1)M_t} - T_{l,t}e^{(j_t-1)M_t}]\,m_{l',t}\} + R_{l+1,t+1}\,,$$
$$O_{l+1,t+1} = [(N_{l+1,t}+O_{l+1,t})\,e^{-M_t} - (C_{l+1,t}+D_{l+1,t})\,e^{(y_t-1)M_t} - T_{l+1,t}e^{(j_t-1)M_t}](1-m_{l+1,t}), \quad (1)$$

where

$N_{l,t}$	is newshell crab abundance in length class *l* and year *t*,
$O_{l,t}$	is oldshell crab abundances in length class *l* and year *t*,
M	is the instantaneous natural mortality,
$m_{l,t}$	is the molting probability for length class *l* and year *t*,
$R_{l,t}$	is recruitment into length class *l* in year *t*,
y_t	is the lag in years between the assessment survey and the mid fishery time in year *t*,
j_t	is the lag in years between the assessment survey and the mid Tanner crab fishery time in year *t*,
$P_{l',l}$	is the proportion of molting crabs growing from length class *l'* to *l* after one molt,
$C_{l,t}$	is the retained catch of length class *l* in year *t*, and
$D_{l,t}$	is the discarded mortality catch of length class *l* in year *t*, including directed pot and trawl bycatch,
$T_{l,t}$	is the discarded mortality catch of length class *l* in year *t* from the Tanner crab fishery.

The minimum carapace length for males is set at 65 mm, and crab abundance is modeled with a length-class interval of 5 mm. The last length class includes all crabs ≥160-mm CL. There are 20 length classes/groups. $P_{l',l}$, m_l, $R_{l,t}$, $C_{l,t}$, and $D_{l,t}$ are computed as follows:

Mean growth increment per molt is assumed to be a linear function of pre-molt length:

$$G_l = a + b\,\iota, \quad (2)$$

where *a* and *b* are constants. Growth increment per molt is assumed to follow a gamma distribution:

$$g(x \mid \alpha_l, \beta) = x^{\alpha_l - 1} \; e^{-x/\beta} / [\beta^{\alpha_l} \; \Gamma(\alpha_l)]. \tag{3}$$

The expected proportion of molting individuals growing from length class l_1 to length class l_2 after one molt is equal to the sum of probabilities within length range $[\iota_1, \iota_2)$ of the receiving length class l_2 at the beginning of the next year:

$$P_{l_1,l_2} = \int_{\iota_1 - \iota}^{\iota_2 - \iota} g(x \mid \alpha_l, \beta) dx, \tag{4}$$

where ι is the mid-length of length class l_1. For the last length class L, $P_{L,L} = 1$.

The molting probability for a given length class l is modeled by an inverse logistic function:

$$m_{l,t} = 1 - \frac{1}{1 + e^{-\beta\ (l - L_{50})}}, \tag{5}$$

where

β, L_{50} are parameters with three sets of values for three levels of molting probabilities, and ι is the mid-length of length class l.

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, and size-dependent variables, U_l, representing the proportion of recruits belonging to each length class. R_t was assumed to consist of crabs at the recruiting age with different lengths and thus represents year class strength for year t. $R_{l,t}$ is computed as

$$R_{l,t} = R_t U_l, \tag{6}$$

where U_l is described by a gamma distribution similar to equations (3) and (4) with a set of parameters α_r and β_r. Because of different growth rates, recruitment was estimated separately for males and females under a constraint of approximately equal sex ratios of recruitment over time.

Before 1990, no observed bycatch data were available in the directed pot fishery; the crabs 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 potlift 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. For bycatch, all fishery catch and discard mortality bycatch are estimated as:

$$C_{l,t} \; or \; D_{l,t} = (N_{l,t} + O_{l,t}) \; e^{-y_t M_t} (1 - e^{-s_l F_t}) \tag{7}$$

where

s_l is selectivity for retained, pot or trawl discarded mortality catch of length class *l*, and

F_t is full fishing mortality of retained, pot or trawl discarded mortality catch in year *t*.

For discarded mortality bycatch from the Tanner crab fishery, y_t is replaced by j_t in the right side of equation (7).

The female crab model is the same as the male crab model except that the retained catch equals zero, molting probability equals 1.0 to reflect annual molting (Powell 1967), and growth matrix, *P*, changes over time due to change in size at maturity for females. The minimum carapace length for females is set at 65 mm, and the last length class includes all crabs ≥140-mm CL, resulting in length groups 1-16. Three sets of growth increments per molt are used for females due to changes in sizes at maturity over time (Figures A2 and A3).

ii. Fisheries Selectivities

Retained selectivity, female pot bycatch selectivity, and both male and female trawl bycatch selectivity are estimated as a function of length:

$$s_l = \frac{1}{1+e^{-\beta\ (\iota - L_{50})}}, \qquad (8)$$

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. Because some catches were from the foreign fisheries during 1968-1972, a different set of parameters (β, L_{50}) are estimated for retained males for this period and a third parameter, sel_62.5mm, is used to explain the high proportion of catches in the last length group.

Male pot bycatch selectivity is modeled by two linear functions:

$$\begin{aligned} s_l &= \varphi + \kappa\iota, \quad if\ \iota < 135\,\text{mm CL}, \\ s_l &= s_{l-1} + 5\gamma, \quad if\ \iota > 134\,\text{mm CL} \end{aligned} \qquad (9)$$

Where

φ, κ, γ are parameters.

During 2005-2008, a portion of legal males were also discarded in the pot fishery. The selectivity for this high grading was estimated to be the retained selectivity in each year times a high grading parameter, hg_t.

iii. Trawl Survey Selectivities/Catchability

Trawl survey selectivities/catchability are estimated as

$$s_l = \frac{Q}{1 + e^{-\beta\ (l - L_{50})}}, \quad (10)$$

with different sets of parameters (β, L_{50}) estimated for males and females as well as four different periods (1968-69, 1970-72, 1973-81 and 1982-09). 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 except during 1970-1972 when the survey catchability was small.

Assuming that the BSFRF survey caught all crabs 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 crabs are in the shallow water areas that are not accessible for the trawl survey, NMFS survey catchability/selectivity consists of capture probability and crab availability.

b. Software Used: AD Model Builder (Otter Research Ltd. 1994).

c. Likelihood Components

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

$$Rf = \prod_{l=1}^{L} \prod_{t=1}^{T} \prod_{s=1}^{2} \prod_{sh=1}^{2} \frac{\left\{ \exp\left[-\frac{(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh})^2}{2\sigma^2} \right] + 0.01 \right\}}{\sqrt{2\pi\sigma^2}}, \quad (11)$$

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

where

L is the number of length groups,

T is the number of years, and

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

The weighted negative log-likelihood functions are:

$$
\begin{aligned}
&\textit{Length compositions}: \quad -\sum \ln(Rf_i)\,, \\
&\textit{Biomasses other than survey}: \quad \lambda_j \sum \left[\ln(C_t / \hat{C}_t)^2\right], \\
&\textit{NMFS survey biomass}: \quad \sum \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))\right], \\
&\textit{BSFRF mature males}: \quad \sum [\ln(\ln(CV_t^2 + 1))^{0.5} + \ln(N_t / \hat{N}_t)^2 / (2\ln(CV_t^2 + 1))], \\
&\textit{R variation}: \quad \lambda_R \sum [\ln(R_t / \overline{R})^2]\,, \qquad (12) \\
&\textit{R sex ratio}: \quad \lambda_s [\ln(\overline{R}_M / \overline{R}_F)^2]\,, \\
&\textit{Trawl bycatch fishing mortalities}: \lambda_t [\ln(F_{t,t} / \overline{F}_t)^2]\,, \\
&\textit{Pot female bycatch fishing mortalities}: \lambda_p [\ln(F_{t,f} / \overline{F}_f)^2]\,.
\end{aligned}
$$

Where

R_t is the recruitment in year t,

$\overline{R}$ is the mean recruitment,

$\overline{R}_M$ is the mean male recruitment,

$\overline{R}_F$ is the mean female recruitment,

$\overline{F}_t$ is the mean trawl bycatch fishing mortality,

$\overline{F}_f$ Is the mean pot female bycatch fishing mortality.

For BSFRF mature male abundance or total survey biomass, *CV* is the survey *CV* plus *AV*, where *AV* is additional *CV* and estimated in the model. The mature male abundance is used for all scenarios except scenario 2. Total survey biomass is used for scenario 2.

Weights λ_j are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, 10 for recruitment sex ratio, 0.2 for pot female bycatch fishing mortality and 0.1 for trawl bycatch fishing mortality. These λ_j values represent prior assumptions about the accuracy of the observed catch biomass data 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 hg_t were estimated to be 0.2785 in 2005, 0.0440 in 2006, 0.0197 in 2007, and 0.0198 in 2008 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.

(2). Length-weight Relationship

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

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

Ovigerous Females: $W = 0.003593\, L^{2.666076}$, (13)

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

where

W is weight in grams, and
L is 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 1968-1993 and 1994-2008, respectively, and the data presented in Gray (1963) were used to estimate those for mature females (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 1968-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2008, females matured at a slightly higher size, so the growth increment per molt was shifted to high increments for immature crabs (Figure A2). Once mature, the growth increment per molt for male crabs decreases slightly and annual molting probability decreases, whereas the growth increment for female crabs decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

(4). Sizes at Maturity for Females

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 1994-08).

(5). Sizes at Maturity for Males

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: directed pot fishery, 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. 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° 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 crabs 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 crabs. But we lack stomach samples in shallow waters (juvenile habitat) and during the period when red king crabs molt. Also cannibalism occurs during molting periods for red king crabs. 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 crabs, and disease for all crabs. 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 crabs: total recruits for each year (year class strength R_t for t = 1969 to 2009), total abundance in the first year (1968), 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 crabs. 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. NMFS survey catchabilities Q for 1968-69 and 1973-2009 and Q_m (for males) and Q_f (for females) for 1970-72 were also estimated. Annual fishing mortalities were also estimated for the directed pot fishery for males (1968-2008), pot-discarded females from the directed fishery (1990-2008), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93), and groundfish trawl discarded males and females (1976-2008). Three additional mortality parameters for Mm_t and Mf_t were also estimated. The total number of parameters to be estimated was 223. 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 (crabs >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.

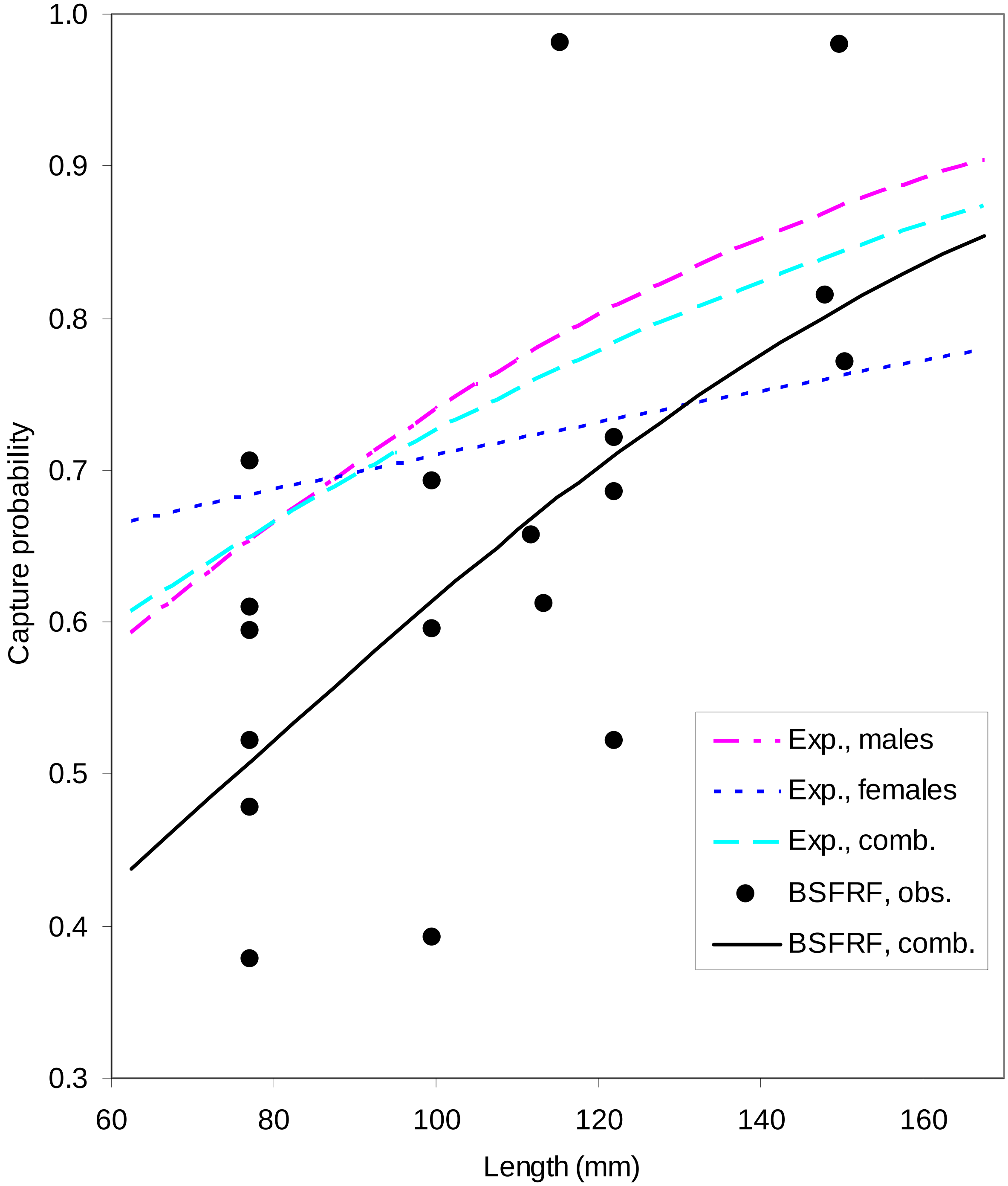

Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.

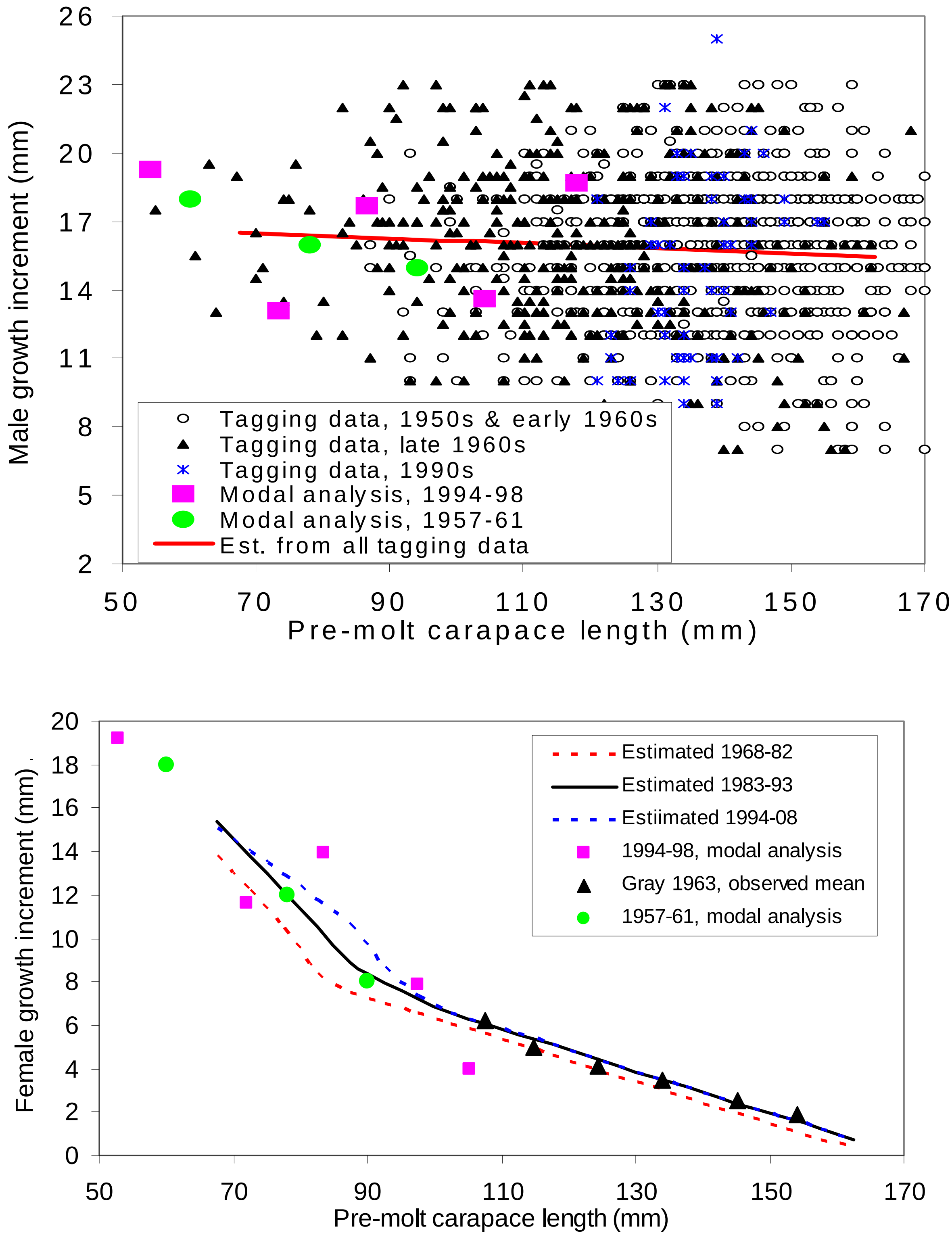

Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis.

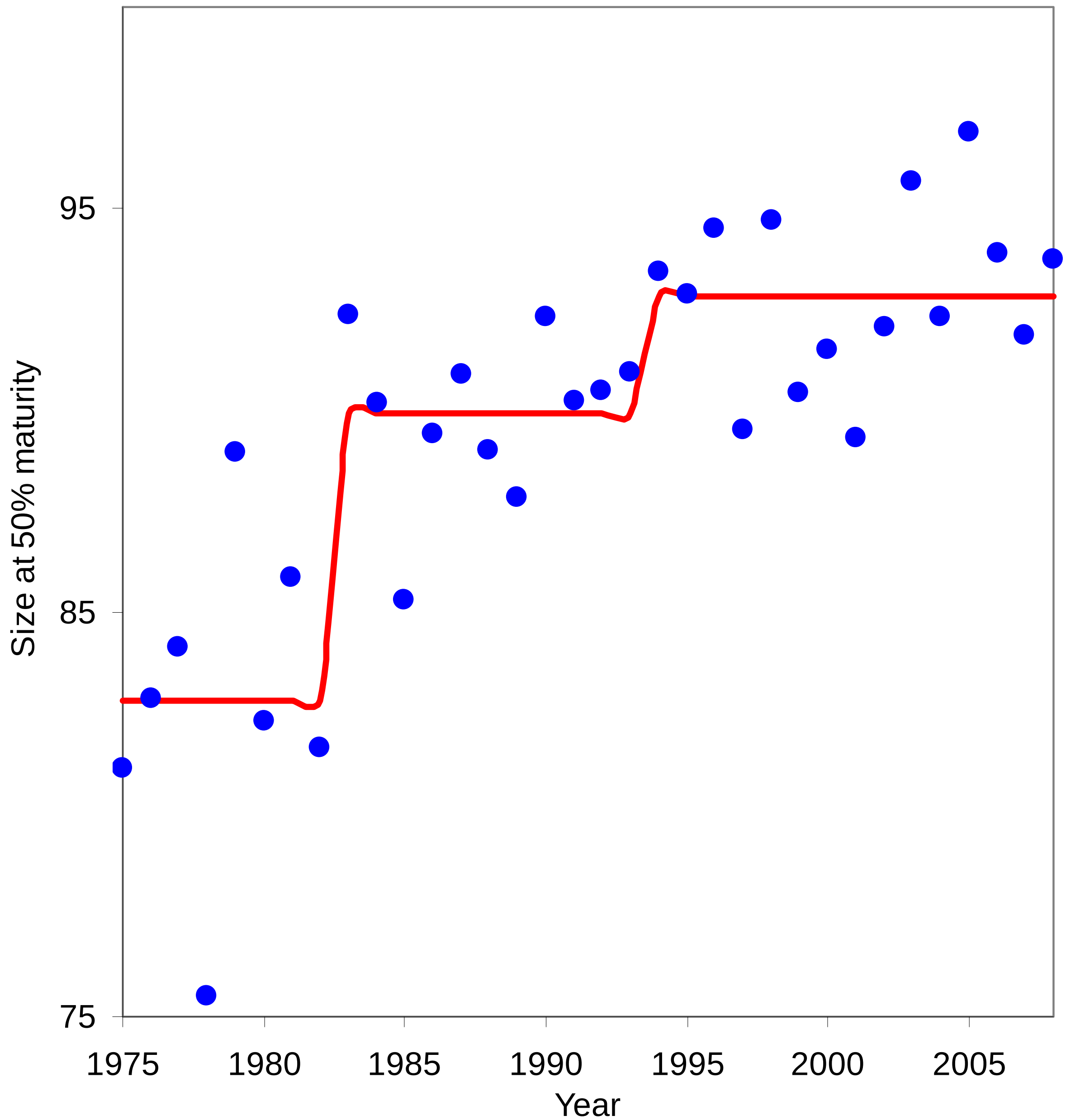

Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

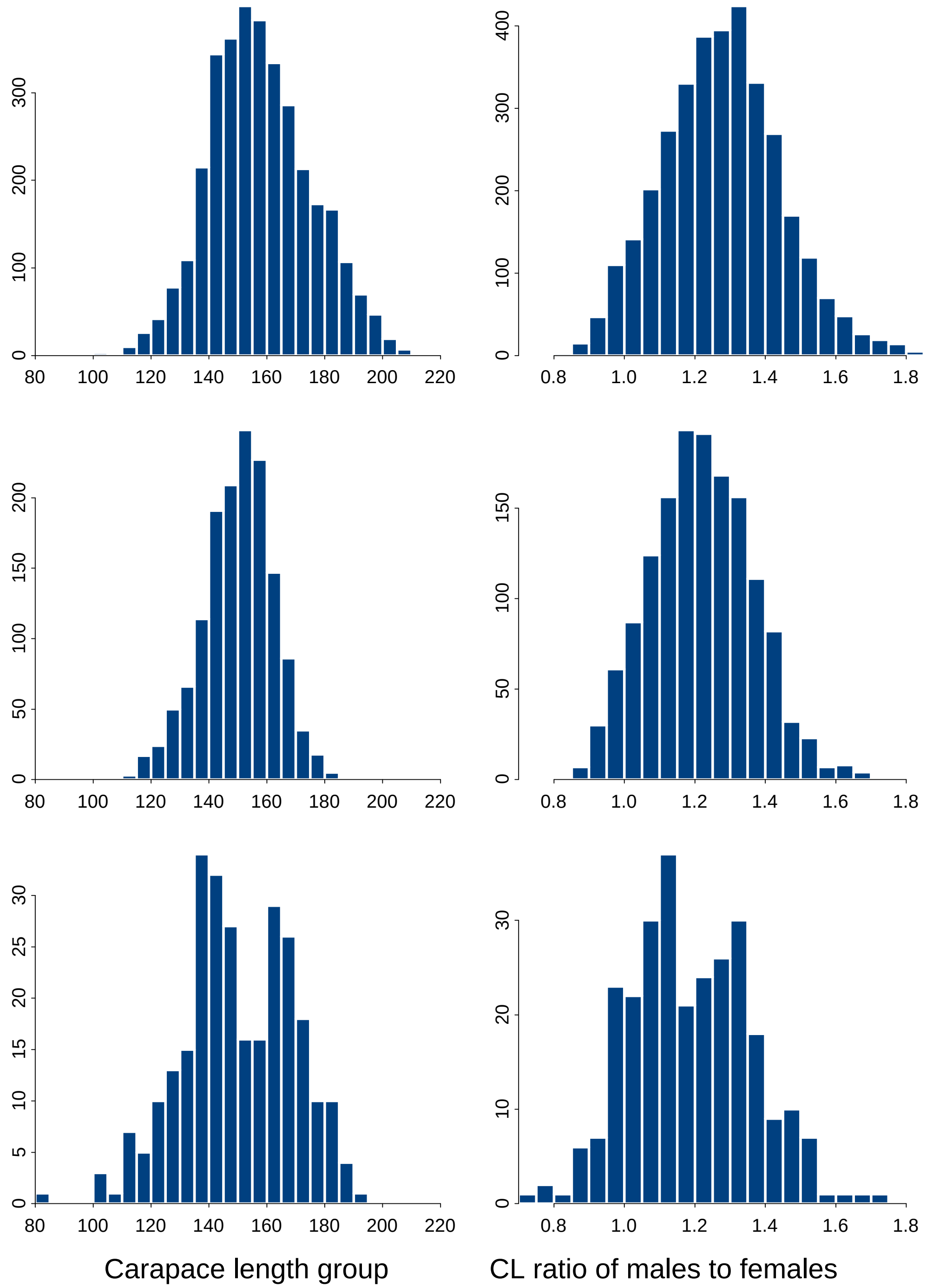

Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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

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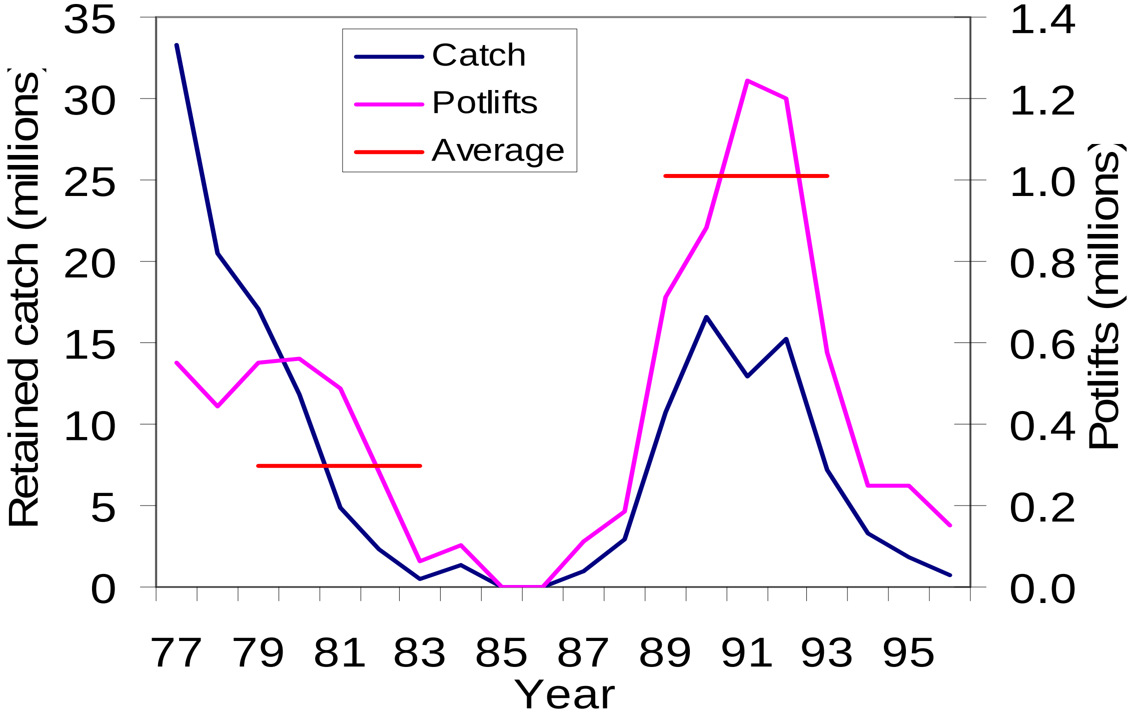

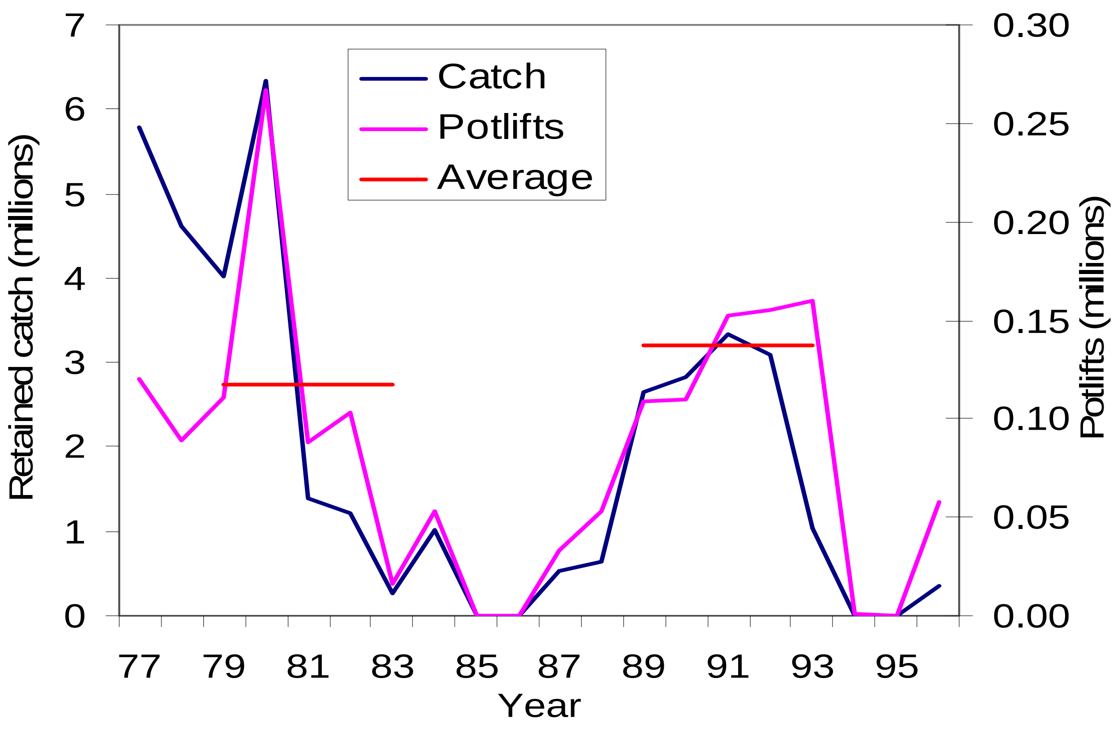

Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163^{o} W (bottom).

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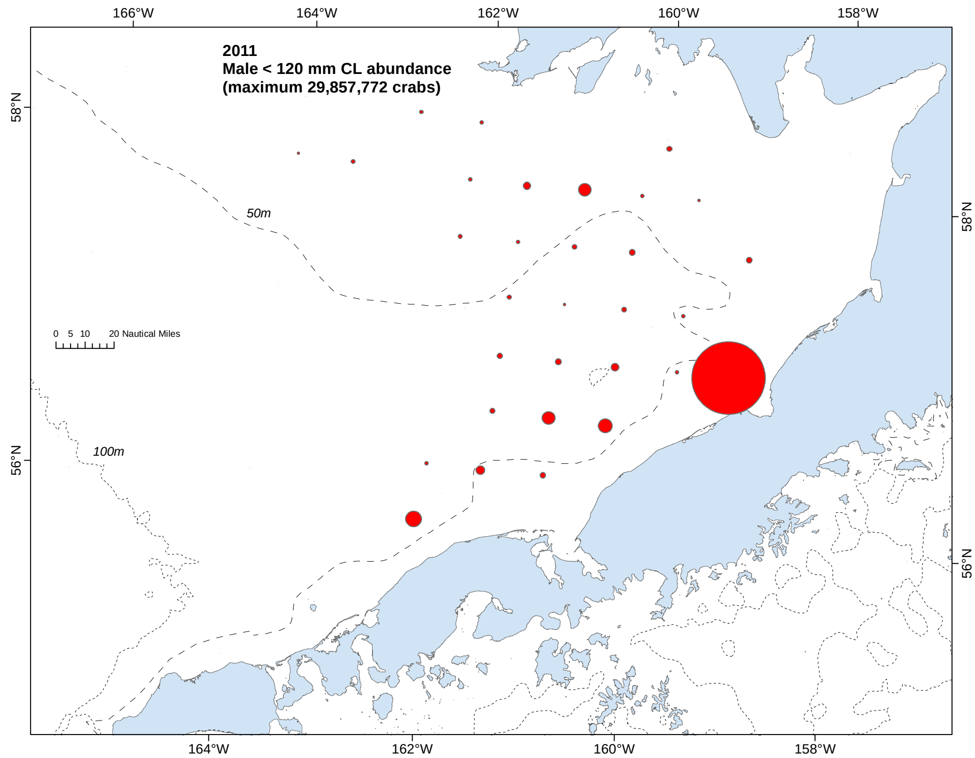
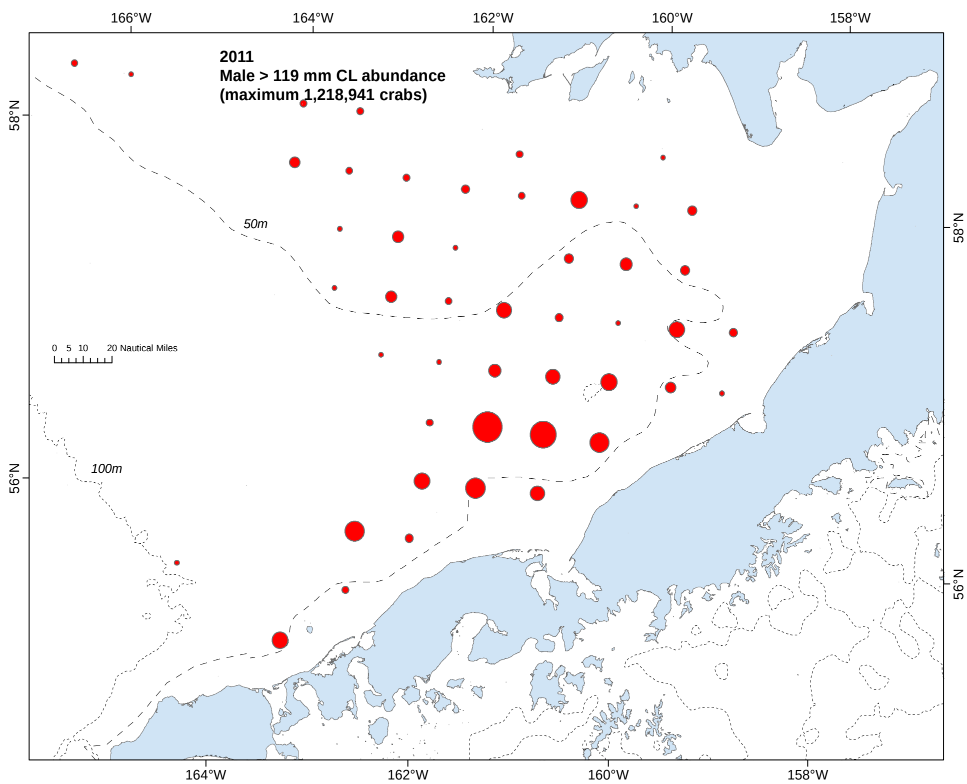
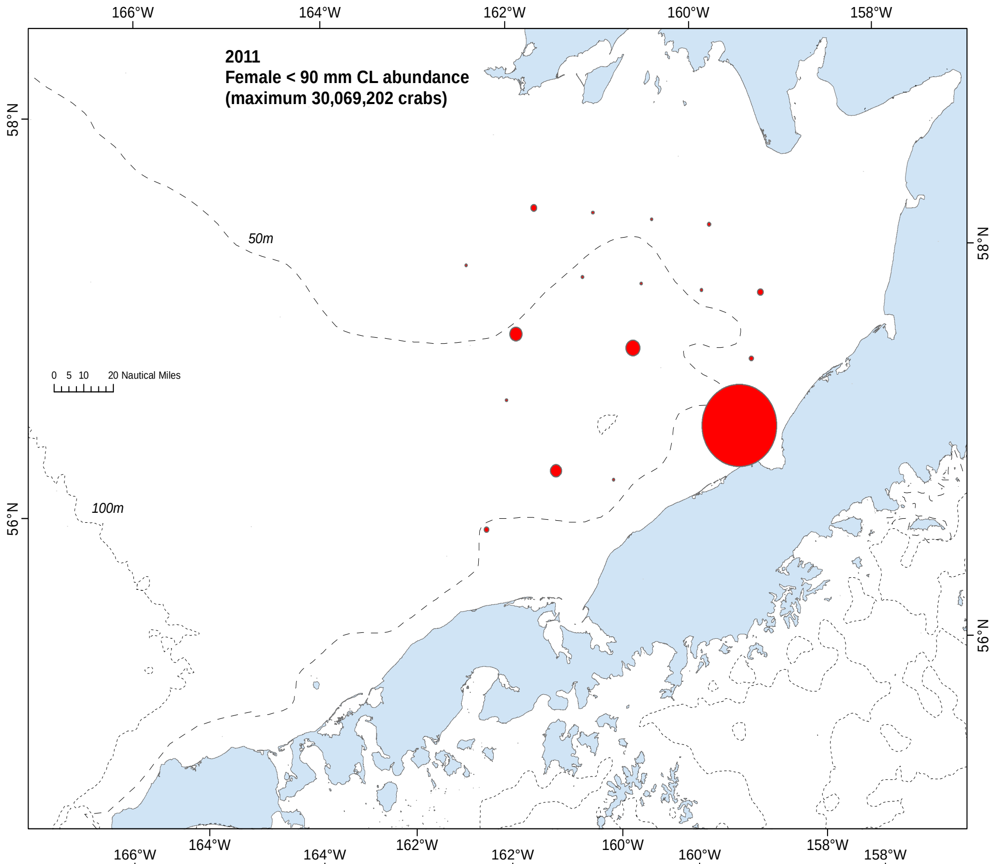
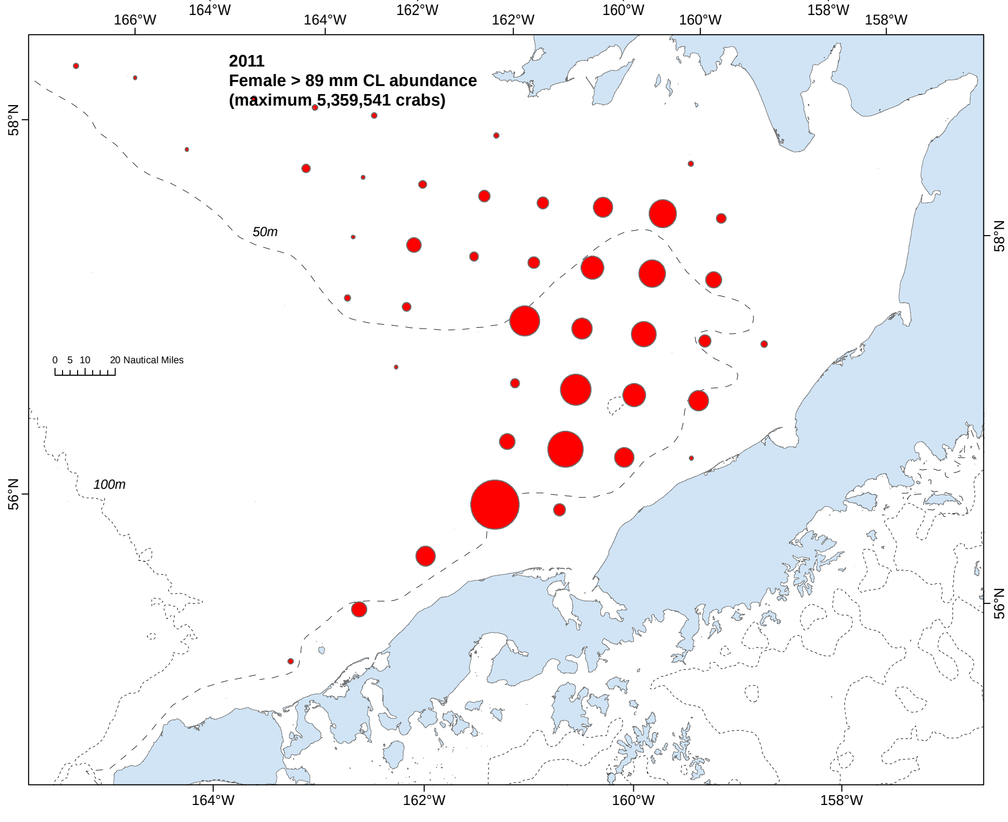
Appendix B. Spatial distributions of mature and juvenile male and female red king crabs in Bristol Bay from 2011-2013 summer standard trawl surveys.



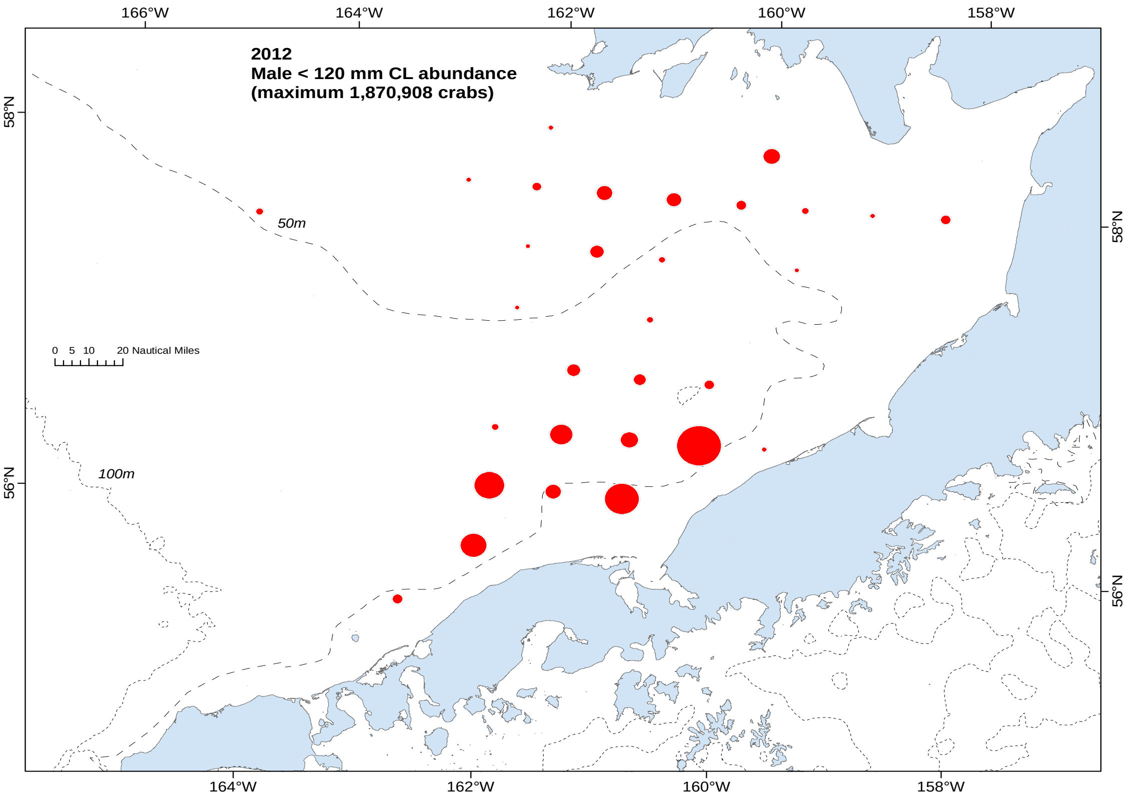


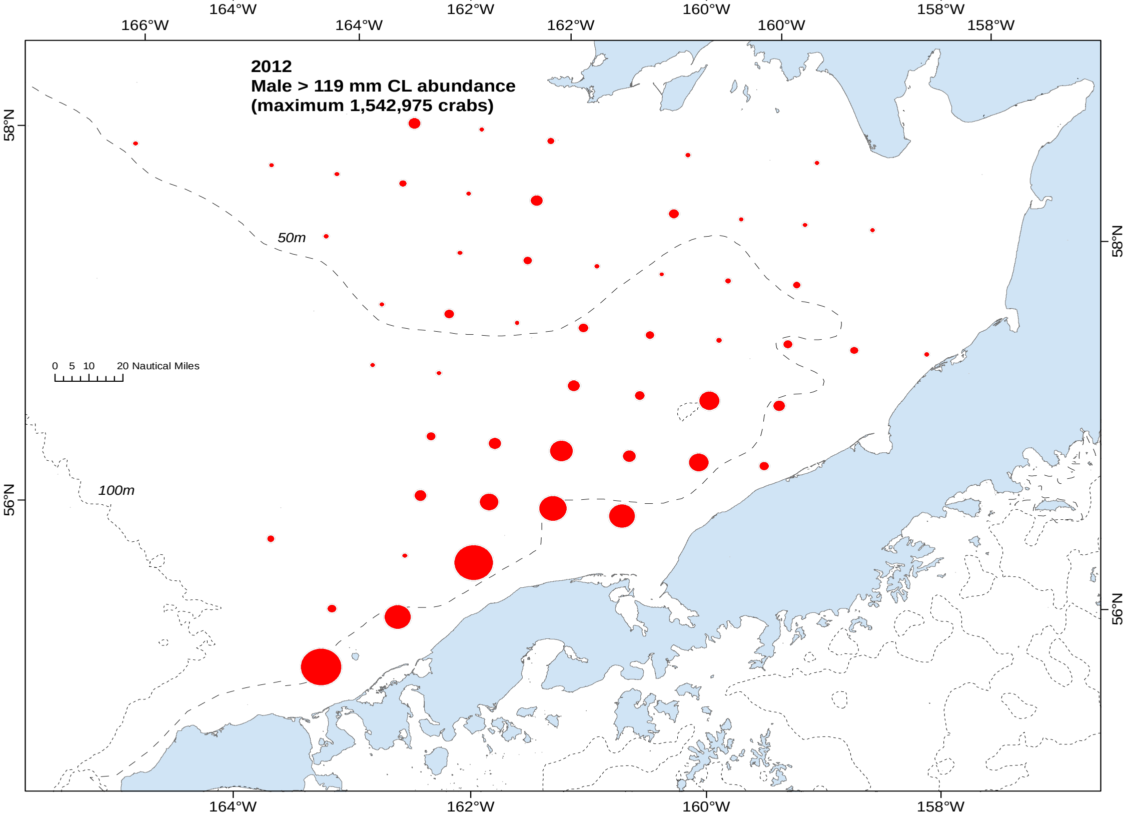
169


2011
Female < 90 mm CL abundance
(maximum 30,069,202 crabs)
50m
100m
0 5 10 20 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

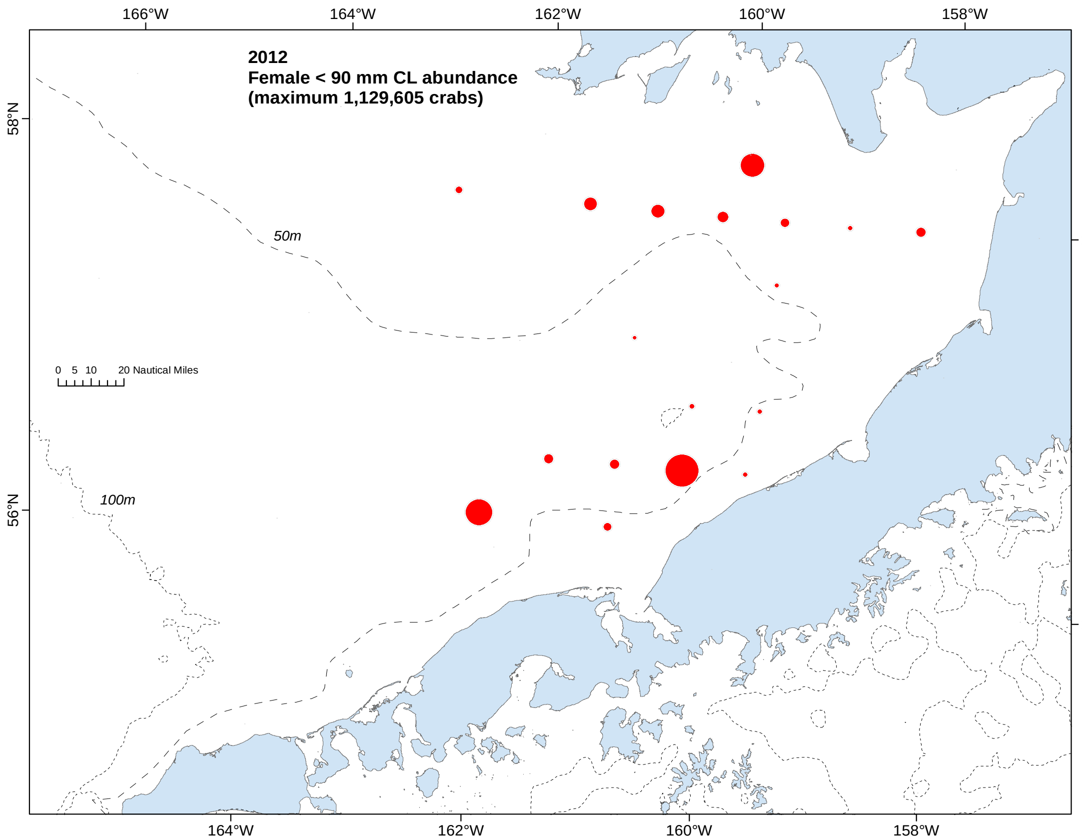

2011
Female > 89 mm CL abundance
(maximum 5,359,541 crabs)
50m
100m
0 5 10 20 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

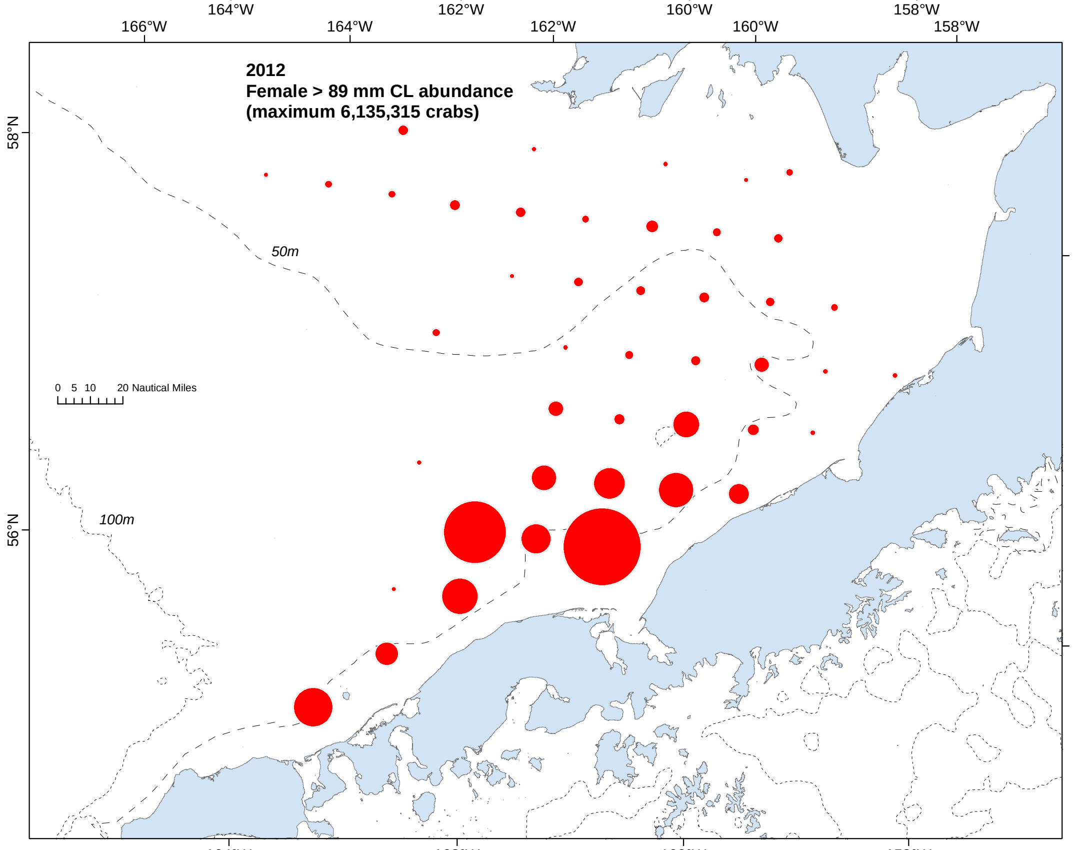
170


2012
Male < 120 mm CL abundance
(maximum 1,870,908 crabs)
50m
100m
0 5 10 20 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

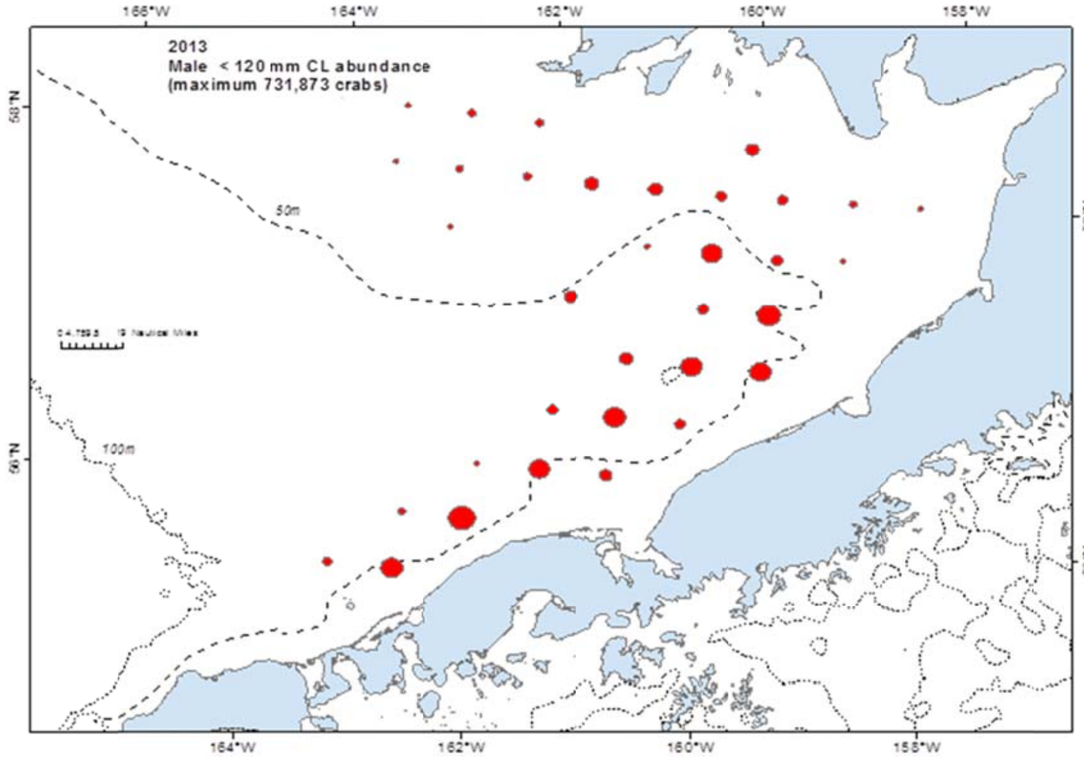

2012
Male > 119 mm CL abundance
(maximum 1,542,975 crabs)
50m
100m
0 5 10 20 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

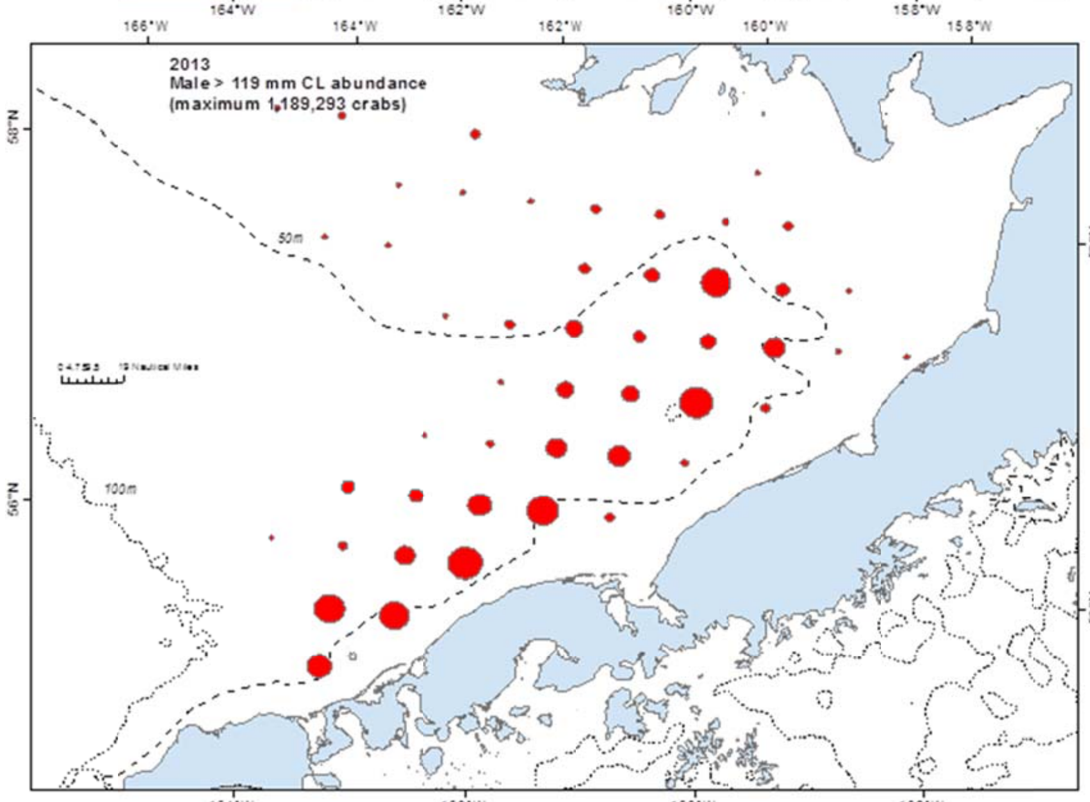
171


2012
Female < 90 mm CL abundance
(maximum 1,129,605 crabs)
166°W
164°W
162°W
160°W
158°W
58°N
56°N
50m
100m
0 5 10 20 Nautical Miles

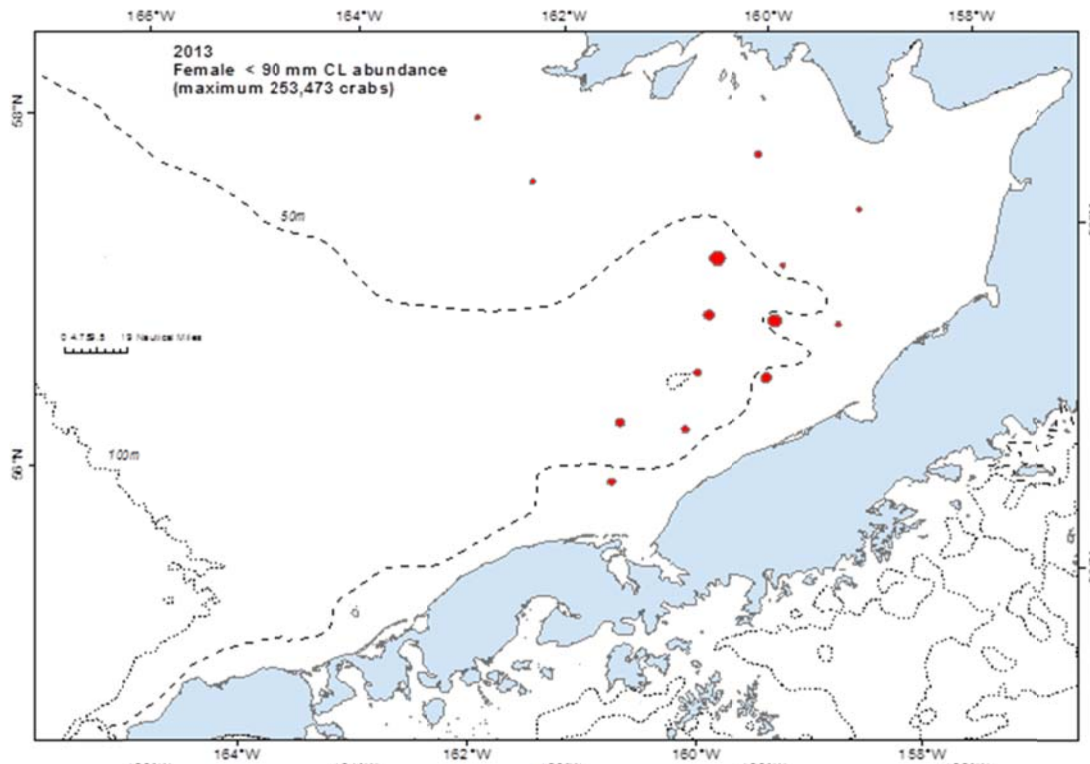

2012
Female > 89 mm CL abundance
(maximum 6,135,315 crabs)
166°W
164°W
162°W
160°W
158°W
58°N
56°N
50m
100m
0 5 10 20 Nautical Miles

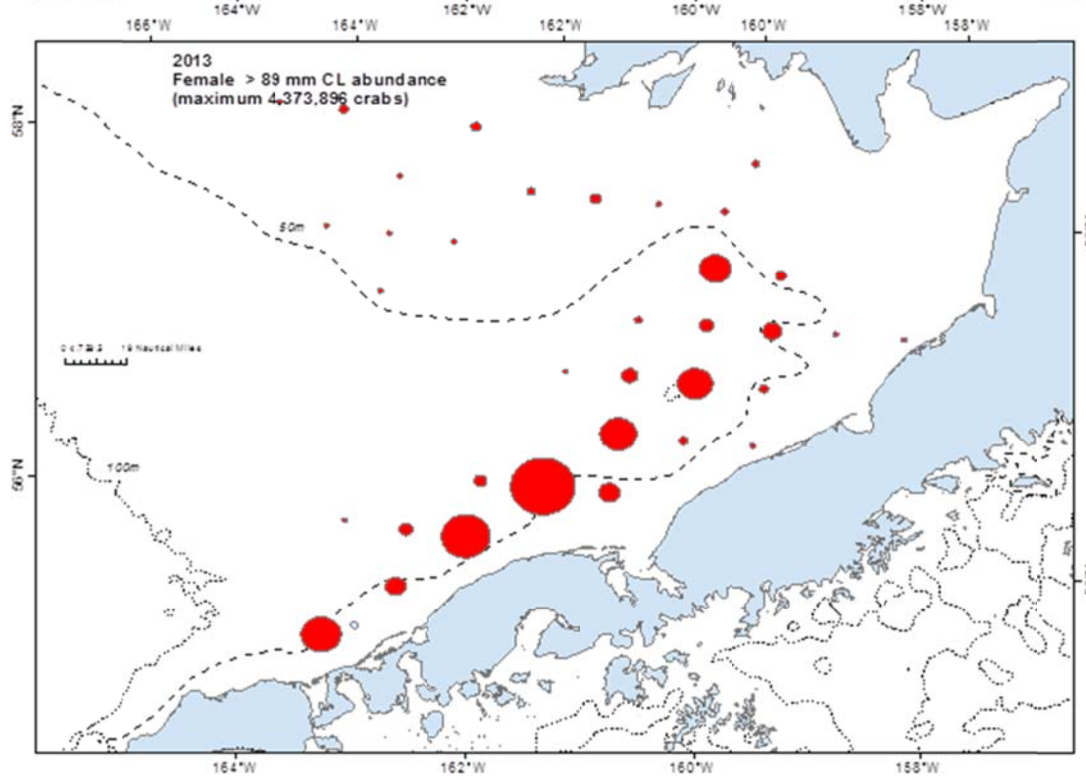
172


2013
Male < 120 mm CL abundance
(maximum 731,873 crabs)
50m
100m


2013
Male > 119 mm CL abundance
(maximum 1,189,293 crabs)
50m
100m

173


2013
Female < 90 mm CL abundance
(maximum 253,473 crabs)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N


2013
Female > 89 mm CL abundance
(maximum 4,373,896 crabs)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

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Draft 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

William T. Stockhausen, Benjamin J. Turnock and Louis J. Rugolo
Alaska Fisheries Science Center
20 September 2013

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 has been closed by the State of Alaska (SOA) during the 2010/11, 2011/12, and 2012/13 fishing years (July 1-June 30) because estimated female stock metrics have not met the required threshold in the state harvest strategy. Prior to these closures, the retained catch averaged 0.77 thousand t per year between 2005/06-2009/10.

Non-retained females and sub-legal males are caught in the directed fishery as bycatch and discarded. 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 797 t for the five year period 2007/08-2011/12. Bycatch in the snow crab fishery in 2012/13 was 1,196 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the five year time period, averaging 395 t, and has been declining steadily 2006/07. Bycatch in the groundfish fisheries in 2012/13 was 112 t, the lowest value in the time series. The Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 53 t over the five year time period, with 44 t caught and discarded in 2012/13

In order to account for mortality of discarded crab, mortality rates are assumed to be 50% 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 principal author's preferred model, estimated MMB in 2012/13 was 59.4 thousand t (Table 14, Figure 30). This was essentially unchanged from that in 2011/12 (59.3 thousand t). MMB has undergone a slight downward trend since its most recent peak in 2009/10 but it remains above the very low levels seen in the mid-1990s to early 2000s (1990 to 2005 average: 31.5 thousand t). However, it is considerably below historic levels in the early 1970s when MMB peaked at 352.5 thousand t (1972/73).

4. Recruitment: trends and current levels relative to virgin or historic levels.
From the principal author's preferred model, estimated male recruitment in 2013/14 (number of crab entering the population on July 1) was 120,593 thousand crab (Table 13, Figure 27; the number of

females recruiting to the population is assumed identical to male recruitment). This represents a 2.6-fold increase over that in 2012/13 (33,758 thousand crab), but a 5.9 decrease over that in 2011/12 (128,170 thousand crab). It was also smaller than those occurring in 2009/10 and 2010/11, but larger than those occurring in 2005/06-2008/09. Going back to 1990/91, the 2013/14 estimated male recruitment ranked the 6^{th} largest (out of 24 years). However, the estimated 2013/14 male recruitment is substantially smaller than those occurring from the early-1960s to 1990, which averaged 317,073 thousand crab.

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
2009/10	92.37[B]	62.70[B]	1.34[a/]	1.32	3.62	5.00[A]	
2010/11	91.87[C]	58.93[C]	0.00	0.00	1.92	3.20[B]	
2011/12	25.13[D]	129.17[D]	0.00	0.00	2.73	6.06[C]	5.47 [C]
2012/13	36.97[E]	130.84[E]	0.00	0.00	1.57	41.93[D]	18.01[D]
2013/14		117.07[E]				55.89[E]	17.64[F]

(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
2009/10	41.90[B]	28.44[B]	0.61[a/]	0.6	1.64	2.27[A]	
2010/11	41.67[C]	26.73[C]	0	0	0.87	1.45[B]	
2011/12	11.40[D]	58.59[D]	0	0	1.24	2.75[C]	2.48[C]
2012/13	16.77[E]	59.35[E]	0	0	0.71	19.02[D]	8.17[D]
2013/14		53.1[E]				25.35[E]	8.0[F]

a/ Only the area east of 166^{o} W opened in 2009/10.
A—Calculated from the assessment reviewed by the Crab Plan Team in 2009.
B—Calculated from the assessment reviewed by the Crab Plan Team in 2010.
C—Calculated from the assessment reviewed by the Crab Plan Team in 2011.
D—Calculated from the assessment reviewed by the Crab Plan Team in 2012.
E—Calculated from the assessment reviewed by the Crab Plan Team in 2013.
F—Recommended by the assessment author in 2013.

6. Basis for the OFL

Basis for the OFL (thousands t).

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2012/13[A]	3a	33.45	58.59	1.75	0.61 yr^{-1}	1982-2012	0.23 yr^{-1} [B]
2013/14[C]	3a	33.54	59.35	1.77	0.73 yr^{-1}	1982-2013	0.23 yr^{-1} [D]

A—Calculated from the assessment reviewed by the Crab Plan Team in 2012.
B—Nominal rate of natural mortality. Actual rates used in the 2012 assessment were 0.25 yr^{-1} for immature females and all males and 0.34 yr^{-1} for mature females.
C—As calculated from the author's preferred model in the 2013 assessment.
D—Nominal rate of natural mortality. Actual rates used in the 2013 assessment were 0.25 yr^{-1} for immature females and all males and 0.34 yr^{-1} for mature females.

Current male spawning stock biomass (MMB) is estimated at 59.35 thousand t. B_{MSY} for this stock is calculated to be 33.54 thousand t, so the minimum stock size threshold (MSST=0.5 B_{MSY}) is 16.77 thousand t. Because current MMB > MSST, **the stock is not overfished**. Total catch mortality (retained + discard mortality in all fisheries) in 2012/13 was 0.71 thousand t, which was less than the OFL for 2012/13 (19.02 thousand t); consequently **overfishing did not occur**.

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, 2012) 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.
Based on a newly-accepted assessment model (Rugolo and Turnock, 2012a), 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. Status determination and OFL setting for Tier 4 stocks generally depends 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.

2. Changes to the input data
No new data sources were incorporated into this assessment. The following table summarizes existing data sources that have been updated for this assessment:

Updated data sources.

Updated data source	Agency	Data types
2013 NMFS EBS Bottom Trawl Survey	NMFS	abundance, size compositions
2012/13 Snow Crab Fishery	ADF&G	discard biomass, effort, size compositions
2012/13 Bristol Bay Red King Crab Fishery	ADF&G	discard biomass, effort, size compositions
2012/13 Groundfish Fisheries	NMFS	discard biomass, size compositions

3. Changes to the assessment methodology.
The assessment methodology (i.e., a Tier 3 assessment model) remains unchanged. However, the model's computer code has undergone (and will be undergoing) extensive revision by the (new principal) author of the assessment. The main focus of this revision is to improve the model's computational speed, flexibility, model output, and general user friendliness. The purpose is not to change the fundamental nature of the model itself, which underwent extensive review prior to approval by the Crab Plan Team (CPT) and SSC. As part of this revision of the model code, a few algorithmic errors in the original code have been identified and corrected, but these appear to have very little impact on model results (based on before/after model runs). These changes are discussed in more detail in Section E.2.

4. Changes to the assessment results
Results from the author's preferred model are quite similar to those from the previous assessment.

B. Responses to SSC and CPT Comments

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

September 2012 Crab Plan Team Meeting
Comment: The CPT "would strongly encourage authors to follow the TOR in so much as it is applicable to individual assessments…"
Response: The assessment authors are endeavoring to fulfill this request. However, a new analyst (Stockhausen) has taken over primary responsibility for the Tanner crab assessment this year and has not been able to completely fulfill this request.

Comment: "One specific recommendation is that information should be reported in assessments regarding whether parameters are hitting bounds."
Response: Table(s) have been included that list values, standard errors, initial estimation phase, indices, parameter bounds, parameter names (in the model code) and parameter types for all model-estimated parameters. Values in the tables are highlighted if they are at either boundary of the valid range.

October 2012 SSC Meeting
No general comments.

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

May 2012 Crab Plan Team Meeting
Comment 1: "Update the weights in table 1 (the weights for all compositional data should be 1.0). Also, replace the weights with CVs where possible."
Response: This was addressed in the 2012 SAFE chapter (see Table 9 in Rugolo and Turnock, 2012).

Comment 2: "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 3: "Indicate the reference size for defining survey-q on plots of survey-q vs. size."
Response: This was addressed in the 2012 SAFE chapter (see Fig.s 66-67 in Rugolo and Turnock, 2012).

Comment 4: "Include a summary of the Somerton and Otto underbag experiments, expressing their estimates of survey q (by sex, mixed species, etc.) in a way that allows direct comparison with the prior assumed for survey-q in the assessment. Confirm that the variance of survey-q from Somerton and Otto matches that assumed in the assessment."
Response: This was addressed in the 2012 SAFE chapter.

Comment 5: "Add an appendix which details the effort series and their derivation."
Response: A table of effort time series (Appendix B) was included in the 2012 SAFE chapter. Doug Pengilly (ADFG) compiled the effort data from ADFG reports. If further information is required, he will need to provide any additional documentation.

Comment 6: "Add the formula used to calculate the input effective sample sizes."
Response: This was included in the 2012 SAFE chapter.

Comment 7: "Add equations which detail how full-selection fishing mortality is calculated for the years without catch using effort and a fishing mortality-effort relationship."
Response: Addressed in the 2012 SAFE chapter.

Comment 8: "Update the plot of M vs. time for Bristol Bay red king crab."
Response: This was addressed in the 2012 assessment. The figure is not repeated here.

Comment 9: "Check that bubble plots are based on Pearson residuals, and check that the summary plots are indeed sums over observed and predicted proportions. Add a key to the Pearson plots which indicates what the largest circle means."
Response: This was addressed in the 2012 assessment. The bubble plots presented in this assessment are based on Pearson residuals. The summary plots are based on means (not sums). Keys are provided to bubble size.

Comment 10: "Add confidence intervals on the data to the summary plots for the compositional data."
Response: Confidence intervals based on the variance-at-size of the observed size compositions (and assumed normal distributions) have been added to all summary plots for compositional data.

Comment 11: "Label the selectivity patterns better so that which curve applies to which year can be better determined."
Response: Selectivity curves for the directed fishery are now labeled by year, while curves corresponding to different time periods in the discard fisheries are now colored differently. The labeling by year for the directed fishery curves is not entirely satisfactory and the author welcomes suggestions on providing more informative graphs.

Comment 12: "Clearly indicate the year on Fig. 39."
Response: Figure 39 is not included in this assessment.

Comment 13: "Add horizontal lines to Fig. 1, indicating the average input effective samples by fleet."
Response: This was addressed in the 2012 SAFE chapter.

Comment 14: "The biomass at the time of the survey should be a dotted line while the model estimate of survey biomass should be a straight line when plotting the fit to the survey data (e.g., Fig.s 17 & 18)."
Response: This was addressed in the 2012 SAFE chapter.

Comment A: "Use the ADMB derivative checker to check for possible impacts of the non-differentiability of the objective function implemented in the code."
Response: The 2012 assessment authors assert that the code is differentiable.

Comment B: "Explore sensitivity to dropping the lower bound for the input effective sample sizes (a lower bound of 4 was imposed for the reference model)."
Response: This was addressed in the 2012 assessment. No lower bound is imposed in the current model.

Comment C: "Explore sensitivity to allowing the input effective sample sizes for the survey to vary over time (with an average effective sample size of 200). The effective sample size for a given category of data in a given year would be 200 multiplied by the annual sample size divided by the average sample size (no caps or minimum effective sample sizes)."
Response: This was addressed in the 2012 assessment. The accepted model used an effective sample size of 200 used for all compositional data from the survey, as is done here.

Comment D: "Allow for a difference in selectivity by sex for the groundfish fishery to see if this resolves the poor residual pattern for this fishery."
Response: This was addressed in the 2012 assessment. It does not resolve this issue.

Comment E: "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: The change in female M in this period is small and could be eliminated (but has not been for consistency with the 2012 assessment). This will be addressed prior to the May 2014 CPT meeting.

Comment F: "Include plots which show the fits to the survey biomass indices from the reference model presented to the 2011 CPT Meeting, the model at the end of the January 2012 workshop, and the final reference model."
Response: This comparison was addressed in the 2012 assessment.

Comment G: "Include the following runs for consideration by the CPT as a potential reference model for September 2012: a) the current reference model (modified based on recommendations "C" and "D" above; b) alternative specifications related to which Ms are estimated and which are fixed; c)a likelihood profile for survey-q for males; and d) the other runs identified in the ToR (e.g., retrospective patterns; runs based on changing the emphasis on different likelihood components).
Response: All components of this comment except d) were addressed in the 2012 SAFE chapter. The current model code structure does not easily allow retrospective analyses to be conducted and time did not permit these to be run for this assessment. This issue will be addressed prior to the May 2014 CPT meeting as part of the ongoing model code revision.

Comment H: "The assessment document should only contain detailed results…and diagnostics for the current reference model, as well as plots of recruitment and MMB time-series and tables of likelihood components for the remaining analyses. The full set of diagnostic plots should be made available electronically…."
Response: This was addressed in the 2012 assessment.

Comment 1 (Longer-term tasks): "Consider implementing the ability to change the penalty weight on F-deviations as a function of estimation phase…"
Response: Not yet addressed. This will be addressed prior to the May 2014 CPT meeting as part of the model code revision.

Comment 2 (Longer-term tasks): "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 3 (Longer-term tasks): "Consider different effective sample sizes for each category of survey compositional data (males+females*mature+immature)."
Response: Different effective sample sizes are currently used for male and female compositional survey data, but these are not broken down further. This will be addressed prior to the May 2014 CPT meeting.

Comment 4 (Longer-term tasks): "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 5 (Longer-term tasks): "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 6 (Longer-term tasks): "Base the assessment on code which is fully documented and for which the objective function is differentiable."
Response: The objective function of the assessment model is fully differentiable (Rugolo and Turnock, 2012). The code is undergoing a complete review and revision by the new assessment author.

Comment Action 1 (rebuilding analysis): "Add a scenario in which the full-selected F on Tanner crab due to the snow crab fishery is set based on snow crab $F_{35\%}$..."
Response: No rebuilding analyses were required for this assessment, so this comment was not addressed.

Comment Action 2 (rebuilding analysis): "Estimate the stock-recruitment relationship autocorrelation parameter and the extent of implementation error for Tanner crab."
Response: This was addressed in the 2012 SAFE chapter.

Comment Action 3 (rebuilding analysis): "Base analyses on a broad range of $B_{35\%}$ definitions."
Response: No rebuilding analyses were required for this assessment. However, results based on six recruitment-averaging scenarios are presented for determining $B_{35\%}$ for status determination and OFL setting based on the author's preferred model.

Comment Action 4 (rebuilding analysis): "Keep the total selectivity the same but change the retained selectivity for the fishery west of 166^{o}W to reflect the change in minimum size limit."
Response: This was implemented for calculating the OFL. See Fig. 74.

June 2012 SSC Meeting
Comment: "The SSC…recommends the authors bring forward several plausible models using various recruitment time series including a scenario that includes all years with reasonably estimated recruitment."
Response: Five recruitment-averaging scenarios were presented as the basis for status determination and rebuilding analyses in the 2012 SAFE chapter. Six scenarios are presented here for status determination and OFL setting.

September 2012 Crab Plan Team Meeting
Comment: "Plot input sample sizes for LF data vs. effective sample sizes inferred by the fit of the model"
Response: Not yet addressed.

Comment: "Add an appendix which details the effort series and their derivations."
Response: The effort time series were provided in the 2012 SAFE chapter as Appendix B. Doug Pengilly (ADFG) compiled the effort data from ADFG reports. If further information is required, he will need to provide any additional documentation.

Comment: "Add confidence intervals on the data to the summary plots for the compositional data."
Response: Confidence intervals based on the variance-at-size of the observed size compositions (and assumed normal distributions) have been added to all summary plots for compositional data.

Comment: "The description of the model should be carefully checked. Two errors in model description were noted: (a) fishing mortality by the Bristol Bay red king crab and EBS snow crab fisheries is related to effort not catch; and (b) selectivity for bycatch by the EBS snow crab fishery is assumed to be dome-shaped and not asymptotic."
Response: Not yet addressed. The model description included in the SAFE chapter will be rewritten prior to the May 2014 CPT meeting.

Comment: "The parameter table (Table 8) is useful but (a) some parameters were missed, (b) the upper and lower bounds of the parameters were missing, and (c) some derived quantities (length at 50% selectivity for the fishery) were reported by the standard errors were incorrect."
Response: The parameter table now lists all the values of all parameters estimated within the model, associated uncertainties (standard errors), initial estimation phase, min and max bounds on each parameter, and highlights those parameter estimates that lie on a boundary.

Comment: "Correct the labels on Figures 24 and 25."
Response: The labels in the 2012 SAFE chapter were correct. The figures are not repeated here.

Comment: "The seemingly anomalous values [for length at 50% selectivity] may be due to confounding among parameters and need to be explored further."
Response: Not yet addressed.

Comment: "The fits to the groundfish length-frequency data (e.g. Fig. 51) and to the total catch are unexpectedly poor. Model configurations which better capture the data should be explored."
Response: Not yet addressed.

Comment: "The caption to Fig. 46 should indicate this figure pertains to the directed fishery and not all fisheries."
Response: The figure caption (but not necessarily the graph title) clearly indicates this figure refers to the directed fishery. The graph title will be corrected.

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 for May 2013."
Response: Not yet addressed.

Comment: "The table of model-predicted discards should start when the model first predicts discards. Similarly, the tables of model-predicted MMB and recruitment should include all years included in the model."
Response: Tables for predicted MMB and recruitment now include all years included in the model. The table for predicted discards .includes only those years for which observed discards exist. If desired, this could be extended in future assessments, to include the full range of model years.

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: Not yet addressed.

October 2012 SSC Meeting

Comment: "The SSC encourages the analysts to continue to explore alternative model formulations (variable growth, variable mortality, etc.) that may address patterns in model residuals (e.g., Fig. 37 and 39)."
Response: Not yet addressed.

Comment: "The SSC requests further analysis alternative time periods by the stock assessment authors and Crab Plan Team to include options based on years in which recruitment was reasonable [sic] estimated, additional break-point analyses, and evidence for shifts in Tanner crab life history and ecology. The SSC requests that one option should include a time series spanning the extent of reasonably estimated recruitments based on confidence intervals for recruitment."
Response: This request is partially addressed in Appendix A to this chapter.

Comment: "The SSC requests the assessment authors to include a plot similar to Fig. 54 of the assessment chapter in which recruitment (y-axis) is plotted against egg production indices (x-axis) from Fig. 14."
Response: Not yet addressed.

C. Introduction

1. Scientific name.
*Chionocoetes bairdi.*Tanner crab is one of five species in the genus *Chionoecetes*. 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 (Figure 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, 2011b). 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 (1981a) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

Although the State of Alaska's (SOA) harvest strategy and management controls for this stock are different east and west of 166^{o}W, the unit stock of Tanner crab in the EBS appears to encompass both regions and comprises crab throughout the geographic range of the NMFS bottom trawl survey. 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 particularly 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, we have consequently lumped crab classified into SCs 3-5 as “old-shell” crab, indicating that these are crab likely to have not molted within the previous year. In a similar fashion, we have combined crab classified in SCs 0-2 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 sadly lacking and in this assessment we use ones derived from data collected near Kodiak Island in the Gulf of Alaska (Munk pers. comm., Donaldson et al. 1981). Using this data, Rugolo and Turnock (2012a) derived growth relationships for male and female Tanner crab using data on observed growth for males to approximately 140 mm carapace width (CW) and for females to approximately 115 mm CW. 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 Stone et al. (2003), Somerton (1981), and Donaldson et al. (1981).

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 Length

Rugolo and Turnock (2012a) derived weight-at-size relationships for male (regardless of maturity state), 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 grams and z is size in mm CW, were fit to the survey data. The resulting parameter estimates are given in the following table:

parameter	males	females	
	all	immature	mature
a	0.00016	0.00064	0.00034
b	3.136	2.794	2.956

These relationships are used in the assessment model to convert individual size to biomass.

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 status 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 2004a). 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 2004a).

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 waest 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 (2011) 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 2011). 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 (2011) 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 or further subdivide 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 (Figure 1) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36'N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173°W. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168°W and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit 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). For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas: above 5.5" (138 mm CW) in the east and 5" (>127 mm CW) in the west.

In this report, we will use the terms "east region" and "west region" as shorthand to refer to the regions demarcated by 166°W. We will also use the term "legal males" to refer to male crab ≥ 138 mm CW, although this is no longer strictly correct given the new lower size limit west of 166°W.

Landings of Tanner crab in the Japanese pot and tangle net fisheries were reported in the period 1965-1978, peaking at 19.95 thousand t in 1969. The Russian tangle net fishery was prosecuted during 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s (Table 1; Figures 2, 3). Foreign fishing for Tanner crab ended in 1980.

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1, 2; Figures 2, 3). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery (Table 1). 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 1, 2; Figure 2). 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. The domestic Tanner crab fishery re-opened in 2005/06 and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Tables 1, 2). For the 2010/11-2012/13 seasons, the State of Alaska has closed directed commercial fishing for Tanner crab due to estimated female stock metrics being below thresholds adopted in the state harvest strategy.

Discard and bycatch losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Table 3, Fig. 4). Discard mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). The pattern of total discard/bycatch losses is similar to that of the retained catch. Losses were persistently high during the early-1970s; a subsequent peak mode of discard losses occurred in the early-1990s. In the early-1970s, the groundfish fisheries contributed significantly to total bycatch losses, although the combined crab pot fisheries are the principal source of contemporary non-retained losses to the stock.

D. Data

1. Summary of new information

No new data sources were incorporated into this assessment. The following table summarizes existing data sources that have been updated for this assessment:

Updated data sources.

Updated data source	Agency	Data types
2013 NMFS EBS Bottom Trawl Survey	NMFS	abundance, size compositions
2012/13 Snow Crab Fishery	ADF&G	discard biomass, effort, size compositions
2012/13 Bristol Bay Red King Crab Fishery	ADF&G	discard biomass, effort, size compositions
2012/13 Groundfish Fisheries	NMFS	discard biomass, size compositions

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. As a shorthand, “2008” should be understood to represent 2008/09.

a. Total catch

Retained catch (1000’s t) in the directed fisheries for Tanner crab conducted by the foreign fisheries (Japan and Russia) and the domestic fleet, starting in 1965/66, is presented in Table 1 (and Fig.s 2, 3) by fishery year. More detailed information on retained catch in the directed domestic pot fishery is provided in Table 2, which lists total annual catches in numbers of crab and biomass (lb), 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 discards (1000’s t) of Tanner crab by sex are provided in Table 3 (and Fig.s 4, 5) 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 Figure 6 for new and old shell crab from 1980/81-2009/10 (the last year the directed fishery was conducted). Relative size compositions of total catch (retained + discards) from crab observer sampling in 1991/92-2009/10 are presented in Fig. 7 for new and old shell male crab and in Fig. 8 for female crab (all shell conditions combined). Relative size compositions for bycatch in the snow crab fishery from crab observer sampling is presented in Fig. 9 by shell condition for male Tanner crab and in Fig. 10 for undifferentiated females. Fig.s 11 and 12 present similar information from crab observer sampling for the BBRKC fishery. Figures 13 and 14 present 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 4-8.

d. Survey biomass estimates
Annual estimates (1000's t) of mature biomass by sex from the summertime NMFS bottom trawl survey are given in Table 9 (and plotted in Fig. 15), as is abundance (numbers) of "legal" crab (≥ 138 mm CW). The percent change in survey estimates of mature biomass and "legal" male abundance from 2012 to 2013 is plotted in Fig. 16.

e. Survey catch-at-length
Plots of survey catch-at-size are presented for male and female crab in Fig.s 17 and 18, respectively, by maturity state (immature, mature). For males, the number of new shell crab that were mature (immature) was estimated by applying Rugolo and Turnock's (2010) fraction mature-at-size curve (1.0-the curve) to the numbers-at-size for new shell males found in the survey. For females, maturity status was determined in the field from morphological observations. Sample sizes for these size compositions are presented in Table 10.

f. Other time series data.
The spatial patterns of abundance in the 2010-2013 NMFS bottom trawl surveys are plotted in Fig.s 19-23 for immature males, mature males, "legal" 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 11).

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. 24. These curves provide the basis for priors on sex-specific growth estimated within the assessment model.

b. Weight-at size
Weight-at-size curves used in the assessment model for males, immature females, and mature females are presented in Fig. 25.

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.
None.

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. Review findings and recommendations by the January 2012 Workshop and 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, 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. In an ongoing effort, I have attempted to modify the TCSAM computer code to improve code readability, computational speed, model output, and user friendliness without altering its underlying dynamics and overall framework. In the process, I have found a few minor coding errors that do not appear to have had a substantial impact on model performance.

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 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.

b. Changes since the previous assessment.

The C++ code used to implement the model has undergone (and will be undergoing) extensive revision by the (new) principal author of the assessment. The main focus of this revision is to improve the model's computational speed, flexibility, model output, and general user friendliness. The purpose is not to change the fundamental nature of the model itself, which underwent extensive review prior to approval by the Crab Plan Team and SSC. As part of this revision of the model code, a few algorithmic errors in the original code have been identified and corrected, but these appear to have very little impact on model results (based on before/after model runs).

The principal algorithmic error occurs in the following C++ code fragment from the 2012 TCSAM model:

```
if(i>=lyr_mort && i<=uyr_mort && mort_switch==1) {
 natl_inew_fishtime(sex,i) = mfexp(-catch_midpt(i)*M(sex))*natlength_inew(sex,i);
 natl_iold_fishtime(sex,i) = mfexp(-catch_midpt(i)*M(sex))*natlength_iold(sex,i);
 natl_mnew_fishtime(sex,i) = mfexp(-
      catch_midpt(i)*M_matn(sex)*mat_big(sex))*natlength_mnew(sex,i);
 natl_mold_fishtime(sex,i) = mfexp(-
      catch_midpt(i)*M_mato(sex)*mat_big(sex))*natlength_mold(sex,i);
 natl_new_fishtime(sex,i) = natl_inew_fishtime(sex,i)+natl_mnew_fishtime(sex,i);
 natl_old_fishtime(sex,i) = natl_iold_fishtime(sex,i)+natl_mold_fishtime(sex,i);
}
natl_inew_fishtime(sex,i) = mfexp(-catch_midpt(i)*M(sex))*natlength_inew(sex,i);
natl_iold_fishtime(sex,i) = mfexp(-catch_midpt(i)*M(sex))*natlength_iold(sex,i);
natl_mnew_fishtime(sex,i) = mfexp(-catch_midpt(i)*M_matn(sex))*natlength_mnew(sex,i);
natl_mold_fishtime(sex,i) = mfexp(-catch_midpt(i)*M_mato(sex))*natlength_mold(sex,i);
natl_new_fishtime(sex,i) = natl_inew_fishtime(sex,i)+natl_mnew_fishtime(sex,i);
natl_old_fishtime(sex,i) = natl_iold_fishtime(sex,i)+natl_mold_fishtime(sex,i);
```

The intent of this code fragment is to apply `mat_big(sex)` as a multiplier to `M_matn(sex)` and `M_mato(sex)` during years `i` that fall within a period of increased natural mortality on mature crab when calculating `natl_mnew_fishtime` and `natl_mold_fishtime` inside the set of brackets (highlighted in yellow). These quantities are calculated if `lyr_mort≤i≤uyr_mort`. However, `natl_mnew_fishtime` and `natl_mold_fishtime` are immediately recalculated when execution of the code emerges from block in brackets, thus removing the effect of the period of increased natural mortality. Ultimately, this error affected the predicted numbers caught, not the numbers surviving to the next year. Model 01 was run with this error corrected. From a practical standpoint, as will be seen, the effects of this error were extremely small.

Another change to the model code involved how "devs" of different types were handled. In the 2012 model, log-scale recruitment deviations ("devs") in the first model year were identical to those in the second model year (i.e., the same "dev" value was applied to recruitment in both 1949 and 1950). While this seems like it should have very little effect on model results (and it doesn't where data is available to inform the model), it apparently results in an overall scaling of "early recruitment" (see below). Additionally, the indexing of log-scale fishing mortality "devs" in the directed Tanner crab fishery was changed by one year relative to the population model.

i. Methods used to validate the code used to implement the model

The model code has been reviewed by members of the CPT and the new principal author of the assessment.

3. Model Selection and Evaluation

a. Description of alternative model configurations

Two alternative model configurations were considered in this assessment. Model 00 is based directly on the 2012 assessment model configuration. The alternative, Model 01, incorporates bug fixes to the TCSAM computer code.

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

Parameter values from the converged model runs are compared in Table 12 for the previous assessment model (2012 Model) and the two alternative models considered here. Parameter bounds, initial estimation phase, valid indices, type and name in the corresponding TCSAM code are also listed. The parameter estimates from the two alternative models considered in this assessment are quite similar. The parameter estimates from the 2012 assessment model and the two alternative models are, on the whole, quite similar except for parameters related to “early recruitment” (recruitment prior to 1974; both log-scale mean [`mean_log_rec1_early/pMnLnRecEarly`] and deviations [`rec_devf_early/pRecDevsEarly`]), log-scale fishing mortality deviations in the directed fishery (`fmort_dev/pFmDevsTCF`), and size at 50% selectivity for female bycatch in the BBRKC pot fishery (`rkfish_disc_sel50_f1`, `rkfish_disc_sel50_f2`, `rkfish_disc_sel50_f3`).

For the selectivity parameters, the 2012 model parameter estimates were at the allowed upper bounds (150, 150, and 170, respectively), while those for the two alternative models were well within the bounds (~95, ~105, ~163, respectively) (Table 12). A small set of parameters hit their bounds in all three models. These are primarily sex-specific parameters (“matestm”, “matestf” in Table 12) concerned with estimating the probability of immature shell crab molting to maturity as a function of size. The parameters that describe these probabilities at small sizes go to the lower bounds (indicating the probability of maturing is 0 for small crab, as one would expect, while the ones describing the probabilities at large sizes go to the upper bounds (again, as one would expect). Other parameters that hit bounds describe certain selectivity curves associated with the discard fisheries. These are both areas where model reparameterization or imposing “priors” (soft penalties) rather than hard bounds might be helpful to model convergence and stability.

The differences in “early recruitment” parameters noted previously result in somewhat similar population trajectories (Table 13, Fig. 27), but at different overall levels) prior to 1965 (when actual observations are first available in the models). Subsequent to 1965, estimated annual recruitment levels are quite similar.

The differences between the log-scale fishing mortality deviations for the 2012 model and the two 2013 alternative models reflects an apparent indexing error in the 2012 assessment model code that has subsequently been corrected in the current model code. This is apparent by comparing the `fmort_dev/pFMDevsTCF` values (Table 12) starting at index 4 for the value in the 2012 model and comparing it with the values at the next index (e.g., 5) for Model 00. It should also be noted that the final value of `fmort_devs` (index 35) in the 2012 model was 0. However, the impact of this indexing error is quite small, as can be seen in Fig.s 28 and 29. The estimated fully-selected fishing mortality in the directed fishery on all males (Fig. 28) and on retained males (Fig. 29) is essentially identical for the 2012 assessment model and Model 00 after 1969. The effect of the corrections to the model code involving the increased mortality on mature crab (`big_mort`; discussed above) in the early 1980s can also be seen in the figures: the timing of the peak in fishing mortality for the directed fishery is shifted from 1979 in Model 00 to 1980 in Model 01.

The differences noted among the models appear to have no real cumulative effect on estimates of recent population trends (i.e., post-1985, say), as evidenced by the similarities in estimates of: 1) recruitment time series (Table 13, Fig. 27); 2) fully-selected fishing mortality in the directed fishery (Fig.s 28-29); 3) MMB (Table 14, Fig. 30); 4) abundance of “legal-sized” males (Table15, Fig. 31); and 5) fully-selected bycatch fishing mortalities in the snow crab (Fig. 32), BBRKC fishery (Fig. 33), and groundfish fisheries (Fig. 34).

The 2012 model and the alternative models considered here also result in nearly identical fits to fishery catch data, as evidenced by comparisons of model-predicted to observed values for retained catch (Table 16, Fig. 35), total male catch (Table 17, Fig. 36), and discard mortality on females in the directed fishery (Table 18, Fig. 37).

c. Evidence of search for balance between realistic (but possibly overparameterized) and simpler (but not realistic) models.

No such search was conducted for this assessment.

d. Convergence status and convergence criteria for the base-case model

Convergence in both alternative models was assessed by running the models from a set of different initial parameter configurations. For each of these initial runs, the final parameter estimates from the run were used as initial parameter estimates in a following run and this sequence was repeated until the final objective function value obtained was identical to that from the previous run. The final model with the smallest objective function value was selected as the "converged" model.

e. Sample sizes assumed for the compositional data

Sample sizes assumed for compositional data 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.

f. Parameter sensibility

All model parameter estimates obtained from both alternative models appear to be reasonable, except for the final two values of the `matestm` parameter vector. These two parameters are related to the probability of an immature male crab in the two largest size classes in the model (172, 177 mm CW) becoming mature upon molting. In both alternative models, the parameter estimates are such that this probability is less than 1. If there were immature crab this large, it seems highly unlikely that they would not become mature following their next molt. This would seem to be a deficiency in the model specification, because there is no constraint on the probability at size of maturing on molt that it be a strictly increasing function (which it intuitively should be), although there is a constraint on smoothness.

g. Criteria used to evaluate the model or to choose among alternative models

Although goodness of fit and likelihood criteria were examined in comparing the two alternative models, the criterion for model selection that was used was, ultimately, the perceived correctness of the underlying model code.

h. Residual analysis

Residual analysis for the preferred model is presented below.

i. Evaluation of the model(s)

The final values of the objective function (the negative log-likelihood with penalties) minimized in the parameter estimation were 1,439.85 for Model 00 and 1,441.18 for Model 01. It is somewhat disappointing that Model 01, the model using the corrected computer code, did not achieve a better overall fit to the data (smaller objective function) than Model 00, but there was no real a priori reason to think this would be the case. The largest individual contributions to the objective function for both models, not surprisingly, came from the fits to the survey size compositions and survey mature biomass (Fig. 38, Table 19).

Model 01 achieved better fits to the data than Model 00 for mature male size compositions and mature survey biomass (Fig. 39), whereas Model 00 achieved better fits to the size compositions for the groundfish fishery, immature males in the survey, and mature males in the survey.

The author's preferred model is Model 01. It was selected because it is based on the most correct model code.

4. Results (best model(s))

Model 01 is the author's preferred model and is considered the "best" model.

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 4-8. Input sample sizes for all survey-related size compositions were set to 200. Weighting factors for likelihood components and penalties are listed in Table 19, as are the associated negative log-likelihood and 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 12.

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

Estimates of MMB are listed in Table 14. Estimates of the number of "legal" males (≥ 138 mm CW) are listed in Table 15.

iii. Recruitment time series

The estimated recruitment time series is listed in Table 13.

iv. Time series of catch divided by biomass.

Catch divided by biomass (i.e., exploitation rate) is plotted for the author's preferred model (Fig. 49), but is not presented in a table.

c. Graphs of estimates

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

Model-estimated growth curves are compared with empirical curves developed from growth data on tanner crab in the GOA near Kodiak Island are shown in Figure 40. 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. The model-estimated sex-specific probabilities at size of immature crab molting to maturity are shown in Figure 41. As noted above, the curve for males suggests an unlikely decline at the largest sizes. 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.

Estimates of natural mortality by sex and maturity state are shown in Figure 42. Mortality rates are assumed equal by sex for immature crab, but are allowed to be different 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 (Jie et al., 2012) and was identified as a separate period for Tanner crab in the 2012 assessment. The values estimated by the author's preferred model are almost identical to those estimated by the 2012 assessment model, except that the 2012 model estimated a larger reduction in mature female M during the 1980-1984 time period (from 0.34 to o.275 yr^{-1}) than did Model 01 (from 0.34 to 0.31 yr^{-1}).

Estimated total selectivity for males in the directed fishery shows a fairly wide variation over time, with a spread of size at 50% selection varying over ~50 mm CW (Fig. 43). Retained selectivity shows a much narrower range over time, with only the curve for 2009/10 standing out from the rest. This may reflect the closure of the area west of 166^{o} W to fishing in 2009/10.

Estimated bycatch selectivity curves for males and females are shown in Fig. 44 for the snow crab fishery, in Fig. 45 for the BBRKC fishery, and in Fig. 46 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.

Estimated survey selectivity curves for males and females in three time periods (1974-1981, 1982-1987, and 1988-present) are shown in Fig. 47, together with the selectivity curves inferred from Somerton's "underbag" experiments (Somerton and Otto, 1999). The curves are quite similar to those obtained by the 2012 assessment momdel.

iii. Estimated full selection F over time

Model-estimated full selection fishing mortality in the directed fishery (Fig. 48) peaked in 1980 at a value larger than 2, then rapidly declined and was at low levels in the mid-1980s. It peaked again in 1993 and has subsequently declined to low levels (when the fishery was open). Exploitation rates (catch/biomass) in the directed fishery for total catch and legal-sized males followed similar trends (Fig. 49), with exploitation rates reaching almost 80% on legal 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 in Fig. 50. The model under-predicts mature female survey biomass in the early 1980s and 1990s. It also under-predicts mature male survey biomass in the early 1990s as well as in the mid-2000s. The scale of the standardized log-scale residuals (Fig. 51) indicates a mediocre fit 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 total mature biomass in the survey is compared to the model-predicted total mature biomass in the survey in Fig. 52. Also plotted is the model-predicted total mature biomass at the time of the survey. The model consistently underestimates total mature biomass as seen in the survey.

The time series of model-predicted MMB (i.e., mature male biomass at the time of mating), mature female biomass at the time of mating, and total mature biomass at the time of mating in Fig. 53. All three time series build relatively slowly from zero in 1949 (when the model starts) until the mid-1960s, when the spawning stock rapidly builds to a peak in 1972 and just as rapidly declines to a minimum in 1985. It rebuilds somewhat to a much lower peak in 1989 and subsequently declines to a minimum in 1999. Since 1999, MMB has increased rather steadily while mature female biomass at mating time has remained low.

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

The model fit to retained catch in the directed fishery is provided in Fig. 35. The model fit to total male (retained + discarded) catch in the directed fishery is provided in Fig. 36. The model fit to female discard mortality in the directed fishery is shown in Fig. 37. The fits are quite good for males, but less so for females.

ii. Graphs of model fits to survey numbers

Model predictions for total numbers of legal males (≥ 138 mm CW) in the population and in the survey are compared with observations from the survey in Fig. 54. The model appears to over-predict numbers of crab in recent years. Model-estimated numbers of males and females in the survey are compared with observed numbers in Fig. 55. The model underpredicts the decline in survey numbers of both males and females in the mid-1980s and anticipates the subsequent increase in survey numbers to 1990. More recently, the model seems to be under-estimating the numbers of both sexes in the survey. The model appears to predict survey numbers of all mature female crab (Fig. 56) and all mature male crab (Fig. 57) reasonably well, but not as sub-components broken into new shell and old shell categories. It also appears to estimate the fraction of mature crab by sex fairly well (Fig. 58).

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.s 59 and 60. The model appears to fit the observed proportions quite well, except at the smallest retained sizes in the 1980/81-1996/97 time period. The data suggests some sub-legal crab (≤ 138 mm CW) were retained in the 125-130 and 130-135 mm CW bins (although the overall proportions were quite small) and the model under-estimates these proportion relative to that observed. Conversely, the model over-estimates the proportion retained in the 135-140 mm CW size bin (the first size bin in which legal crab at the time would have been observed). It seems possible that the model's retention function may rise from 0 too steeply to accommodate the pattern seen in the directed fishery. This pattern is less apparent in the most recent fishery period (2005/06 -2009/10), when the residuals are much smaller.

Model-predicted patterns for the proportion caught-at-size in the directed fishery for all males is shown in Fig.s 61 and 62. Residual patterns again indicate, but more strongly than with the retained catch, that the fishery catches a larger proportion of smaller crab than predicted by the model and catches fewer larger 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. Similar patterns are evident for females taken as bycatch in the directed fishery (Fig.s 63 and 64), as well. It should be noted, however, that the scale of the residuals for males is about twice as large as that for females.

iv. Graphs of model fits to survey proportions by length

Model fits to observed proportions at size in the annual NMFS trawl survey are shown for males in Fig.s 65 and 66 (the latter as a bubble plot) respectively. The model appears to be suitably sensitive to relatively large cohorts recruiting to the model size range (e.g., 1997-2002), but appears to be less able to track strong cohorts through time (the mode in the model proportions at ~100 mm CW in 1982 disappears after two years, but appears to last until at least 1985 in the observed proportions. After 1982, the model tends to under-predict size proportions for males in the 70-120 mm range and over-predict the proportion of large (> 120 mm CW) males after 2000. Model fits to proportions at size in the survey for females are shown in Fig.s 67 and 68. The model tends to over-predict proportions-at-size in the 65-85 mm CW range. The patterns of residuals for males and females evinced in the bubble plots (Fig.s 66, 68) are almost identical to those obtained from the 2012 model in last year's assessment (Rugolo and Turnock, 2012b, Fig.s 61 and 64).

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

Model-predicted marginal fits of the proportion of crab by size in the directed fishery catch (Fig. 69) are quite good at all sizes for retained males but underestimate the proportions caught for all males (retained and discarded) at smaller sizes (< 130 mm CW) and over-estimate the proportion at larger sizes. A similar effect is evident for the model-predicted marginal proportion at size for female bycatch in the directed fishery (Fig. 69, bottom plot).

The observed and predicted marginal proportions of 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. 70). 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. 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. These patterns are all quite similar to those obtained with the 2012 model in last year's assessment.

The patterns of residuals for predicted proportions at size of males and females taken in the groundfish fishery are also similar to those obtained with the 2012 model in last year's assessment. Unfortunately, these patterns indicate a sex-specific bias in the fits to the groundfish fisheries size compositions, given that male proportions-at-size are consistently underestimated in the model and female proportions-at-size are almost always overestimated. This may be indicative of model mis-specification or an error in the model code.

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 will be addressed in the future.

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 2012 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 2012/13 was 19.02 thousand t while the total catch mortality for 2012/13 was 0.71 thousand t, based on applying discard mortality rates of 0.5 for pot fisheries and 0.8 for the groundfish fisheries to the reported catch by fleet for 2012/13 (Table 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 (see Fig. 72 also):

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* $F_{OFL} \le F_{MSY}^{\dagger}$	

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 $\bar{R}$, $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2013/14 require estimates of $B = MMB_{2012/13}$ (the most recent year for which MMB at mating time can be estimated), $F_{35\%}$, 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. 72). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if *B* is less than ½ $B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

The estimate of *B* from Model 01 (the author's preferred model) is 59.35 thousand t (Table 21). Spawning biomass per recruit in an unfished stock was calculated using the TCSAM population dynamics equations (Rugolo and Turnock, 2012b) with total recruitment set to 1 and fishing mortality from all sources (directed fishery and all bycatch fisheries) set to 0, resulting in $\phi(0)$ = 0.452 kg/recruit. Fully-selected fishing mortality and selectivity curves (Fig. 73) in the bycatch fisheries were set using the same approach as in the 2012 assessment (Rugolo and Turnock, 2012b), as were selectivities for all (retained+discarded) males and for retained males in the directed Tanner crab fishery (Fig. 74). The value for $F_{35\%}$ was then estimated using an iterative approach by varying the fully-selected F on males in the directed fishery until

$\phi(F) = 0.35 \cdot \phi(0)$. The resulting value for $F_{35\%}$ is 0.73 yr^{-1}, which is somewhat larger than that calculated in 2012 (0.61). The major contributor to this difference is the change in total selectivity in the directed fishery for all males between the 2012 assessment model and Model 01 (Fig. 75). Although the size at 50% selected is similar between the two models, the slope at 50% selected is smaller for the 2012 assessment model. Changes from the 2012 assessment model to Model 01 in the probability of males maturing at size, bycatch mortality in the groundfish fisheries, and bycatch selectivity in the snow crab fishery accounted for small changes in the estimated value for $F_{35\%}$, as well.

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 ($\bar{R}$). Five averaging scenarios (R1-R5) related to alternative hypotheses regarding changes in stock productivity were considered in the 2012 assessment (Table 20; Rugolo and Turnock, 2012). The 2012 assessment authors, the CPT and the SSC each selected a different preferred scenario, with final status determination and OFL setting based on the SSC's selection of scenario R3 (averaging period 1982-2012). The issue of the averaging time period was regarded to remain open and was revisited at the May 2012 CPT meeting and June 2012 SSC meeting, with the analysis included in Appendix A to this chapter presented to both groups. No definitive decisions were made as to the appropriate averaging time period for this stock, so here we present results based on all five averaging scenarios considered in 2012, updated to include 2013, as well as a 6th scenario (R6: 1971-2013) requested by a member of the SSC. Values for $\bar{R}$ using results from the author's preferred model (Model 01) range from 74,235 million (R5, the scenario favored by the CPT) to 518,765 million (R1, the scenario favored by the 2012 assessment authors). The value of $\bar{R}$ for the scenario adopted by the SSC (R3) is 105,959 million. The estimates of average recruitment, for a given scenario, are quite similar between the 2012 assessment model and the author's preferred model (Table 21).

The value of B_{MSY}=$B_{35\%}$ depends on the recruitment scenario selected (Table 21); values range from 23.50 thousand t (R5) to 164.22 thousand t (R1). $B_{35\%}$ for R3, the scenario equivalent to that selected by the SSC last year, is 33.54 thousand t. Under all scenarios except R1, the stock would be declared "not overfished" because $B/B_{35\%} > 0.5$ (i.e., B > MSST). For R1, the stock would be declared "overfished" because $B/B_{35\%} < 0.5$, but a directed fishery could potentially be prosecuted because $B/B_{35\%} > \beta$ (=0.25).

Once F_{OFL} is determined using the control rule (Fig. 72), 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, 2013 as estimated by the assessment model.

Assessment uncertainty was included in the calculation of OFL using the same approach as that used for the 2012 assessment (Rugolo and Turnock, 2012). Basically, initial numbers at size on July 1, 2013 were randomized based on an assumed lognormal assessment error distribution and the cv of estimated MMB for 2012/13 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 for each of the six recruitment scenarios (shown for scenario R3 in Fig. 76). The OFL for each recruitment scenario was taken as the median of the resulting distribution. Values for the OFLs ranged from 13.47 thousand t for recruitment scenario R1 to 25.25 thousand t for scenarios R3-R6 (Table 21).

After examining the issue of selecting the appropriate period (and method) over which to calculate average recruitment (Appendix A), the principal author has not found compelling evidence or arguments to make a strong case against using the recruitment scenario adopted in 2012 by the SSC (R3), which begins in 1982, for calculating the OFL. 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 breakpoint analysis presented in Appendix A suggests two potential change point periods in stock productivity, circa 1980 and 1990 (recruitment years; 1975 and 1985 fertilization years). The earlier period is in the ballpark of the 1976/77 regime shift, whereas the latter period is not consistent with other identified regime shifts (1989 and 1998; Rodionov and Overland, 2005).

Adopting scenario R3 for calculating the B_{MSY} proxy as $B_{35\%}$, MSST = 0.5 B_{MSY} = 16.77 thousand t. Because current *B* = 59.35 thousand t > MSST, the stock is not overfished. The population state (directed F vs. MMB) is plotted for each year from 1965-2012 in Fig. 77, with the Tier 3 harvest control rule based on recruitment scenario R3.

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 2011/12, however, the SSC adopted a buffer of 10% on OFL for all crab stocks for calculating ABC (Method 1). Here we provide ABCs 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 21). ABCs were also calculated using the SSC's 10% OFL buffer (Table 21). These ranged from 12.12 thousand t (recruitment scenario R1) to 22.82 thousand t (R3-R6).

The P* ABC corresponding to R3, the recruitment scenario adopted by the SSC in October 2012 for OFL specification, is 25.31 thousand t. The 10%-Buffer ABC is 22.82 thousand t.

However, the author wishes to point out that taking even the 10%-Buffer ABC (22.82 thousand t) would amount to an exploitation rate near 40% for the stock (Fig.s 78 and 49). The last time the stock was fished near this rate (~1990), stock abundance subsequently collapsed to historically low levels from which it is still in the process of recovering. Given the overall uncertainty associated with this assessment (e.g., the appropriate time period over which to average recruitment), as well as the absence of a directed fishery in recent years, it would seem prudent, therefore, to adopt a much lower ABC on the basis of a precautionary approach. In October 2012, the SSC adopted a stair-step approach to setting ABC for this stock over a 3-year period. As the first step in this stair, the SSC selected 8.17 thousand t as the ABC for 2012/13. Because there was no directed fishery conducted in 2012/13, the response of the stock to this approach could not be assessed this year. As a consequence, this author recommends re-starting the stair-step process with an ABC of 8 thousand t (last year's ABC, rounded to the nearest thousand t) for 2013/14.

G. Rebuilding Analyses

Tanner crab is not currently under a rebuilding plan. Consequently no rebuilding analyses were conducted.

H. Data Gaps and Research Priorities

Information on growth-per-molt should be collected for the EBS Tanner crab stock. An extensive collection of data of this type exists for Tanner crab in the GOA, but assessment model results suggest that growth rates for males in the EBS are different from those in the GOA. Secondarily, data on temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock.

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.

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. 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 (Fig. 79), suggesting a potential climatic driver. The observation that "very old shell" females have much higher rates of barrenness and are more likely to exhibit smaller clutch sizes also (Fig. 80) suggests that older females decline into senescence and it may not be as important to maintain "old, fat" female crabs as is appears to be for many species of fish. senesce. The trend in the fraction of new shell mature females (ones that mate for the first time following the molt to maturity) with clutches one-half full or is also potentially troubling (Fig. 80). Prior to 1991, this rate was similar to that for old shell (multiparous) females. After 1991, the rate increased to 20-40%, similar to that for very old shell females. Rugolo and Turnock (2010) developed an Egg Production Index (EPI) by female shell condition that incorporated observed clutch size measurements taken on the bottom trawl survey and fecundity by carapace width for 1976-2009 (Fig. 81). Figure 81 also includes estimates of male and female mature biomass relative to the shell condition class EPIs in these years. Although both male and female mature biomass increased after 2005, egg production has not increased proportionally to mature biomass. Thus use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health.

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 (Fig.s 82, 83; 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

The Tanner crab fishery currently has no effects on the ecosystem because, of course, the fishery has been closed since 2010/11. However, now that Tanner crab has been found not to be overfished, there is every likelihood that a directed fishery for Tanner crab will develop. Some potential effects of a 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	no fishery at present	unlikely to have substantial effects	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	no fishery at present	unlikely to have substantial effects	minimal to none
Marine mammals and birds	no fishery at present	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	rationalization has substantially reduced fishery concentration in time	likely true of future Tanner crab fishery, as well	probably of little concern for future fishery development
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 for future fishery
Fishery contribution to discards and offal production	discarded crab suffer substantial mortality (assumed 50% in assessment)	May impact female spawning biomass and numbers recruiting to the fishery	possible concern for future fishery
Fishery effects on age-at-maturity and fecundity	none	unknown	unknown

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Tables

Table 1. 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

Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Communnity Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Number of crabs caught and harvest includes deadloss. The "Fishery Year" YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADF&G year (in parentheses, if different from the "Fishery Year") indicates the year ADF&G assigned to the fishery season in compiled reports.

year (ADF&G year)	Total Crab (no.)	Total Harvest (lbs)	GHL/TAC (millions lbs)	Vessels (no.)	Season
1968/69 (1969)	353,300	1,008,900			
1969/70 (1970)	482,300	1,014,700			
1970/71 (1971)	61,300	166,100			
1971/72 (1972)	42,061	107,761			
1972/73 (1973)	93,595	231,668			
1973/74 (1974)	2,531,825	5,044,197			
1974/75	2,773,770	7,028,378		28	
1975/76	8,956,036	22,358,107		66	
1976/77	20,251,508	51,455,221		83	
1977/78	26,350,688	66,648,954		120	
1978/79	16,726,518	42,547,174		144	
1979/80	14,685,611	36,614,315	28-36	152	11/01-05/11
1980/81 (1981)	11,845,958	29,630,492	28-36	165	01/15-04/15
1981/82 (1982)	4,830,980	11,008,779	12-16	125	02/15-06/15
1982/83 (1983)	2,286,756	5,273,881	5.6	108	02/15-06/15
1983/84 (1984)	516,877	1,208,223	7.1	41	02/15-06/15
1984/85 (1985)	1,272,501	3,036,935	3	44	01/15-06/15
1985/86 (1986)	closed	closed	closed	closed	closed
1986/87 (1987)	closed	closed	closed	closed	closed
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
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

Table 3. Total bycatch (1000's t) of Tanner crab in various fisheries. Discard mortality rates have not been applied.

Discards (1000 t) of Tanner Crab by Fishery							
	Tanner Crab		Snow Crab		Red King Crab		Groundfish
Year	Male	Female	Male	Female	Male	Female	?+?
1973/74							17.737
1974/75							24.450
1975/76							9.410
1976/77							4.700
1977/78							2.776
1978/79							1.868
1979/80							3.395
1980/81							2.114
1981/82							1.472
1982/83							0.449
1983/84							0.672
1984/85							0.646
1985/86							0.397
1986/87							0.650
1987/88							0.638
1988/89							0.464
1989/90							0.672
1990/91							0.945
1991/92							2.543
1992/93	10.986	1.787	25.759	1.787	1.188	0.029	2.760
1993/94	6.831	1.814	14.530	1.814	2.967	0.198	1.758
1994/95	3.130	1.270	7.124	1.271	0.000	0.000	2.096
1995/96	2.762	1.760	4.797	1.759	0.000	0.000	1.525
1996/97	0.236	0.091	0.833	0.229	0.027	0.004	1.594
1997/98	0.000	0.000	1.750	0.226	0.165	0.003	1.180
1998/99	0.000	0.000	1.989	0.175	0.119	0.003	0.935
1999/00	0.000	0.000	0.695	0.145	0.076	0.004	0.631
2000/01	0.000	0.000	0.146	0.022	0.067	0.002	0.742
2001/02	0.000	0.000	0.323	0.011	0.043	0.002	1.185
2002/03	0.000	0.000	0.557	0.037	0.062	0.003	0.719
2003/04	0.000	0.000	0.193	0.026	0.056	0.003	0.424
2004/05	0.000	0.000	0.078	0.014	0.048	0.003	0.675
2005/06	0.286	0.027	0.968	0.043	0.042	0.002	0.621
2006/07	1.243	0.322	1.462	0.169	0.026	0.003	0.717
2007/08	2.100	0.100	1.872	0.102	0.056	0.009	0.695
2008/09	0.431	0.014	1.119	0.050	0.270	0.004	0.533
2009/10	0.071	0.002	1.324	0.014	0.150	0.001	0.321
2010/11	0.000	0.000	1.344	0.016	0.033	0.001	0.217
2011/12	0.000	0.000	2.119	0.014	0.010	0.000	0.208
2012/13	0.000	0.000	1.187	0.009	0.043	0.001	0.112

Table 4. Sample sizes for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment.

year	new + old shell	
	N	N'
1981/82	13310	89.8
1982/83	11311	76.3
1983/84	13519	91.2
1984/85	1675	11.3
1985/86	2542	17.1
1988/89	12380	83.5
1989/90	4123	27.8
1990/91	120676	200.0
1991/92	126299	200.0
1992/93	125193	200.0
1993/94	71622	200.0
1994/95	27658	186.5
1995/96	1525	10.3
1996/97	4430	29.9
2005/06	705	4.8
2006/07	2940	19.8
2007/08	5827	39.3
2008/09	3490	23.5
2009/10	14315	96.5

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

	N		N'	
year	males	females	males	females
1991/92	13386	2984	90.3	20.1
1992/93	15007	1374	101.2	9.3
1993/94	13511	2871	91.1	19.4
1994/95	5792	2132	39.1	14.4
1995/96	5589	3119	37.7	21.0
1996/97	352	168	2.4	1.1
2005/06	15459	879	104.2	5.9
2006/07	24226	4432	163.4	29.9
2007/08	26091	1577	175.9	10.6
2008/09	19797	294	133.5	2.0
2009/10	16229	147	109.4	1.0

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

year	N		N'	
	males	females	males	females
1992/93	11,708	686	78.9	4.6
1993/94	6,280	859	42.3	5.8
1994/95	6,969	1,542	47.0	10.4
1995/96	2,982	1,523	20.1	10.3
1996/97	1,898	428	12.8	2.9
1997/98	3,265	662	22.0	4.5
1998/99	2,747	515	18.5	3.5
1999/00	870	271	5.9	1.8
2000/01	103	22	0.7	0.1
2001/02	892	38	6.0	0.3
2002/03	2,086	140	14.1	0.9
2003/04	565	49	3.8	0.3
2004/05	162	21	1.1	0.1
2005/06	686	692	4.6	4.7
2006/07	9,212	368	62.1	2.5
2007/08	9,468	1,256	63.8	8.5
2008/09	13,113	728	88.4	4.9
2009/10	8,435	722	56.9	4.9
2010/11	11,014	474	74.3	3.2
2011/12	12,073	250	81.4	1.7
2012/13	9,453	189	63.7	1.3

Table 7. Sample sizes for total bycatch-at-size in theBBRKC 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	13.9	0.7
1993/94	2,647	1,196	17.8	8.1
1996/97	15	5	0.1	0.0
1997/98	1,030	41	6.9	0.3
1998/99	335	18	2.3	0.1
1999/00	130	10	0.9	0.1
2000/01	605	36	4.1	0.2
2001/02	372	26	2.5	0.2
2002/03	555	43	3.7	0.3
2003/04	440	40	3.0	0.3
2004/05	412	41	2.8	0.3
2005/06	980	70	6.6	0.5
2006/07	691	68	4.7	0.5
2007/08	1,123	89	7.6	0.6
2008/09	2,574	98	17.4	0.7
2009/10	2,611	70	17.6	0.5
2010/11	581	28	3.9	0.2
2011/12	324	4	2.2	0.0
2012/13	503	48	3.4	0.3

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

year	N		N'	
	males	females	males	females
1973/74	1,604	1,212	8.2	10.8
1974/75	4,155	2,789	18.8	28.0
1975/76	16	24	0.2	0.1
1976/77	2,928	2,526	17.0	19.7
1977/78	10,873	9,803	66.1	73.3
1978/79	11,724	8,105	54.7	79.1
1979/80	24,924	16,953	114.3	168.1
1980/81	10,424	5,598	37.7	70.3
1981/82	12,956	6,817	46.0	87.4
1982/83	7,690	5,694	38.4	51.9
1983/84	14,112	7,983	53.8	95.2
1984/85	24,303	10,589	71.4	163.9
1985/86	26,334	12,765	86.1	177.6
1986/87	3,224	1,776	12.0	21.7
1987/88	3,310	1,690	11.4	22.3
1988/89	3,082	1,918	12.9	20.8
1989/90	2,812	2,188	14.8	19.0
1990/91	3,015	1,985	13.4	20.3
1991/92	14,432	6,155	41.5	97.3
1992/93	4,903	1,749	11.8	33.1
1993/94	1,148	279	1.9	7.7
1994/95	854	328	2.2	5.8
1995/96	4,404	2,248	15.2	29.7
1996/97	3,458	2,364	15.9	23.3
1997/98	12,176	5,314	35.8	82.1
1998/99	10,139	4,282	28.9	68.4
1999/00	12,037	4,399	29.7	81.2
2000/01	12,391	3,701	25.0	83.6
2001/02	12,910	2,485	16.8	87.1
2002/03	15,498	3,232	21.8	104.5
2003/04	13,542	3,292	22.2	91.3
2004/05	11,110	2,788	18.8	74.9
2005/06	13,424	4,097	27.6	90.5
2006/07	17,129	3,498	23.6	115.5
2007/08	17,513	3,150	21.2	118.1
2008/09	10,658	2,832	19.1	71.9
2009/10	6,435	1,973	13.3	43.4
2010/11	5,952	2,096	14.1	40.1
2011/12	2,055	697	4.7	13.9
2012/13	8,911	4,159	28.0	60.1
2013/14	3,470	1,845	15.9	36.9

Table 9. Trends in mature Tanner crab biomass and abundance of legal crab (≥ 138 mm CW) in the NMFS summer bottom trawl survey.

Observed Survey Mature Male and Female Biomass and Legal Male Abundance				
	Mature Biomass (1000 t)			Male ? 138 mm (10^6 crab)
Year	Male	Female	Total	
1974	212.01	55.76	267.77	87.53
1975	265.07	38.76	303.83	151.45
1976	152.09	45.99	198.08	86.07
1977	130.41	47.59	177.99	68.49
1978	80.62	26.43	107.06	37.65
1979	47.82	20.43	68.25	21.33
1980	86.33	70.42	156.76	28.53
1981	50.67	45.24	95.91	10.14
1982	49.67	64.76	114.43	6.82
1983	29.04	20.72	49.76	4.7
1984	26.15	14.72	40.87	6.19
1985	11.71	5.68	17.39	3.54
1986	13.18	3.49	16.67	2.27
1987	24.18	5.27	29.46	5.73
1988	59.51	25.57	85.08	15.6
1989	101.48	25.47	126.96	32.73
1990	103.17	36.36	139.52	42.93
1991	110.82	45.56	156.37	33.89
1992	108.12	27.76	135.88	39.65
1993	62.12	11.91	74.03	18.22
1994	44.55	10.37	54.92	14.81
1995	33.86	13.44	47.3	9.45
1996	27.32	9.8	37.12	8.56
1997	11.07	3.53	14.6	3.24
1998	10.56	2.31	12.87	1.97
1999	12.4	3.81	16.21	2.07
2000	16.45	4.17	20.63	4.6
2001	18.2	4.61	22.81	5.97
2002	18.23	4.48	22.71	5.94
2003	23.71	8.35	32.06	6.31
2004	25.56	4.7	30.26	4.5
2005	43.99	11.62	55.61	10.41
2006	66.89	15.79	82.68	13.36
2007	72.63	13.33	85.97	10.9
2008	59.7	11.33	71.03	14.39
2009	37.6	8.22	45.82	6.91
2010	36.14	5.44	41.59	8.01
2011	46.3	8.67	54.97	13.68
2012	43.15	15.83	58.97	7.09
2013	64.97	17.88	82.84	8.61

Table 10. Sample sizes for NMFS survey catch-at-size. In the model, an effective sample size of 200 is used for all survey-related compositional data.

Year	total hauls	Females				Males			
		new shell		old shell		new shell		old shell	
		non-zero hauls	crab	non-zero hauls	crab	non-zero hauls	crab	non-zero hauls	crab
1975	136	99	2,813	40	712	127	6,800	80	398
1976	209	154	4,660	80	872	169	7,282	92	598
1977	158	88	1,964	61	748	114	3,734	79	484
1978	230	104	2,593	67	1,320	147	4,548	103	699
1979	443	146	2,263	76	728	247	5,034	156	937
1980	360	156	3,409	80	723	202	9,636	101	854
1981	348	127	2,033	112	1,433	194	6,373	150	1,085
1982	342	117	1,338	104	2,391	181	3,182	147	2,083
1983	353	128	2,700	102	2,159	166	3,870	132	1,183
1984	355	146	2,228	99	1,543	176	2,528	126	1,399
1985	355	155	1,129	65	601	178	1,513	86	459
1986	353	175	1,855	68	338	213	2,772	115	468
1987	356	200	4,780	73	387	226	6,081	103	496
1988	373	220	5,611	102	538	252	7,754	102	476
1989	416	257	7,631	134	1,018	276	12,785	170	1,222
1990	383	230	4,826	134	1,597	261	9,103	163	1,541
1991	377	192	3,623	147	2,681	233	7,341	187	3,087
1992	355	151	2,391	123	2,205	215	5,099	177	1,925
1993	389	138	1,566	127	1,445	215	3,922	188	1,949
1994	376	112	1,088	107	1,403	179	2,089	176	1,902
1995	380	122	1,105	113	1,156	159	1,438	142	1,770
1996	375	131	1,086	99	1,000	150	1,390	135	1,427
1997	376	135	1,839	85	510	165	1,965	126	588
1998	375	154	1,989	75	350	177	2,529	129	640
1999	404	156	3,318	95	542	189	4,142	136	619
2000	395	162	2,672	57	349	200	3,708	144	686
2001	375	171	4,621	72	647	213	5,173	145	817
2002	375	162	4,062	70	502	188	4,485	155	1,093
2003	380	173	4,182	85	757	208	6,062	156	1,356
2004	383	192	4,439	86	1,028	245	6,101	187	1,912
2005	373	214	4,229	76	934	255	6,030	185	1,754
2006	410	228	6,013	134	1,452	275	8,457	241	4,569
2007	412	218	4,321	148	1,463	280	7,645	229	3,215
2008	410	189	2,821	127	1,804	258	6,199	219	2,334
2009	408	194	3,207	117	1,337	227	4,726	205	2,093
2010	403	205	3,877	111	1,011	234	5,888	180	2,080
2011	396	205	6,479	104	724	222	8,136	175	2,056
2012	396	219	5,141	103	768	235	7,987	148	1,367
2013	376	178	4,880	109	1,048	208	8,850	138	1,360

Table 11. Effort data (1000’s potlifts) in the snow crab and BBRKC fisheries.

Year	Effort (1000's Potlifts)	
	BBRKC Fishery	Snow Crab Fishery
1951/52		
1952/53		
1953/54	30.083	--
1954/55	17.122	--
1955/56	28.045	--
1956/57	41.629	--
1957/58	23.659	--
1958/59	27.932	--
1959/60	22.187	--
1960/61	26.347	--
1961/62	72.646	--
1962/63	123.643	--
1963/64	181.799	--
1964/65	180.809	--
1965/66	127.973	--
1966/67	129.306	--
1967/68	135.283	--
1968/69	184.666	--
1969/70	175.374	--
1970/71	168.059	--
1971/72	126.305	--
1972/73	208.469	--
1973/74	194.095	--
1974/75	212.915	--
1975/76	205.096	--
1976/77	321.01	--
1977/78	451.273	--
1978/79	406.165	190.746
1979/80	315.226	255.102
1980/81	567.292	435.742
1981/82	536.646	469.091
1982/83	140.492	287.127
1983/84	0	173.591
1984/85	107.406	370.082
1985/86	84.443	542.346
1986/87	175.753	616.113
1987/88	220.971	747.395
1988/89	146.179	665.242
1989/90	205.528	912.718
1990/91	262.761	1394.897
1991/92	227.555	1281.796
1992/93	206.815	972.118
1993/94	254.389	716.524
1994/95	0.697	507.603
1995/96	0.547	520.685
1996/97	77.081	754.14
1997/98	91.085	930.794
1998/99	145.689	945.533
1999/00	151.212	182.634
2000/01	104.056	191.2
2001/02	66.947	326.977
2002/03	72.514	153.862
2003/04	134.515	123.709
2004/05	97.621	75.095
2005/06	116.324	120.582
2006/07	72.807	89.419
2007/08	113.943	144.039
2008/09	140.055	163.536
2009/10	118.521	137.018
2010/11	132.183	147.244
2011/12	45.166	270.602
2012/13	38.827	225.489

Table 12. Comparison of parameter estimates and approximate standard deviations from the 2012 model and 2013 alternative models. Parameter bounds, initial estimation phase, valid indices, and parameter name in the 2012 and 2013 model codes are also given. Blue highlighting indicates the parameter estimate is at the lower bound set for the parameter, whereas red highlighting indicates the parameter estimate is at the upper bound.

Parameter Caracteristics								2012 Model		Model 00		Model 01	
index	phase	idx.mn	idx.mx	min	max	parameter type	Name (2012 model / 2013 Model)	value	std. dev.	value	std. dev.	value	std.dev
1	8	1	1	0.4	0.7	'param_init_bounded_number'	af1	0.681	5.25E-02	0.6838	5.18E-02	0.6822	5.20E-02
1	8	1	1	0.6	1.2	'param_init_bounded_number'	bf1	0.888	1.25E-02	0.8879	1.24E-02	0.8884	1.24E-02
1	8	1	1	0.3	0.6	'param_init_bounded_number'	am1	0.442	2.29E-02	0.4418	2.28E-02	0.4431	2.28E-02
1	8	1	1	0.7	1.2	'param_init_bounded_number'	bm1	0.966	5.35E-03	0.9663	5.34E-03	0.9663	5.33E-03
1	7	1	1	0.2	2	'param_init_bounded_number'	Mmult_imat	1.082	5.16E-02	1.0777	5.14E-02	1.0747	5.13E-02
1	7	1	1	0.1	1.9	'param_init_bounded_number'	Mmultm	1.094	4.21E-02	1.1013	4.20E-02	1.0917	4.21E-02
1	7	1	1	0.1	1.9	'param_init_bounded_number'	Mmultf	1.463	3.61E-02	1.4622	3.62E-02	1.4587	3.63E-02
1	8	1	2	0.1	10	'param_init_bounded_vector'	mat_big	0.833	1.05E-01	0.8418	1.05E-01	0.9380	1.05E-01
2	8	1	2	0.1	10	'param_init_bounded_vector'	mat_big	2.928	4.20E-01	3.0007	4.27E-01	2.8914	3.70E-01
1	1	1	1	-Inf	Inf	'param_init_number'	mean_log_rec1 / pMnLnRec	11.233	7.71E-02	11.2267	8.82E-02	11.2190	8.66E-02
1974	1	1974	2013	-15	15	'param_init_bounded_vector'	/ pRecDevs	--	--	-1.2155	1.99E+00	-1.1639	1.93E+00
1975	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.816	2.54E-01	1.0233	2.70E-01	1.0285	2.76E-01
1976	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	1.648	1.43E-01	1.6225	1.44E-01	1.6889	1.41E-01
1977	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	1.282	1.72E-01	1.3261	1.80E-01	1.3759	1.78E-01
1978	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	1.203	1.59E-01	1.2125	1.65E-01	1.2513	1.62E-01
1979	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.115	3.63E-01	-0.0757	3.61E-01	-0.0695	3.57E-01
1980	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.720	1.14E+00	-1.6856	1.13E+00	-1.6156	1.05E+00
1981	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.346	2.82E-01	-0.3259	2.84E-01	-0.3534	2.82E-01
1982	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.281	4.74E-01	-1.2618	4.74E-01	-1.2679	4.69E-01
1983	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.997	1.19E-01	0.9995	1.27E-01	0.9686	1.27E-01
1984	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.826	1.81E-01	0.8305	1.86E-01	0.7988	1.87E-01
1985	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	1.565	1.32E-01	1.5708	1.39E-01	1.5680	1.37E-01
1986	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	1.334	1.57E-01	1.3386	1.62E-01	1.3352	1.61E-01
1987	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	1.301	1.50E-01	1.3091	1.56E-01	1.3040	1.56E-01
1988	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.974	1.59E-01	0.9737	1.64E-01	0.9860	1.61E-01
1989	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.389	1.73E-01	0.3941	1.78E-01	0.3945	1.77E-01
1990	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.466	2.45E-01	-0.4606	2.48E-01	-0.4559	2.46E-01
1991	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.156	3.00E-01	-1.1523	3.02E-01	-1.1504	3.00E-01
1992	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.394	2.66E-01	-1.3883	2.69E-01	-1.3950	2.68E-01
1993	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.585	2.55E-01	-1.5779	2.58E-01	-1.5847	2.57E-01
1994	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.603	2.40E-01	-1.6035	2.45E-01	-1.6143	2.44E-01
1995	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.255	1.90E-01	-1.2551	1.95E-01	-1.2678	1.94E-01
1996	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.140	1.99E-01	-1.1373	2.04E-01	-1.1492	2.03E-01
1997	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.195	1.11E-01	-0.1906	1.20E-01	-0.2025	1.18E-01
1998	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-1.054	1.89E-01	-1.0509	1.95E-01	-1.0623	1.94E-01
1999	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.079	1.11E-01	0.0820	1.20E-01	0.0668	1.19E-01
2000	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.467	1.84E-01	-0.4597	1.90E-01	-0.4728	1.88E-01
2001	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.672	1.02E-01	0.6768	1.12E-01	0.6615	1.11E-01
2002	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.289	1.98E-01	-0.2800	2.03E-01	-0.2873	2.01E-01
2003	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.288	1.45E-01	0.3052	1.53E-01	0.2877	1.52E-01
2004	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.964	9.52E-02	0.9914	1.05E-01	0.9813	1.04E-01
2005	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.271	2.05E-01	-0.2386	2.08E-01	-0.2428	2.06E-01
2006	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.472	2.21E-01	-0.4386	2.24E-01	-0.4443	2.23E-01
2007	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.731	2.58E-01	-0.6834	2.60E-01	-0.6914	2.59E-01
2008	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.629	2.58E-01	-0.5731	2.59E-01	-0.5865	2.58E-01
2009	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.944	1.38E-01	1.0018	1.35E-01	0.9876	1.34E-01
2010	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	1.183	1.49E-01	1.1645	1.42E-01	1.1623	1.40E-01
2011	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	0.552	2.06E-01	0.5418	1.89E-01	0.5419	1.88E-01
2012	1	1974	2013	-15	15	'param_init_bounded_vector'	rec_devf / pRecDevs	-0.847	4.66E-01	-0.7936	4.18E-01	-0.7922	4.16E-01
2013	1	1974	2013	-15	15	'param_init_bounded_vector'	/ pRecDevs	--	--	0.4837	2.41E-01	0.4810	2.40E-01
1	1	1	1	-Inf	Inf	'param_init_number'	mean_log_rec1_early / pMnLnRecEarly	12.417	2.91E-01	11.8605	5.04E-01	11.8160	5.04E-01
1949	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.780	1.49E+00	-1.5144	1.61E+00	-1.5397	1.61E+00
1950	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.775	1.34E+00	-1.5116	1.46E+00	-1.5369	1.46E+00
1951	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.767	1.19E+00	-1.5048	1.33E+00	-1.5301	1.33E+00
1952	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.755	1.05E+00	-1.4926	1.20E+00	-1.5180	1.20E+00
1953	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.736	9.22E-01	-1.4730	1.08E+00	-1.4983	1.08E+00
1954	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.710	8.07E-01	-1.4429	9.70E-01	-1.4683	9.70E-01
1955	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.672	7.16E-01	-1.3980	8.79E-01	-1.4235	8.80E-01
1956	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.620	6.59E-01	-1.3320	8.08E-01	-1.3577	8.09E-01
1957	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.546	6.44E-01	-1.2350	7.57E-01	-1.2610	7.58E-01
1958	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.443	6.69E-01	-1.0911	7.26E-01	-1.1177	7.26E-01
1959	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.297	7.11E-01	-0.8729	7.10E-01	-0.9008	7.11E-01
1960	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.064	7.13E-01	-0.5283	7.09E-01	-0.5585	7.09E-01
1961	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.386	6.63E-01	0.0337	7.20E-01	0.0005	7.19E-01
1962	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.929	6.02E-01	0.8341	7.22E-01	0.8023	7.21E-01
1963	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	1.256	5.65E-01	1.5891	7.09E-01	1.5699	7.08E-01
1964	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	1.279	5.67E-01	1.9168	6.90E-01	1.9111	6.89E-01
1965	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	1.138	5.64E-01	1.8745	6.91E-01	1.8811	6.90E-01
1966	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.990	5.39E-01	1.6956	6.90E-01	1.7153	6.90E-01
1967	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.891	5.17E-01	1.5422	6.74E-01	1.5792	6.74E-01
1968	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.820	5.31E-01	1.4591	6.60E-01	1.5149	6.58E-01
1969	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.549	4.57E-01	1.4087	6.75E-01	1.4754	6.74E-01
1970	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.165	3.97E-01	1.1355	6.16E-01	1.1982	6.17E-01
1971	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	0.159	3.53E-01	0.7330	5.69E-01	0.7814	5.70E-01
1972	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-0.300	3.63E-01	0.6402	5.47E-01	0.6892	5.48E-01
1973	1	1949	1973	-15	15	'param_init_bounded_vector'	rec_devf_early / pRecDevsEarly	-1.099	4.58E-01	0.5341	5.45E-01	0.5921	5.45E-01

Table 12 (cont.)

Parameter Caracteristics								2012 Model		Model 00		Model 01	
index	phase	idx.mn	idx.mx	min	max	parameter type	Name (2012 model / 2013 Model)	value	std. dev.	value	std. dev.	value	std.dev
1	1	1	1	-Inf	Inf	'param_init_number'	log_avg_fmort / pAvgLnFmTCF	-1.566	1.02E-01	-1.5351	1.10E-01	-1.5002	1.07E-01
1	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-1.358	2.05E-01	-0.5109	4.95E-01	-0.5118	4.96E-01
2	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.091	2.78E-01	-0.7520	3.84E-01	-0.7541	3.84E-01
3	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.088	3.17E-01	0.4129	3.45E-01	0.4104	3.46E-01
4	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.291	3.23E-01	0.1949	3.30E-01	0.1914	3.30E-01
5	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.101	3.17E-01	0.3020	3.22E-01	0.2966	3.24E-01
6	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.156	2.88E-01	0.0870	3.15E-01	0.0779	3.18E-01
7	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.372	2.29E-01	-0.1713	2.89E-01	-0.1891	2.94E-01
8	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.627	1.46E-01	-0.3875	2.32E-01	-0.4185	2.37E-01
9	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.408	9.35E-02	-0.6471	1.50E-01	-0.6937	1.52E-01
10	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.112	8.62E-02	-0.4353	9.78E-02	-0.4941	9.92E-02
11	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.700	8.51E-02	-0.1425	9.09E-02	-0.2079	9.22E-02
12	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	1.370	9.17E-02	0.6732	9.00E-02	0.6019	9.14E-02
13	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	1.520	1.17E-01	1.3353	9.49E-02	1.2521	9.73E-02
14	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	2.340	2.31E-01	1.4511	1.18E-01	1.3523	1.23E-01
15	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	1.966	2.36E-01	2.3323	2.39E-01	2.1496	2.23E-01
16	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.289	1.46E-01	1.8937	2.29E-01	2.3046	2.51E-01
17	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.666	1.33E-01	0.2530	1.45E-01	0.6141	1.38E-01
18	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-1.754	2.44E-01	-0.6985	1.36E-01	-0.4165	1.31E-01
19	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.676	1.71E-01	-1.7765	2.45E-01	-1.5504	2.52E-01
20	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.925	2.16E-01	-0.6928	1.73E-01	-0.4544	1.87E-01
21	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.232	1.13E-01	-0.9326	2.18E-01	-0.9893	2.17E-01
22	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.833	9.21E-02	-0.2399	1.16E-01	-0.2894	1.16E-01
23	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	1.318	9.76E-02	0.8264	9.63E-02	0.7747	9.55E-02
24	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	1.214	1.16E-01	1.3123	1.02E-01	1.2588	1.00E-01
25	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	1.700	1.27E-01	1.2027	1.20E-01	1.1618	1.20E-01
26	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	1.167	1.36E-01	1.6983	1.31E-01	1.6439	1.29E-01
27	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.559	1.52E-01	1.1677	1.40E-01	1.1069	1.37E-01
28	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.028	1.47E-01	0.5628	1.56E-01	0.4995	1.52E-01
29	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-0.433	3.60E-01	0.0244	1.50E-01	-0.0222	1.49E-01
30	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-2.129	2.22E-01	-0.4003	3.58E-01	-0.5757	3.69E-01
31	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-1.556	1.51E-01	-2.1421	2.24E-01	-2.1766	2.22E-01
32	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-1.507	1.39E-01	-1.5723	1.54E-01	-1.6052	1.53E-01
33	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-1.630	1.80E-01	-1.5268	1.43E-01	-1.5607	1.41E-01
34	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	-1.034	2.89E-01	-1.6479	1.83E-01	-1.6865	1.81E-01
35	2	1	35	-15	15	'param_init_bounded_vector'	fmort_dev / pFmDevsTCF	0.000	6.97E-01	-1.0534	2.90E-01	-1.1001	2.88E-01
1	2	1	1	-Inf	Inf	'param_init_number'	log_avg_fmortt / pAvgLnFmGTF	-4.556	7.64E-02	-4.5890	7.27E-02	-4.5661	7.24E-02
1973	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.877	8.94E-02	0.8974	8.63E-02	0.8792	8.73E-02
1974	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	1.321	7.82E-02	1.3391	7.48E-02	1.3155	7.57E-02
1975	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.528	8.02E-02	0.5457	7.68E-02	0.5190	7.77E-02
1976	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.037	9.31E-02	0.0548	9.02E-02	0.0261	9.11E-02
1977	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.225	1.21E-01	-0.2107	1.19E-01	-0.2420	1.20E-01
1978	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.405	1.60E-01	-0.3928	1.58E-01	-0.4313	1.59E-01
1979	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.306	1.18E-01	0.3175	1.16E-01	0.2597	1.16E-01
1980	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.104	1.63E-01	-0.0968	1.61E-01	-0.0062	1.51E-01
1981	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.323	1.98E-01	-0.3088	1.96E-01	-0.1967	1.92E-01
1982	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-1.049	3.81E-01	-1.0316	3.82E-01	-0.9178	3.88E-01
1983	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.589	3.39E-01	-0.5659	3.40E-01	-0.4463	3.47E-01
1984	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.369	3.60E-01	-0.3408	3.61E-01	-0.2370	3.71E-01
1985	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.649	4.47E-01	-0.6212	4.50E-01	-0.6117	4.52E-01
1986	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.610	3.63E-01	-0.5815	3.64E-01	-0.5768	3.66E-01
1987	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.922	3.52E-01	-0.8933	3.53E-01	-0.8978	3.54E-01
1988	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-1.310	3.80E-01	-1.2823	3.81E-01	-1.2900	3.81E-01
1989	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-1.179	3.21E-01	-1.1509	3.22E-01	-1.1612	3.22E-01
1990	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.865	2.64E-01	-0.8366	2.64E-01	-0.8468	2.64E-01
1991	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.233	1.25E-01	0.2623	1.23E-01	0.2512	1.23E-01
1992	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.585	1.18E-01	0.6152	1.16E-01	0.6026	1.16E-01
1993	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.480	1.63E-01	0.5101	1.62E-01	0.4978	1.61E-01
1994	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.976	1.42E-01	1.0085	1.40E-01	0.9967	1.40E-01
1995	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	1.011	1.78E-01	1.0470	1.77E-01	1.0368	1.76E-01
1996	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	1.345	1.68E-01	1.3837	1.67E-01	1.3741	1.66E-01
1997	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	1.354	2.30E-01	1.4083	2.29E-01	1.3949	2.28E-01
1998	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	1.103	3.21E-01	1.1575	3.22E-01	1.1448	3.20E-01
1999	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.675	4.58E-01	0.7235	4.65E-01	0.7139	4.60E-01
2000	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.755	3.76E-01	0.8073	3.80E-01	0.7938	3.77E-01
2001	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	1.057	2.45E-01	1.1131	2.44E-01	1.0960	2.43E-01
2002	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.392	3.69E-01	0.4426	3.72E-01	0.4284	3.69E-01
2003	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.166	4.68E-01	-0.1201	4.73E-01	-0.1324	4.70E-01
2004	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.050	3.64E-01	-0.0017	3.66E-01	-0.0167	3.64E-01
2005	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.269	3.70E-01	-0.2235	3.72E-01	-0.2382	3.71E-01
2006	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.238	3.28E-01	-0.1948	3.29E-01	-0.2095	3.28E-01
2007	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.355	3.28E-01	-0.3179	3.28E-01	-0.3337	3.27E-01
2008	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.614	3.71E-01	-0.5848	3.72E-01	-0.6005	3.70E-01
2009	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.877	4.42E-01	-0.8537	4.44E-01	-0.8679	4.42E-01
2010	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.962	4.85E-01	-0.9428	4.87E-01	-0.9568	4.85E-01
2011	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	-0.951	4.93E-01	-0.9363	4.96E-01	-0.9515	4.94E-01
2012	3	1973	2012	-15	15	'param_init_bounded_vector'	fmortt_dev / pFmDevsGTF	0.045	1.01E+00	-1.1447	5.05E-01	-1.1615	5.03E-01
1	3	1	1	-Inf	Inf	'param_init_number'	log_avg_fmortd_snow / pAvgLnFmSCF	-3.453	1.39E-01	-3.4190	1.36E-01	-3.4257	1.32E-01
1992	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	2.116	1.51E-01	2.0897	1.52E-01	2.0886	1.46E-01
1993	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	1.894	1.59E-01	1.8678	1.60E-01	1.8669	1.54E-01
1994	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	1.534	1.71E-01	1.5113	1.72E-01	1.5104	1.66E-01
1995	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	1.510	1.83E-01	1.4921	1.84E-01	1.4914	1.78E-01
1996	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	0.075	4.45E-01	0.0707	4.41E-01	0.0658	4.41E-01
1997	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	0.679	2.85E-01	0.6629	2.81E-01	0.6708	2.81E-01
1998	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	0.730	3.04E-01	0.7186	3.00E-01	0.7217	3.01E-01
1999	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.360	5.90E-01	-0.3566	5.82E-01	-0.3597	5.86E-01
2000	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.826	6.04E-01	-0.8290	6.00E-01	-0.8295	6.01E-01
2001	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.781	5.64E-01	-0.7859	5.58E-01	-0.7859	5.60E-01
2002	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.705	5.16E-01	-0.7132	5.10E-01	-0.7129	5.12E-01
2003	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-1.086	5.27E-01	-1.0968	5.23E-01	-1.0941	5.24E-01
2004	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-1.366	5.16E-01	-1.3794	5.12E-01	-1.3767	5.13E-01
2005	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.625	4.04E-01	-0.5865	4.04E-01	-0.5879	4.05E-01
2006	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.286	3.13E-01	-0.2492	3.10E-01	-0.2480	3.10E-01
2007	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.179	2.62E-01	-0.1451	2.59E-01	-0.1452	2.58E-01
2008	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.725	3.38E-01	-0.7057	3.36E-01	-0.7051	3.36E-01
2009	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.573	3.23E-01	-0.5637	3.21E-01	-0.5619	3.21E-01
2010	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.468	3.30E-01	-0.4663	3.29E-01	-0.4664	3.29E-01
2011	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	0.050	2.53E-01	0.0481	2.50E-01	0.0466	2.49E-01
2012	4	1992	2012	-15	15	'param_init_bounded_vector'	fmortd_snow_dev / pFmDevsSCF	-0.610	7.64E-01	-0.5839	3.57E-01	-0.5891	3.57E-01

Table 12 (cont.).

				Parameter Caracteristics				2012 Model		Model 00		Model 01	
index	phase	idx.mn	idx.mx	min	max	parameter type	Name (2012 model / 2013 Model)	value	std. dev.	value	std. dev.	value	std.dev
1	3	1	1	0.25	1.001	'param_init_bounded_number'	fish_fit_slope_mn1	0.738	1.43E-01	0.7409	1.43E-01	0.7331	1.41E-01
1	3	1	1	85	160	'param_init_bounded_number'	fish_fit_sel50_mn1	137.950	3.99E-01	137.9080	3.96E-01	138.0300	4.08E-01
1	3	1	1	0.25	2.001	'param_init_bounded_number'	fish_fit_slope_mn2	1.018	2.83E-01	1.0191	2.84E-01	1.0197	2.83E-01
1	3	1	1	85	160	'param_init_bounded_number'	fish_fit_sel50_mn2	137.700	2.44E-01	137.6950	2.43E-01	137.6900	2.42E-01
1	3	1	1	0.05	0.75	'param_init_bounded_number'	fish_slope_1	0.129	9.88E-03	0.1291	9.78E-03	0.1303	9.95E-03
1	3	1	1	0.1	0.4	'param_init_bounded_number'	fish_slope_yr_3	0.134	9.23E-03	0.1344	9.18E-03	0.1342	9.21E-03
1	3	1	1	4	5	'param_init_bounded_number'	log_avg_sel50_3	4.902	2.01E+01	4.8807	1.22E-02	4.8753	1.28E-02
1	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	-0.012	2.01E+01	0.0115	2.20E-02	0.0140	2.27E-02
2	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	0.038	2.01E+01	0.0619	1.48E-02	0.0640	1.55E-02
3	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	0.016	2.01E+01	0.0410	1.73E-02	0.0421	1.80E-02
4	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	0.003	2.01E+01	0.0285	2.27E-02	0.0283	2.35E-02
5	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	-0.087	2.01E+01	-0.0621	3.12E-02	-0.0617	3.23E-02
6	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	0.001	2.01E+01	0.0313	6.86E-02	0.0025	8.65E-02
7	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	-0.130	2.01E+01	-0.1063	2.38E-02	-0.1021	2.43E-02
8	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	-0.128	2.01E+01	-0.1049	2.17E-02	-0.1003	2.22E-02
9	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	-0.148	2.01E+01	-0.1240	1.96E-02	-0.1192	2.01E-02
10	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	0.009	2.01E+01	0.0321	1.97E-02	0.0369	2.02E-02
11	3	1	11	-0.5	0.5	'param_init_bounded_vector'	log_sel50_dev_3	0.169	2.01E+01	0.1910	2.10E-02	0.1954	2.14E-02
							log_sel50_dev_3 /	0.270	2.21E+02	--	--	--	--
1	3	1	1	0.1	0.4	'param_init_bounded_number'	fish_disc_slope_f	0.128	1.07E-02	0.1264	1.06E-02	0.1270	1.06E-02
1	3	1	1	80	150	'param_init_bounded_number'	fish_disc_sel50_f	115.930	2.86E+00	116.7150	2.96E+00	116.2400	2.90E+00
1	4	1	1	0.05	0.5	'param_init_bounded_number'	snowfish_disc_slope_f_1	0.050	1.32E-05	0.0500	1.12E-05	0.0500	1.09E-05
1	4	1	1	50	150	'param_init_bounded_number'	snowfish_disc_sel50_f_1	118.810	5.84E+00	119.2220	5.99E+00	118.4700	5.69E+00
1	4	1	1	0.05	0.5	'param_init_bounded_number'	snowfish_disc_slope_f_2	0.220	1.31E-01	0.2210	1.31E-01	0.2254	1.34E-01
1	4	1	1	50	120	'param_init_bounded_number'	snowfish_disc_sel50_f_2	80.591	5.98E+00	80.5003	5.91E+00	80.1510	5.80E+00
1	4	1	1	0.05	0.5	'param_init_bounded_number'	snowfish_disc_slope_f_3	0.136	4.79E-02	0.1274	4.34E-02	0.1299	4.44E-02
1	4	1	1	50	120	'param_init_bounded_number'	snowfish_disc_sel50_f_3	87.448	7.84E+00	89.6373	8.70E+00	89.0000	8.38E+00
1	4	1	1	0.1	0.5	'param_init_bounded_number'	snowfish_disc_slope_m_1	0.321	9.91E-02	0.3190	9.82E-02	0.3210	9.89E-02
1	4	1	1	60	150	'param_init_bounded_number'	snowfish_disc_sel50_m_1	88.000	1.99E+00	88.0505	2.01E+00	87.9940	1.96E+00
1	4	1	1	0.1	0.5	'param_init_bounded_number'	snowfish_disc_slope_m2_1	0.124	6.92E-02	0.1212	6.69E-02	0.1279	6.98E-02
1	4	1	1	40	200	'param_init_bounded_number'	snowfish_disc_sel50_m2_1	135.790	6.31E+00	135.2700	6.50E+00	135.8700	6.06E+00
1	4	1	1	0.1	0.5	'param_init_bounded_number'	snowfish_disc_slope_m_2	0.254	9.06E-02	0.2525	8.98E-02	0.2533	9.03E-02
1	4	1	1	60	150	'param_init_bounded_number'	snowfish_disc_sel50_m_2	92.534	3.01E+00	92.6388	3.03E+00	92.5630	3.02E+00
1	4	1	1	0.1	0.5	'param_init_bounded_number'	snowfish_disc_slope_m2_2	0.173	1.05E-01	0.1722	1.06E-01	0.1743	1.07E-01
1	4	1	1	40	200	'param_init_bounded_number'	snowfish_disc_sel50_m2_2	141.720	5.41E+00	141.6990	5.45E+00	141.8300	5.41E+00
1	4	1	1	0.1	0.5	'param_init_bounded_number'	snowfish_disc_slope_m_3	0.166	2.13E-02	0.1654	1.84E-02	0.1662	1.86E-02
1	4	1	1	60	150	'param_init_bounded_number'	snowfish_disc_sel50_m_3	103.430	2.21E+00	105.4920	2.10E+00	105.2900	2.08E+00
1	4	1	1	0.1	0.5	'param_init_bounded_number'	snowfish_disc_slope_m2_3	0.227	4.65E-02	0.1953	3.59E-02	0.1962	3.59E-02
1	4	1	1	40	200	'param_init_bounded_number'	snowfish_disc_sel50_m2_3	137.390	1.63E+00	136.9030	1.80E+00	136.9900	1.78E+00
1	3	1	1	0.05	0.5	'param_init_bounded_number'	rkfish_disc_slope_f1	0.168	4.14E-02	0.2620	1.52E-01	0.2515	1.45E-01
1	3	1	1	50	150	'param_init_bounded_number'	rkfish_disc_sel50_f1	150.000	1.17E+00	94.9829	1.07E+01	96.0510	1.14E+01
1	3	1	1	0.05	0.5	'param_init_bounded_number'	rkfish_disc_slope_f2	0.144	7.44E-02	0.1632	1.76E-01	0.1652	1.74E-01
1	3	1	1	50	150	'param_init_bounded_number'	rkfish_disc_sel50_f2	150.000	3.00E+00	105.3190	6.33E+01	104.4300	5.67E+01
1	3	1	1	0.05	0.5	'param_init_bounded_number'	rkfish_disc_slope_f3	0.167	6.55E-02	0.1735	6.46E-02	0.1729	6.44E-02
1	3	1	1	50	170	'param_init_bounded_number'	rkfish_disc_sel50_f3	169.990	9.85E+01	162.8670	6.16E+02	162.8800	6.18E+02
1	3	1	1	0.01	0.5	'param_init_bounded_number'	rkfish_disc_slope_m1	0.185	7.25E-02	0.1819	7.10E-02	0.1802	6.99E-02
1	3	1	1	95	150	'param_init_bounded_number'	rkfish_disc_sel50_m1	115.640	5.36E+00	115.9750	5.40E+00	116.2100	5.41E+00
1	3	1	1	0.01	0.5	'param_init_bounded_number'	rkfish_disc_slope_m2	0.089	2.83E-02	0.0888	2.79E-02	0.0895	2.85E-02
1	3	1	1	95	150	'param_init_bounded_number'	rkfish_disc_sel50_m2	134.270	1.47E+01	134.7260	1.47E+01	134.0400	1.45E+01
1	3	1	1	0.01	0.5	'param_init_bounded_number'	rkfish_disc_slope_m3	0.073	8.31E-03	0.0733	7.95E-03	0.0730	7.94E-03
1	3	1	1	95	150	'param_init_bounded_number'	rkfish_disc_sel50_m3	150.000	1.62E-03	150.0000	1.66E-03	150.0000	1.71E-03
1	3	1	1	0.01	0.5	'param_init_bounded_number'	fish_disc_slope_tf1	0.140	3.00E-02	0.1405	3.01E-02	0.1360	3.03E-02
1	3	1	1	40	125.01	'param_init_bounded_number'	fish_disc_sel50_tf1	42.298	2.00E+00	42.1841	1.98E+00	42.7660	2.09E+00
1	3	1	1	0.005	0.5	'param_init_bounded_number'	fish_disc_slope_tf2	0.177	7.90E-02	0.1783	7.90E-02	0.1785	7.88E-02
1	3	1	1	40	250.01	'param_init_bounded_number'	fish_disc_sel50_tf2	40.000	1.46E-04	40.0000	1.44E-04	40.0000	1.47E-04
1	3	1	1	0.01	0.5	'param_init_bounded_number'	fish_disc_slope_tf3	0.096	1.19E-02	0.0988	1.16E-02	0.0993	1.17E-02
1	3	1	1	40	150.01	'param_init_bounded_number'	fish_disc_sel50_tf3	67.703	3.13E+00	69.0290	2.97E+00	68.7720	2.96E+00
1	3	1	1	0.01	0.5	'param_init_bounded_number'	fish_disc_slope_tm1	0.150	2.68E-02	0.1495	2.67E-02	0.1476	2.61E-02
1	3	1	1	40	120.01	'param_init_bounded_number'	fish_disc_sel50_tm1	47.017	1.96E+00	47.0011	1.96E+00	47.4300	2.00E+00
1	3	1	1	0.01	0.5	'param_init_bounded_number'	fish_disc_slope_tm2	0.150	1.16E-01	0.1498	1.16E-01	0.1479	1.15E-01
1	3	1	1	40	120.01	'param_init_bounded_number'	fish_disc_sel50_tm2	41.858	5.19E+00	41.8720	5.20E+00	42.0000	5.27E+00
1	3	1	1	0.01	0.5	'param_init_bounded_number'	fish_disc_slope_tm3	0.076	1.09E-02	0.0781	1.09E-02	0.0782	1.10E-02
1	3	1	1	40	120.01	'param_init_bounded_number'	fish_disc_sel50_tm3	81.210	4.74E+00	83.1448	4.60E+00	82.8730	4.60E+00
1	4	1	1	0.5	1.001	'param_init_bounded_number'	srv2_q	0.526	3.52E-02	0.5171	3.45E-02	0.5131	3.50E-02
1	4	1	1	0	100	'param_init_bounded_number'	srv2_seldiff	21.505	3.53E+00	21.6585	3.57E+00	21.7950	3.57E+00
1	4	1	1	0	90	'param_init_bounded_number'	srv2_sel50	45.364	1.92E+00	45.3081	1.94E+00	45.5260	1.93E+00
1	4	1	1	0.2	2	'param_init_bounded_number'	srv3_q	0.717	3.67E-02	0.7199	3.66E-02	0.7206	3.64E-02
1	4	1	1	0	100	'param_init_bounded_number'	srv3_seldiff	61.792	9.31E+00	61.5279	9.00E+00	60.2860	8.81E+00
1	4	1	1	0	69	'param_init_bounded_number'	srv3_sel50	30.139	3.56E+00	30.6638	3.44E+00	30.1740	3.40E+00
1	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-15.000	2.74E-03	-15.0000	2.69E-03	-15.0000	2.71E-03
2	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-13.676	7.77E-01	-13.6868	7.77E-01	-13.6840	7.77E-01
3	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-12.305	1.17E+00	-12.3258	1.17E+00	-12.3210	1.17E+00
4	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-10.841	1.26E+00	-10.8689	1.26E+00	-10.8620	1.26E+00
5	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-9.235	1.12E+00	-9.2688	1.12E+00	-9.2608	1.12E+00
6	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-7.447	8.26E-01	-7.4828	8.27E-01	-7.4748	8.28E-01
7	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-5.462	4.93E-01	-5.4964	4.94E-01	-5.4895	4.95E-01
8	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-3.393	2.20E-01	-3.4189	2.20E-01	-3.4135	2.20E-01
9	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-1.828	9.97E-02	-1.8351	9.93E-02	-1.8286	9.92E-02
10	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-0.888	5.87E-02	-0.8854	5.82E-02	-0.8806	5.79E-02
11	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-0.544	4.28E-02	-0.5418	4.26E-02	-0.5394	4.24E-02
12	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-0.414	4.32E-02	-0.4093	4.31E-02	-0.4061	4.31E-02
13	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-0.173	4.27E-02	-0.1728	4.21E-02	-0.1683	4.18E-02
14	5	1	16	-15	0	'param_init_bounded_vector'	matestf	0.000	2.12E-05	0.0000	1.83E-05	0.0000	1.54E-05
15	5	1	16	-15	0	'param_init_bounded_vector'	matestf	0.000	5.60E-05	0.0000	2.70E-05	0.0000	2.15E-05
16	5	1	16	-15	0	'param_init_bounded_vector'	matestf	-0.002	6.08E-03	-0.0001	4.58E-03	-0.0001	4.45E-03
1	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-15.000	6.39E-03	-15.0000	6.37E-03	-15.0000	6.37E-03
2	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-13.911	1.10E+00	-13.9093	1.10E+00	-13.9130	1.10E+00
3	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-12.781	1.66E+00	-12.7781	1.66E+00	-12.7860	1.66E+00
4	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-11.571	1.80E+00	-11.5658	1.80E+00	-11.5780	1.80E+00
5	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-10.240	1.61E+00	-10.2327	1.61E+00	-10.2500	1.62E+00
6	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-8.755	1.24E+00	-8.7451	1.24E+00	-8.7666	1.24E+00
7	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-7.111	8.60E-01	-7.0976	8.56E-01	-7.1236	8.62E-01
8	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-5.428	6.33E-01	-5.4120	6.25E-01	-5.4414	6.32E-01
9	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-4.480	3.70E-01	-4.4628	3.64E-01	-4.4865	3.68E-01
10	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-3.891	2.67E-01	-3.8675	2.63E-01	-3.8878	2.64E-01
11	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-3.335	2.07E-01	-3.3084	2.03E-01	-3.3255	2.04E-01
12	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-2.774	1.62E-01	-2.7547	1.60E-01	-2.7680	1.60E-01
13	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-2.242	1.32E-01	-2.2331	1.30E-01	-2.2429	1.31E-01
14	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-1.689	1.06E-01	-1.6869	1.04E-01	-1.6954	1.05E-01
15	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-1.371	9.09E-02	-1.3611	8.96E-02	-1.3706	9.00E-02
16	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-1.190	8.28E-02	-1.1732	8.11E-02	-1.1801	8.13E-02
17	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-1.043	7.54E-02	-1.0295	7.39E-02	-1.0300	7.40E-02
18	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-0.812	6.75E-02	-0.8062	6.60E-02	-0.8031	6.59E-02
19	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-0.585	6.28E-02	-0.5803	6.10E-02	-0.5757	6.09E-02
20	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-0.302	5.55E-02	-0.3028	5.41E-02	-0.2962	5.37E-02
21	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-0.119	4.05E-02	-0.1205	4.00E-02	-0.1166	3.90E-02
22	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-0.002	1.49E-02	-0.0021	1.49E-02	-0.0010	1.46E-02
23	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	1.07E-05	0.0000	1.04E-05	0.0000	9.52E-06
24	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	6.34E-06	0.0000	6.13E-06	0.0000	5.36E-06
25	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	8.43E-06	0.0000	7.96E-06	0.0000	6.56E-06
26	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	7.58E-06	0.0000	7.24E-06	0.0000	6.43E-06
27	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	9.72E-06	0.0000	9.40E-06	0.0000	8.65E-06
28	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	1.59E-05	0.0000	1.55E-05	0.0000	1.45E-05
29	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	3.97E-05	0.0000	3.86E-05	0.0000	3.56E-05
30	5	1	32	-15	0	'param_init_bounded_vector'	matestm	0.000	1.84E-04	0.0000	1.75E-04	0.0000	2.25E-04
31	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-0.042	3.47E-01	-0.0383	3.45E-01	-0.0693	3.66E-01
32	5	1	32	-15	0	'param_init_bounded_vector'	matestm	-0.083	1.23E+00	-0.0749	1.23E+00	-0.1414	1.25E+00
1	4	1	1	0.5	1.001	'param_init_bounded_number'	srv2_femQ	0.709	2.02E-01	0.6870	1.91E-01	0.6917	1.99E-01
1	4	1	1	0	100	'param_init_bounded_number'	srv2_seldiff_f	55.065	1.98E+01	54.5992	2.02E+01	55.4170	2.01E+01
1	4	1	1	-200	100.01	'param_init_bounded_number'	srv2_sel50_f	60.627	1.39E+01	59.7153	1.37E+01	60.7590	1.41E+01
1	4	1	1	0.5	1.001	'param_init_bounded_number'	srv3_femQ	0.558	4.22E-02	0.5487	4.07E-02	0.5609	4.11E-02
1	4	1	1	0	100	'param_init_bounded_number'	srv3_seldiff_f	100.000	5.98E-04	100.0000	6.76E-04	100.0000	6.46E-04
1	4	1	1	-200	100.01	'param_init_bounded_number'	srv3_sel50_f	7.898	1.40E+01	3.4813	1.47E+01	4.9558	1.42E+01

Table 13. Comparison of estimated male recruitment (in 1000's) from the two alternative models and the 2012 model.

year	Model 00	Model 01	2012 Model	year	Model 00	Model 01	2012 Model
1949	31,134	29,032	113,246	1980	13,920	14,818	13,531
1950	31,223	29,115	113,246	1981	54,219	52,353	53,484
1951	31,435	29,313	113,760	1982	21,267	20,979	20,990
1952	31,820	29,671	114,666	1983	204,071	196,374	204,827
1953	32,451	30,259	116,103	1984	172,330	165,707	172,653
1954	33,443	31,182	118,268	1985	361,297	357,612	361,450
1955	34,978	32,610	121,451	1986	286,429	283,330	287,010
1956	37,365	34,829	126,093	1987	278,103	274,624	277,721
1957	41,173	38,365	132,888	1988	198,865	199,821	200,085
1958	47,545	44,274	143,000	1989	111,392	110,604	111,485
1959	59,136	55,002	158,508	1990	47,386	47,252	47,418
1960	83,462	77,448	183,545	1991	23,727	23,595	23,786
1961	146,410	135,458	231,616	1992	18,741	18,476	18,754
1962	325,974	302,011	363,162	1993	15,503	15,283	15,497
1963	693,575	650,674	625,255	1994	15,111	14,837	15,210
1964	962,444	915,319	867,231	1995	21,409	20,981	21,550
1965	922,650	888,247	886,887	1996	24,085	23,624	24,172
1966	771,474	752,564	770,283	1997	62,075	60,885	62,209
1967	661,805	656,764	664,407	1998	26,261	25,768	26,331
1968	609,030	615,844	602,120	1999	81,529	79,700	81,779
1969	579,059	592,041	560,416	2000	47,431	46,464	47,373
1970	440,643	448,683	427,603	2001	147,786	144,453	148,007
1971	294,631	295,752	291,329	2002	56,769	55,933	56,599
1972	268,516	269,704	289,581	2003	101,914	99,399	100,791
1973	241,492	244,744	182,979	2004	202,427	198,884	198,115
1974	22,274	23,278	82,263	2005	59,167	58,480	57,634
1975	208,970	208,490	170,911	2006	48,441	47,807	47,146
1976	380,471	403,576	392,900	2007	37,924	37,338	36,384
1977	282,888	295,106	272,234	2008	42,343	41,470	40,302
1978	252,494	260,540	251,577	2009	204,540	200,135	194,213
1979	69,632	69,546	67,388	2010	240,677	238,350	246,705
1980	13,920	14,818	13,531	2011	129,124	128,170	131,287
				2012	33,966	33,758	32,391
				2013	121,834	120,593	

Table 14. Comparison of time series of estimated mature male biomass (1000's t) at mating from the 2012 assessment model and the two alternative models.

year	2012 model	Model 00	Model 01	year	2012 model	Model 00	Model 01
1949	0.0	0.0	0.0	1981	50.7	51.0	48.7
1950	0.0	0.0	0.0	1982	49.9	49.7	49.9
1951	0.5	0.1	0.1	1983	39.6	39.1	40.2
1952	4.2	1.1	1.1	1984	23.5	23.1	23.7
1953	15.8	4.3	4.1	1985	21.5	21.2	21.7
1954	31.2	8.6	8.1	1986	26.9	26.7	26.9
1955	43.5	12.0	11.3	1987	40.5	40.3	40.1
1956	52.7	14.5	13.7	1988	59.8	59.6	59.0
1957	59.8	16.5	15.6	1989	71.6	71.4	70.6
1958	65.3	18.2	17.2	1990	67.7	67.9	66.7
1959	70.0	19.7	18.6	1991	61.9	62.1	61.2
1960	74.3	21.2	20.0	1992	48.3	48.5	48.0
1961	78.6	23.0	21.8	1993	39.5	39.5	39.2
1962	83.6	25.6	24.2	1994	32.0	31.9	31.6
1963	90.2	29.8	28.1	1995	24.0	23.7	23.5
1964	100.0	38.2	36.1	1996	19.5	19.3	19.1
1965	117.6	56.0	52.8	1997	16.7	16.5	16.4
1966	152.5	98.7	93.3	1998	14.7	14.5	14.5
1967	199.0	162.2	153.2	1999	14.5	14.3	14.3
1968	263.3	246.7	233.8	2000	16.2	16.0	16.0
1969	312.8	309.0	293.7	2001	19.9	19.6	19.6
1970	343.8	343.9	328.8	2002	23.9	23.6	23.6
1971	357.4	357.9	345.5	2003	29.2	28.9	28.9
1972	359.3	360.4	352.5	2004	36.5	36.2	36.1
1973	350.1	353.0	349.8	2005	45.4	45.1	44.9
1974	317.2	321.4	321.2	2006	51.4	51.2	50.9
1975	275.0	278.9	279.9	2007	56.6	56.6	56.4
1976	212.5	215.6	216.6	2008	67.5	67.8	67.6
1977	141.9	146.1	146.9	2009	71.2	71.9	71.6
1978	96.1	99.6	100.4	2010	65.4	66.2	65.9
1979	62.4	64.3	66.8	2011	58.6	59.4	59.3
1980	47.2	48.7	44.1	2012		59.3	59.4

Table 15. Comparison of time series of estimated numbers of male crab ≥ 138 mmCW (millions) on July 1 from the 2012 model and the two alternative models.

year	2012 model	Model 00	Model 01
1974	161.7	162.6	163.0
1975	140.4	141.6	142.7
1976	117.0	117.6	118.9
1977	83.7	84.8	86.1
1978	45.7	47.1	48.2
1979	27.8	27.8	29.0
1980	23.7	24.4	26.7
1981	29.0	29.4	27.9
1982	33.0	33.3	32.8
1983	29.8	29.8	29.9
1984	19.3	19.2	19.5
1985	11.3	11.1	11.3
1986	12.6	12.5	12.5
1987	17.9	17.7	17.7
1988	28.1	27.7	27.5
1989	39.5	39.0	38.9
1990	45.1	44.6	44.5
1991	38.0	37.6	37.4
1992	32.7	32.4	32.3
1993	22.0	21.7	21.7
1994	15.9	15.7	15.7
1995	11.9	11.6	11.6
1996	8.8	8.6	8.6
1997	7.3	7.1	7.1
1998	6.6	6.4	6.5
1999	6.4	6.2	6.2
2000	6.9	6.8	6.8
2001	8.8	8.6	8.6
2002	10.9	10.7	10.7
2003	13.0	12.8	12.8
2004	16.4	16.2	16.2
2005	20.9	20.6	20.7
2006	25.6	25.3	25.3
2007	27.0	26.7	26.7
2008	32.0	31.9	31.9
2009	36.5	36.6	36.6
2010	33.8	34.0	33.9
2011	30.3	30.6	30.5
2012	27.7	28.0	28.0
2013	--	32.1	32.3

Table 16. Comparison of time series of observed retained catch (1000's t) in the directed fishery and predicted catch from the 2012 assessment model and the two alternative models.

Year	Observed	2012 Model	Model 00	Model 01
1965/66	1.92334	1.8996	1.95133	1.95157
1966/67	2.445	2.49885	2.47419	2.47429
1967/68	13.5995	13.5965	13.5936	13.5936
1968/69	18.0041	18.0008	18.0001	18.0001
1969/70	27.4892	27.4847	27.4847	27.4848
1970/71	25.4933	25.4886	25.4887	25.4889
1971/72	20.7122	20.7073	20.7074	20.7076
1972/73	16.9063	16.9008	16.9009	16.9013
1973/74	13.0279	13.022	13.0221	13.0228
1974/75	15.2416	15.2293	15.2296	15.2305
1975/76	17.6548	17.6514	17.6515	17.6528
1976/77	30.0159	30.0096	30.0099	30.0111
1977/78	35.5273	35.521	35.5212	35.5226
1978/79	21.0932	21.0885	21.0881	21.0898
1979/80	19.0066	18.9679	18.9686	18.9689
1980/81	13.4271	13.4353	13.4331	13.4318
1981/82	4.98979	5.03321	5.03228	5.04395
1982/83	2.39056	2.46532	2.46506	2.47121
1983/84	0.548877	0.793529	0.794777	0.779051
1984/85	1.4289	1.49775	1.49743	1.48953
1985/86	0	0	0	0
1986/87	0	0	0	0
1987/88	0.997959	1.02201	1.02247	1.02485
1988/89	3.17986	3.10399	3.10363	3.10164
1989/90	11.1136	11.0181	11.0172	11.0139
1990/91	18.1901	18.0877	18.0862	18.0831

Year	Observed	2012 Model	Model 00	Model 01
1991/92	14.425	14.308	14.3056	14.3043
1992/93	15.922	15.3182	15.3123	15.3167
1993/94	7.66614	7.48357	7.48452	7.47684
1994/95	3.53822	3.46481	3.46716	3.45587
1995/96	1.9188	1.84268	1.83682	1.83599
1996/97	0.821048	0.801171	0.807136	0.767396
1997/98	0	0	0	0
1998/99	0	0	0	0
1999/00	0	0	0	0
2000/01	0	0	0	0
2001/02	0	0	0	0
2002/03	0	0	0	0
2003/04	0	0	0	0
2004/05	0	0	0	0
2005/06	0.430937	0.430428	0.431329	0.433395
2006/07	0.961669	0.933288	0.933965	0.936471
2007/08	0.957133	1.03641	1.03581	1.0375
2008/09	0.880018	0.916516	0.918788	0.920447
2009/10	0.602566	0.686959	0.689901	0.692968
2010/11	0	0	0	0
2011/12	0	0	0	0
2012/13	0		0	0

Table 17. Comparison of time series of observed total (retained+discards) male catch (1000's t) in the directed fishery with the predicted catch from the 2012 assessment model and the two alternative models.

Survey Year	Year	Observed	2012 Model	Model 00	Model 01
1992	1992/93	21.415	21.738	21.741	21.736
1993	1993/94	11.082	11.227	11.224	11.228
1994	1994/95	5.103	5.224	5.220	5.228
1995	1995/96	3.300	3.462	3.461	3.463
1996	1996/97	0.939	1.162	1.153	1.189
1997	1997/98	0.000	0.000	0.000	0.000
1998	1998/99	0.000	0.000	0.000	0.000
1999	1999/00	0.000	0.000	0.000	0.000
2000	2000/01	0.000	0.000	0.000	0.000
2001	2001/02	0.000	0.000	0.000	0.000
2002	2002/03	0.000	0.000	0.000	0.000
2003	2003/04	0.000	0.000	0.000	0.000
2004	2004/05	0.000	0.000	0.000	0.000
2005	2005/06	0.574	0.861	0.863	0.866
2006	2006/07	1.583	1.743	1.746	1.747
2007	2007/08	2.007	2.096	2.099	2.101
2008	2008/09	1.095	1.261	1.263	1.265
2009	2009/10	0.638	0.732	0.735	0.738
2010	2010/11	0.000	0.000	0.000	0.000
2011	2011/12	0.000	0.000	0.000	0.000
2012	2012/13	0.000		0.000	0.000

Table 18. Comparison of time series of observed female discard mortality (1000's t) in the directed fishery with the predicted catch from the 2012 assessment model and the two alternative models.

Survey Year	Year	Observed	2012 Model	Model 00	Model 01
1992	1992/93	0.894	1.557	1.543	1.558
1993	1993/94	0.907	0.720	0.714	0.716
1994	1994/95	0.635	0.296	0.294	0.294
1995	1995/96	0.880	0.127	0.125	0.127
1996	1996/97	0.045	0.059	0.060	0.054
1997	1997/98	0.000	0.000	0.000	0.000
1998	1998/99	0.000	0.000	0.000	0.000
1999	1999/00	0.000	0.000	0.000	0.000
2000	2000/01	0.000	0.000	0.000	0.000
2001	2001/02	0.000	0.000	0.000	0.000
2002	2002/03	0.000	0.000	0.000	0.000
2003	2003/04	0.000	0.000	0.000	0.000
2004	2004/05	0.000	0.000	0.000	0.000
2005	2005/06	0.014	0.014	0.014	0.014
2006	2006/07	0.161	0.028	0.027	0.028
2007	2007/08	0.050	0.033	0.033	0.034
2008	2008/09	0.007	0.033	0.033	0.034
2009	2009/10	0.001	0.059	0.059	0.060
2010	2010/11	0.000	0.000	0.000	0.000
2011	2011/12	0.000	0.000	0.000	0.000
2012	2012/13	0.000		0.000	0.000

Table 19. Comparison of components of the likelihood for the alternative models. Final model estimates are based on minimizing the objective function, which is the sum of the log-likelihood components multiplied by their respective weights.

Model 00			Model 01			
weight	-ln(L)	objective function value	weight	-ln(L)	objective function value	description
1	2.202	2.202	1	2.225	2.225	recruitment penalty
0	0.000	0.000	0	0.000	0.000	sex ratio penalty
1	1.206	1.206	1	1.117	1.117	immatures natural mortality penalty
1	2.053	2.053	1	1.683	1.683	mature male natural mortality penalty
1	42.732	42.732	1	42.079	42.079	mature female natural mortality penalty
1	5.126	5.126	1	5.081	5.081	survey q penalty
1	21.957	21.957	1	20.371	20.371	female survey q penalty
1	0.699	0.699	1	0.680	0.680	prior on female growth parameter a
1	0.517	0.517	1	0.494	0.494	prior on female growth parameter b
1	0.012	0.012	1	0.021	0.021	prior on male growth parameter a
1	0.015	0.015	1	0.016	0.016	prior on male growth parameter b
1	1.217	1.217	1	1.216	1.216	smoothing penalty on female maturity curve
0.5	0.851	0.426	0.5	0.842	0.421	smoothing penalty on male maturity curve
0	0.000	0.000	0	0.000	0.000	1st difference penalty on changes in male size at 50% selectivity in directed fishery
1	42.218	42.218	1	41.871	41.871	penalty on F-devs in directed fishery
0.5	20.177	10.088	0.5	20.171	10.086	penalty on F-devs in snow crab fishery
0	0.000	0.000	0	0.000	0.000	penalty on F-devs in BBRKC fishery
0.5	25.013	12.507	0.5	24.389	12.194	penalty on F-devs in groundfish fishery
1	39.344	39.344	1	39.697	39.697	likelihood for directed fishery: retained males
1	56.665	56.665	1	56.754	56.754	likelihood for directed fishery: total males
1	9.407	9.407	1	9.398	9.398	likelihood for directed fishery: discarded females
1	37.728	37.728	1	38.077	38.077	likelihood for snow crab fishery: discarded males
1	14.379	14.379	1	14.205	14.205	likelihood for snow crab fishery: discarded females
1	26.389	26.389	1	26.198	26.198	likelihood for BBRKC fishery: discarded males
1	2.678	2.678	1	2.550	2.550	likelihood for BBRKC fishery: discarded females
1	26.432	26.432	1	28.949	28.949	likelihood for groundfish fishery
1	289.597	289.597	1	291.013	291.013	likelihood for survey: immature males
1	217.013	217.013	1	214.823	214.823	likelihood for survey: mature males
1	247.222	247.222	1	247.391	247.391	likelihood for survey: immature females
1	87.049	87.049	1	90.527	90.527	likelihood for survey: mature females
1	187.468	187.468	1	185.787	185.787	likelihood for survey: mature survey biomass
10	0.550	5.496	10	0.548	5.480	likelihood for directed fishery: male retained catch biomass
10	0.369	3.685	10	0.389	3.892	likelihood for directed fishery: male total catch biomass
10	1.168	11.677	10	1.182	11.823	likelihood for directed fishery: female catch biomass
10	1.337	13.371	10	1.370	13.698	likelihood for snow crab fishery: total catch biomass
10	1.904	19.040	10	1.912	19.118	likelihood for BBRKC fishery: total catch biomass
10	0.223	2.233	10	0.224	2.245	likelihood for groundfish fishery: total catch biomass

Table 20. Recruitment scenarios and estimated average total (males + females) recruitment (millions) from the author's preferred model (Model 01) and the accepted model from the 2012 assessment.

scenario	time period	Model 01	2012 Model
R1	1966-1972	1,037,529	1,030,211
R2	1966-1988	582,804	575,456
R3	1982-2013	211,918	213,540
R4	1966-2013	358,104	357,569
R5	1990-2013	148,470	145,535
R6	1971-2013	257,144	256,098

Table 21. OFL and ABC determination for the six recruitment scenarios, based on results from the author's preferred model (Model 01) and the Tanner crab projection model. The recruitment scenario adopted by the SSC in October, 2012 (R3), updated to 2013, is highlighted.

Scenario	average recruitment millions	B 1000's t	Fmsy	Bmsy 1000's t	B/Bmsy	OFL 1000's t	ABC (p*) 1000's t	ABC (10% buffer) 1000's t
R1	1,037.5	59.35	0.73	164.22	0.36	13.47	13.44	12.12
R2	582.8	59.35	0.73	92.24	0.64	19.14	19.10	17.23
R3	211.9	59.35	0.73	33.54	1.77	25.35	25.31	22.82
R4	358.1	59.35	0.73	56.68	1.05	25.35	25.31	22.82
R5	148.5	59.35	0.73	23.50	2.53	25.35	25.31	22.82
R6	257.1	59.35	0.73	40.70	1.46	25.35	25.31	22.82

Figures

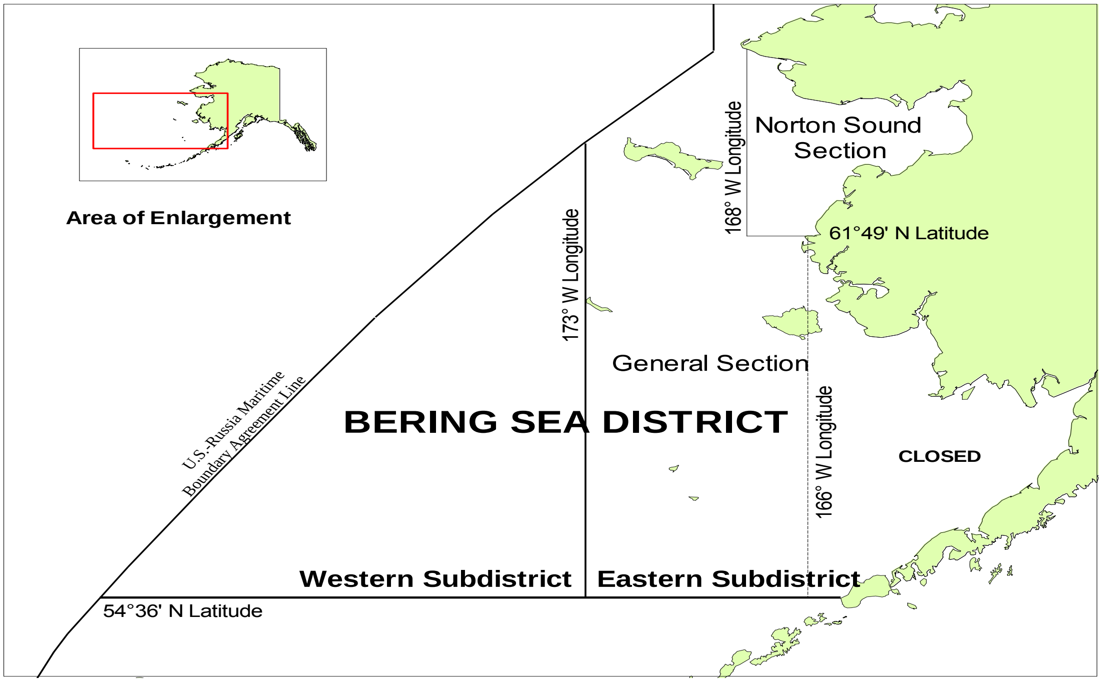


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

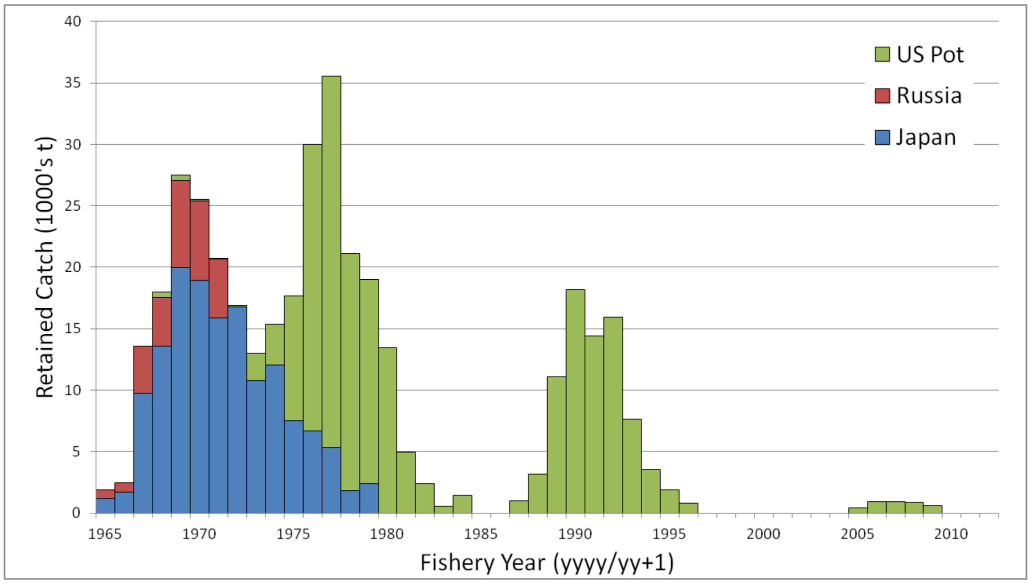


Figure 2. Retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66.

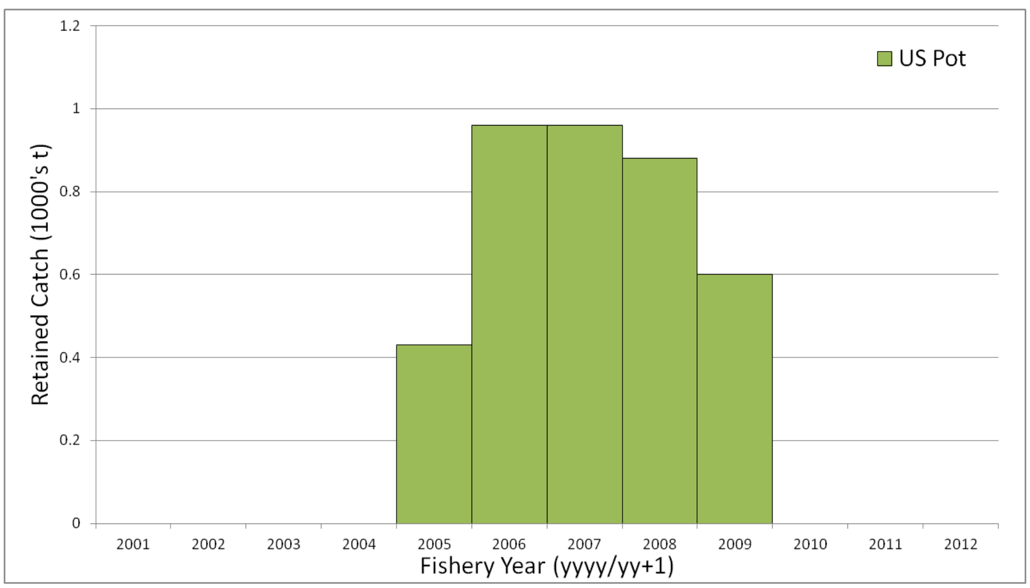


Figure 3. Retained catch (males, 1000's t) in directed fishery for Tanner crab since 2001/02. The directed fishery was closed from 1996/97 to 2004/05 and from 2010/11 to 2012/13.

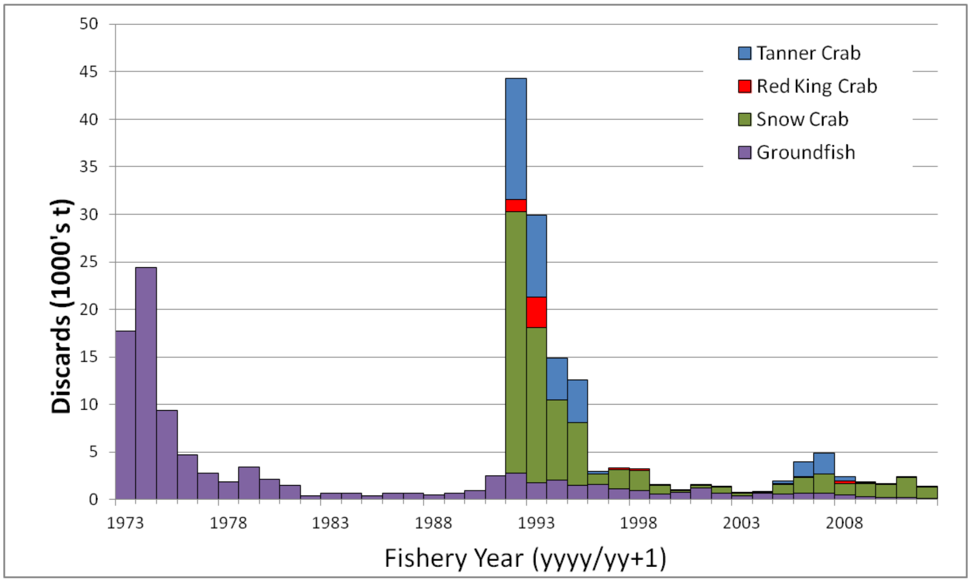


Figure 4. Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries.

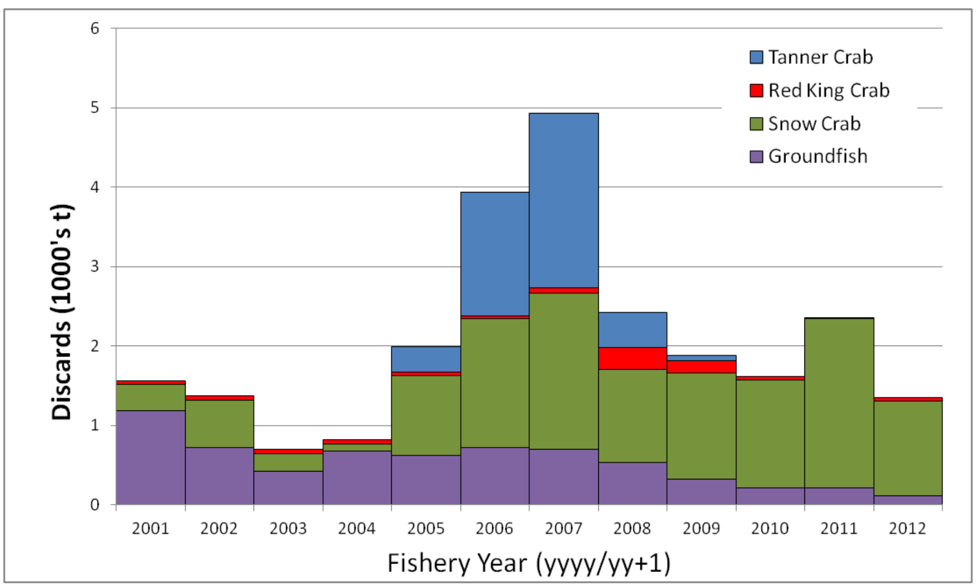


Figure 5.Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries since 2001.

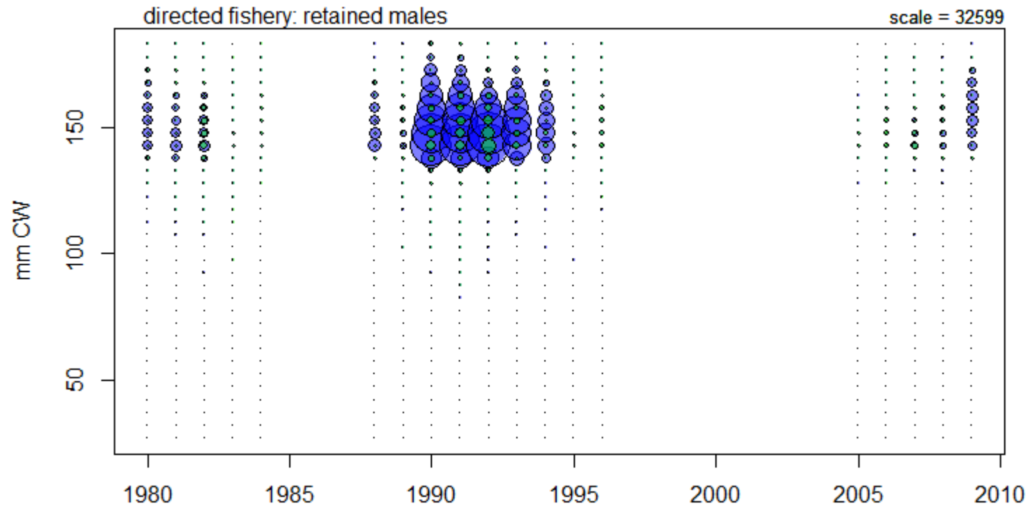


Figure 6. Retained (male) Tanner crab size compositions, by shell condition, in the directed Tanner crab pot fishery, from landed catch. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5. Blue = new shell crab, green = old shell crab.

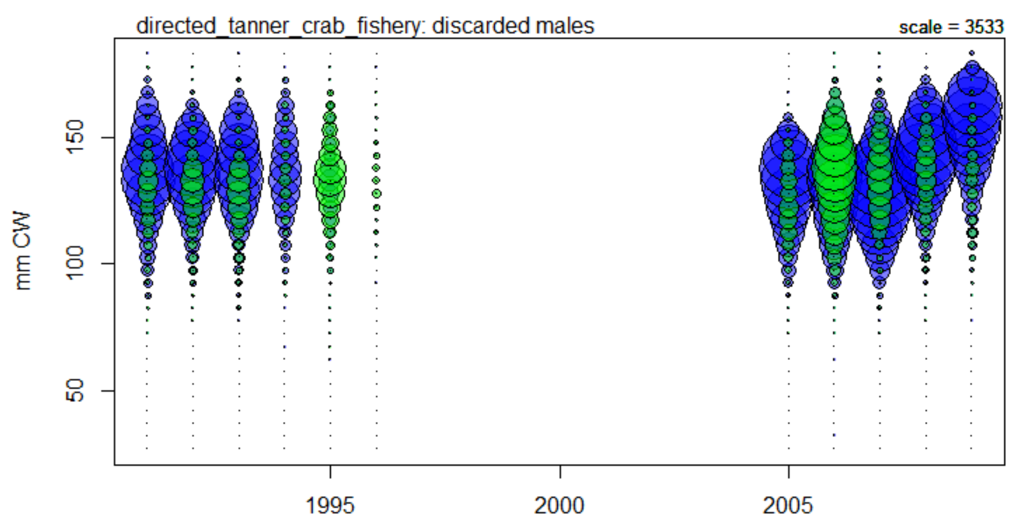


Figure 7. Total male Tanner crab catch (retained + discarded) size compositions by shell condition in the directed Tanner crab pot fishery, from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5.Blue = new shell crab, green = old shell crab.

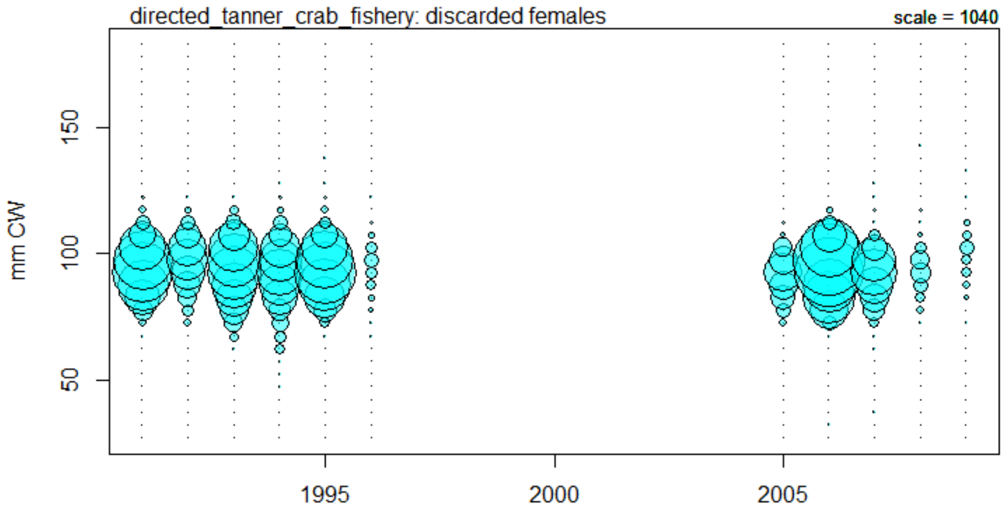


Figure 8. Female Tanner crab bycatch size compositions in the directed Tanner crab pot fishery, from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5. Shell condition is undifferentiated.

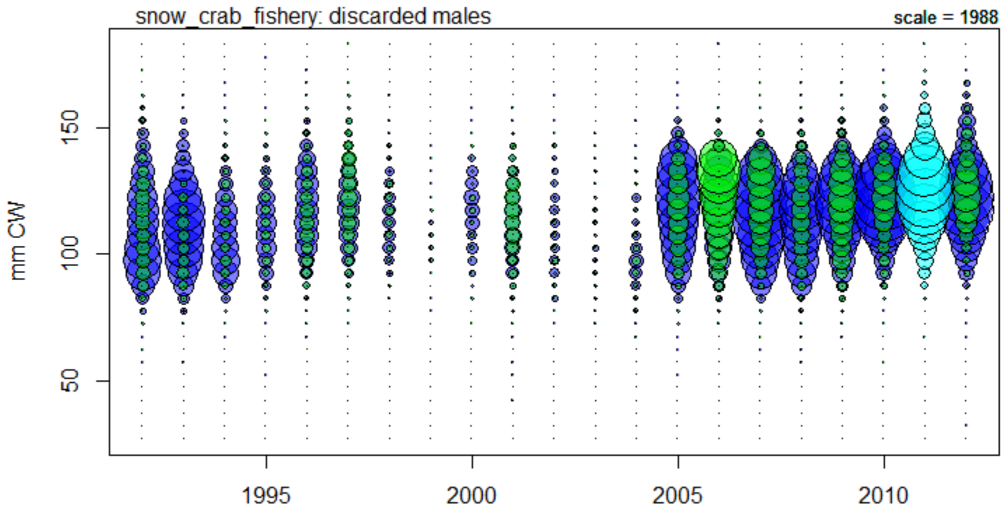


Figure 9. Male Tanner crab bycatch size compositions by shell condition in the snow crab pot fishery, from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5. Male shell condition was undifferentiated in 2011/12. Blue = new shell crab, green = old shell crab, cyan = undifferentiated.

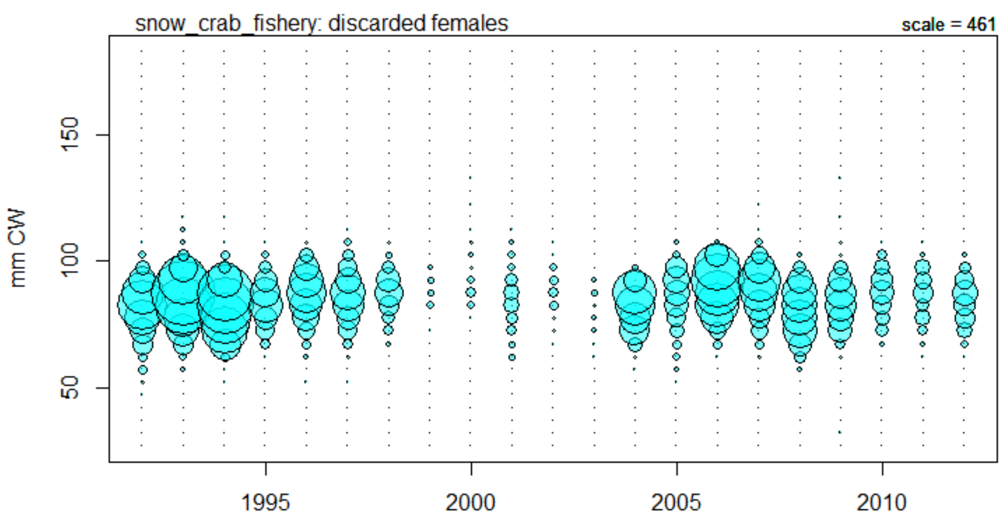


Figure 10. Female Tanner crab bycatch size composition in the snow crab pot fishery, from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5.Shell condition is undifferentiated.

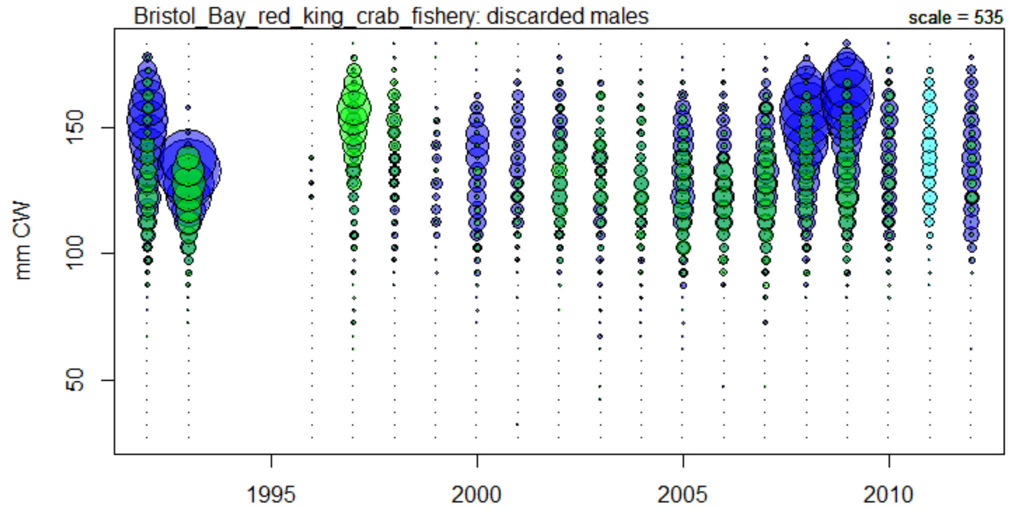


Figure 11. Male Tanner crab bycatch size compositions by shell condition in the BBRKC pot fishery, from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5. Male shell condition ws undifferentiated in 2011/12. Blue = new shell crab, green = old shell crab, cyan = undifferentiated.

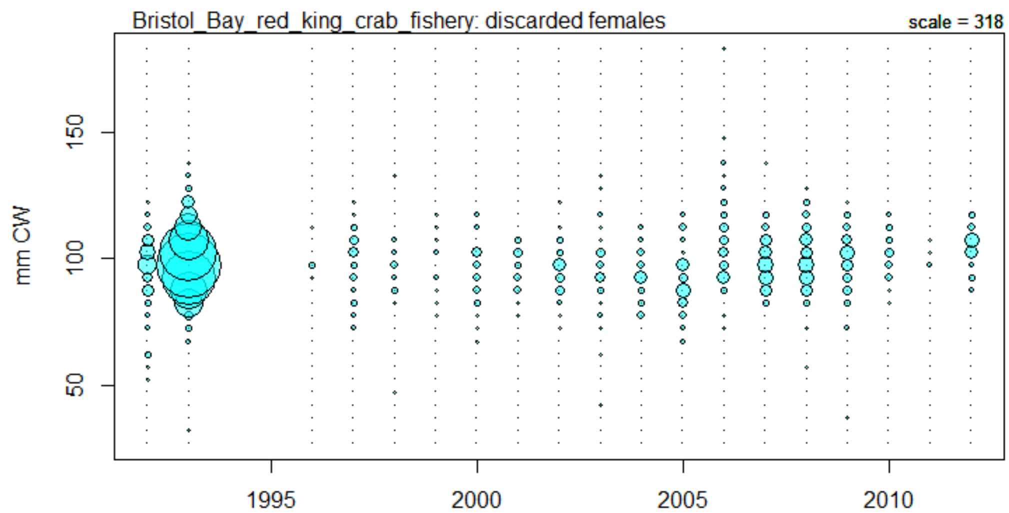


Figure 12. Female Tanner crab bycatch size compositions in the BBRKC pot fishery, from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5. Shell condition is undifferentiated.

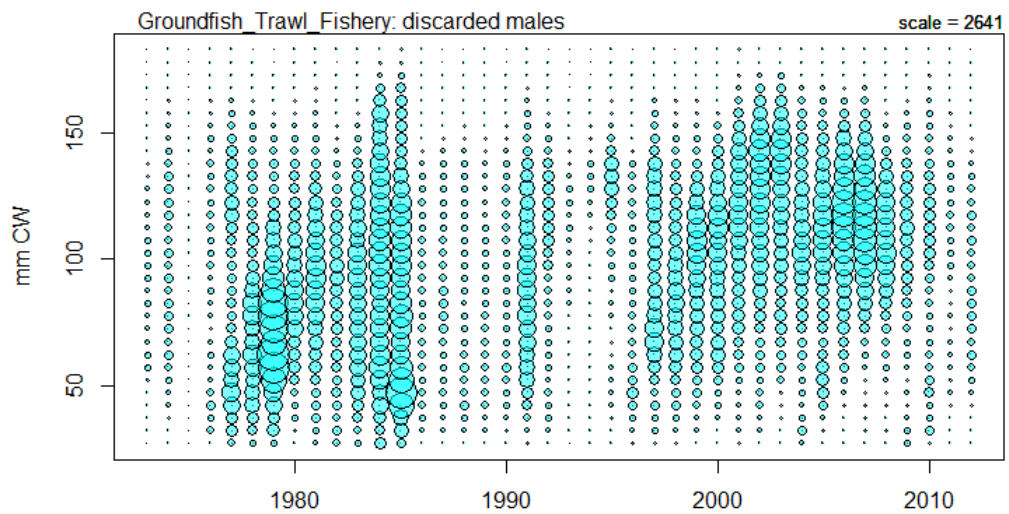


Figure 13. Male Tanner crab bycatch size compositions in the groundfish fisheries from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5. Shell condition is undifferentiated.

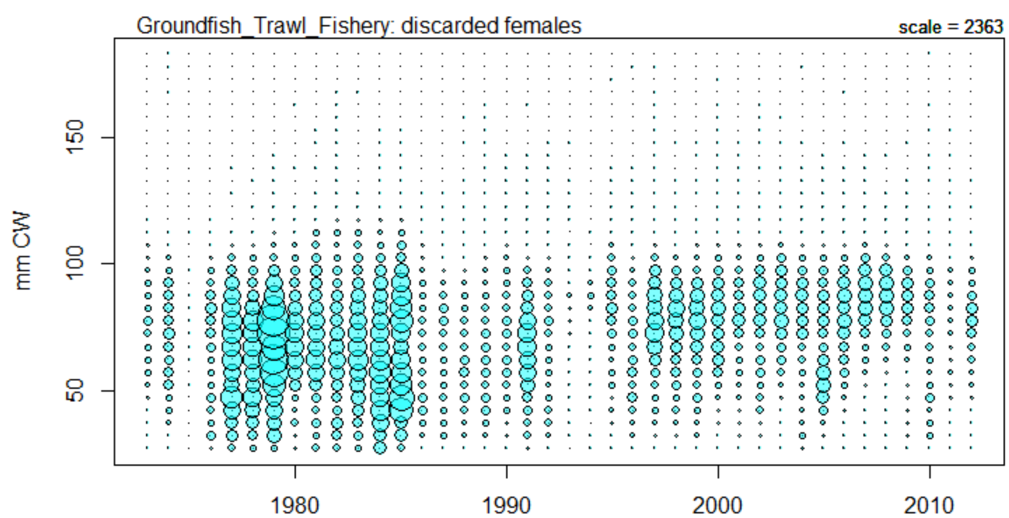


Figure 14. Female Tanner crab bycatch size compositions in the groundfish fisheries from observer sampling. Numbers at size (mm CW) are proportional to symbol area. The scale indicates the relative size of a circle of radius = 0.5. Shell condition is undifferentiated.

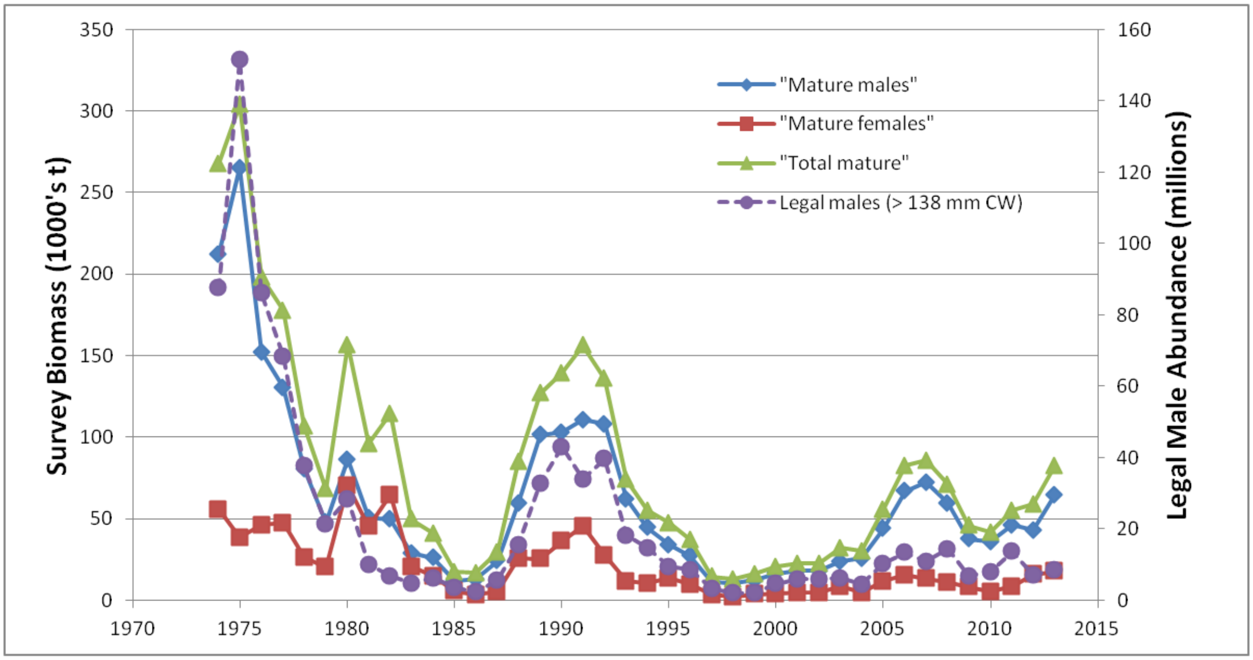


Figure 15. Trends in mature Tanner crab biomass and abundance of legal crab (≥ 138 mm CW) in the summer bottom trawl survey.

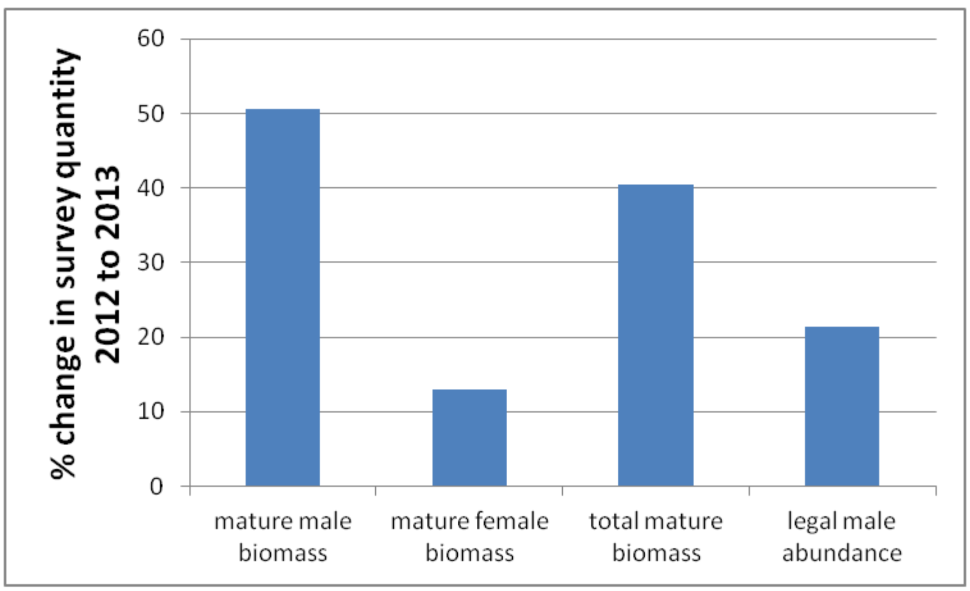


Figure 16. Percent change in mature male biomass, mature female biomass, total mature biomass and number of legal male crab observed in the summer bottom trawl survey.

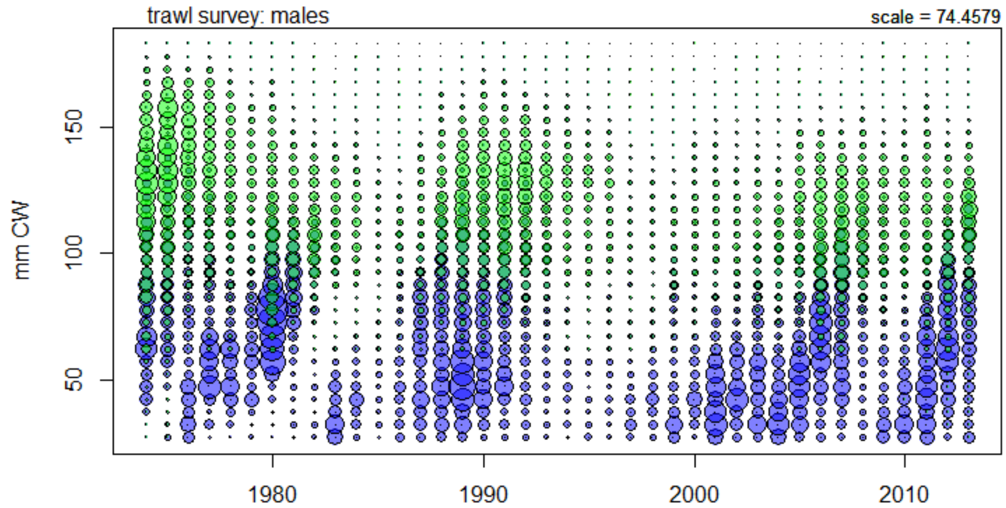


Figure 17. Numbers at size for male Tanner crab, by maturity state, in the summer bottom trawl survey. Blue = immature crab, green = mature crab. Maturity state assigned by size and shell condition: all old shell male crab were assumed mature, the fraction of new shell male crab that were mature was based on an analysis by Rugolo and Turnock (2010).

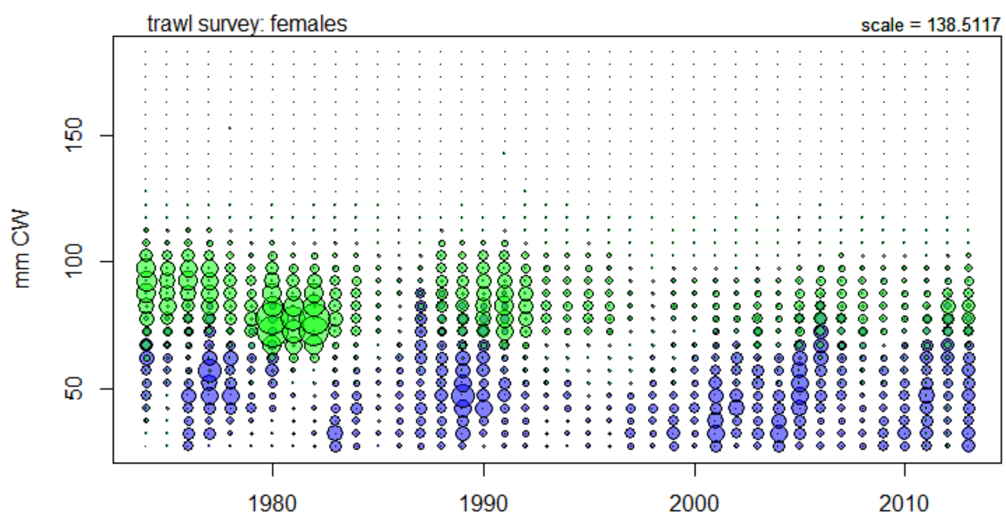


Figure 18. Numbers at size for female Tanner crab, by maturity state, in the summer bottom trawl survey. Blue = immature crab, green = mature crab. Maturity state determined by morphological characteristics.

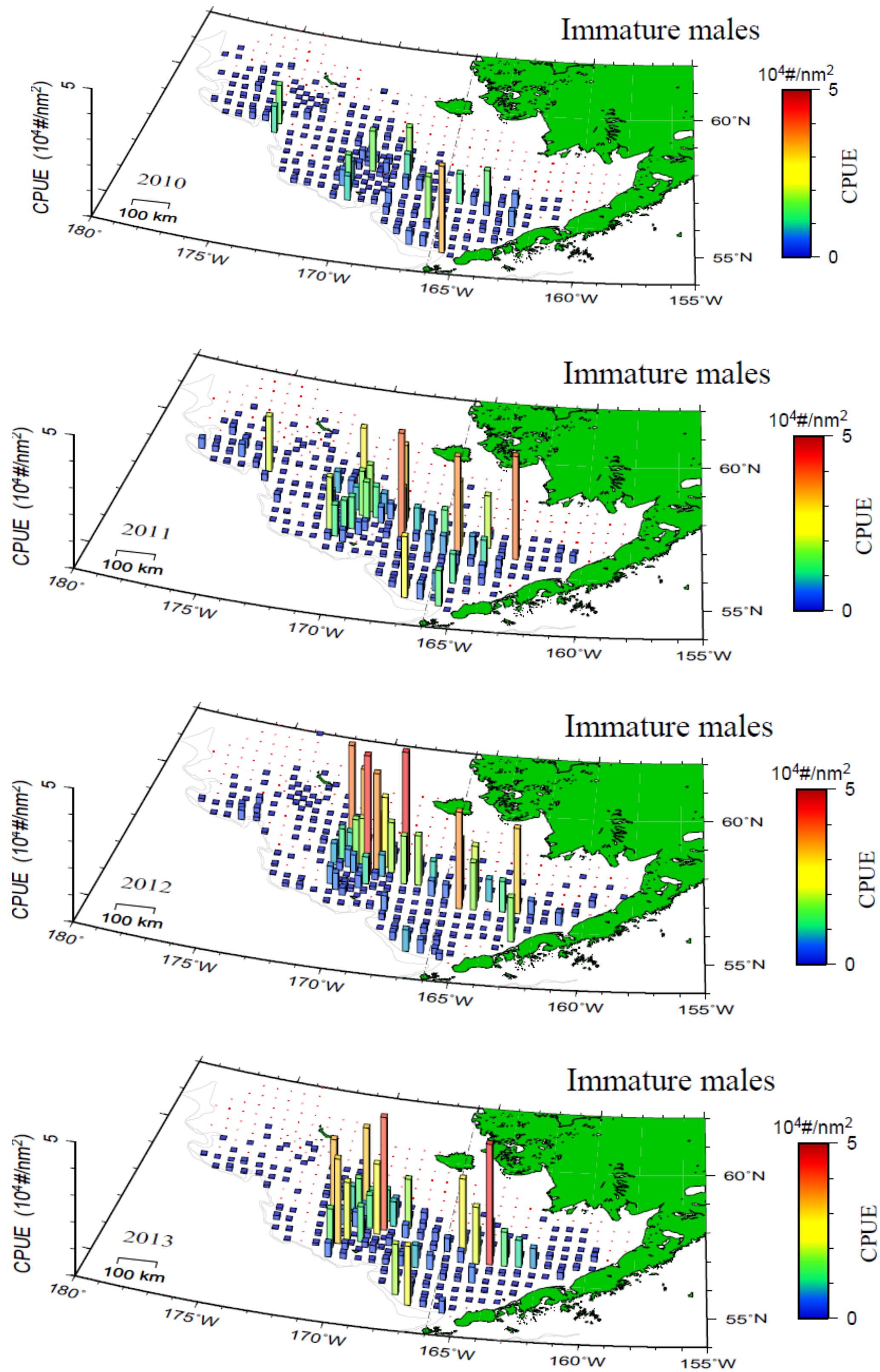


Figure 19. Distribution of immature males (number/ sq. nm) in the summer trawl survey for 2010-13.

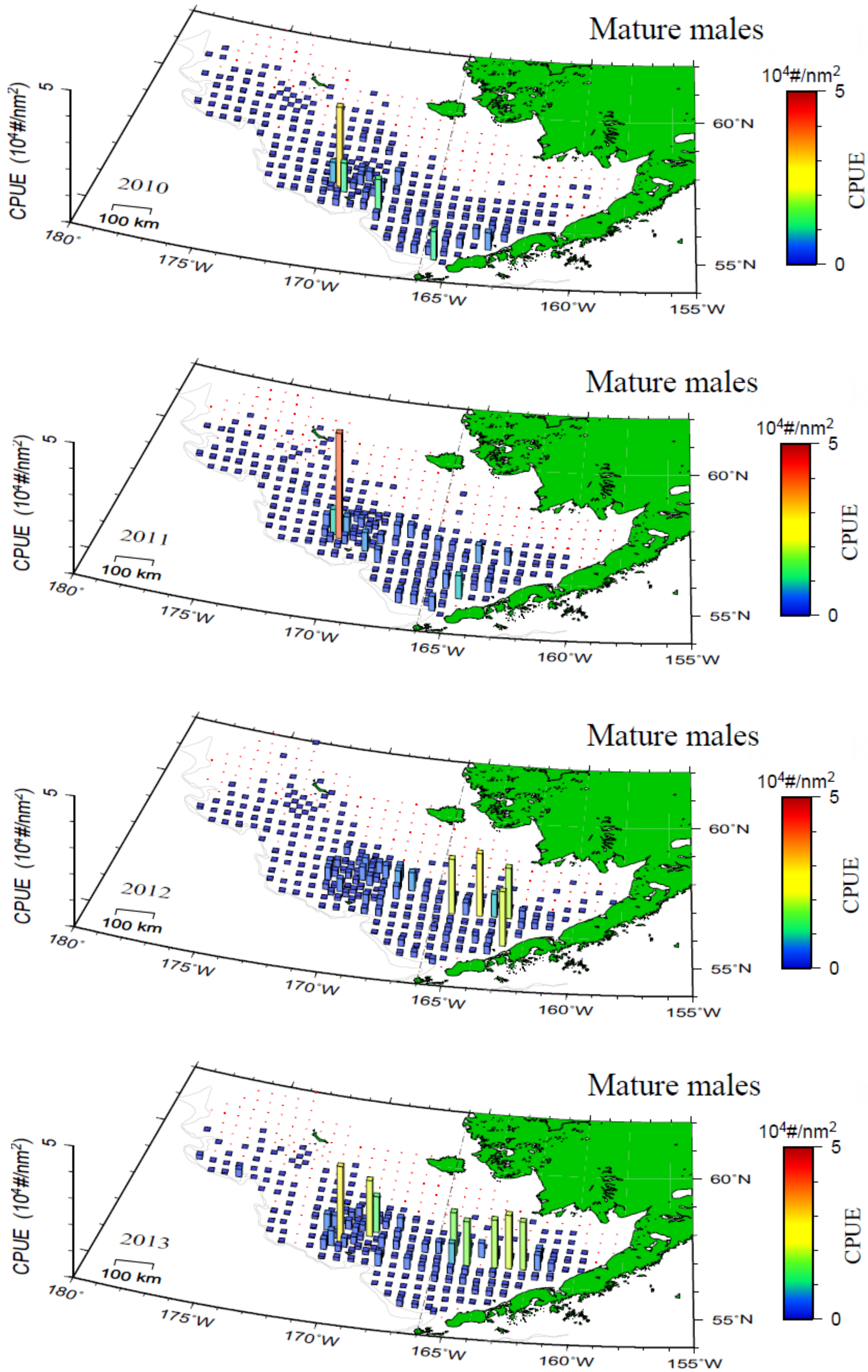


Figure 20. Distribution of mature males (number/ sq. nm) in the summer trawl survey for 2010-13.

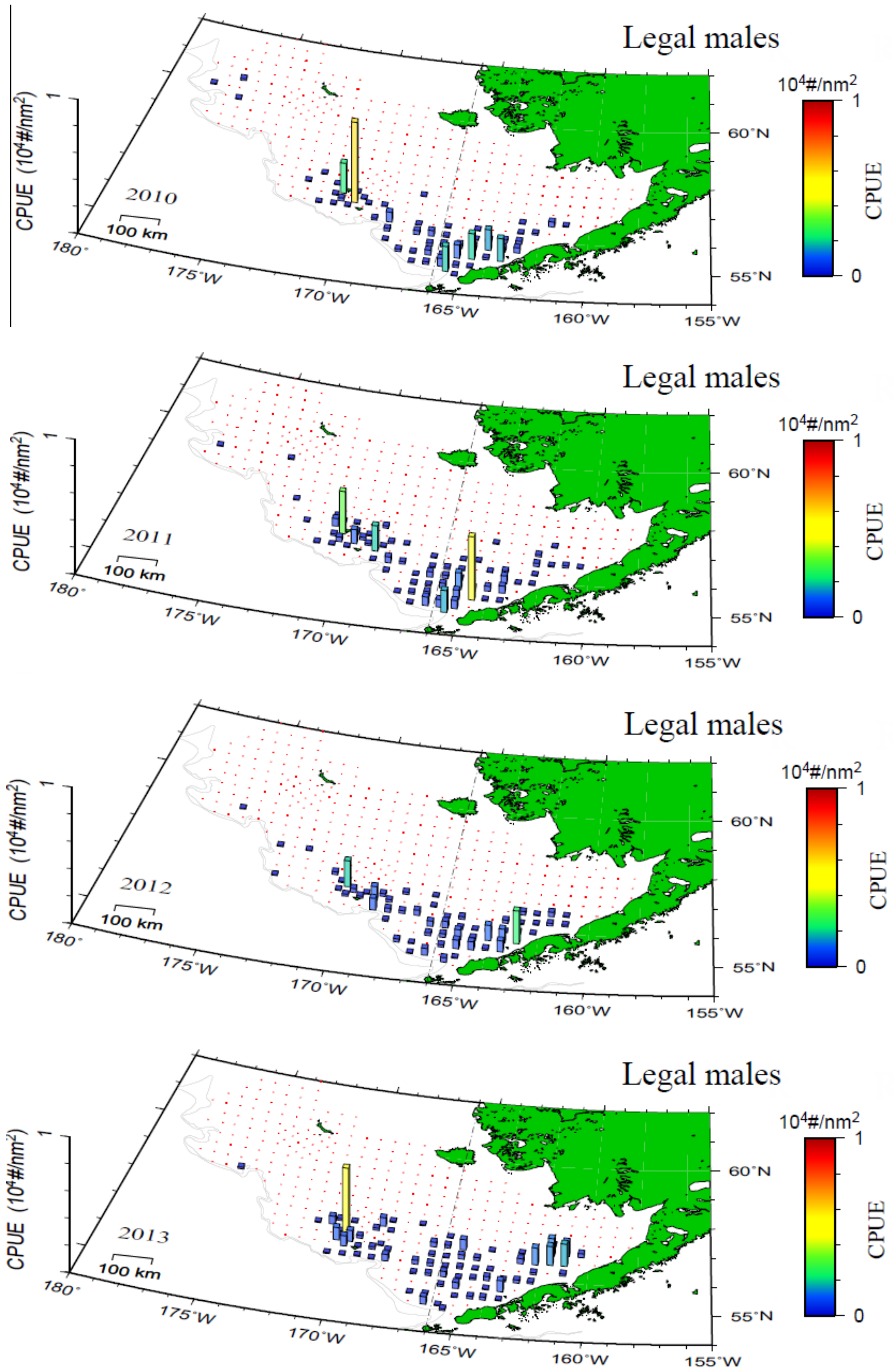


Figure 21. Distribution of "legal males" (≥ 138 mm CW; number/ sq. nm) in the summer trawl survey for 2010-13.

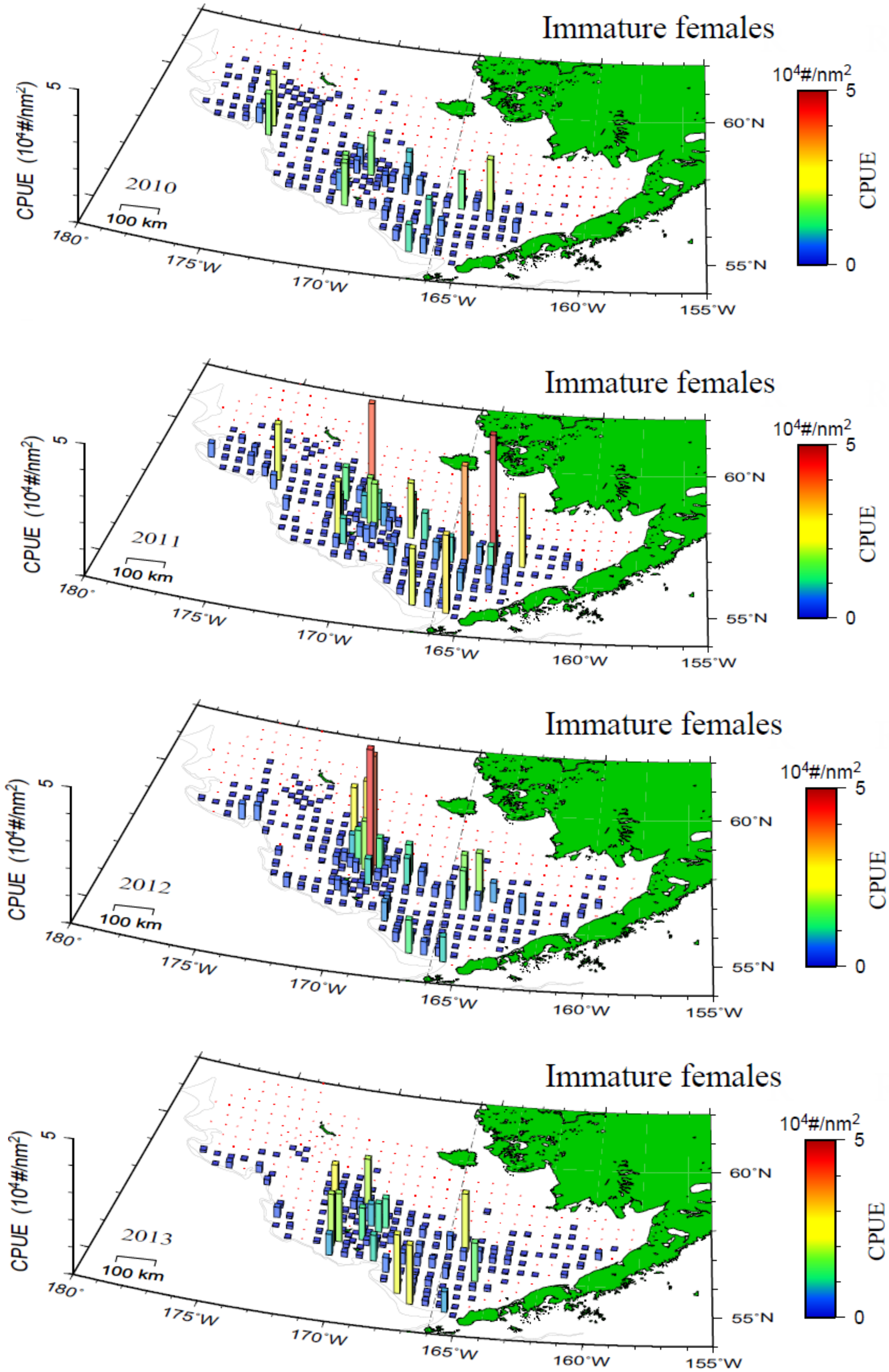


Figure 22. Distribution of immature females (number/ sq. nm) in the summer trawl survey for 2010-13.

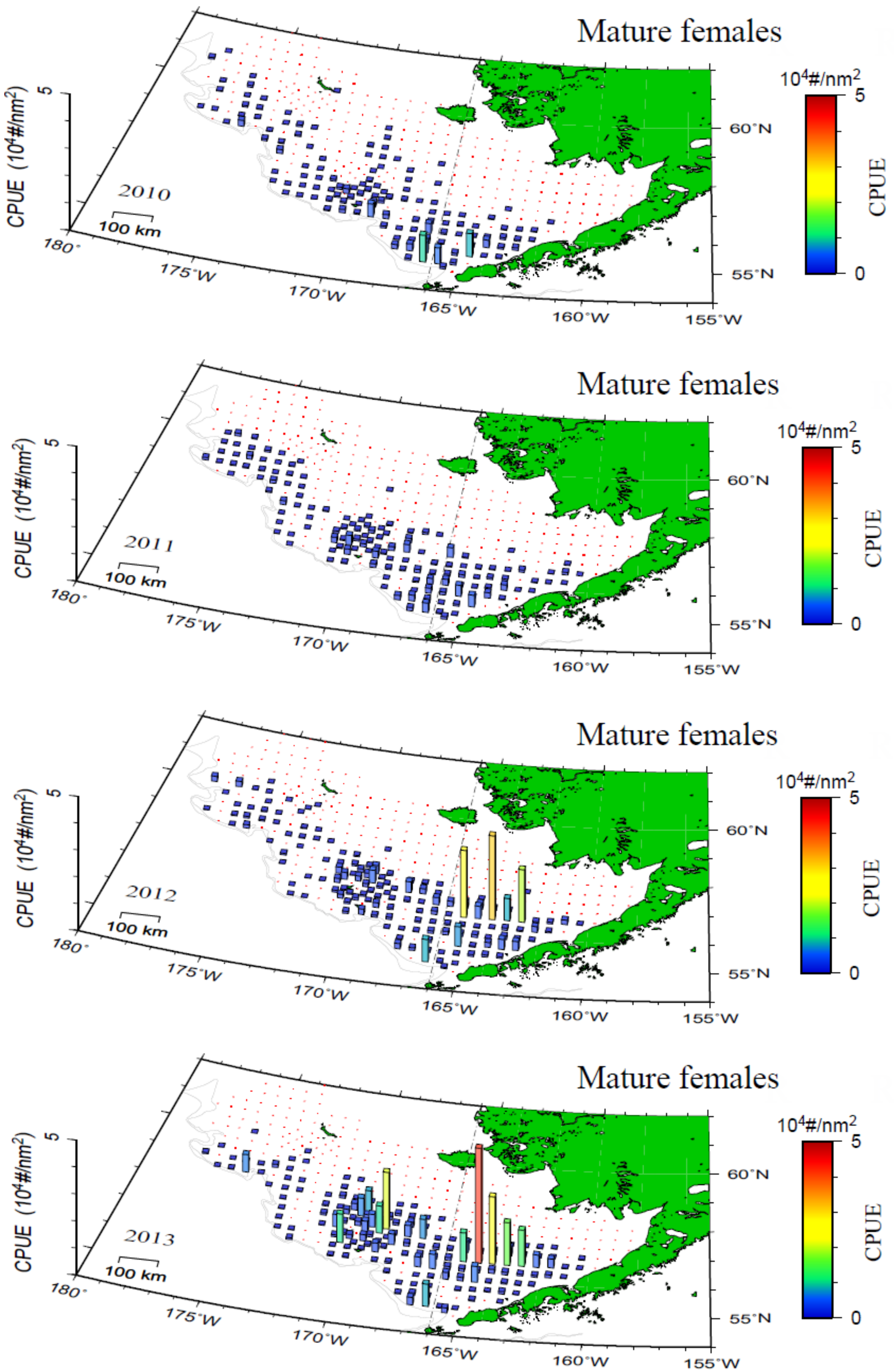
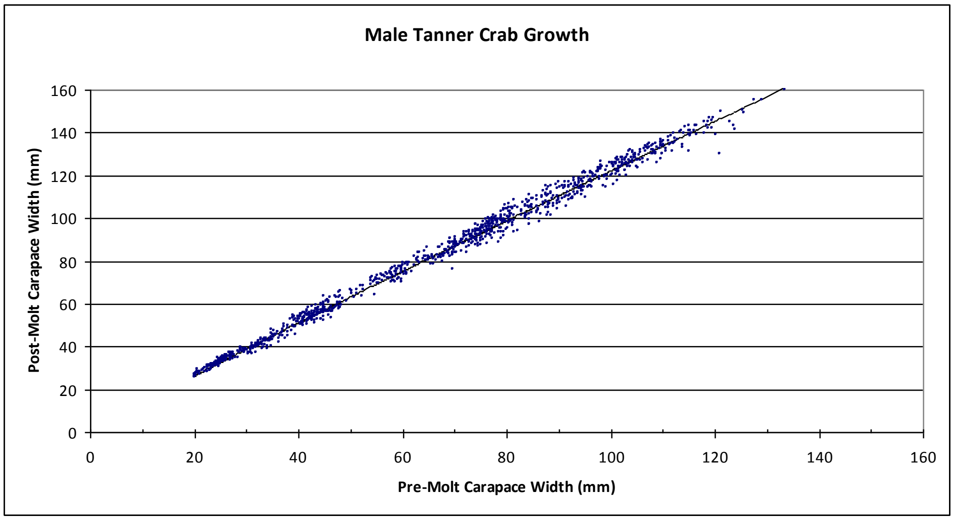


Figure 23. Distribution of mature females (number/ sq. nm) in the summer trawl survey for 2010-13.

(a)



(b)

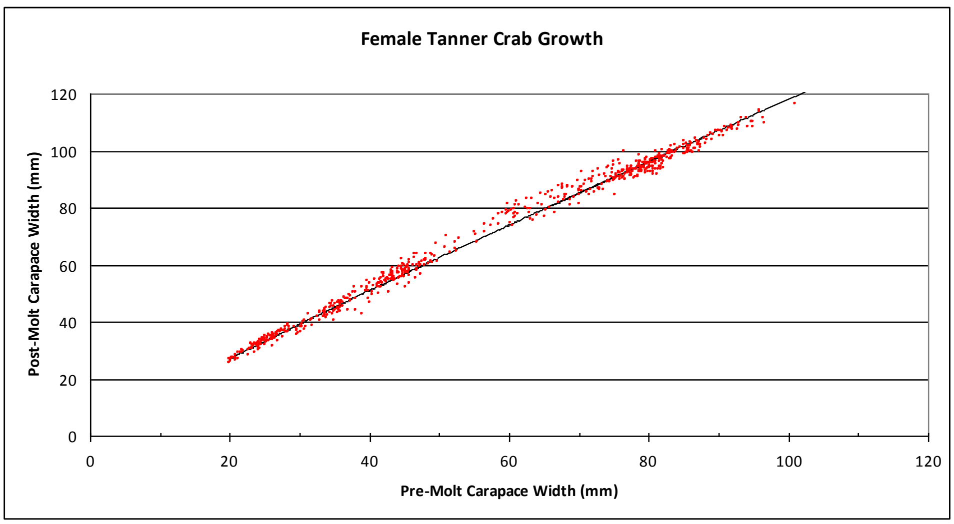


Figure 24. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Estimated by Rugolo and Turnock (2010) based on data from Gulf of Alaska Tanner crab (Munk, unpublished data).

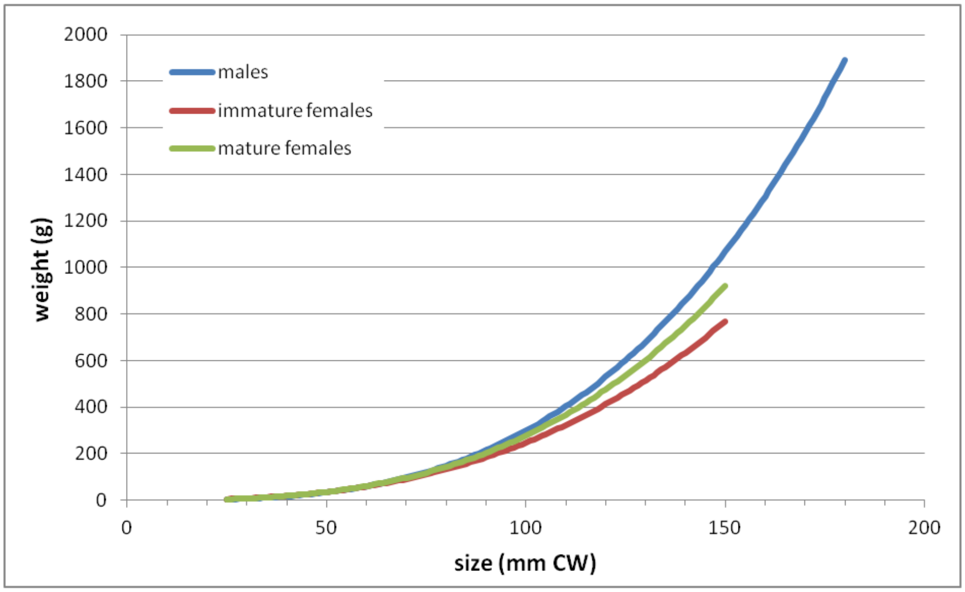


Figure 25. Fitted weight-at size relationships for males (immature and mature; blue line), immature females (red line), and mature females (green line).

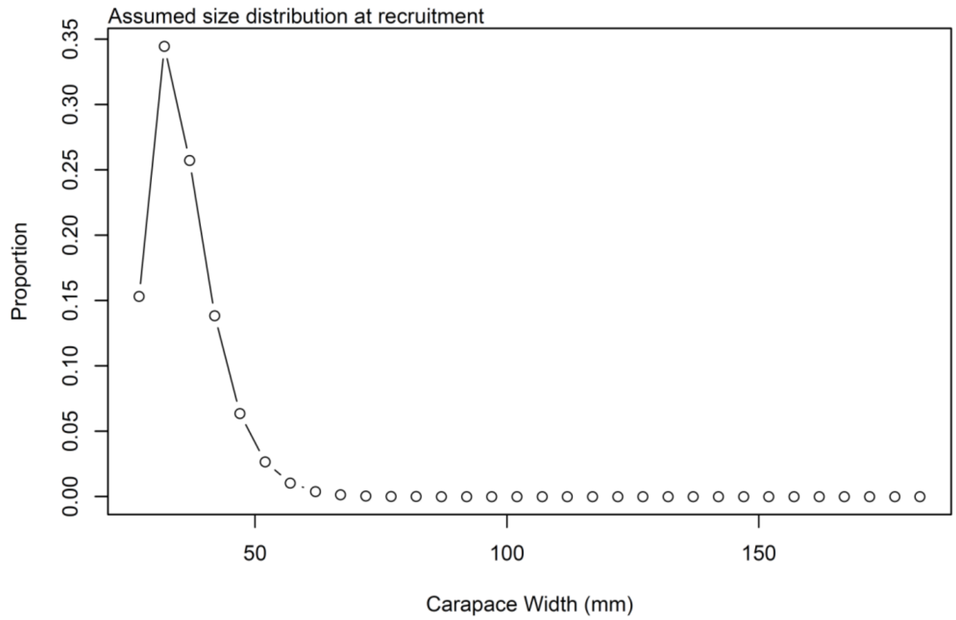


Figure 26. Assumed size distribution for recruits entering the population.

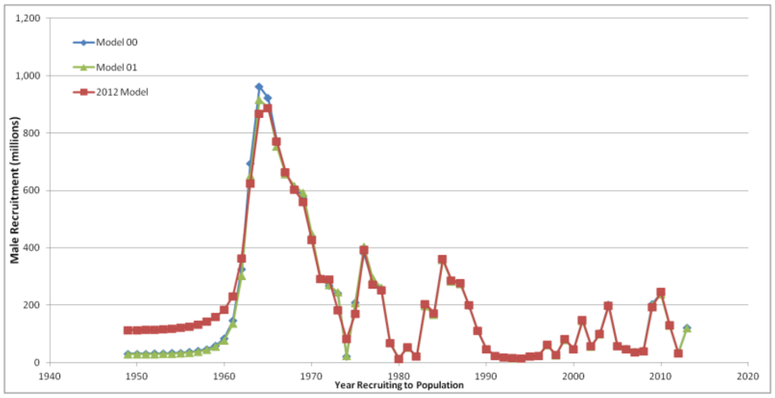


Figure 27. Comparison of estimated time series for (male) recruitment from the two alternative models and the 2012 model.

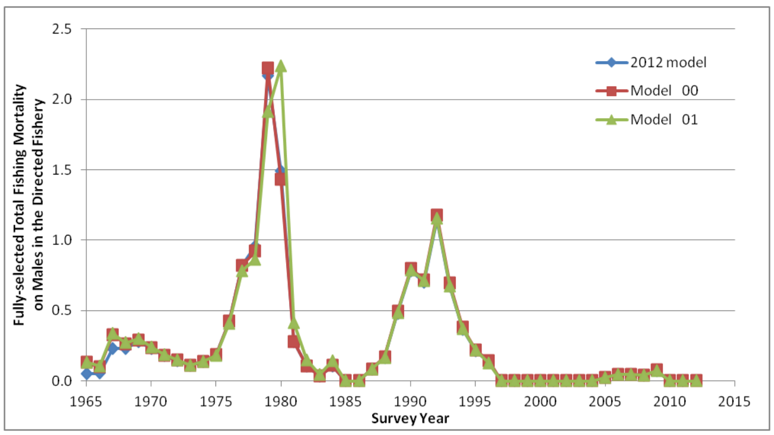


Figure 28. Comparison of estimated time series for fully-selected total F (retained + discards) on males in the directed Tanner crab fishery from the two alternative models and the 2012 model.

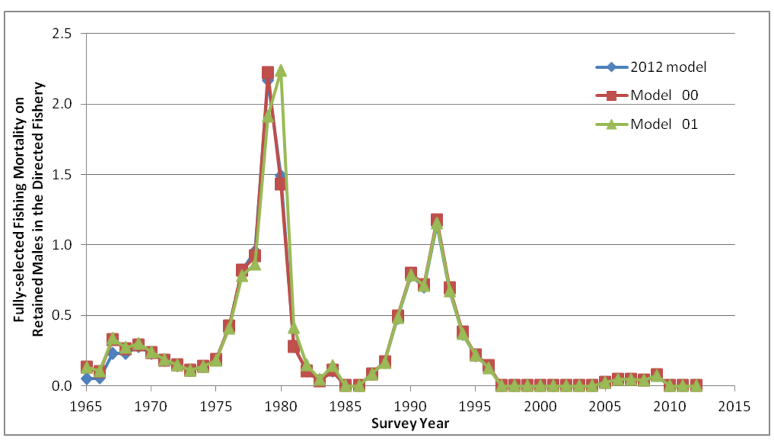


Figure 29. Comparison of estimated time series for fully-selected F on retained males in the directed Tanner crab fishery from the two alternative models and the 2012 model.

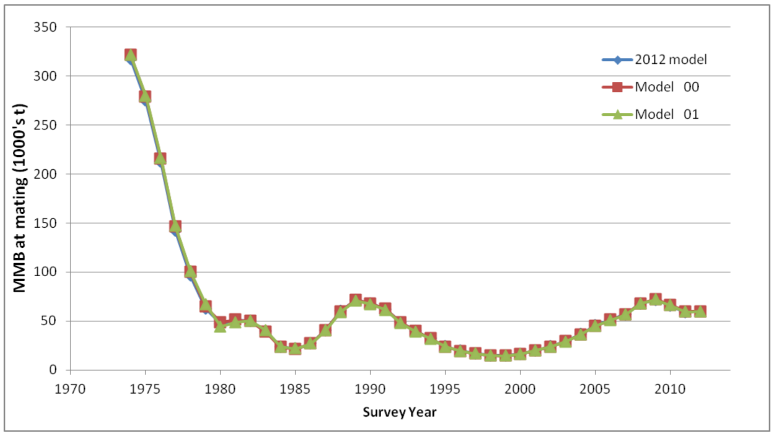


Figure 30. Comparison of estimated time series for mature male biomass at mating time from the two alternative models and the 2012 model.

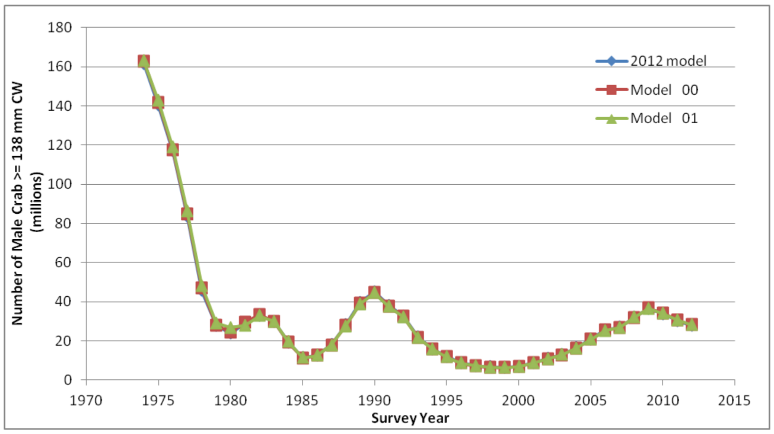


Figure 31. Comparison of estimated time series for the number of males ≥ 138 mm CW from the two alternative models and the 2012 model.

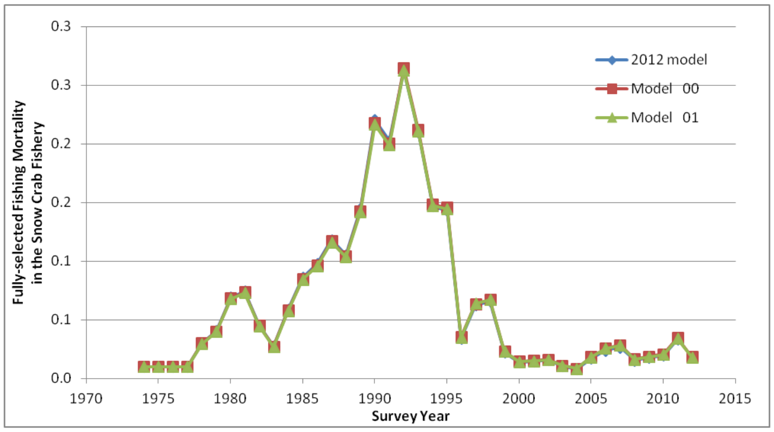


Figure 32. Comparison of estimated time series for fully-selected F in the snow crab fishery from the two alternative models and the 2012 model.

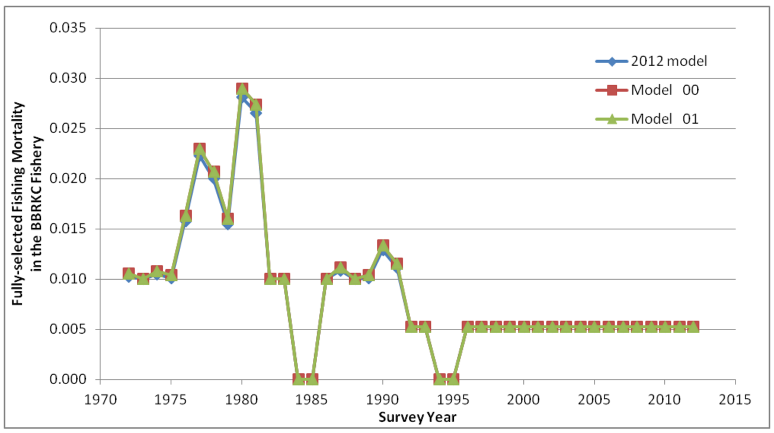


Figure 33. Comparison of estimated time series for fully-selected F in the BBRKC fishery from the two alternative models and the 2012 model.

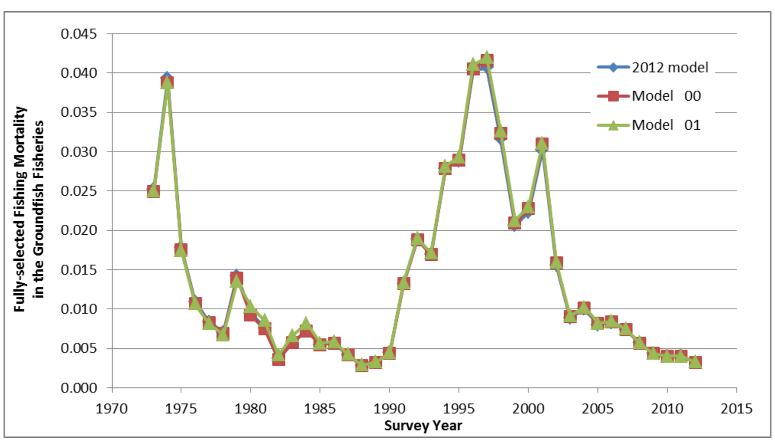


Figure 34. Comparison of estimated time series for fully-selected F in the groundfish fisheries from the two alternative models and the 2012 model.

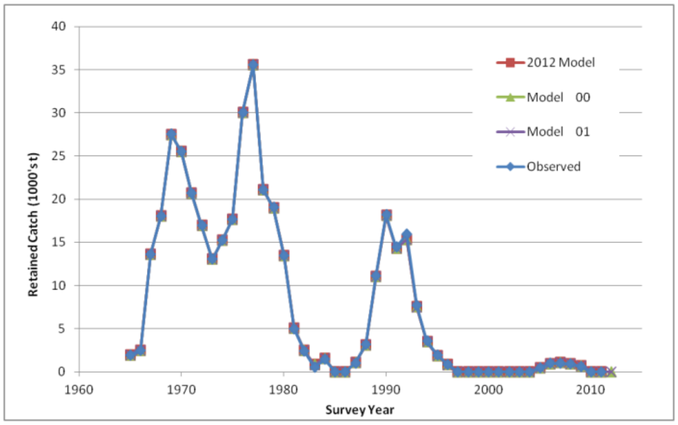


Figure 35. Comparison of estimated time series for retained (male) catch (1000’s t) in the directed tanner crab fishery from the two alternative models and the 2012 model with the observed catches.

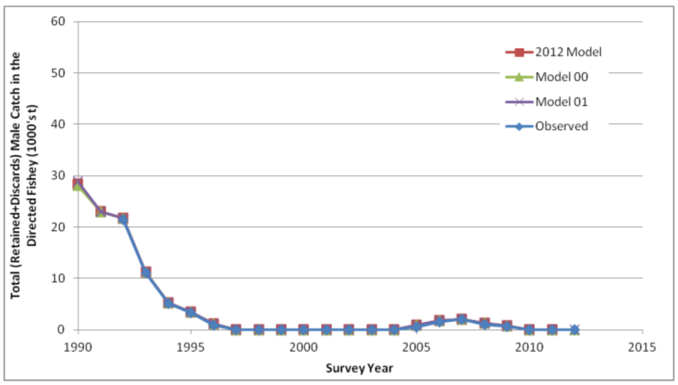


Figure 36. Comparison of estimated time series for total male (retained+discarded) catch (1000’s t) in the directed tanner crab fishery from the two alternative models and the 2012 model with the observed catches.

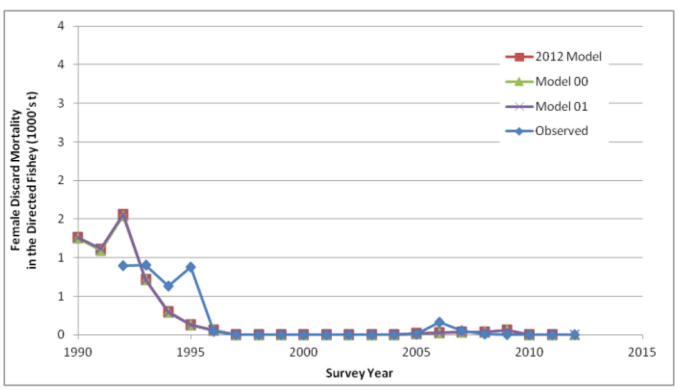


Figure 37. Comparison of estimated time series for female discard mortality (1000’s t) in the directed tanner crab fishery from the two alternative models and the 2012 model with the observed mortality.

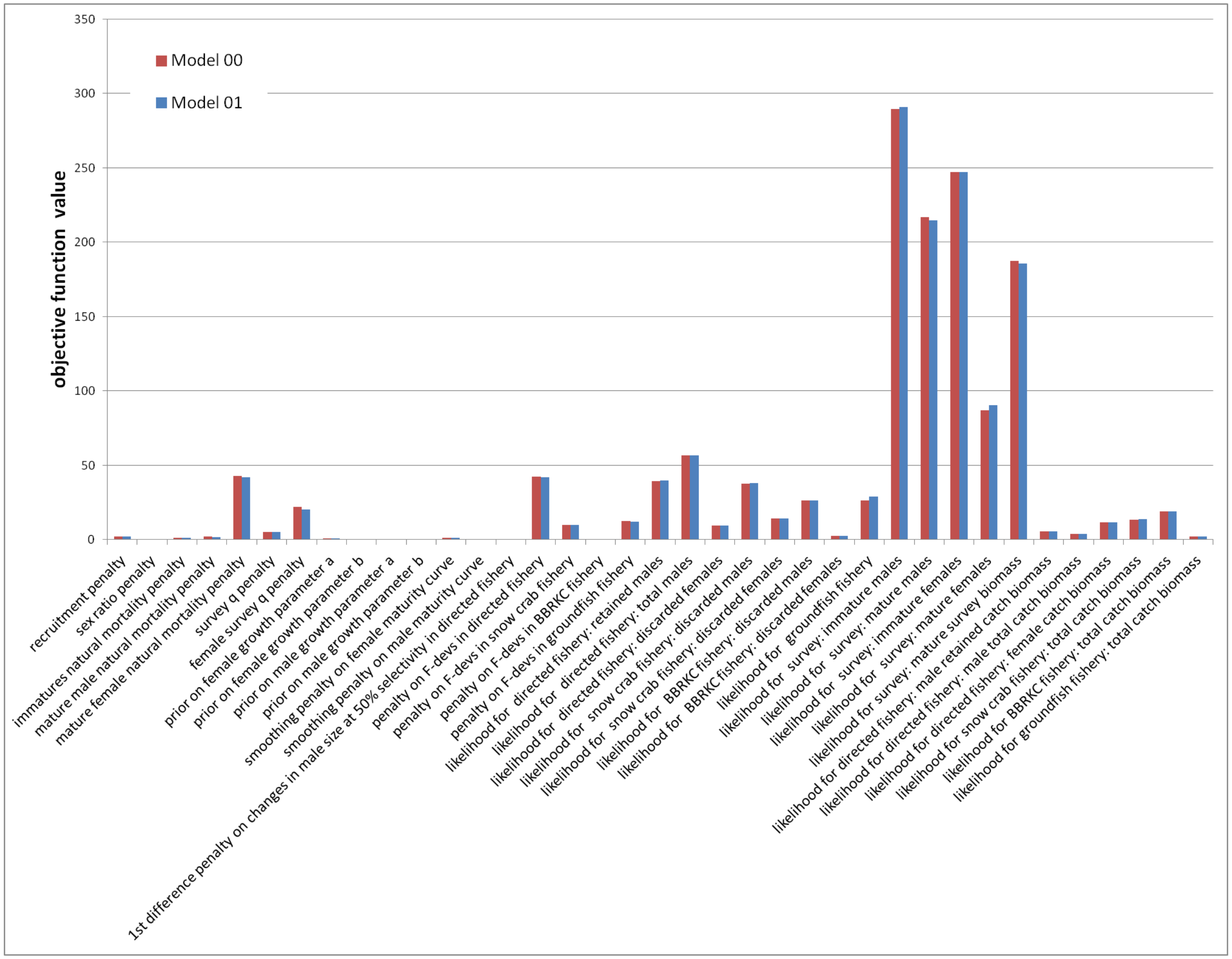


Figure 38. Comparison of the components of the converged objective function values (weights *x* –log-likelihood components) for the two alternative models. The total objective function values for the two models were 1439.85 for Model 00 and 1441.18 for Model 01.

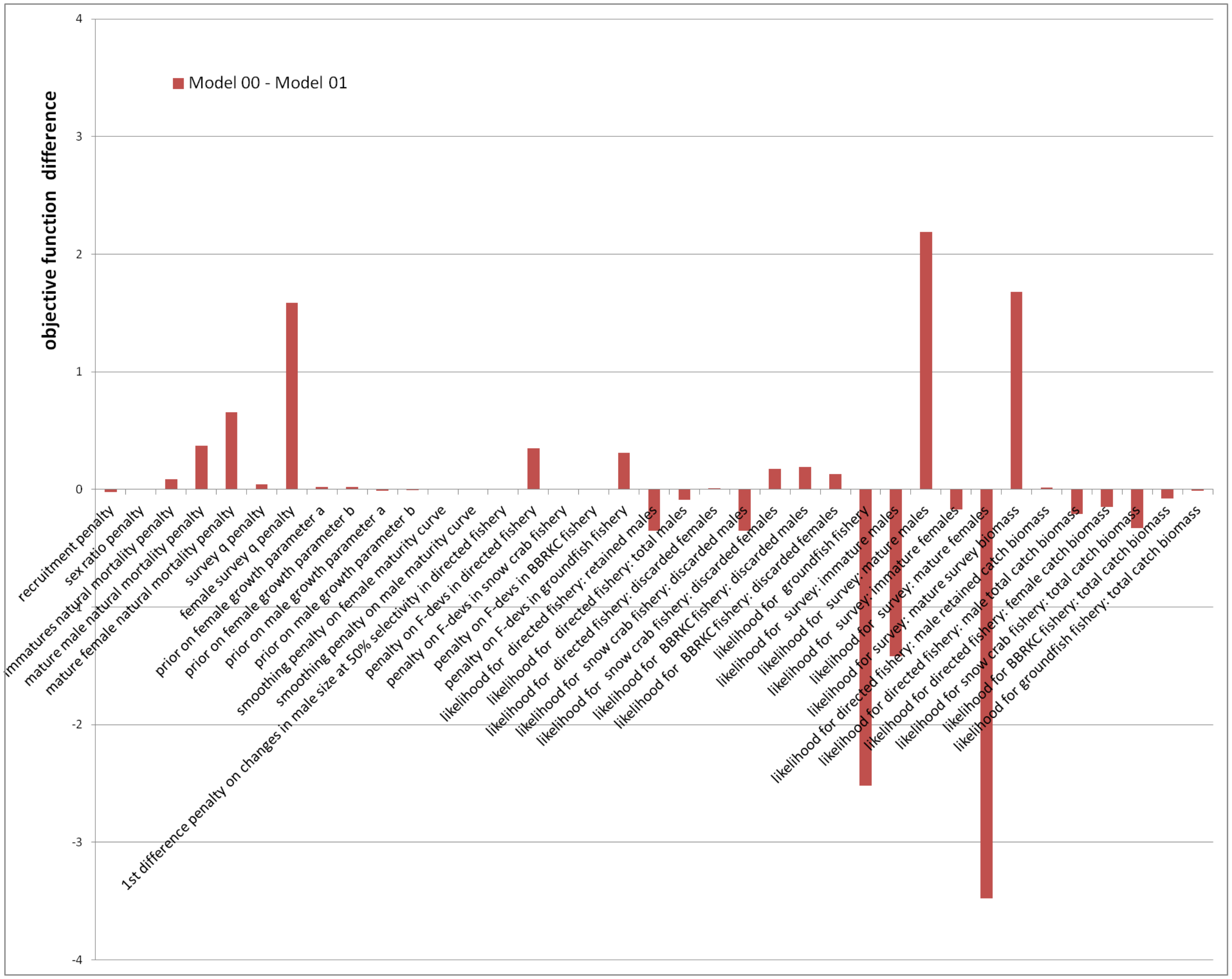


Figure 39. Differences between the alternative models (Model 00 – Model 01) on a component basis for the converged objective function (weights *x* –log-likelihood components). The difference between the total objective functions was -1.33.

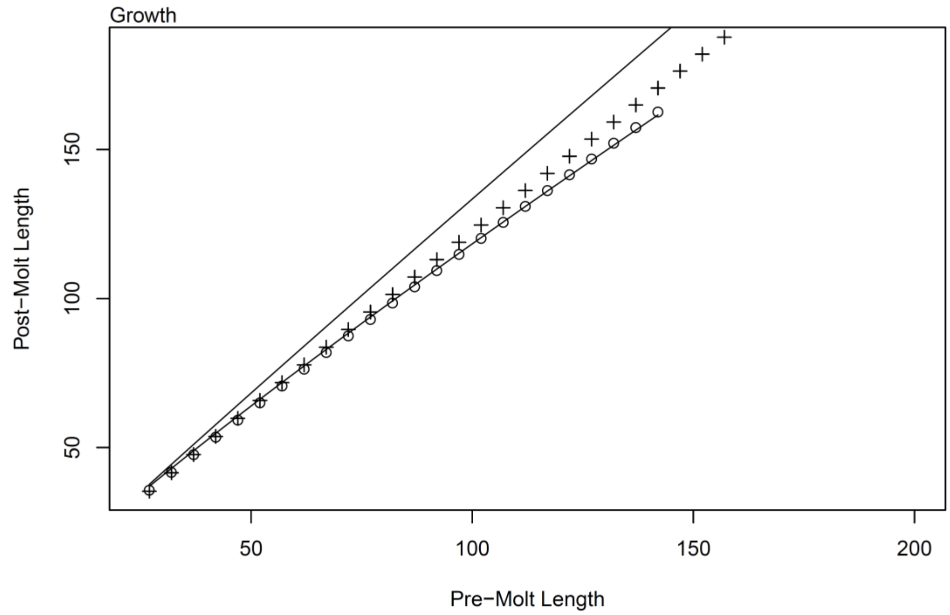


Figure 40. Comparison of model-estimated growth curves (solid lines, upper=males, lower=females) from the author's preferred model, Model 01, and empirical curves ("+"=males, circles=females) developed from growth data on Tanner crab in the Gulf of Alaska near Kodiak Island.

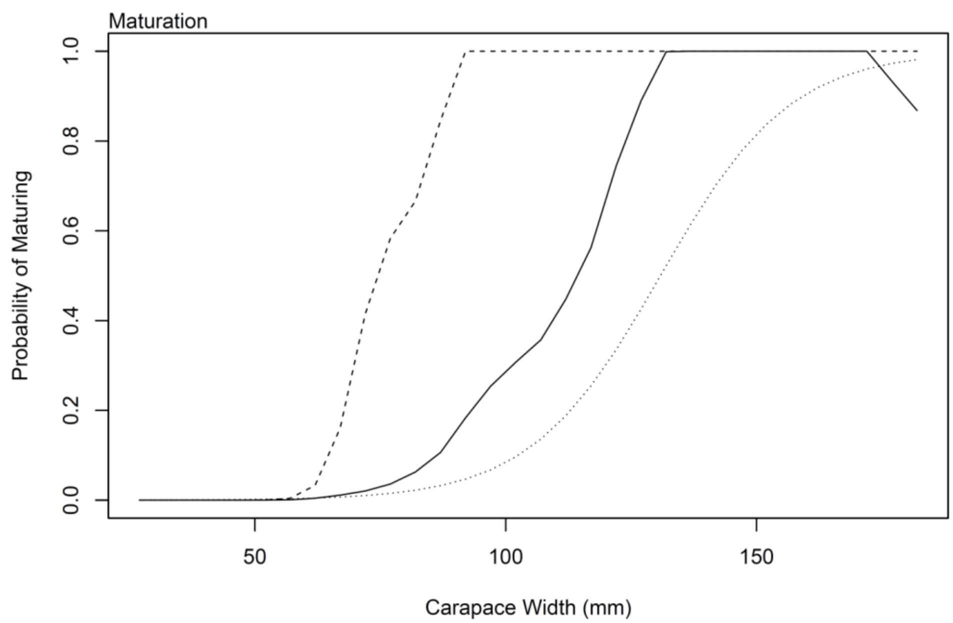


Figure 41. Comparison of model-estimated probability of maturing by size for new shell crab (solid line = males, dashed line = females) from the author's preferred model, Model 01, with that used for males (dotted line) in the Amendment 24 OFL analysis (NPFMC 2007).

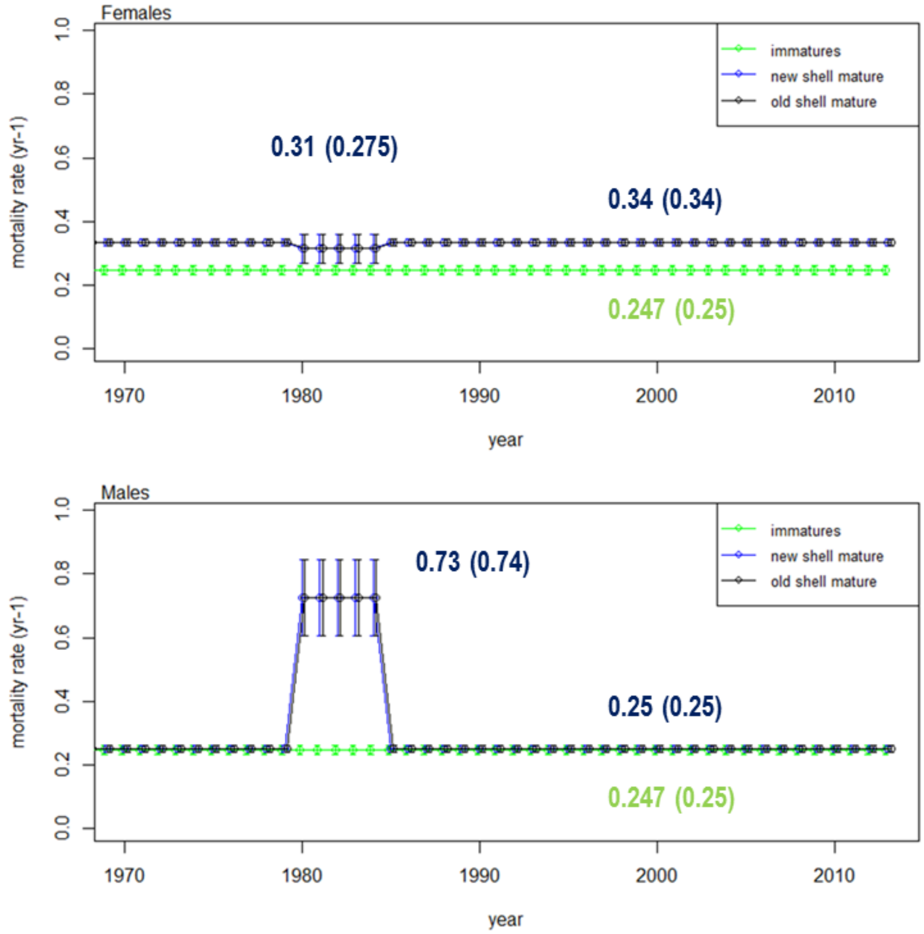


Figure 42. Estimated natural mortality for immature (single time period: 1949-2013) and mature (two time periods: 1949-1979+2005-2013 and 1980-1984) crab by sex (upper graph: females; lower graph: males) from the author's preferred model. Numbers indicate estimated values for the two time periods. Numbers in parentheses indicate estimates from the 2012 assessment model.

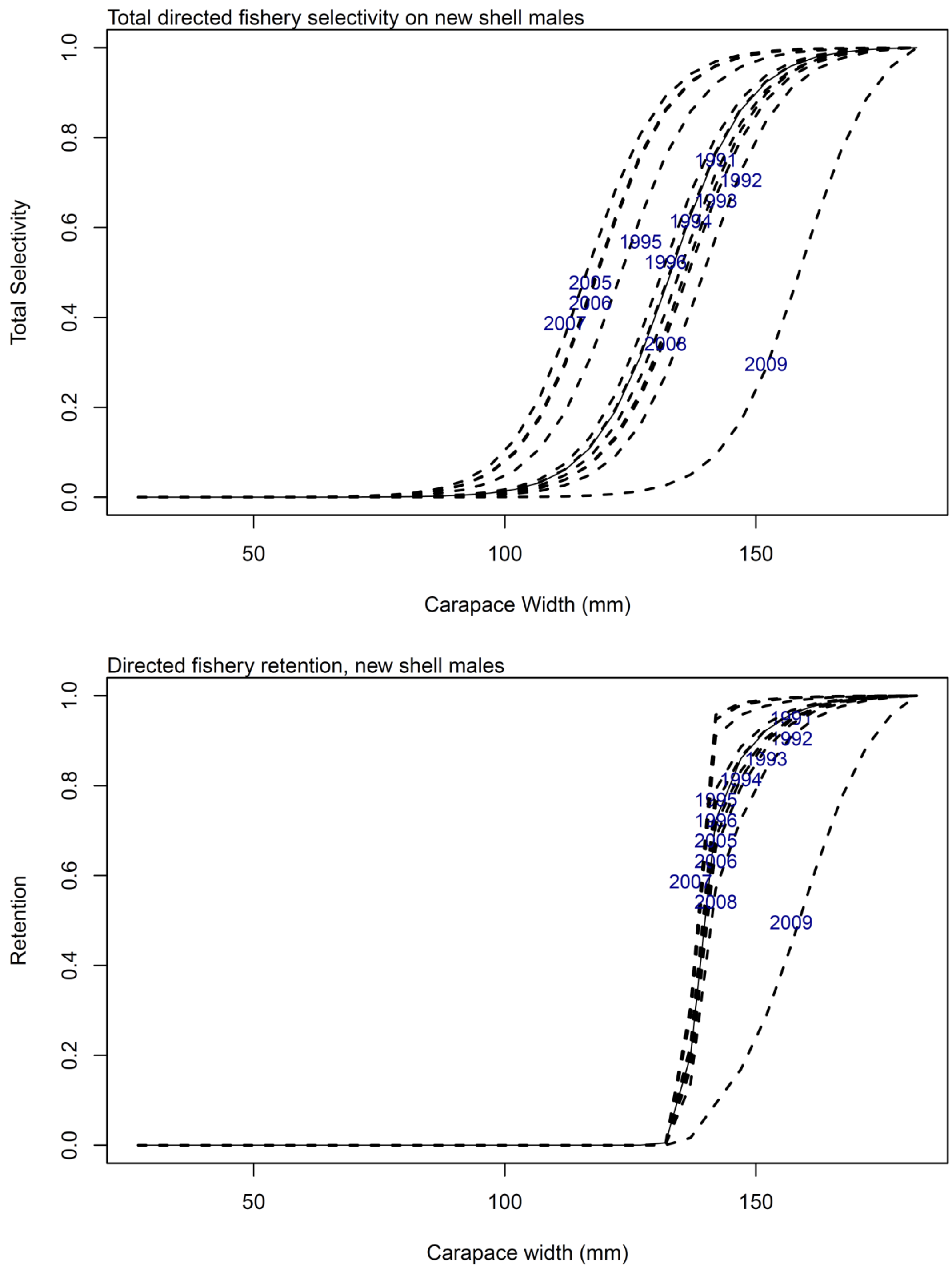


Figure 43.Estimated annual selectivity curves (solid line, pre-1991; dashed lines, 1991-2009) in the directed Tanner crab fishery for all new shell males (upper graph) and retained crab (lower graph) from the author's preferred model, Model 01. The year indicated denotes the beginning of the fishery year; e.g. "2009" indicates the 2009/10 fishery year. Selectivity curves for old shell males are identical to those for new shell males.

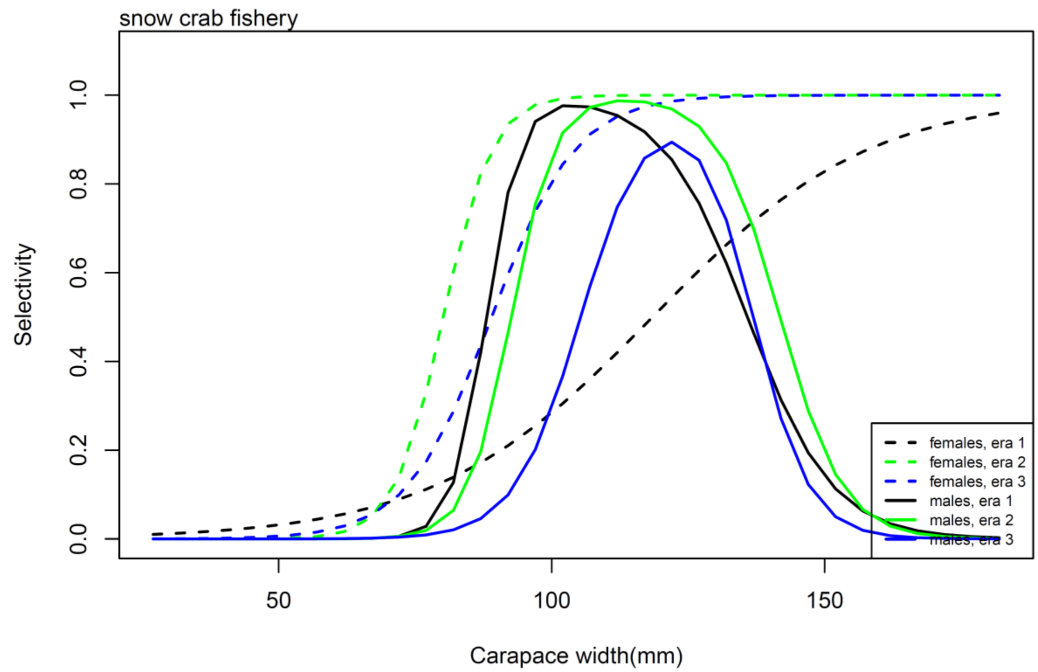


Figure 44. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the snow crab fishery (era 1 [1989-1996] =black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the author's preferred model, Model 01.

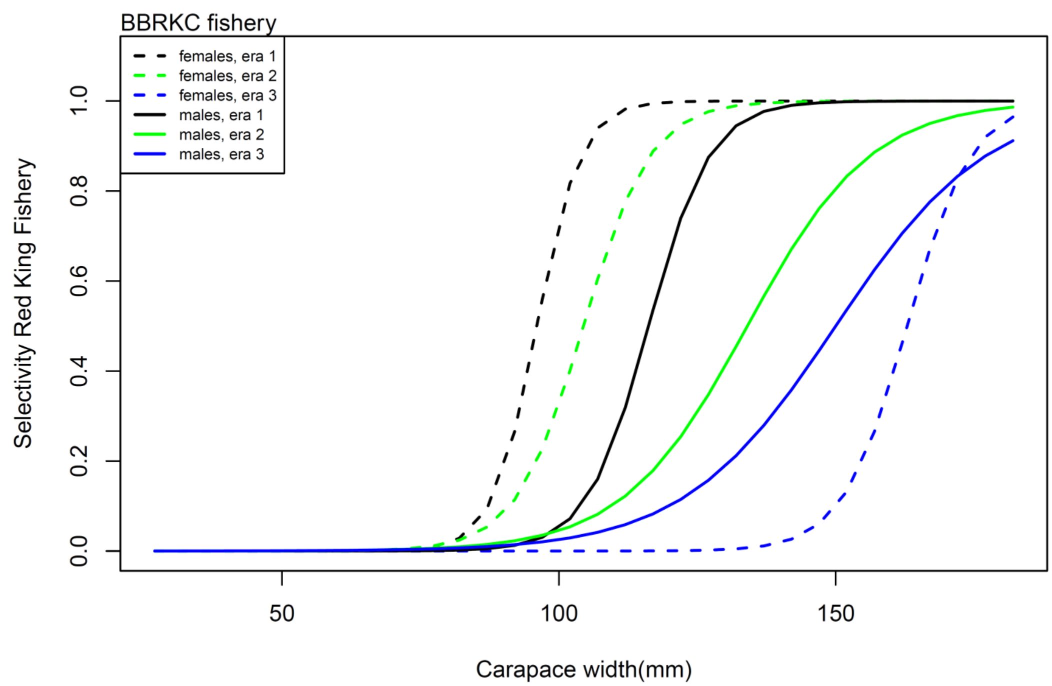


Figure 45. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the BBRKC fishery (era 1 [1989-1996] =black lines, era 2 [1997-2004] = green lines, era 3 [2005-present] = blue lines) from the author's preferred model, Model 01.

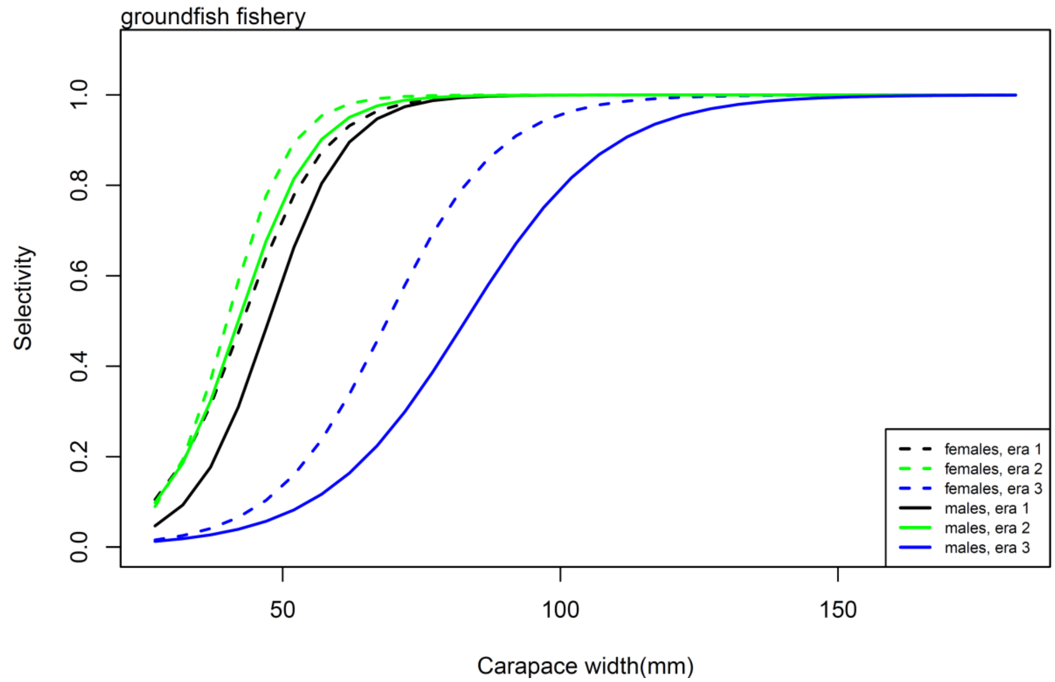


Figure 46. Estimated selectivity curves by sex (solid lines = males, dashed lines = females) for 3 eras in the groundfish fisheries (era 1[1973-1987] =black lines, era 2 [1988-1996] = green lines, era 3 [1997-present] = blue lines) from the author's preferred model, Model 01.

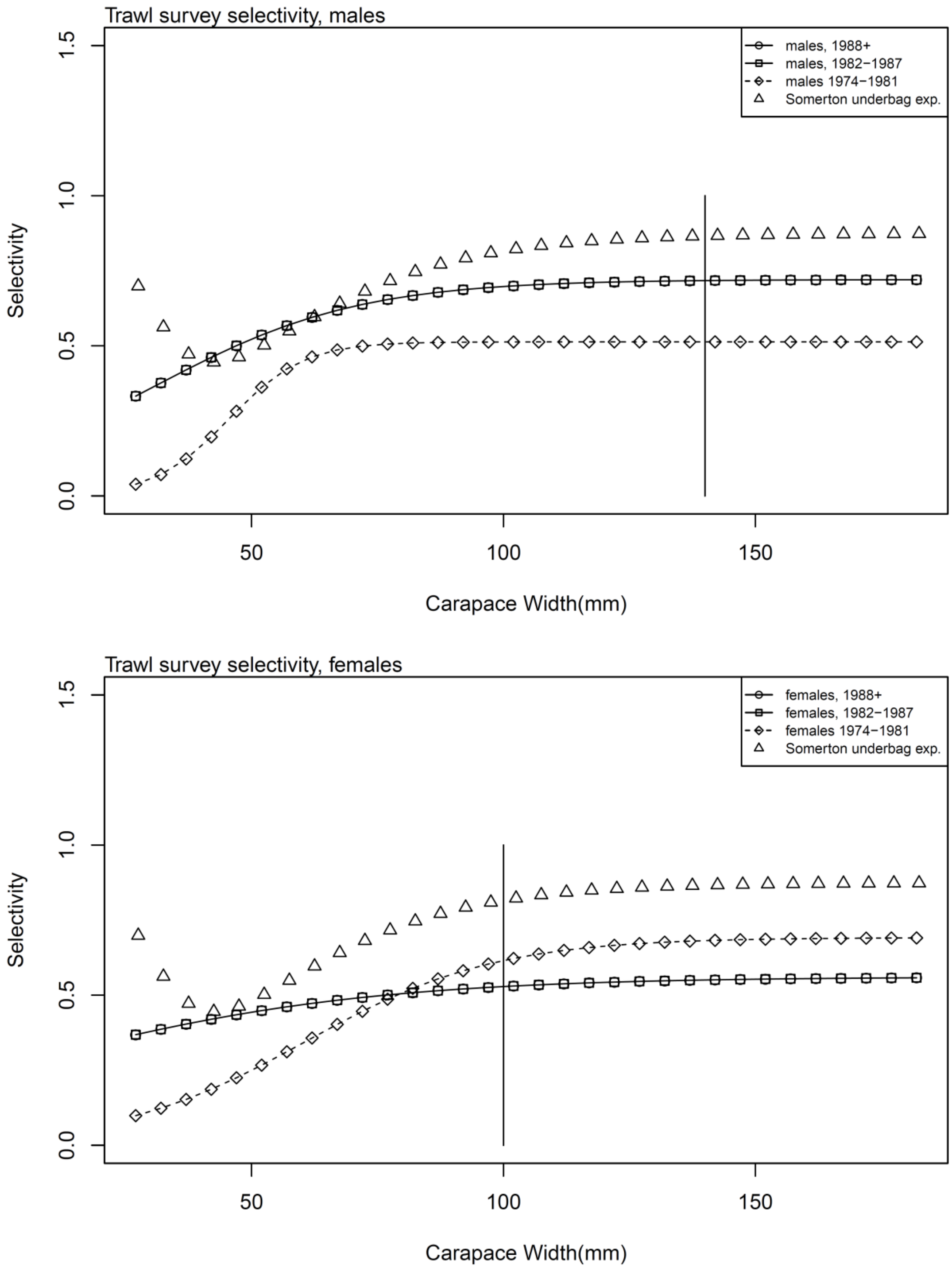


Figure 47. Comparison of estimated sex-specific selectivity curves for the NMFS bottom trawl survey in three time periods from the author's preferred model, Model 01, with those obtained by Somerton and Otto (1999) in the underbag experiment. The curves for 1982-87 and 1988+ are identical. Vertical lines indicate the size corresponding to survey q for both sexes.

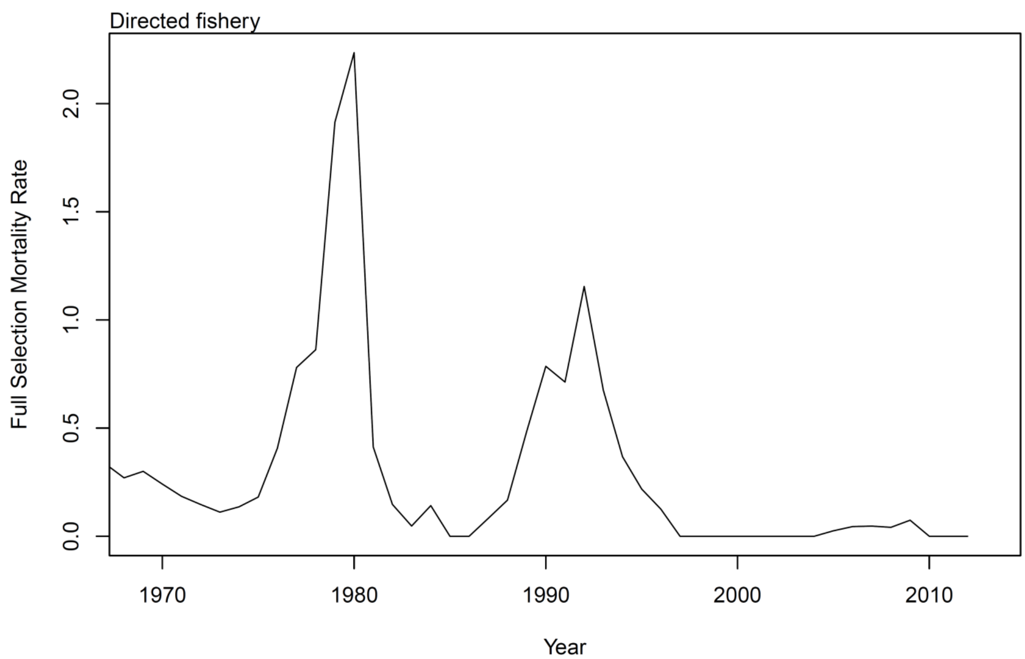


Figure 48. Estimated full selection fishing mortality in the directed fishery from the author's preferred model, Model 01.

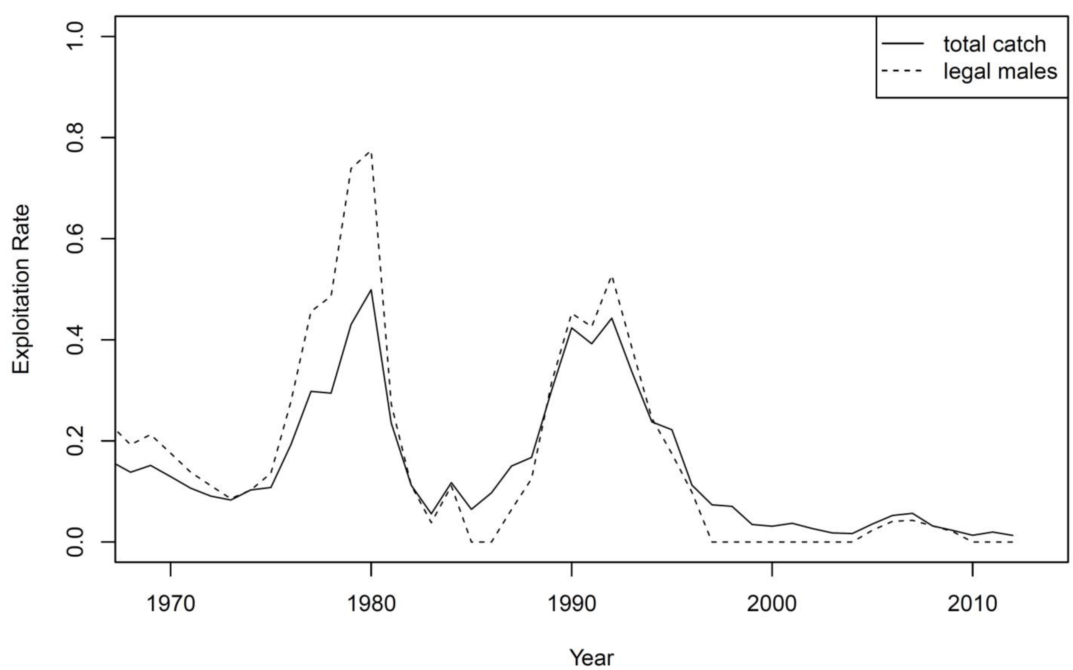


Figure 49. Estimated exploitation rates in the directed fishery for total catch and legal-sized males (≥ 138 mm CW) from the author's preferred model, Model 01.

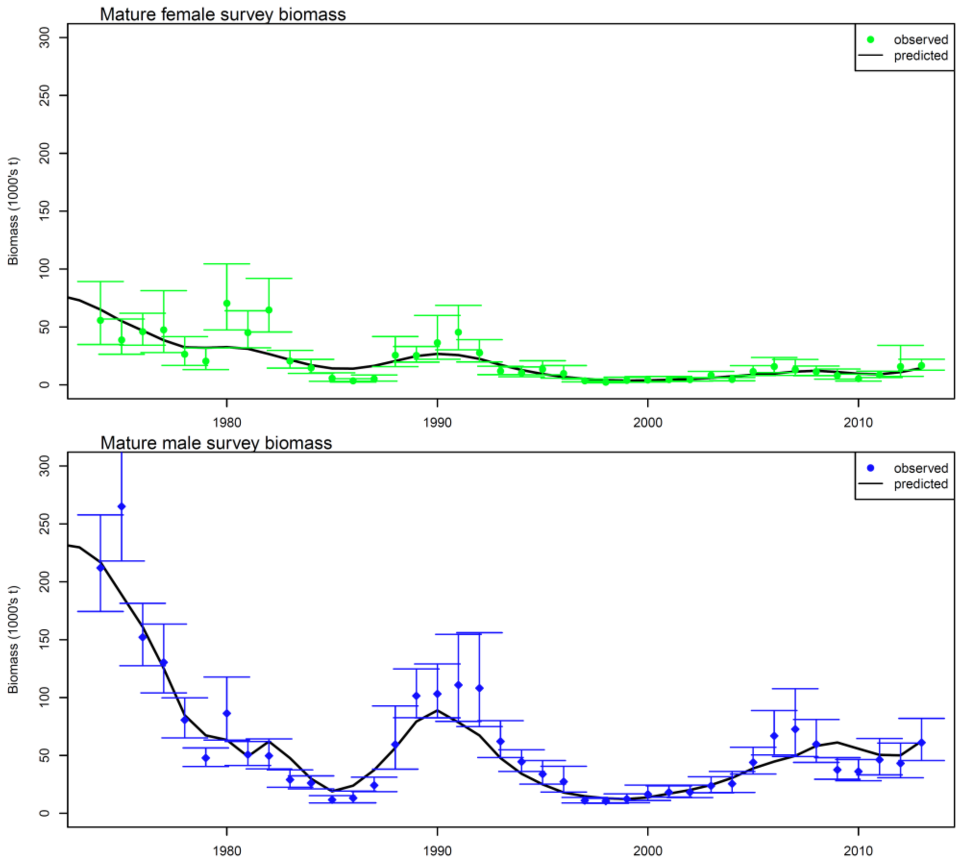


Figure 50. Comparison of observed survey biomass (circles with 95% CIs) and predicted survey biomass (solid line) for mature females (upper graph) and mature males (lower graph) from the author's preferred model, Model 01.

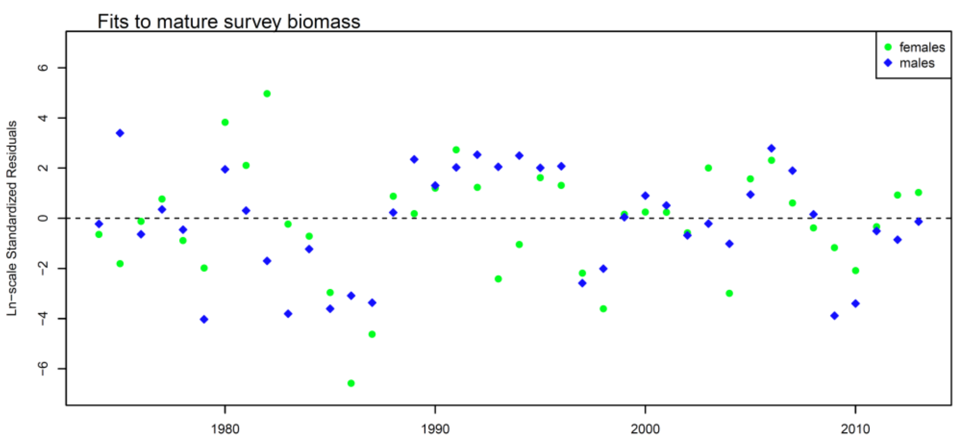


Figure 51. Standardized residuals (ln-scale) of mature survey biomass for the author's preferred model, Model 01.

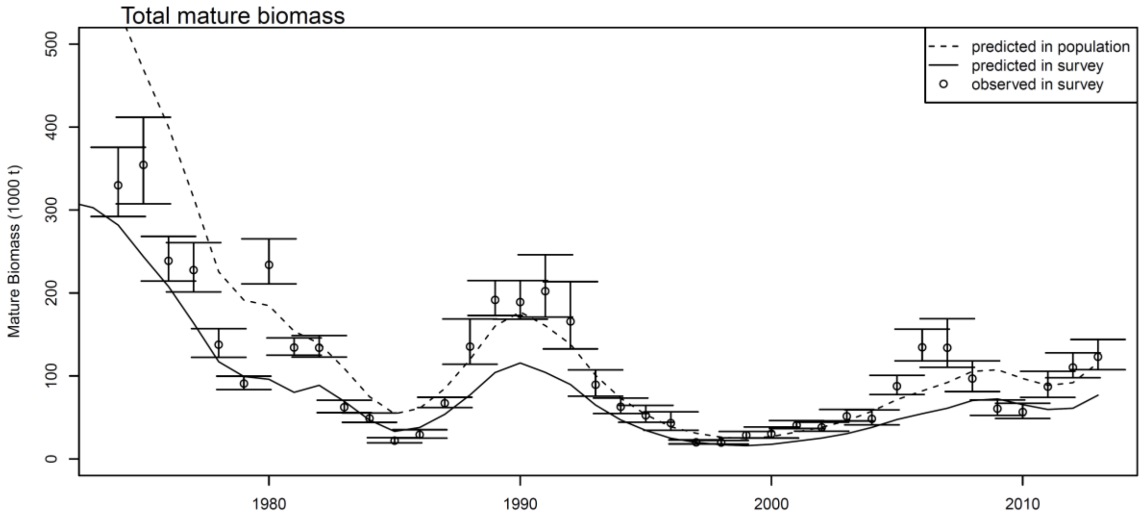


Figure 52. Comparison of observed survey biomass for mature crab (circles with 95% CIs), predicted survey biomass for mature crab (solid line) and predicted spawning (males + females) biomass (dashed line) from the author's preferred model, Model 01.

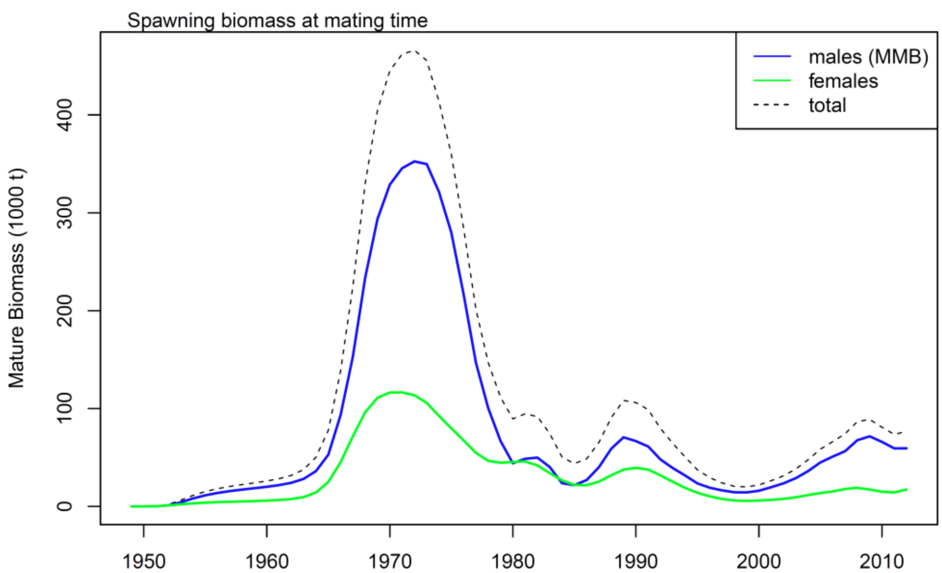


Figure 53.Model-predicted mature biomass at mating time for males (i.e., MMB; blue line), females (green line), and total (dotted line).

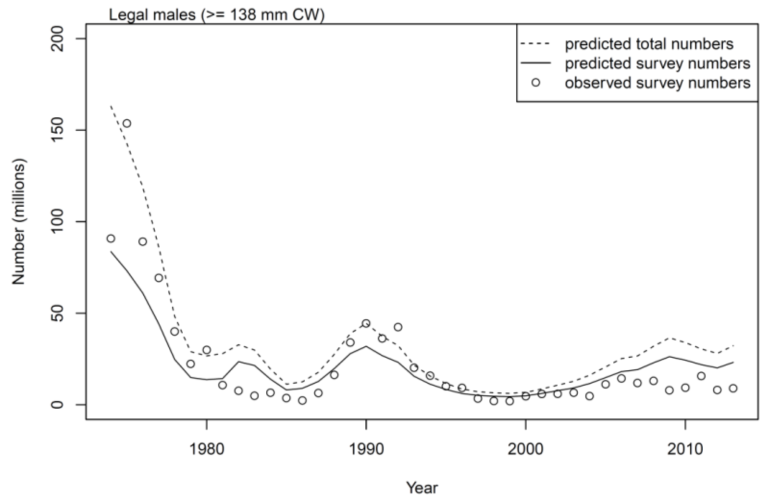


Figure 54. Comparison of predicted total numbers of male crab ≥ 138 mm CW, predicted numbers in the survey, and numbers observed in the survey.

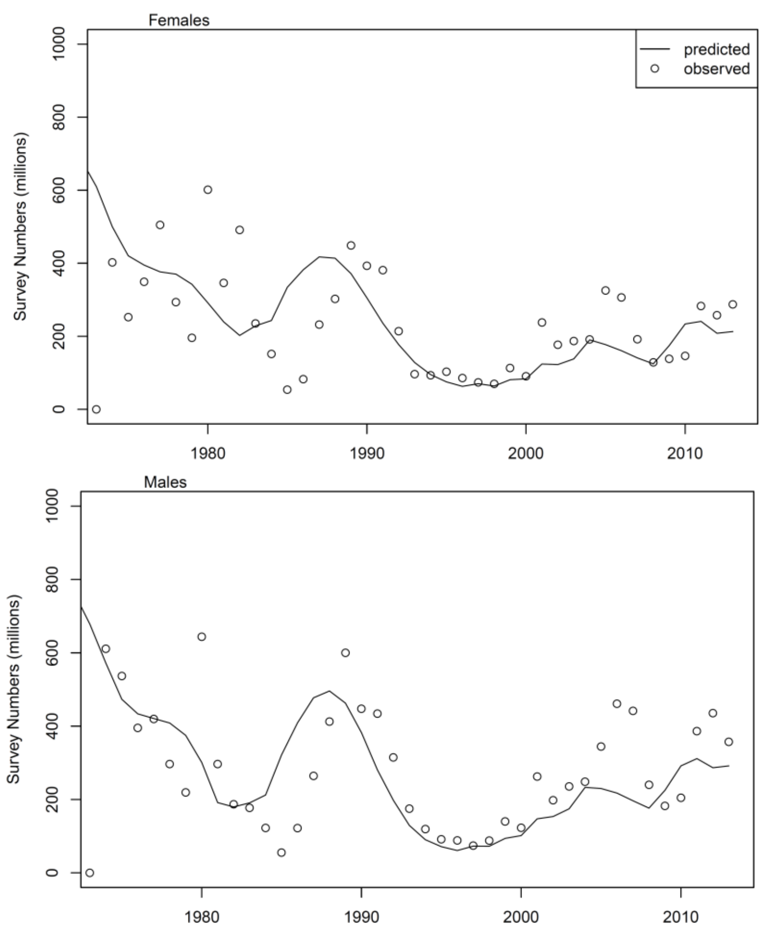


Figure 55. Comparison of observed numbers of crab in the NMFS bottom trawl survey (circles) and predicted survey numbers (solid line) from the author's preferred model, Model 01, for females (top graph) and males (bottom graph).

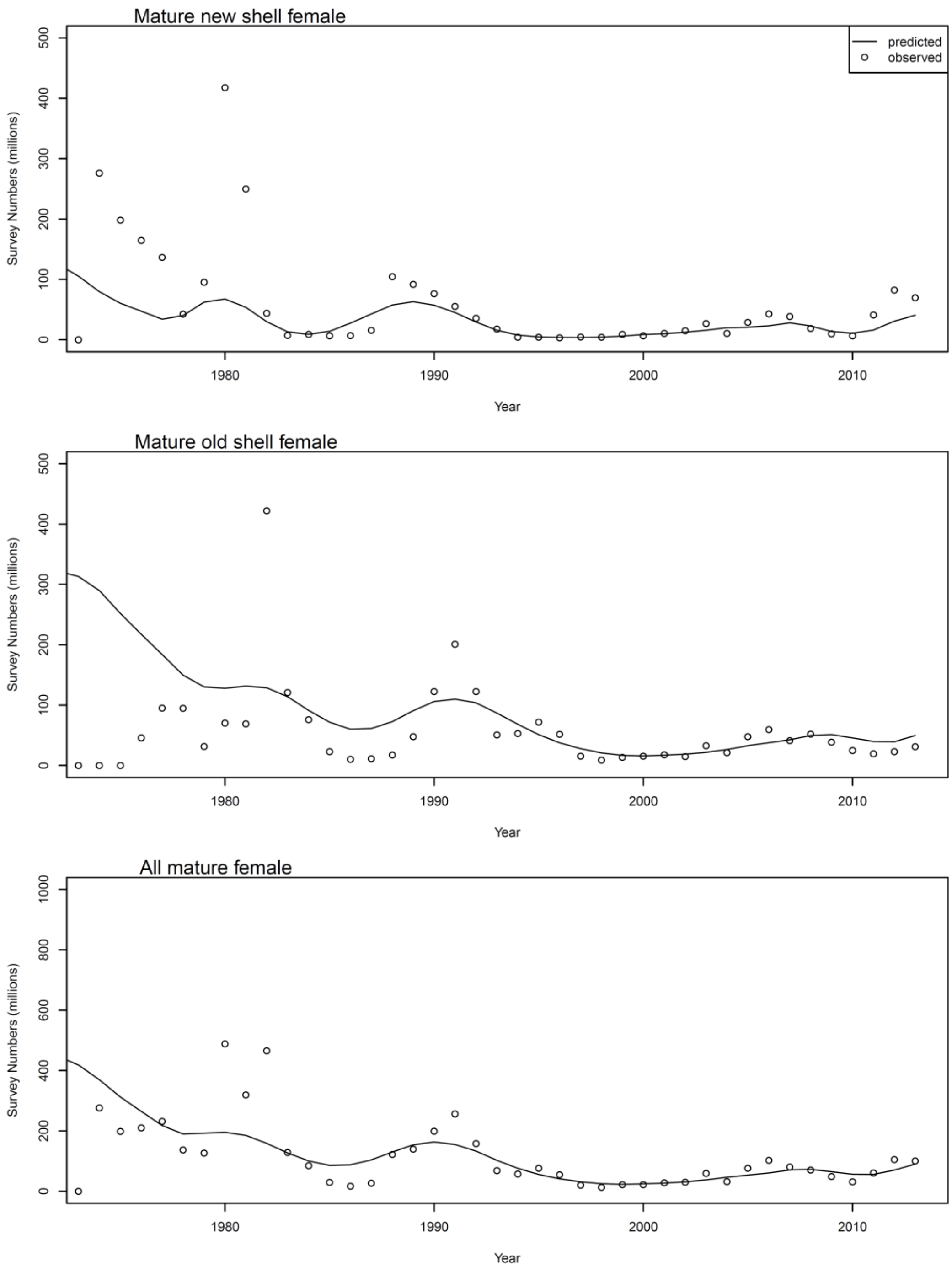


Figure 56. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Model 01.

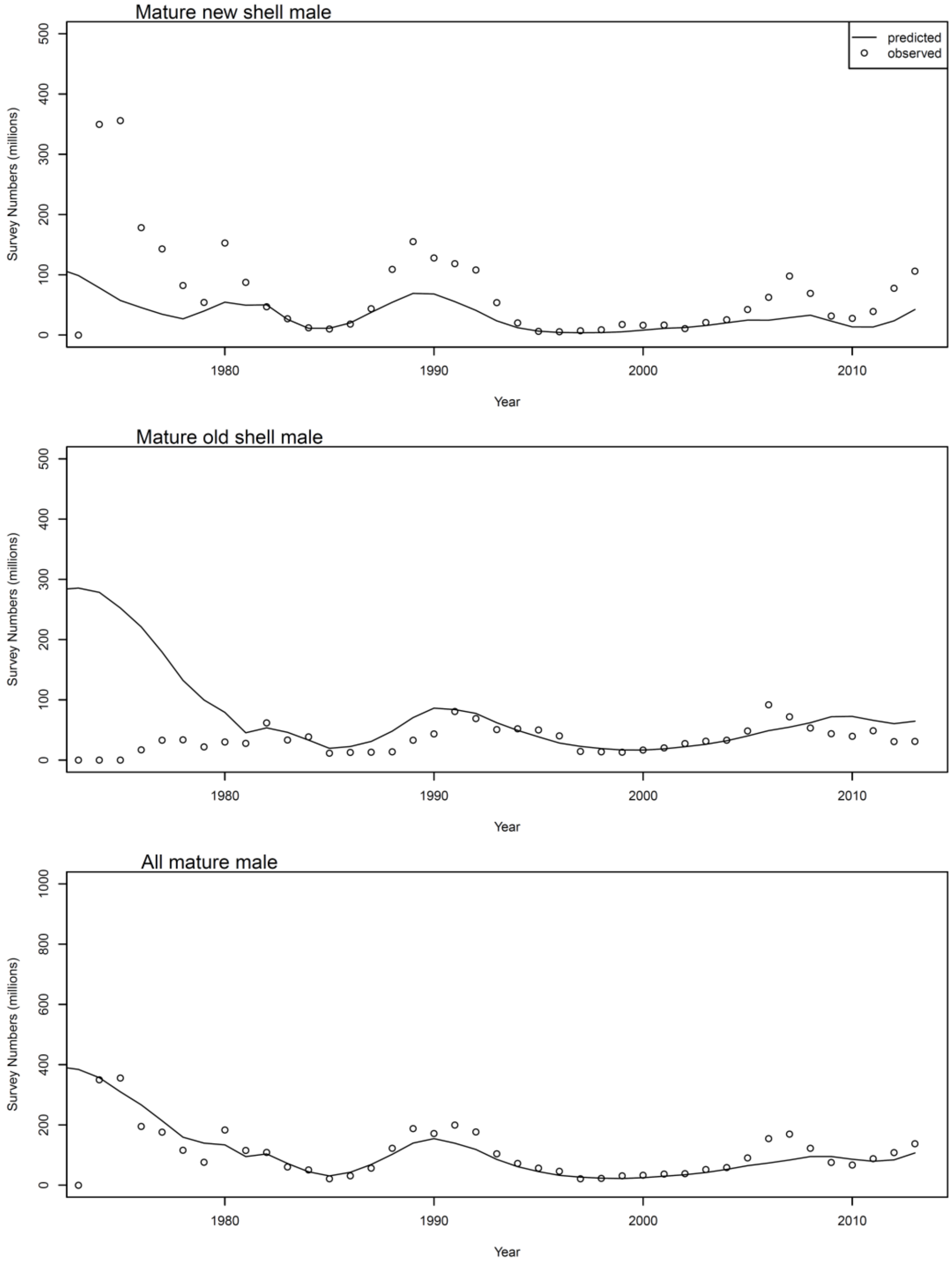


Figure 57. Comparison of observed numbers in the NMFS bottom trawl survey for mature males by shell condition (new shell, old shell) and combined with predictions from the author's preferred model, Model 01.

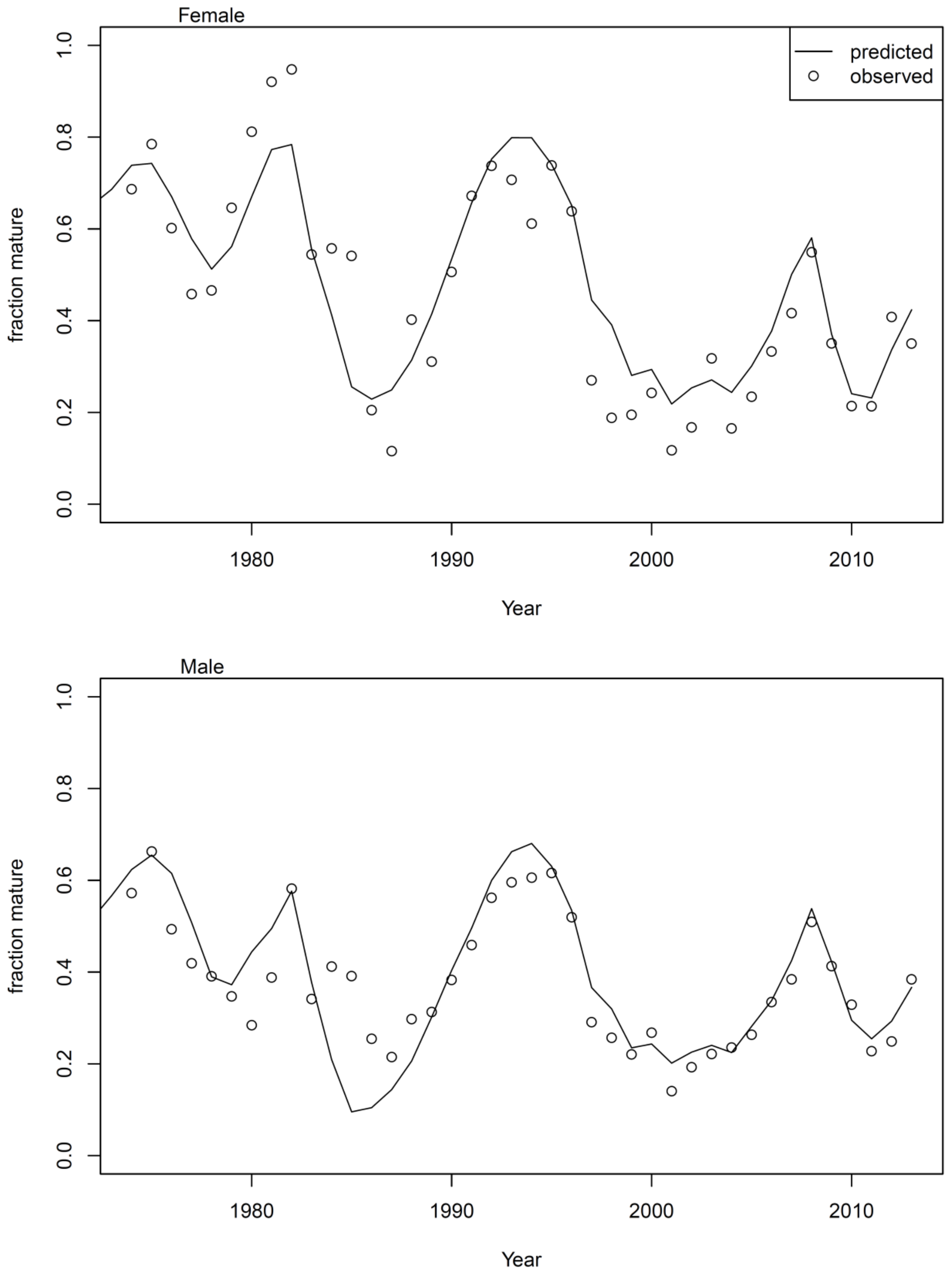


Figure 58. Comparison of estimates of the fraction of mature crab by sex in the NMFS bottom trawl survey and as predicted by the author's preferred model, Model 01.

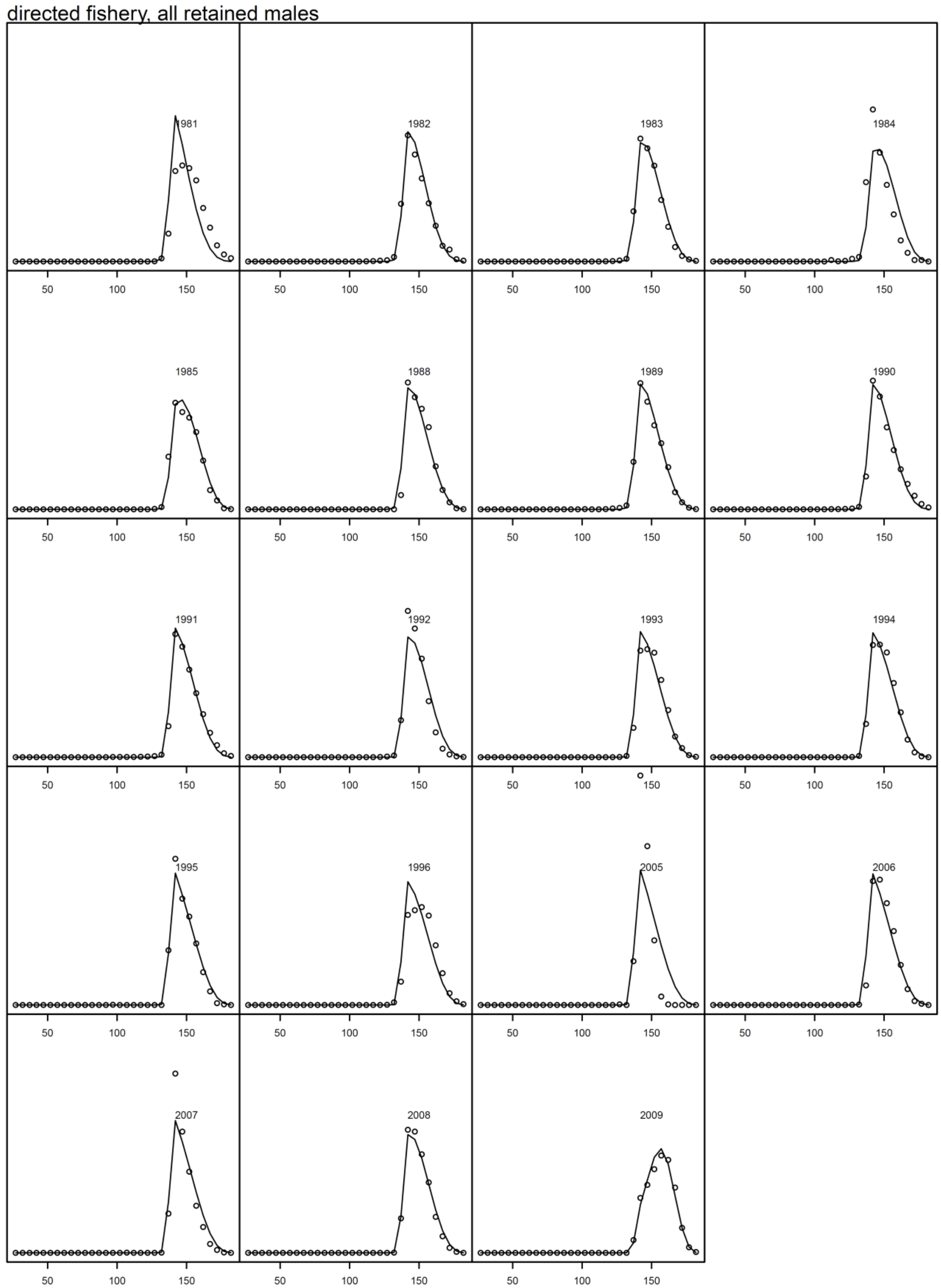


Figure 59. Comparison of predicted (solid line) and observed (circles) proportions-at-size for retained males in the directed Tanner crab fishery.

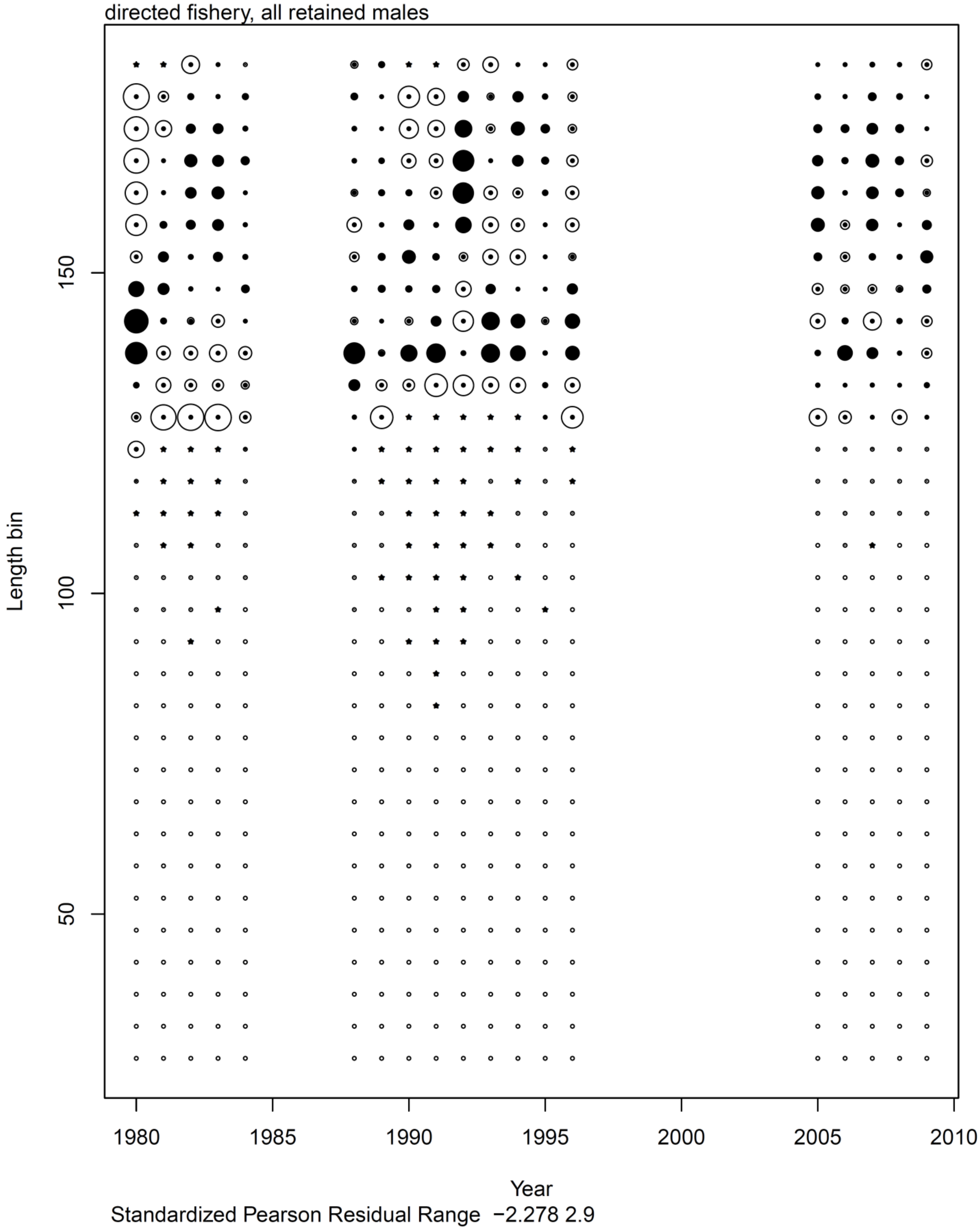


Figure 60.Pearson residuals for predicted proportions at size for retained males in the directed Tanner crab fishery. Black circles represent positive anomalies (predicted > observed), white circles represent negative anomalies.

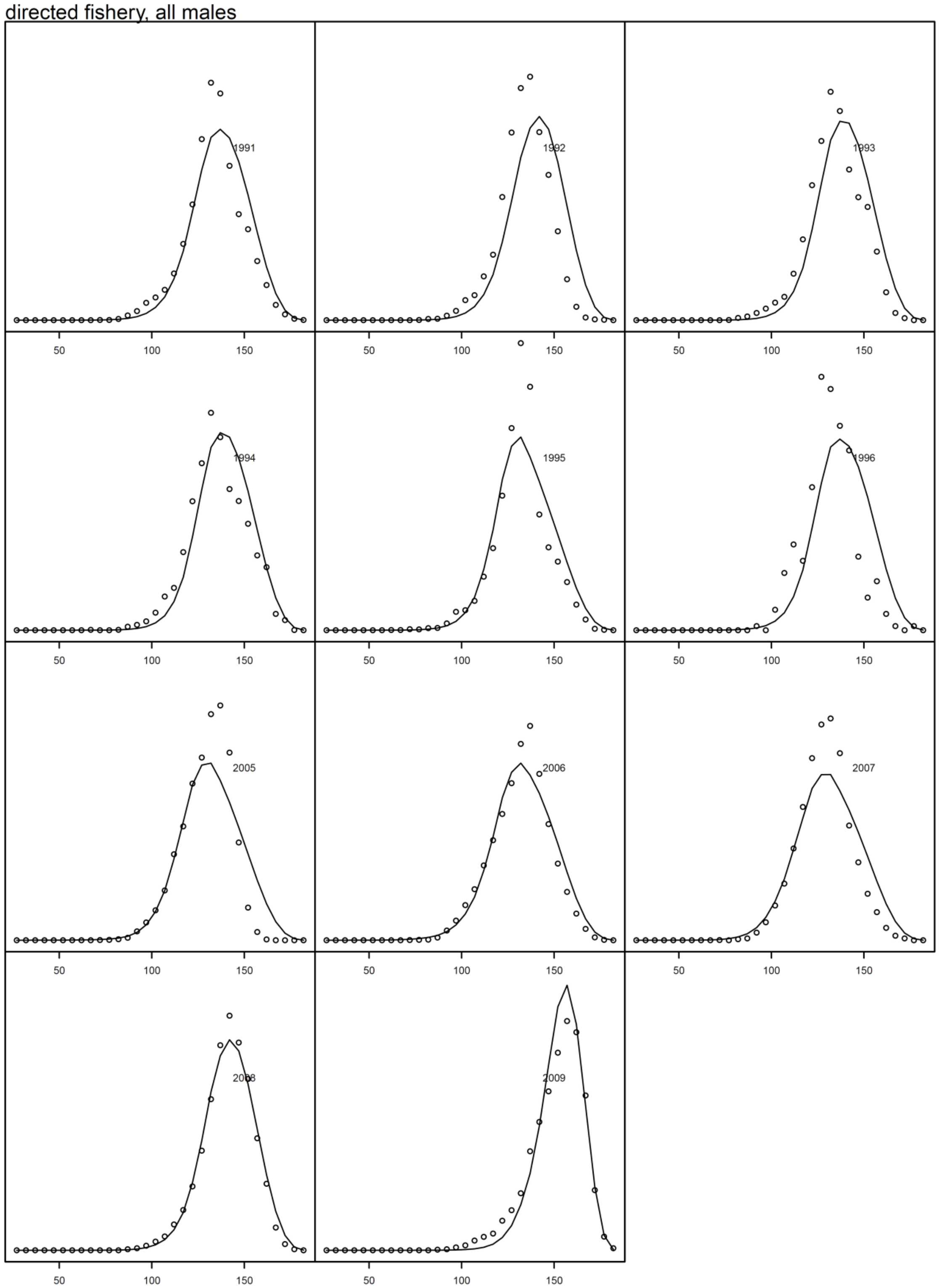


Figure 61. Comparison of predicted (solid line) and observed (circles) proportions-at-size for all males (retained+discarded) males in the directed Tanner crab fishery.

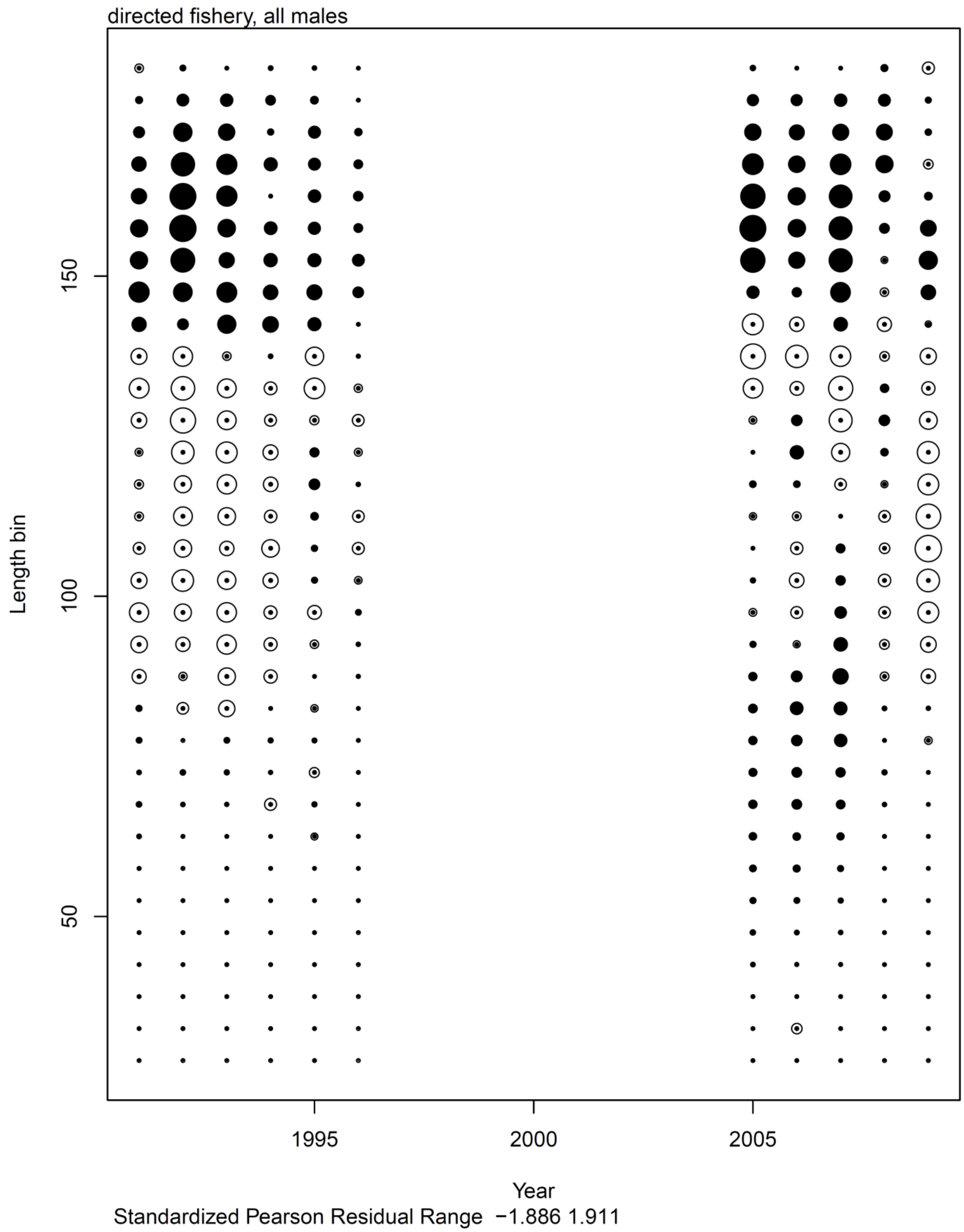


Figure 62.Pearson residuals for predicted proportions at size for all males in the directed Tanner crab fishery. White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

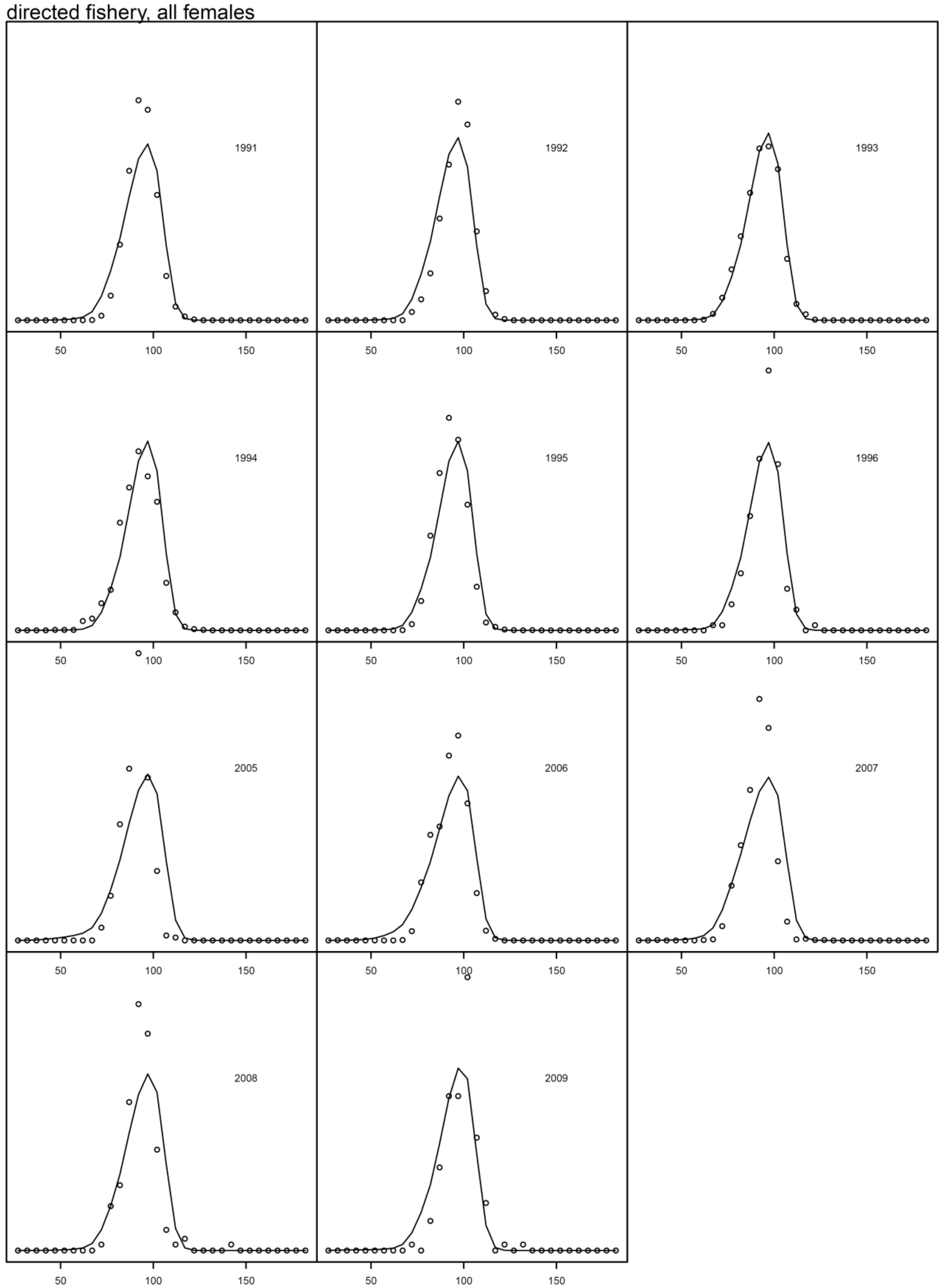


Figure 63.Comparison of predicted (solid line) and observed (circles) proportions at size for females in the directed Tanner crab fishery.

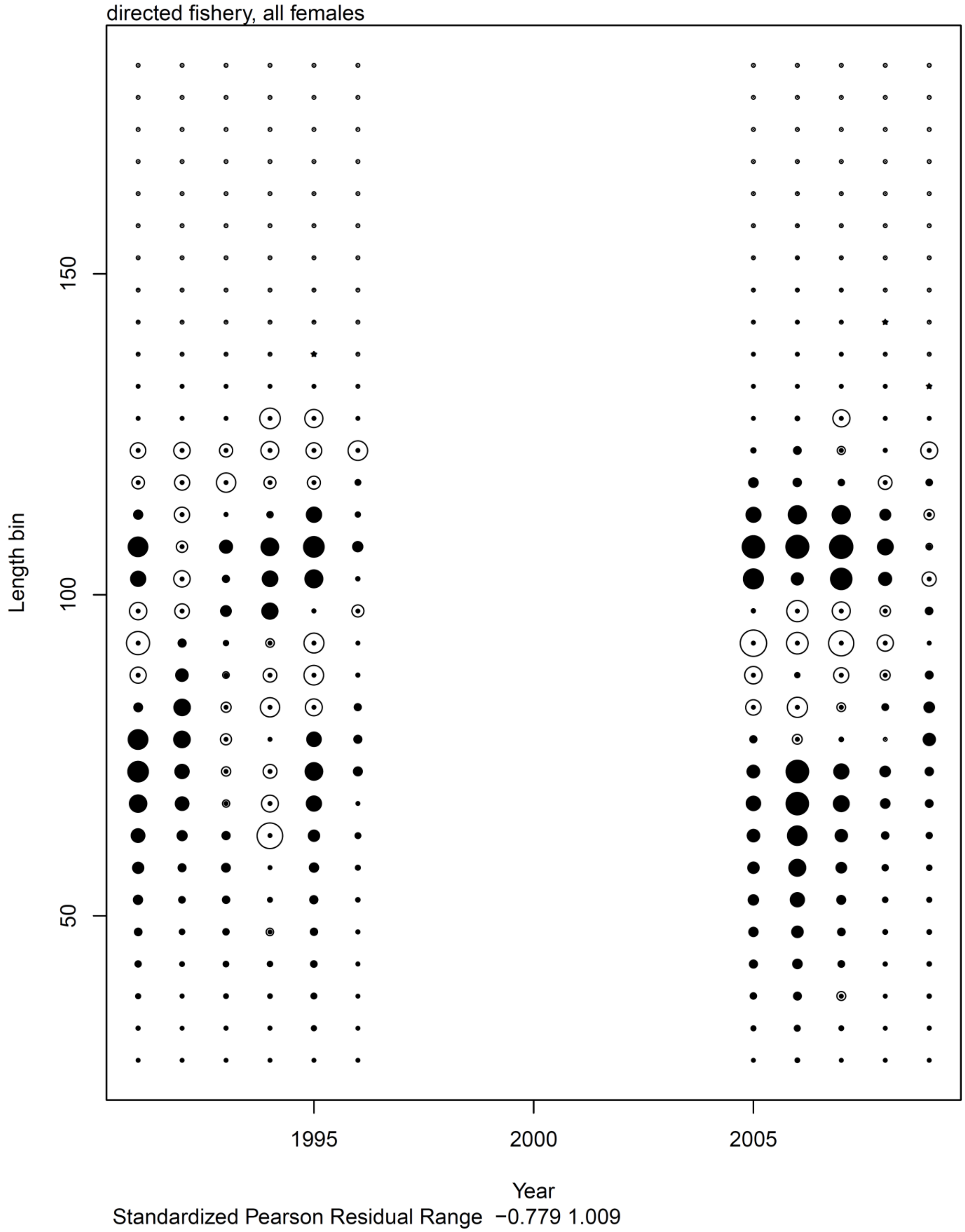


Figure 64. Pearson residuals for predicted proportions at size for females in the directed Tanner crab fishery. White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

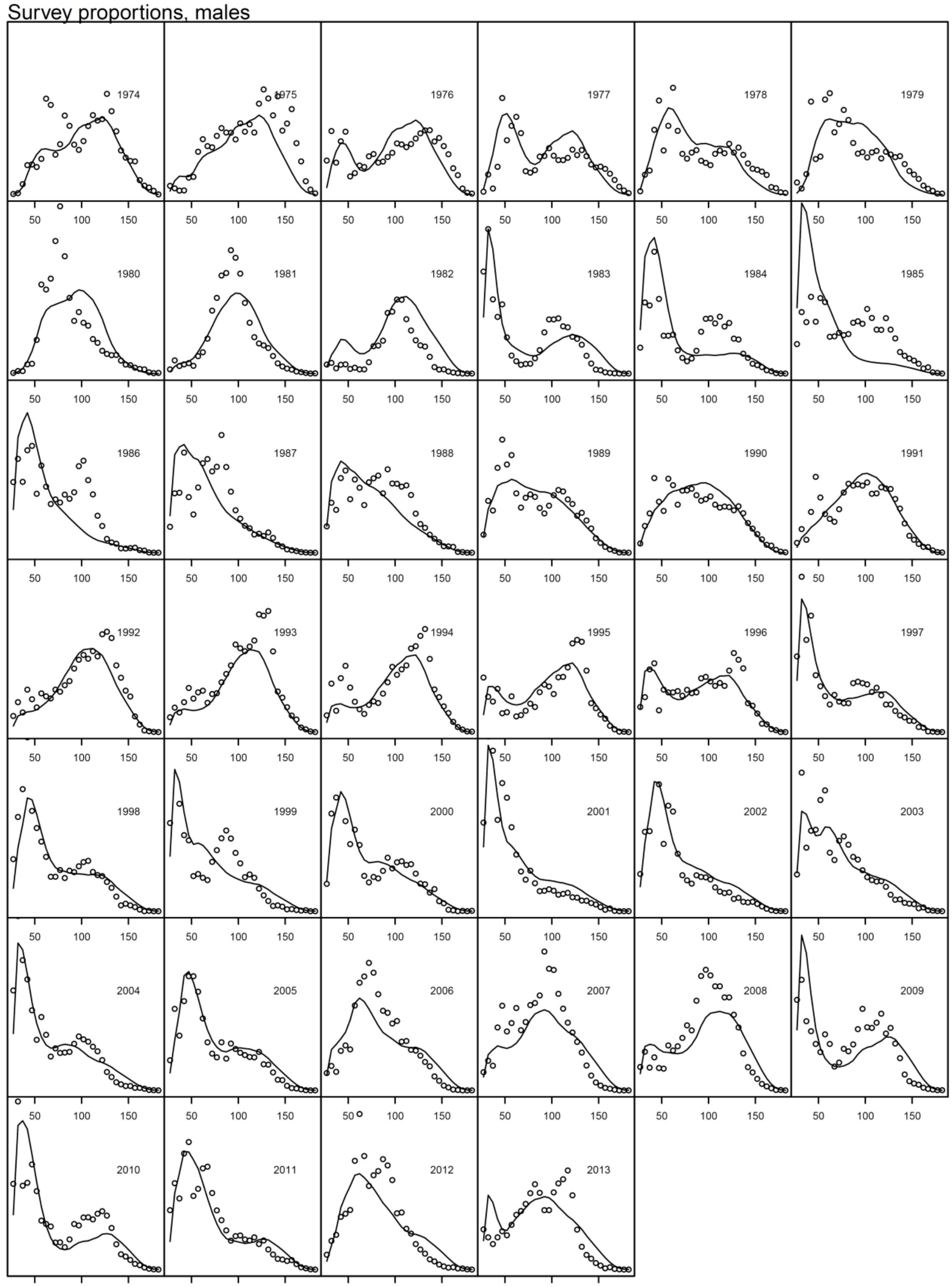


Figure 65. Comparison of predicted (solid line) and observed (circles) proportions-at-size for males in the NMFS bottom trawl survey.

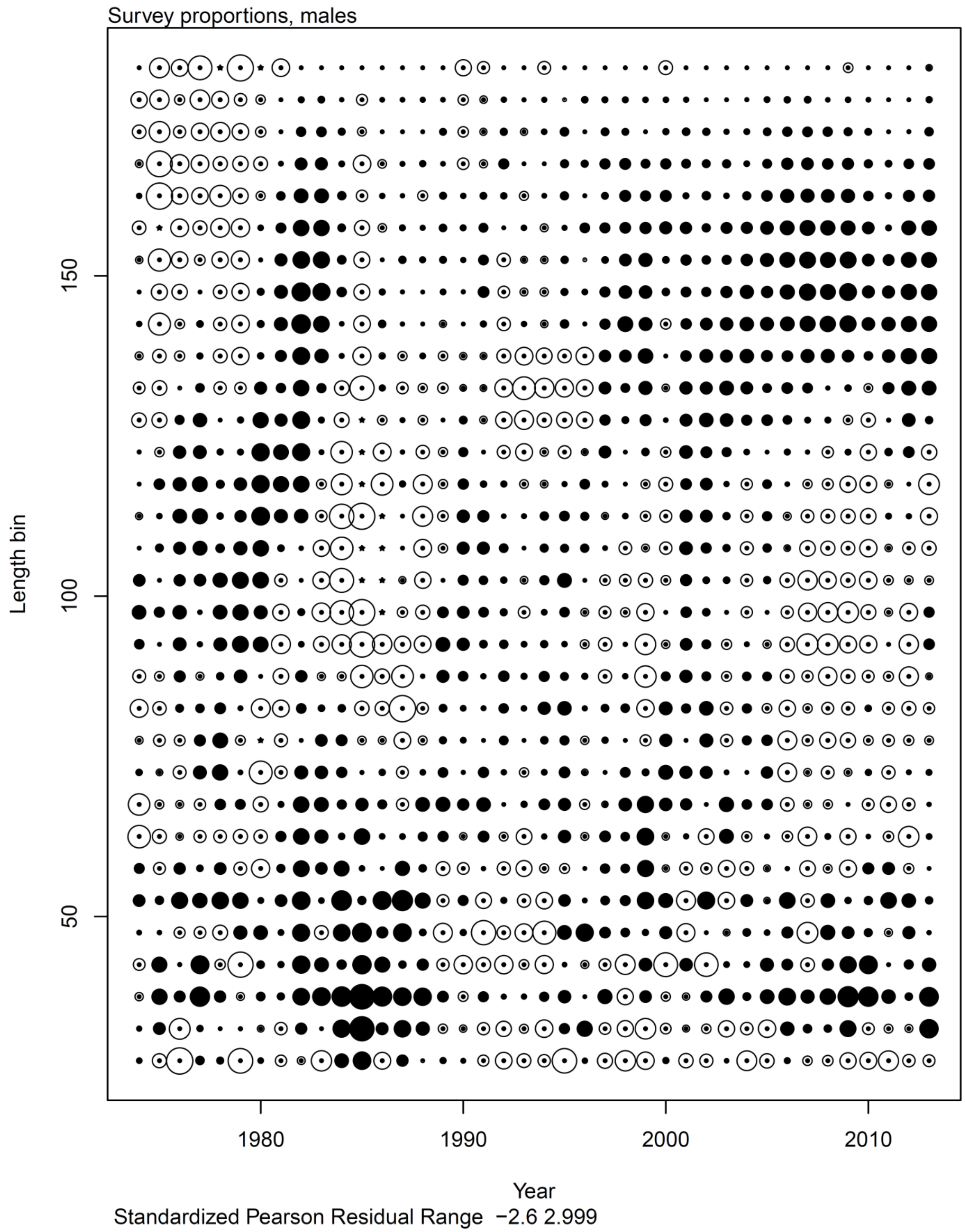


Figure 66.Pearson residuals for predicted proportions at size for all males in the NMFS bottom trawl survey. White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

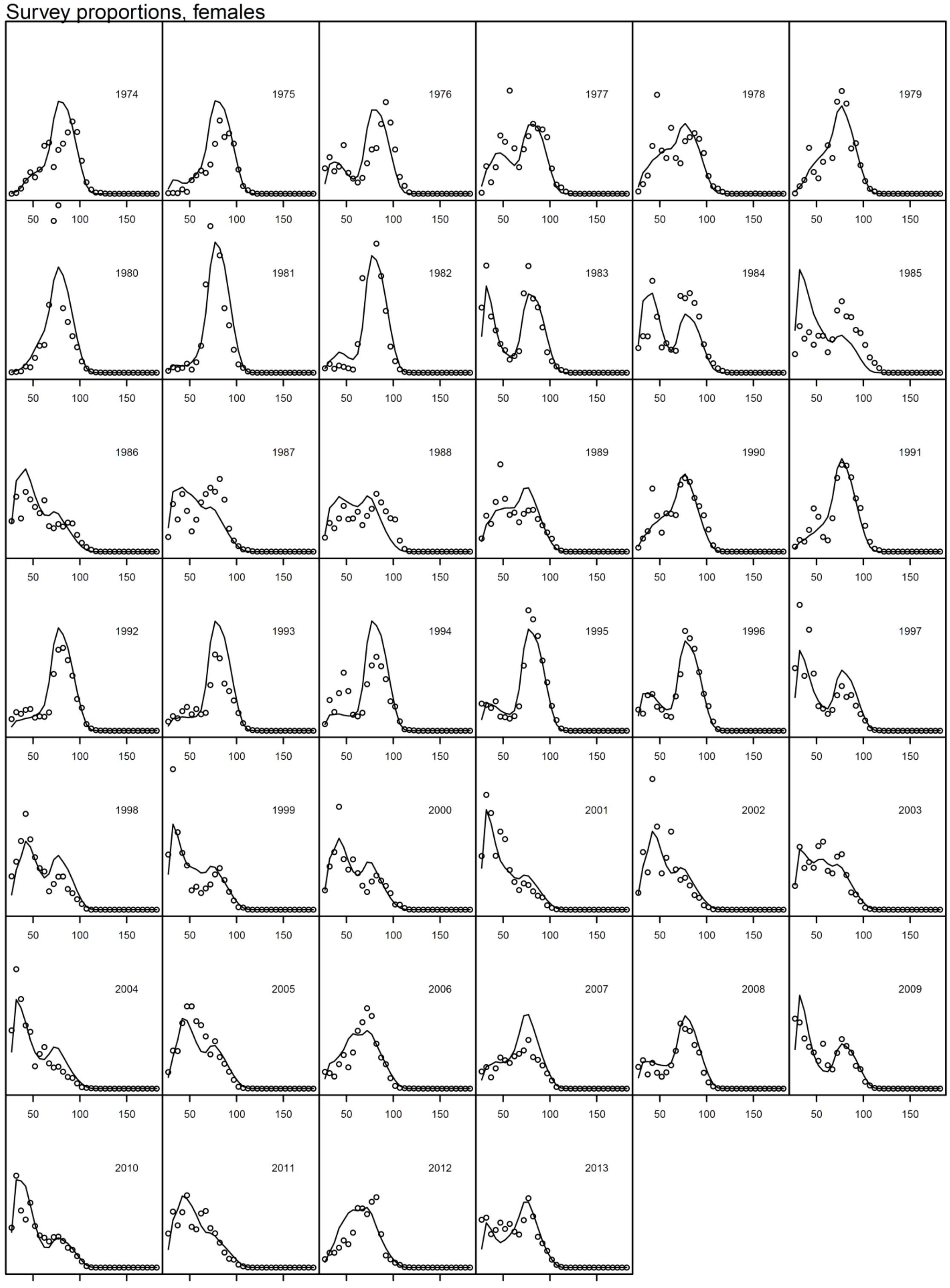


Figure 67.Comparison of predicted (solid line) and observed (circles) proportions-at-size for females in the NMFS bottom trawl survey.

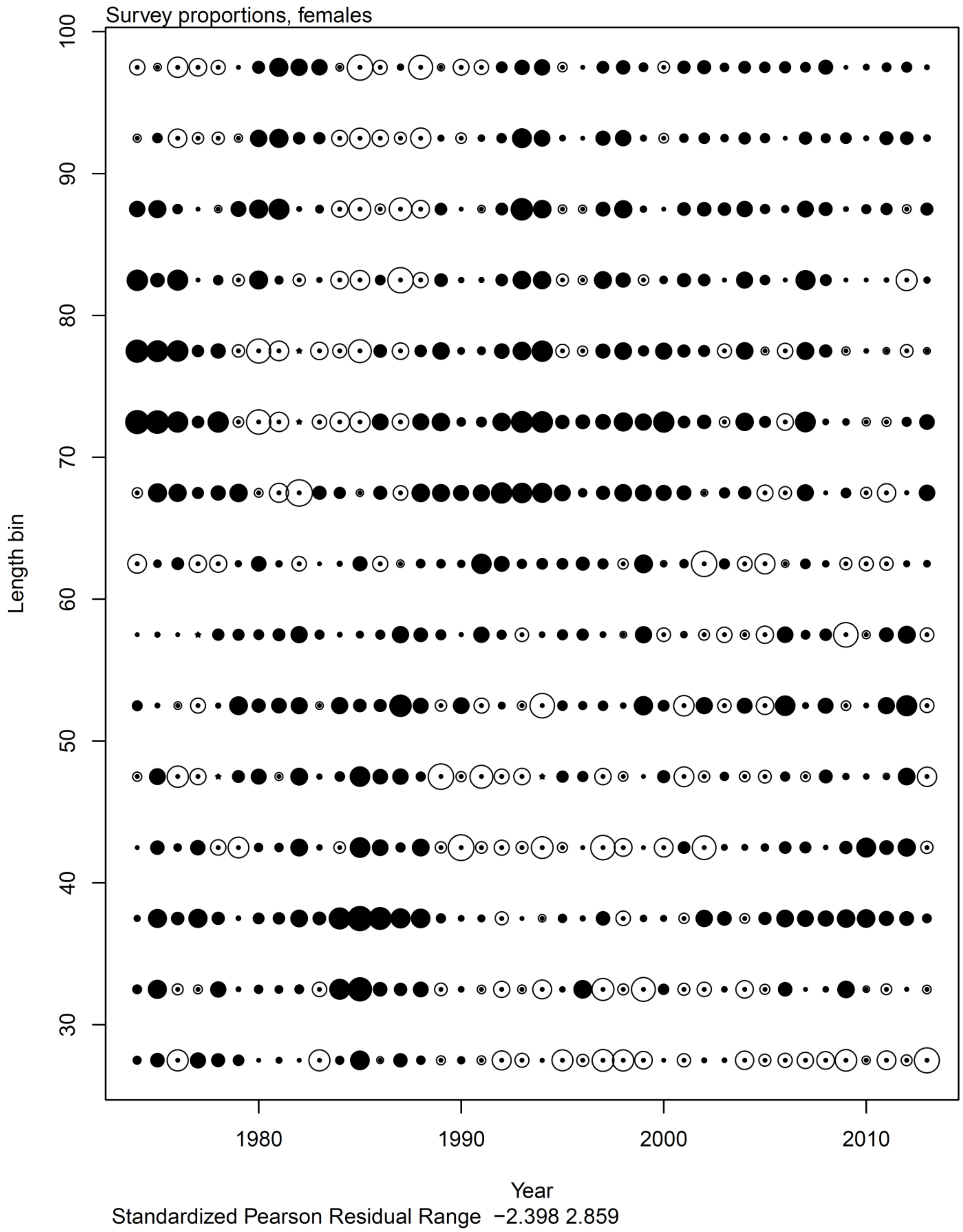


Figure 68.Pearson residuals for predicted proportions at size for females in the NMFS bottom trawl survey. White circles represent positive anomalies (observed>predicted), black circles represent negative anomalies.

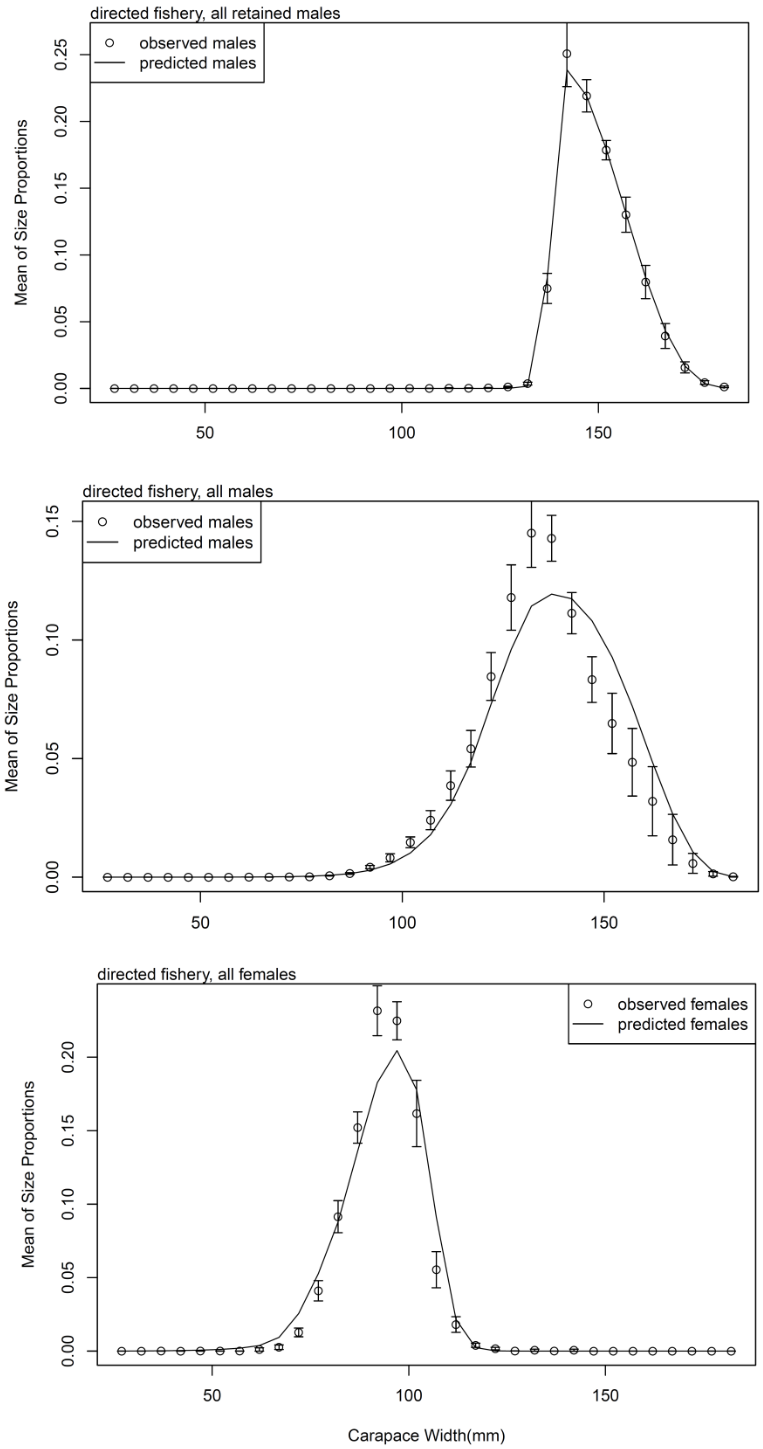


Figure 69. Comparison of marginal (mean) proportions-at-size for retained males (upper plot) and all males (center plot) and females (lower plot) in the directed Tanner crab fishery. 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

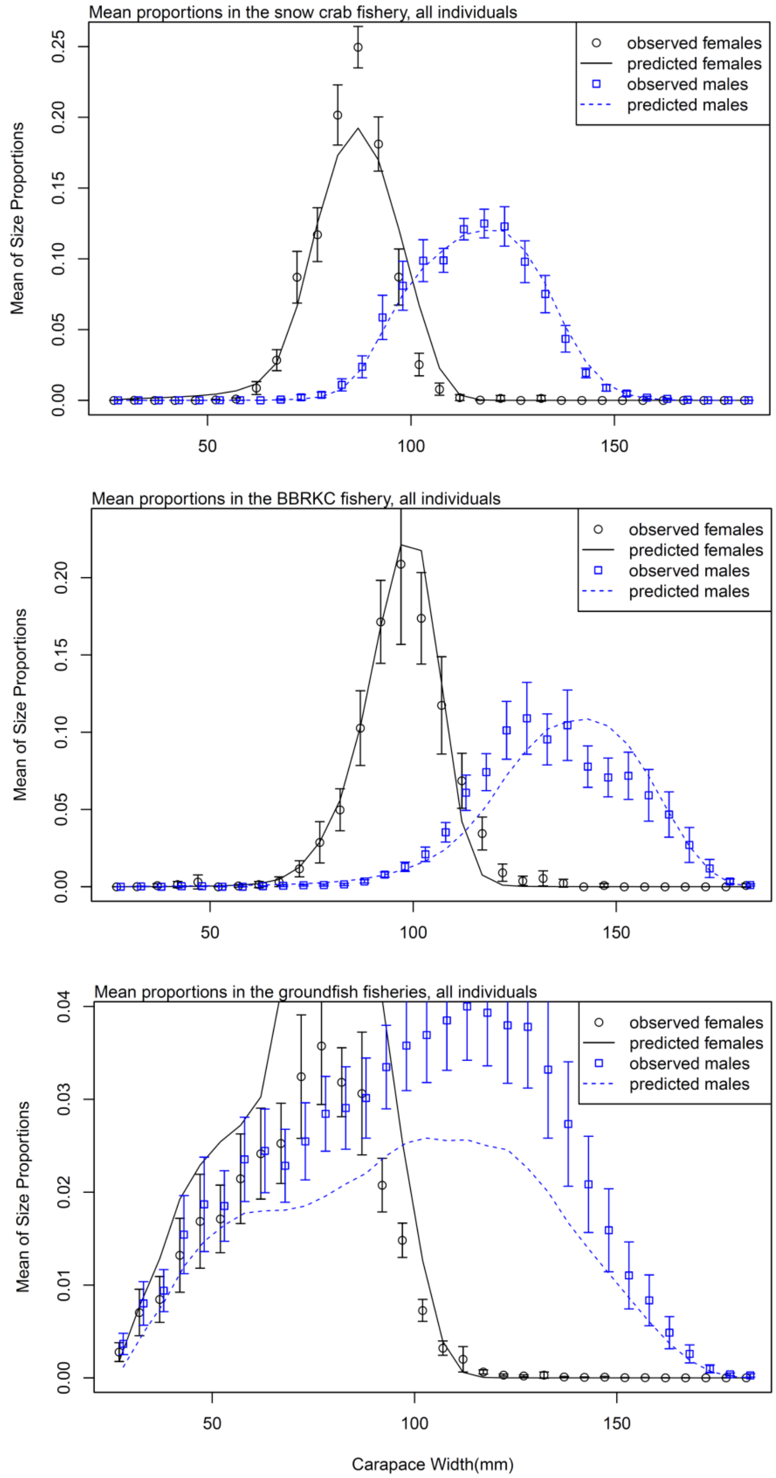


Figure 70. Comparison of marginal (mean) proportions-at-size for males and females in the snow crab fishery (upper plot), the BBRKC fishery (center plot) , and the groundfish fisheries (lower plot). 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

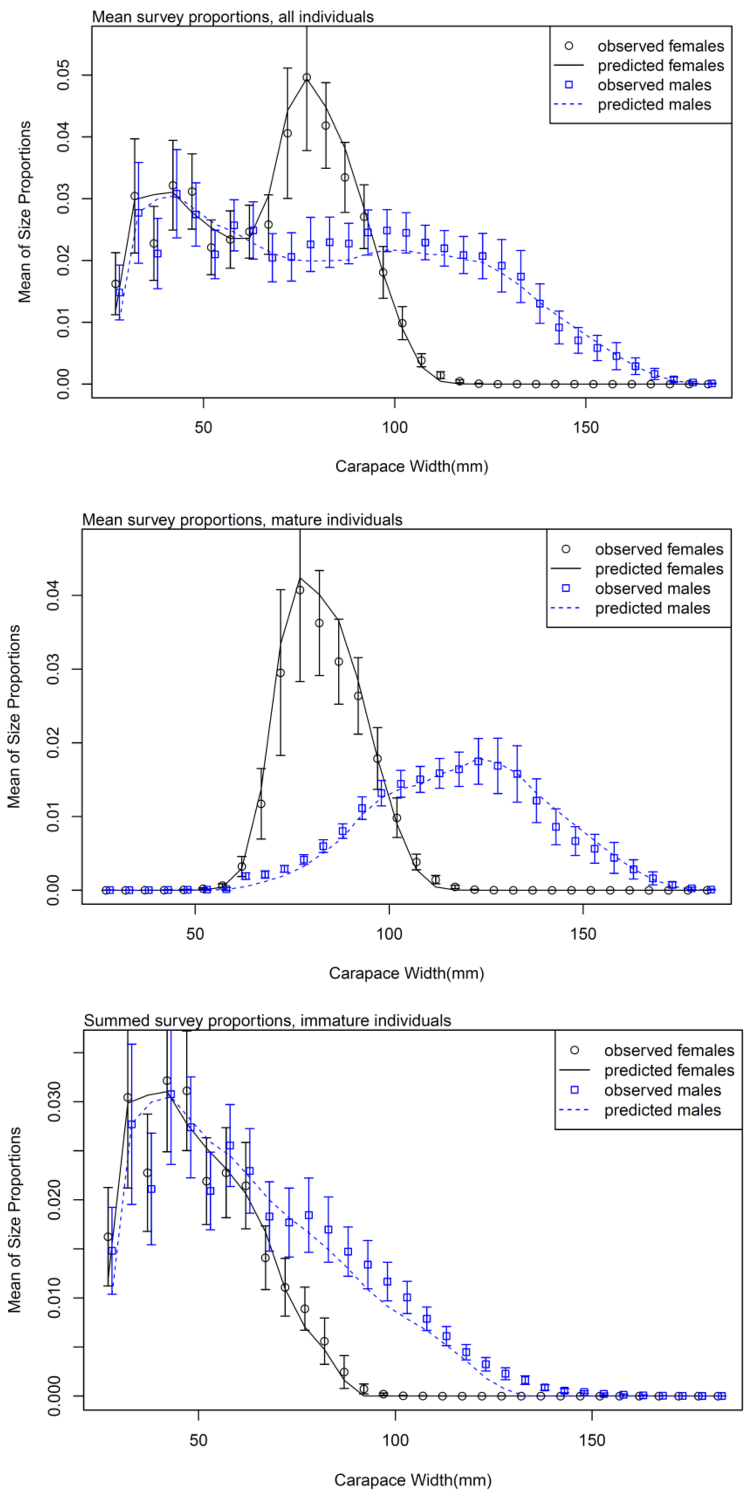


Figure 71. Comparison of marginal (mean) proportions-at-size for all (male+female) crab (upper plot), mature crab (center plot), and immature crab (lower plot) for the NMFS bottom trawl survey . 80% confidence intervals are shown for the observed values, based on observed variance-at-size and assuming normal distributions.

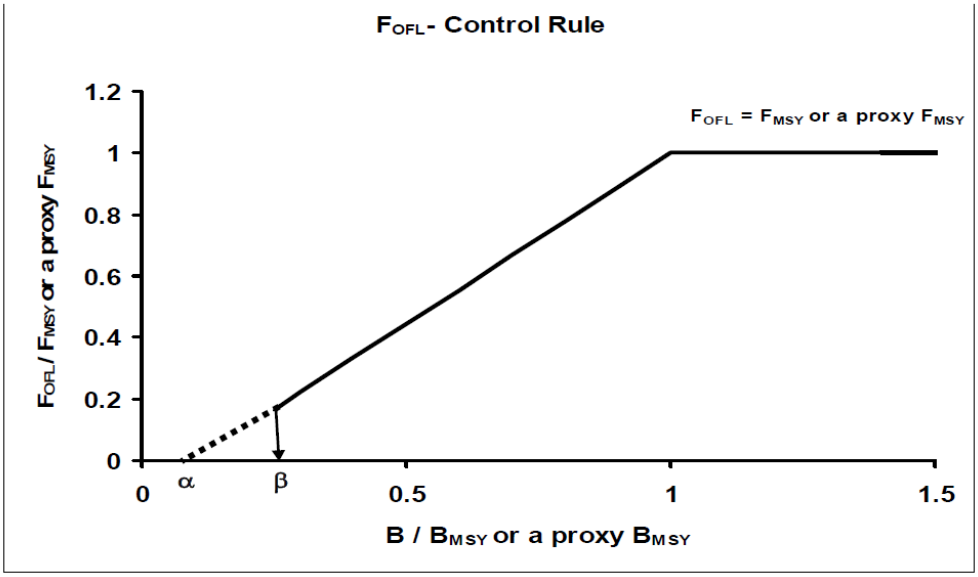


Figure 72. The F_{OFL} harvest control rule. For Tier 3 stocks such as EBS Tanner crab, F_{MSY} and B_{MSY} are based on spawning biomass per recruit proxies, where $F_{MSY} = F_{35\%}$ and $B_{MSY} = B_{35\%}$ and MMB at mating time is used as spawning biomass.

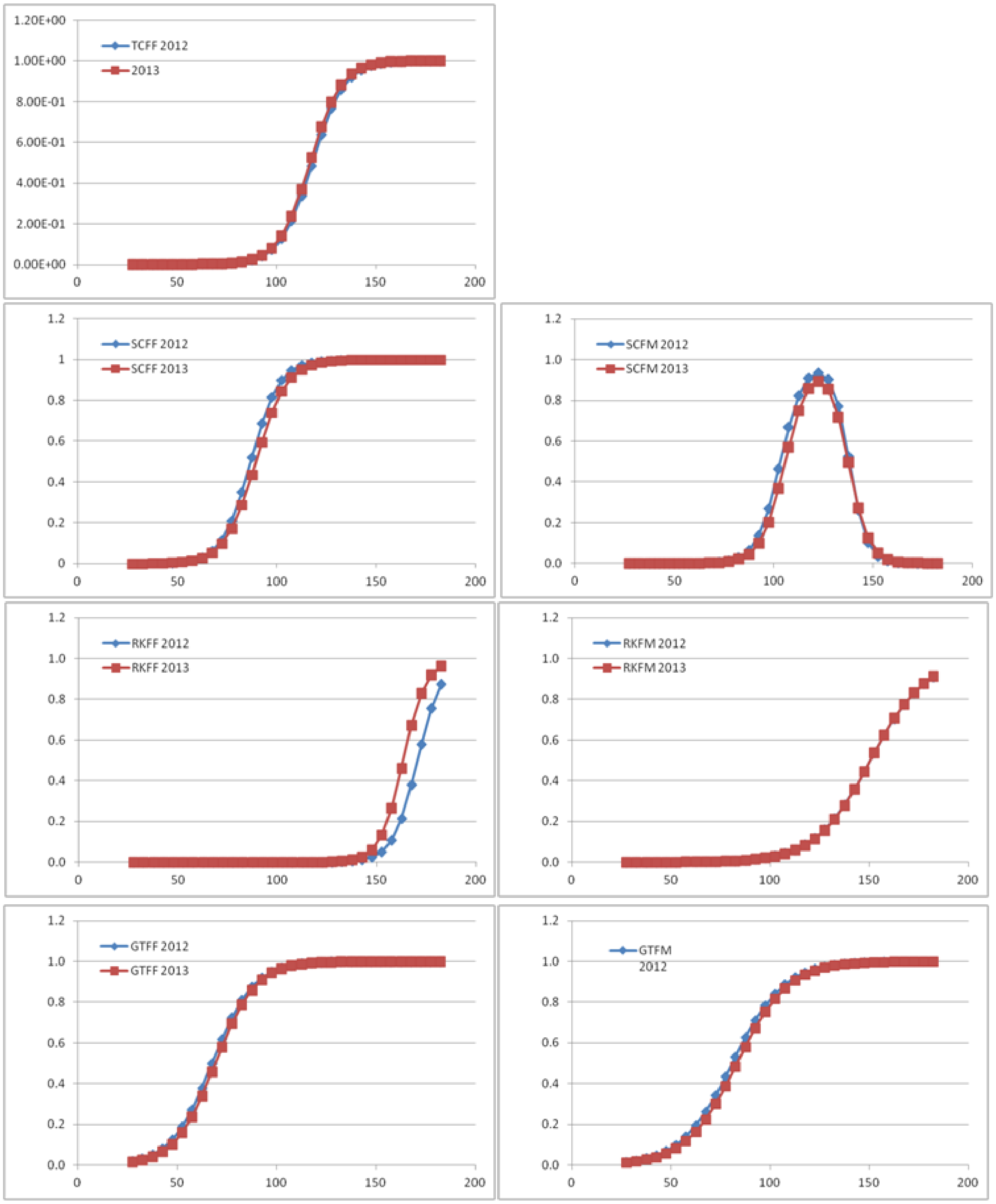


Figure 73. Comparison of selectivity curves used in the projection model for status determination and OFL calculation in 2012 (blue curves) and 2013 (red curves) for females in the directed fishery (upper graph) and both sexes in the snow crab fishery (2nd row from the top), the BBRKC fishery (3rd row from the top), and the groundfish fisheries (bottom row). The left column presents curves for females, the right column presents those for males.

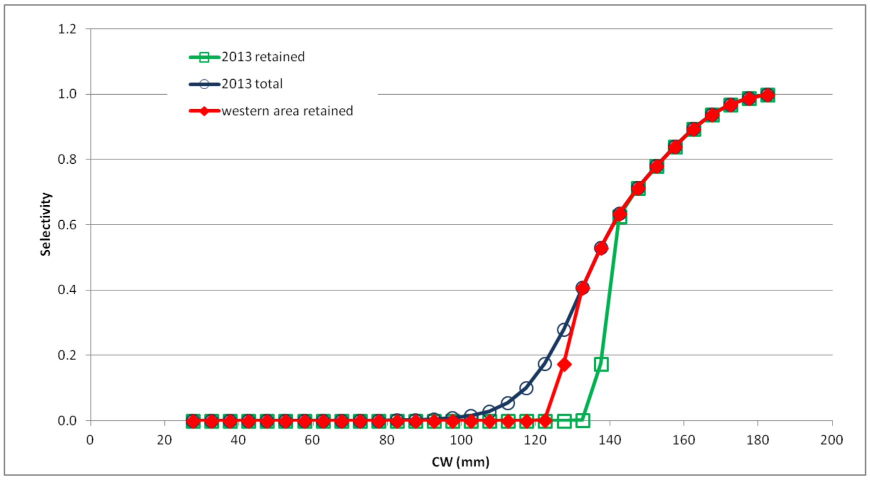


Figure 74. Male selectivity curves used for the directed fishery in the projection model. The total (retained+ discards) selectivity curve (blue circles) is assumed to apply to the fisheries east and west of 166°W longitude. Retained selectivity in the fishery east of 166°W (green curve, squares) is assumed to be the same as the last year of the directed fishery (green curve, squares). Retained selectivity west of 166°W is assumed to be a left-shifted version of that east of 166°W, reflecting the smaller legal size limit there.

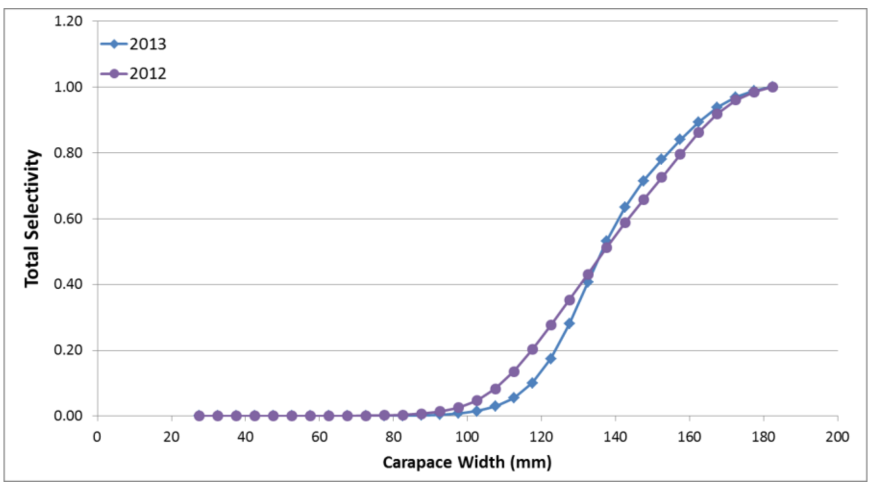


Figure 75.Comparison of selectivity curves from the 2012 assessment model and the author's preferred model for total male catch (retained + discarded) in the directed tanner crab fishery.

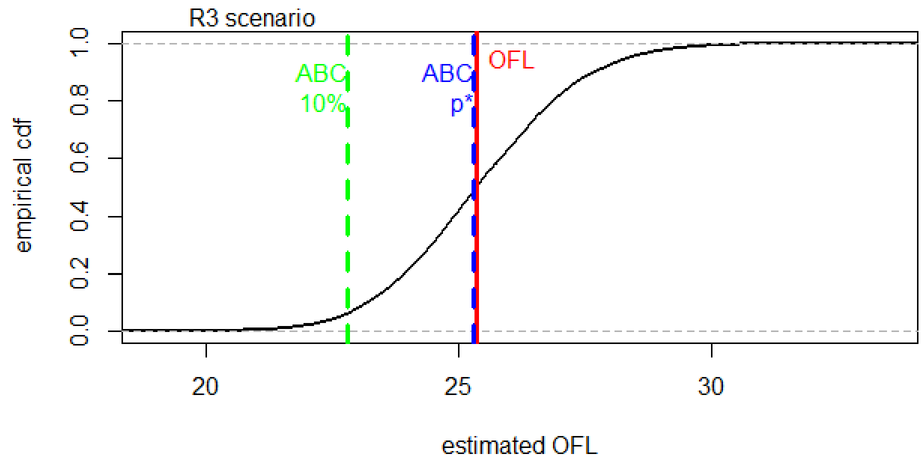


Figure 76. Tier 3 OFL and ABC calculations using the empirical cumulative probability distribution (white line) for the OFL (indicated by the vertical red line) based on 10,000 1-year projection model runs. Initial (July 1, 2013) population numbers-at-size were randomized based on the CV of 2012 MMB at mating time from the author's preferred model and recruitment scenario, Model 01 and R3. For each year, directed fishing mortality was set using F_{msy} = F35% and the Tier 3 F_{OFL} control rule, and total catch was calculated. The OFL is the median of the resulting distribution of catches (possible OFLs). The "p-star" ABC (indicated by the dashed blue line) is the ABC that yields p-star = 0.49—i.e., the probability that the selected ABC exceeds the true OFL is 49%. $ABC_{10\%}$ (indicated by the dashed green line) is the ABC based on applying a 10% buffer to the OFL. The units for OFL and ABC are 1000's t.

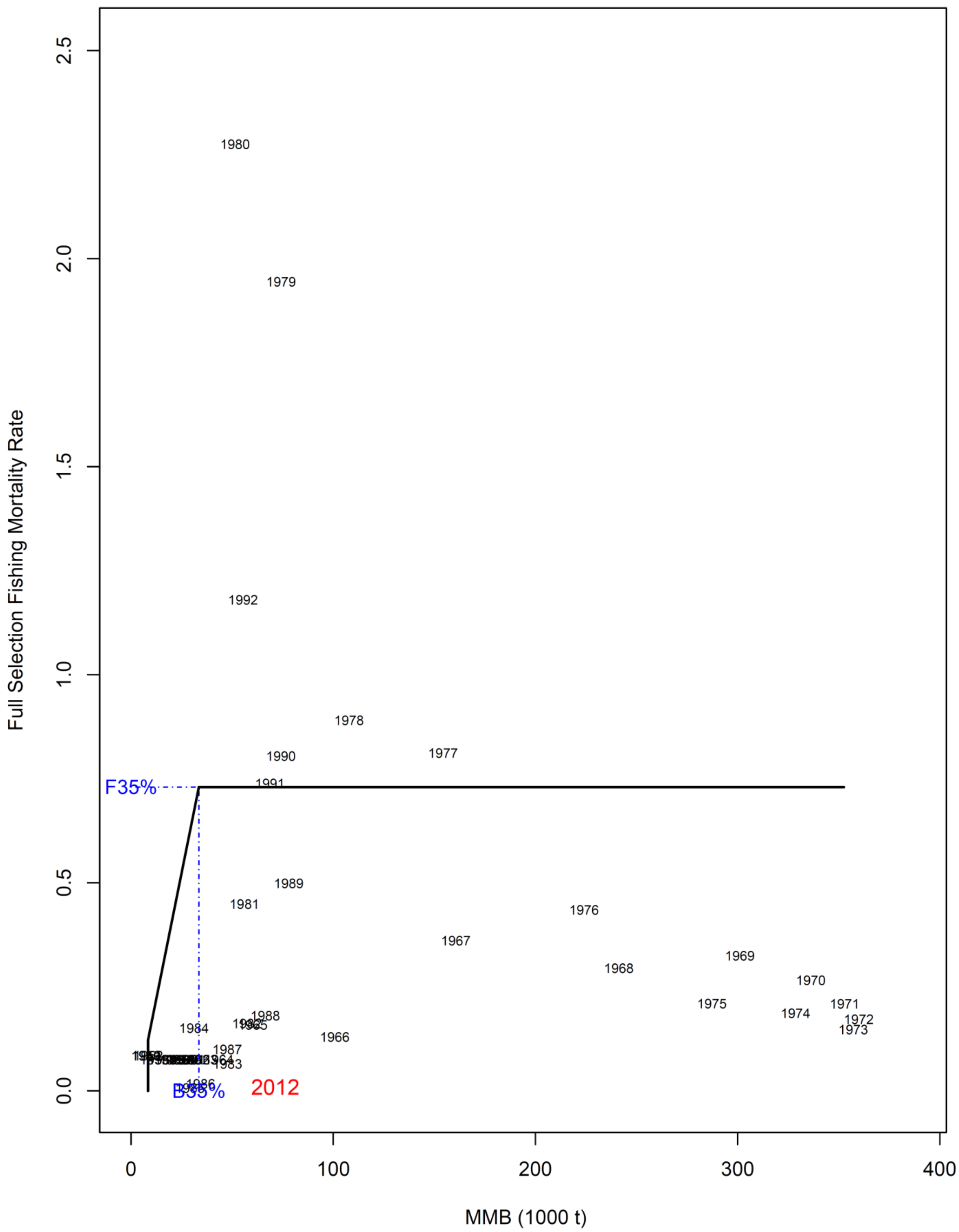


Figure 77. The Tier 3 F_{OFL} harvest control rule, with the population state for each year plotted at coordinates given by MMB at mating on the x axis and total fishing mortality on the y axis, as estimated from the author's preferred model, Model 01. The current year (2012/13) is highlighted in red text.

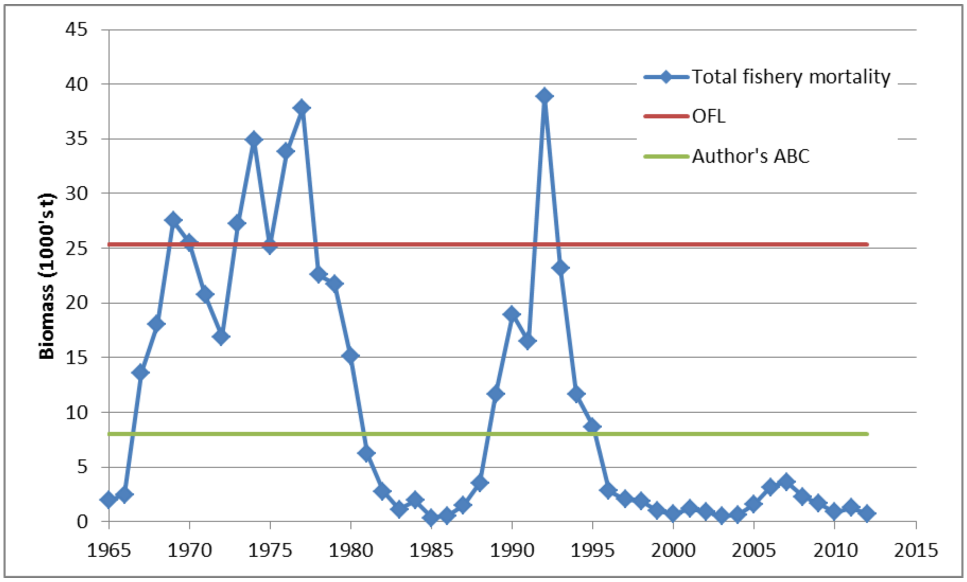


Figure 78. The Tier 3 F_{OFL} harvest control rule, with the population state for each year plotted at coordinates given by MMB at mating on the x axis and total fishing mortality on the y axis, as estimated from the author's preferred model, Model 01. The current year (2012/13) is highlighted in red text.

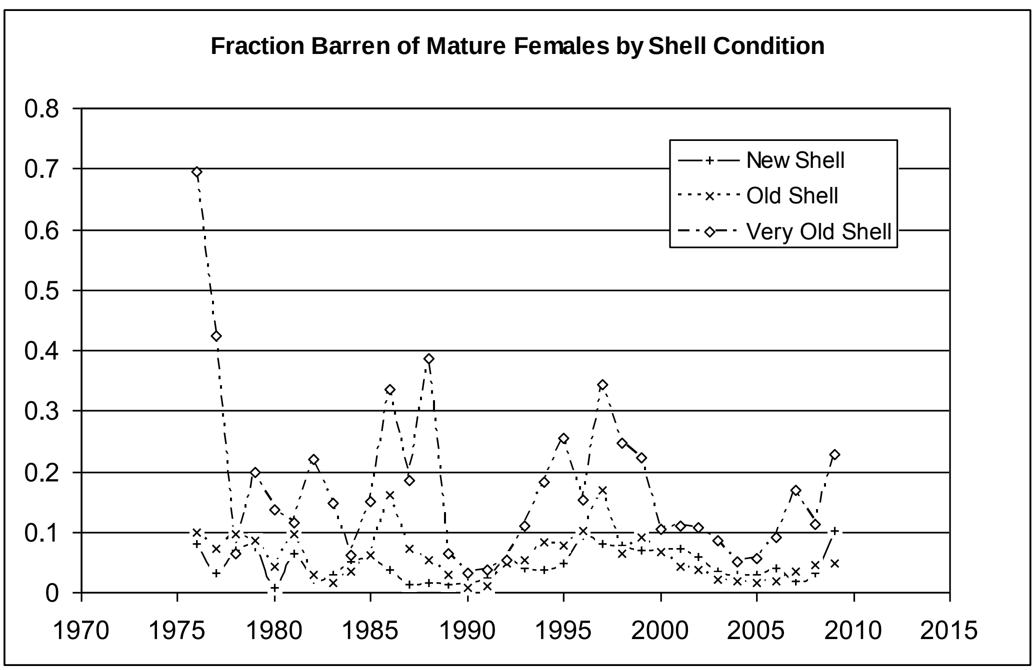


Figure 79. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

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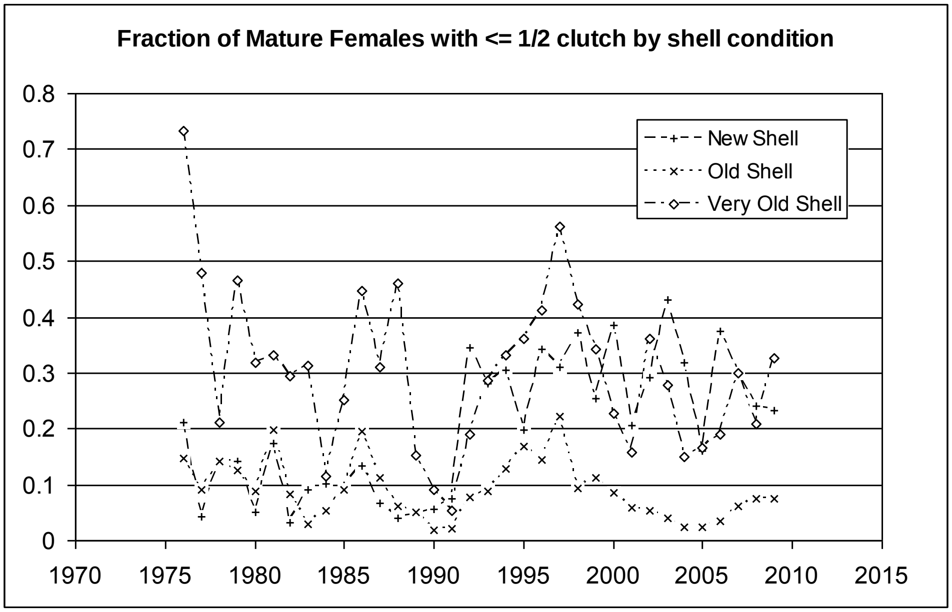

Figure 80. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

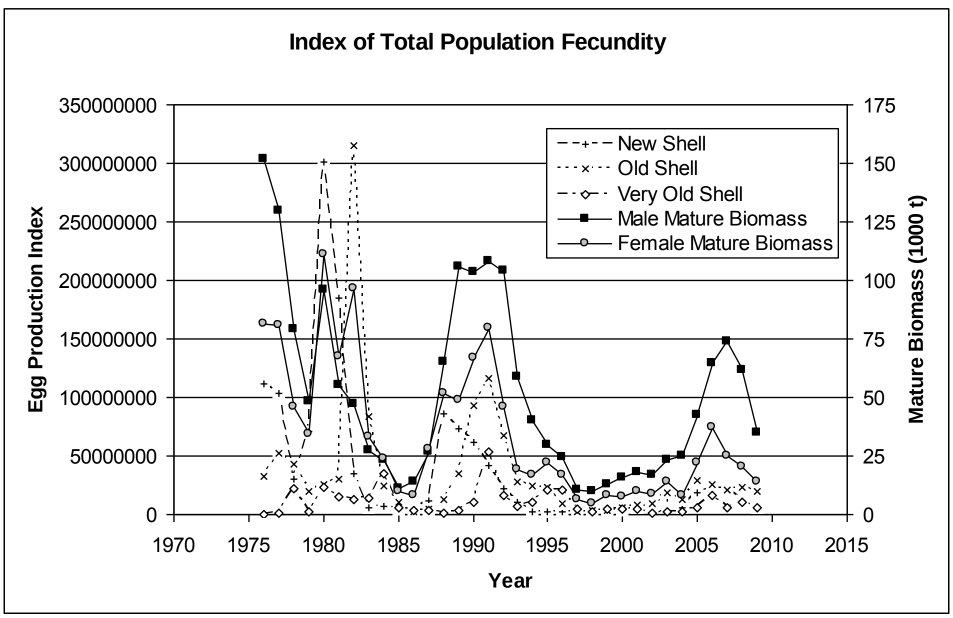

Figure 81. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

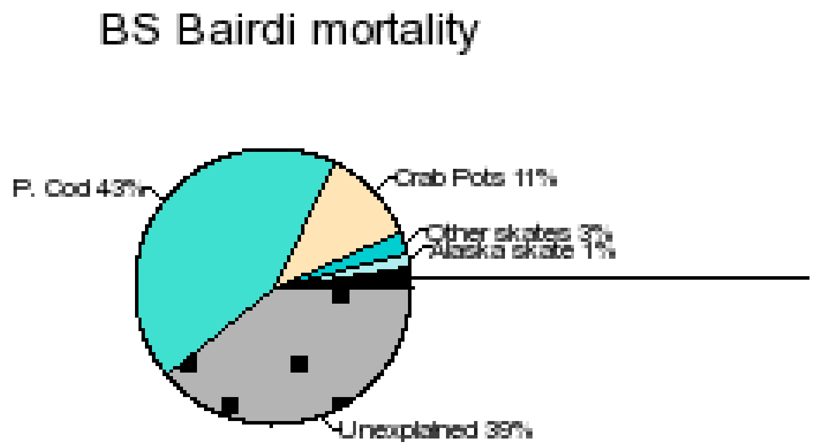

Figure 82. The fraction of annual mortality from major ecosystem components (including fisheries) on mature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

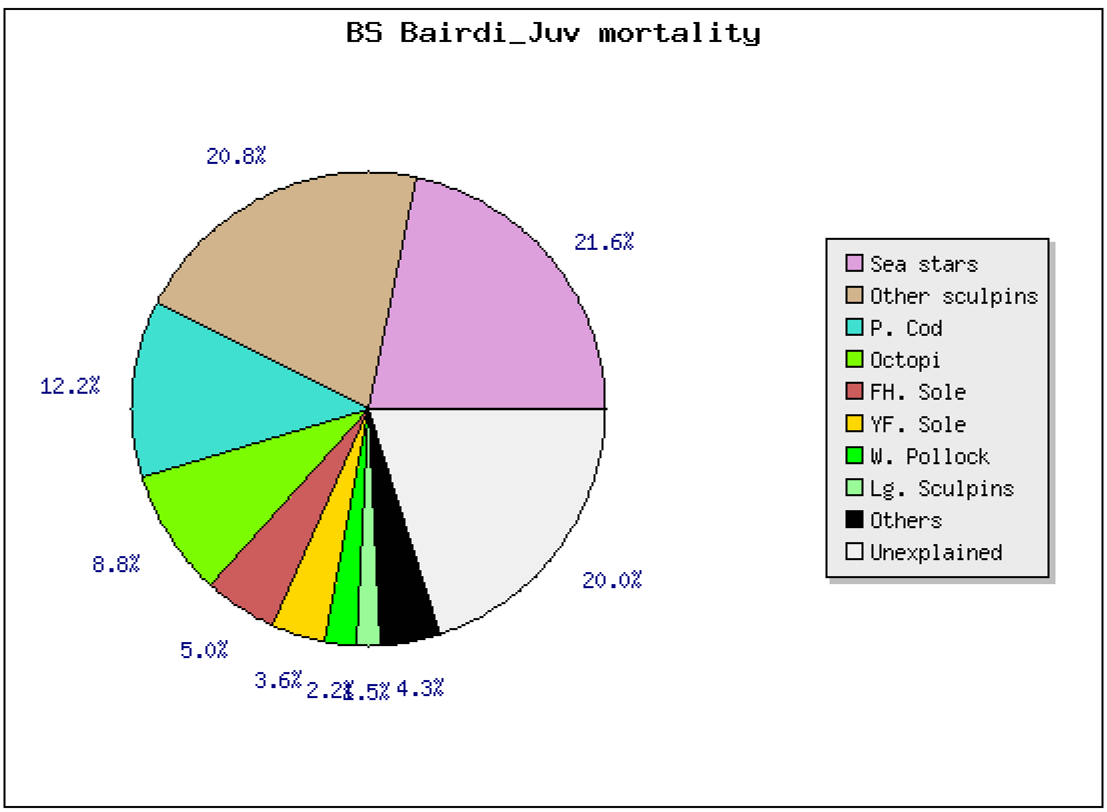

Figure 83. The fraction of annual mortality from major ecosystem components (including fisheries) on immature Tanner crab in the EBS, as estimated by a mass-balance ecosystem model for the EBS (Aydin et al., 2007).

Appendix A to the 2013 BSAI Tanner Crab SAFE Report: Recruitment Analysis for Stock Status Determination and Harvest Recommendations

William T. Stockhausen
Alaska Fisheries Science Center
05 September 2013

Introduction

In June 2012, following recommendations by both the Crab Plan Team (CPT) and the Science and Statistical Committee (SSC), the North Pacific Fishery Management Council accepted the Tanner Crab Stock Assessment Model (TCSAM) developed by Rugolo and Turnock (2012) for use in management of the Tanner crab fishery in 2012. The Council also approved further recommendations by the CPT and SSC that Tanner crab be assessed as a Tier 3 stock for determining stock status and overfishing levels.

Tier 3 stocks are regarded as having reliable estimates of current spawning biomass (B), $F_{35\%}$ and $B_{35\%}$ (as proxies for F_{msy} and B_{msy}, respectively; NMFS 2008). Estimation of $F_{35\%}$ is based on a spawning biomass-per-recruit analysis: if $\phi_{100\%}$ is the spawning biomass-per-recruit for the unfished stock as determined by the assessment model, then $F_{35\%}$ is the fishing mortality rate that results in a spawning biomass-per-recruit equal to $\phi = \phi_{35\%} = 0.35 \text{ x } \phi_{100\%}$. Once $\phi_{100\%}$ and $F_{35\%}$ have been estimated, then $B_{35\%} = \bar{R} \cdot \phi_{35\%} = 0.35 \cdot \bar{R} \cdot \phi_{100\%}$, where $\bar{R}$ represents average recruitment when the stock is harvested at maximum sustainable yield (MSY). For Tier 3 stocks, $\bar{R}$ cannot be determined directly because a reliable stock-recruitment relationship does not exist for these stocks (hence the use of proxies for MSY). Instead, $\bar{R}$ for Tier 3 stocks should be average recruitment over a time period “representative of the stock being fished at an average rate near F_{msy}” (i.e., $F_{35\%}$ for Tier 3 stocks) and thus “fluctuating around B_{msy}” (NMFS 2012). For Tanner crab, spawning biomass is taken as mature male biomass at time of mating (*MMB*).

The assessment authors provided five scenarios for estimating $\bar{R}$ as average recruitment from the accepted TCSAM results: 1) R1: 1966-1972, 2) R2: 1966-1988, 3) R3: 1982-2012, 4) R4: 1966-2012, and 5) R5: 1990-2012 (Rugolo and Turnock, 2012). The range of years for each scenario refers to the years at which recruits enter the modeled population, not the years at which fertilization is assumed to occur (the latter can be obtained by subtracting 5). The assessment authors recommended using R2 (SSC 2012) to determine $\bar{R}$, as this range of years “…although it includes recruitments that did not result from a stock at B_{MSY} nor that subsequently yielded B_{msy}, it captures the mode of secondary *MMB* in 1990 but not beyond mid-1990 when the stock was declared overfished” (Rugolo and Turnock 2012). The CPT recommended using R5 based on a breakpoint analysis of stock recruitment relationships by Andre Punt (Punt 2012) conducted during the Sept. 2012 CPT meeting that identified a potential change in stock productivity (i.e., in the stock-recruit relationship) in fertilization year 1985, corresponding to recruitment year 1990 (CPT 2012).

The SSC was hesitant to accept either the assessment authors’ or the CPT’s recommendations, and instead recommended using R3 as an interim measure pending “…further analysis of alternative recruitment time periods by the stock assessment authors and Crab Plan Team to include options based on years in which recruitment was [reasonably] estimated, additional breakpoint analyses, and evidence for shifts in Tanner crab life history and ecology.” The SSC also requested “that one option should include a time series spanning the extent of reasonably estimated recruitments based on confidence intervals for recruitment…it would seem that this time series should start with fertilization years beginning in the late 1960s (e.g., 1966), corresponding to a years of recruitment to the model starting in the early 1970s (e.g., 1971).”

This appendix is an attempt to address some of the SSC’s requests regarding this issue. In it, I provide expanded results from a re-analysis of Andre Punt’s breakpoint analysis, as well as results from applying four averaging methods to recruitment estimates from the accepted 2012 TCSAM over a variety of potential time intervals, including the R1-R5 scenarios considered in the 2012 SAFE chapter (Rugolo and Turnock 2012) and one labeled “R6” corresponding to the SSC’s specific request to consider the 1971-2012 time frame. The results presented here are based on output from the accepted 2012 TCSAM (Model 0 in Rugolo and Turnock [2012]). The computer code for that model was revised by this author to provide additional model output used here. In doing so, it was realized that the original model output reflecting the estimated covariance matrix for ln(*R/MMB*) provided by Rugolo and Turnock to Andre Punt at the Sept. 2012 CPT meeting was incorrect for one year (fertilization year 1969) due to an indexing error which did not otherwise affect the model results. Consequently, I have re-run Punt’s breakpoint analysis with the corrected TCSAM model output.

The author wishes to acknowledge and thank Jack Turnock and Lou Rugolo for providing the TCSAM model code and Andre Punt for providing his breakpoint analysis code and data.

2012 TCSAM Output

The time series of the 2012 TCSAM estimates for the ratio of total fishing mortality (*F*) to $F_{35\%}$, mature male biomass (MMB) at time of spawning, recruitment (R), and ln(*R/MMB*) are listed in Table 1 for the time period 1950-2007, with recruitment lagged to fertilization year assuming a 5 year span between fertilization year and recruitment into the model size classes. The recruitment and MMB time series are plotted, along with estimated 80% confidence intervals, for the period 1961-2007 in Figure 1. The MMB displays decadal-scale variability, building to its largest value in 1972 (359.3 thousand t), then declining to a local minimum in 1985 (21.5 thousand t), followed by an increase to a much smaller peak (72 thousand t) in 1989, declining again to a local minimum (14.6 thousand t) in 1999, and subsequently increasing to 56.7 thousand t in 2007. The largest uncertainties in MMB, both in absolute and relative terms, occurred early in the time series. After 1970,CV’s were less than 0.3. Estimated recruitment also displays decadal-scale variability, but this tends to be negatively correlated with MMB. The largest recruitments occur early in the time series, declining to a local minimum in 1969; these are also the least well estimated recruitments in terms of absolute uncertainties. However, the largest relative uncertainty in recruitment occurs in fertilization year 1975 (model year 1980; Figure 2). Estimated recruitment CV’s are generally less than 0.3 after 1976 (model year 1981), the exceptions being 1986 (model year 1991) and 2007 (model year 2012).

Stock productivity is reflected by the time series of ln(*R/MMB*) over the 1961-2007 fertilization year, plotted in Figure 3 with estimated 80% confidence intervals (MMB is plotted again for reference, as well). Decadal-scale variability is evident, but with no obvious trends over the entire time period. As with recruitment, this variability appears to be negatively correlated with MMB. A plot of ln(*R/MMB*) vs. MMB (Figure 4) suggests that ln(*R/MMB*) is linearly related to MMB (and consequently follows a Ricker-type stock recruit relationship) but that the relationship exhibited different slopes in at least two time periods (fertilization years 1961 to early 1980s and early 1990s-2007).

Average recruitment

Based on a simple average of estimated recruitment over the appropriate time period, $\bar{R}$ options for the five recruitment scenarios considered in the 2012 SAFE chapter are (number of crab): R1) 515 million, R2) 288 million, R3) 107 million, R4) 179 million, and R5) 73 million. As noted previously, $\bar{R}$ should be “representative of the stock being fished at an average rate near F_{msy}.” Because $F_{35\%}$ represents the Tier 3 proxy for F_{msy}, the ratio $F/F_{35\%}$ indicates when the stock was fished below or above F_{msy} and provides a means for deciding when the stock was fished "at an average rate near F_{msy}." If one adopts the (not unreasonable but rather arbitrary) definition that "near" means $0.25 \leq F/F_{35\%} \leq 4.00$, this results in two time periods across which one might calculate $\bar{R}$: 1) 1973-1987 (excepting 1979), and 2) 1994-2002 (both time periods expressed as recruitment years, not fertilization years, to be consistent with scenarios R1-R5). Taking a simple average of estimated recruitment across these two time periods, one obtains $\bar{R} = 140$ million crab, which results in $B_{35\%}$ = 43.9 thousand t. Under this scenario, the MMB at mating in 2011/2012 would have been 1.34 *x* $B_{35\%}$ and the stock would have been declared rebuilt, similar to status determinations obtained under scenarios R3, R4, and R5.

The SSC also requested "further analysis of alternative recruitment time periods…to include options based on years in which recruitment was [reasonably] estimated" in their October 2012 minutes (SSC, 2012). Based on the estimated CVs for the recruitment estimates (Figure 2), the model years 1981-2011 represent a period in which recruitments were "reasonably" estimated because all CVs except in 2007 were <0.3 in this time period. However, other choices that constitute "reasonably" estimated recruitment estimate result in other time periods being selected. As such, I've calculated average recruitment for the 5 recruitment scenarios considered in the 2012 SAFE report (Rugolo and Turnock 2012; Table 2, Figure 5), as well as all time periods of the form y-2012 for y from 1966 to 2007 (Table 3, Figure 5). In this respect, the SSC specifically requested consideration of the 1971-2012 time period, herein referred to as R6. The value of $\bar{R}$ for R6 using a simple average is 128 million, results in $B_{35\%}$ = 40 thousand t. Under this scenario, the MMB at mating in 2011/2012 would have been 1.46 *x* $B_{35\%}$ and the stock would have been declared rebuilt, similar to status determinations obtained under scenarios R3, R4, and R5.

In addition to the "standard" calculation $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$ for the average of a series of N "observations" $\{x_i\}$, there are a variety of approaches to calculating averages that incorporate observations (i.e., the TCSAM recruitment estimates) with error. Here, I've considered three additional methods to calculate average recruitment over any given time period: a variance-weighted mean, a covariance-weighted mean, and a process-error weighted mean. All four methods can be calculated based on minimizing the following negative log-likelihood function with respect to its parameters

$$-\ln(L) = 0.5 \cdot \ln(|\mathbf{\Omega}|) + 0.5 \cdot \sum_i \sum_j (y_i - \hat{y}_i) \cdot [\mathbf{\Omega}^{-1}]_{i,j} \cdot (y_j - \hat{y}_j) \quad (1)$$

where $\hat{y}_i = \bar{R}$ is estimated mean recruitment, $y_i = R_i$ is the recruitment estimate for year i, and $\mathbf{\Omega}$ incorporates observation and process error in the form $\mathbf{\Omega} = \mathbf{O} + \mathbf{P}$, where $\mathbf{O}$ is the observation error covariance matrix and $\mathbf{P}$ is the process error matrix. Here, $\mathbf{P}$ is assumed to reflect a first-order autoregressive process and has elements $P_{i,j} = \sigma^2 \cdot \rho^{|i-j|}$, where σ^2 represents process error variance and ρ represents the degree of autocorrelation.

For the standard, variance-weighted, and covariance-weighted methods, process error is ignored (both σ^2 and ρ are set to 0) and Equation 1 is minimized with respect to the single parameter $\bar{R}$ (although there is really no need to perform the minimization numerically because exact solutions exist). For the standard method, $\mathbf{O}$ is simply a diagonal matrix with 1's on the diagonal, although in this case estimates of uncertainty obtained from the model hessian are invalid. For the variance-weighted method, $\mathbf{O}$ is a diagonal matrix with $O_{i,i} = \sigma_i^2$, where σ_i^2 is the estimated variance of R_i (available from the .std or .cor file from an ADMB model run). For the covariance-weighted method, $O_{i,j} = \sigma_i \cdot \sigma_j \cdot \rho_{i,j}$, where σ_i^2 is (again) the estimated variance of R_i and $\rho_{i,j}$ is the estimated correlation between R_i and R_j (also available from the .cor file). For the process error-weighted method, $\mathbf{O}$ is the same matrix as in the covariance-weighted method and Equation 1 is minimized with respect to the parameters $\bar{R}$, $\ln(\sigma)$, and $\tan(\rho)$. Equation 1 was solved for each time period and each averaging method using the "mle" function from the R statistical package (Table 2, Figure 5). This analysis was also repeated on the log-scale recruitments and covariance structure, because the error structure in TCSAM is on the natural log scale (Table 3, Figure 6). This yielded estimates of median recruitment (once back-transformed to the arithmetic scale), not average (or mean) recruitment. Rather different results were obtained for the two data types (i.e., arithmetic vs. log-scale recruitment estimates), as well as for each averaging method for a given data type.

Using the arithmetic-scale recruitment estimates as inputs, the four averaging methods tended to give substantially different results for each time period (Table 2, Figure 5). The standard method always yields the largest estimate, the process error-weighted method yields the next largest (~0.8 *x* standard), the variance-weighted method yields the third largest estimate (~0.4 *x* standard), and the covariance-weighted method yields the smallest estimate (~0.1 *x* standard). For time periods of the form *y*-2012, the minimum average recruitment occurred for *y* = 1990 (coincident with the R5 scenario) for the standard, variance-weighted, and process error-weighted methods. It occurred for *y* = 1969 or 1970 for the covariance-weighted method.

The averaging methods that weighted the arithmetic-scale "observations" (i.e., 2012 TCSAM recruitment estimates) by their estimated variances or covariances systematically shrank the estimates of average recruitment over any given time period relative to the standard (unweighted) method. This occurred because the estimated observation variances are positively correlated with the observations themselves, reflecting two factors. The first is that the largest recruitment estimates (observations) occur early in the time series before there is much support by the data going in to the TCSAM, and consequently these have large associated variances because there is little data to constrain them. The second is that recruitment in TCSAM is considered to be lognormally distributed, so that variance is fundamentally related to the observation in a positive fashion. The weighting methods used in Equation 1, however, assume a normal distribution for the observation error structure and it may be inappropriate to use these methods to estimate average recruitment from arithmetic-scale observations using weighting methods.

Using log-scale recruitment estimates as inputs, three of the four averaging methods (standard, variance-weighted, and process error-weighted) tended to give similar estimates of median recruitment for each time period (Table 3, Figure 6), whereas the covariance-weighted method resulted in substantially higher estimates for time periods that started before 1988. For time periods starting after 1988, the covariance-weighted method also gave estimates that were similar to the other methods. For time periods of the form *y*-2012, the minimum median recruitment occurred for *y* = 1990 (coincident with the R5 scenario) for the standard, variance-weighted, and process error-weighted methods (similar to the arithmetic-scale recruitment results), and in 1991 for the covariance-weighted method. Over these time periods, estimated median recruitments for the standard, covariance-weighted, and process error-weighted methods varied by at most a factor of 2 (i.e., max/min). In contrast, estimates for the covariance-weighted method varied by a factor of 4.5.

Although using the estimated log-scale recruitments and corresponding variance/covariance components as inputs to the appropriate averaging methods is more consistent with the error structure assumed in the TCSAM, the conversion of the log-scale estimated mean (median on the arithmetic scale) to an arithmetic scale in order to obtain $\bar{R}$ remains an issue. Typically, if R is lognormally-distributed such that $\ln(R) \sim N(\ln(\hat{R}), \sigma^2)$, one could use $\bar{R} = \hat{R} \cdot e^{\frac{\sigma^2}{2}}$, where $\hat{R}$ is the median and σ^2 is the log-scale variance. However, it is somewhat unclear what value should be used for σ^2 to make the conversion. The simplest choice would be to use the value assumed in the TCSAM, but it could also be estimated from the TCSAM output and the residuals to the weighted fit.

Breakpoint Analysis for Stock-Recruit Relationships

As noted above, the model output reflecting the estimated covariance matrix for ln(R/MMB) originally presented at the Sept. 2012 CPT meeting was incorrect for fertilization year 1969 due to an indexing error which did not otherwise affect the model results. Consequently, I re-ran the breakpoint analysis with the corrected data.

The breakpoint analysis uses a negative log-likelihood in the form of Equation 1, similar to the average recruitment analysis, but with $y_i = \ln(\frac{R}{MMB})_i$, the observation error matrix **O** reflecting the covariance matrix for ln(R/MMB), and $\hat{y}_i$ as the model estimate

$$\hat{y}_i = \begin{cases} \alpha_1 + \beta_1 \cdot MMB & t_i < b \\ \alpha_2 + \beta_2 \cdot MMB & b \le t_i \end{cases} \qquad (4)$$

where α_1 and $\beta_1$are the Ricker stock-recruit function parameters for the early time period before the potential breakpoint in year *b* and α_2 and $\beta_2$are the parameters for the time period after the breakpoint in year *b*. For each candidate breakpoint year *b*, Equation 1 was minimized with respect to the six model parameters: $\alpha_1, \beta_1,\ \alpha_2, \beta_2$, $\ln(\sigma)$, and $\tan(\rho)$. The minimum time span considered as a potential regime was 5 years. Each fertilization year from 1966 to 2002 was evaluated as a potential breakpoint *b* using time series of ln(R/MMB) and MMB for fertilization years 1961-2007. A model with no breakpoint was also evaluated. Models with different breakpoints were then ranked using AIC_c (AIC corrected for small sample size; Burnham and Anderson 2004), with

$$AIC_c = -2 \cdot \ln(L) + \frac{2 \cdot k \cdot (k+1)}{n-k-1}, \qquad (3)$$

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

$$\theta_m = \exp\left[(AICc_m - AICc_{min})/2\right]. \qquad (4)$$

Results from the breakpoint analysis are summarized in Tables 4-5 and Figures 7-9. The results obtained here are qualitatively similar to those obtained by Punt (2012), with a breakpoint in fertilization year 1985 (model year 1990) again resulting in the model with the smallest AICc (supporting use of R5 as the period over which to calculate average recruitment; Table 4, Figur 6). The model with no breakpoint (i.e., a single time period) is over 10 times less probable than the 1985 breakpoint model, suggesting reasonably strong evidence for a change in stock productivity. However, several alternative breakpoints (1974, 1975, 1983, 1984, 1986, and 1987) are reasonably well-supported in addition to 1985. It may be more appropriate to calculate an average recruitment using the appropriately-weighted estimate from all candidate breakpoints (e.g., using the Akaike weights given in Table 4), rather than basing the average recruitment on only the "best" candidate.

An interesting point is that the two sets of "good" models (1974-75 and 1983-1987) imply two very different mechanisms for the presumed change in productivity between the putative early and recent periods. The 1974-75 models indicate that the major difference between the two periods is a decrease in overall productivity at all stock sizes (i.e., a change in the α parameter; Table 5, Figures 8 and 9), whereas the 1983-1987 models indicate that the major difference is an increase in density dependent mortality (i.e., the β parameter). The former suggest a cause resultinged in a proportional effect on early life stage survival regardless of stock size, such as a shift in oceanographic patterns that reduced larval transport from hatching to benthic nursery areas. The latter suggest a cause that increased competition at larger stock sizes, such as reduced available habitat due to changes in the cold pool or a general decrease in carrying capacity. However, mechanisms of either type that would be consistent with these potential breakpoints have not (yet) been explored for eastern Bering Sea Tanner crab.

The plot of ln(R/MMB) vs. MMB (Figure 4) also reveals a potential problem with the current analysis because the confidence intervals on MMB are extremely large early in the time series. This uncertainty is not taken into account in the breakpoint analysis; MMB is treated as known with error.

Discussion

One of the complicating factors in determining a time period for Tanner crab over which to estimate $\bar{R}$ is that the highest recruitments and stock sizes co-occurred early in the modeled time period, with large associated uncertainties, while the lowest recruitments and stock sizes (with much smaller uncertainties) have co-occurred more recently. Attempts that weight the estimate of the mean by model uncertainty, either through the selected averaging method or by selecting a time period when recruitments are "well-estimated," consequently result in lower estimates of mean recruitment than would be obtained otherwise. For a given estimate of current population size, weighting the estimate of mean recruitment by model uncertainty results in a lower $B_{35\%}$—and consequently a more optimistic perception of stock size relative to B_{msy}—than would be obtained otherwise. Conversely, attempts that exclude the recent period of low stock size and low recruitments result in larger estimates of mean recruitment, and consequently $B_{35\%}$, providing a more pessimistic assessment of stock status and resilience than would be obtained otherwise.

The stock-recruitment relationship (SRR) breakpoint analysis presented here, which is qualitatively similar to the one conducted by Andre Punt at the Sept. 2012 CPT meeting, yielded several plausible breakpoint years, but these collectively suggest two very different types of changes in the SRR: one density independent and one density dependent. Further work is needed to link plausible changes in environmental drivers to the candidate breakpoints and to elucidate the mechanisms underlying the putative shifts in the SRR. The impact of the large uncertainties associated with MMB in the early part of the time series used in the breakpoint analysis (Figure 4) also needs to be assessed; currently MMB is treated as having no observation error.

Four potential methods and two potential "data" types for calculating average recruitment (once an appropriate averaging time period has been selected) were also evaluated. Three of the averaging methods (the variance-weighted, covariance-weighted, and process error-weighted methods) attempted to incorporate TCSAM observation and process error into the average recruitment estimate to varying degrees, whereas the fourth (the standard method) did not. The TCSAM recruitment estimates on both the arithmetic and log-scale (with corresponding observation error structures) were considered as input "data" types to the four methods. Given the assumption in TCSAM that recruitment follows a lognormal distribution, it is probably inappropriate to apply weighted-average methods to the arithmetic-scale recruitment estimates. For any given time period considered here, the three weighted-average methods yielded much smaller estimates of average recruitment using the arithmetic-scale TCSAM recruitment estimates than did the standard average calculation (Figure 5), the former driven by the smallest uncertainties (largest weights) being associated with the smallest recruitments.

When "average" recruitment is calculated using the log-scale TCSAM recruitment estimates, the back-transformed result is the arithmetic-scale median, not the arithmetic-scale mean. While the median can be scaled up to the mean using a correction factor, this requires estimating (or assuming a value for) another parameter: the log-scale variance. However, the error structure incorporated in the weighted-average methods is more appropriate for the log-scale recruitment estimates than it is for the arithmetic-scale estimates. On the log-scale, the variance-weighted and process error-weighted methods yielded results that were similar to the standard method for a given time period, and all three methods yielded results that were similar over the range of potential averaging time periods considered. Results for the covariance-weighted method were substantially different from the other three methods for averaging time periods that started before recruitment year 1990 (fertilization year 1985), indicating substantial correlation structure among log-scale TCSAM recruitment estimates before recruitment year 1990. It is notable that this also corresponds to the "best" year for a change in SRR identified in the breakpoint analysis.

Tanner crab is currently a Tier 3 stock, with the implication that a reliable stock-recruit relationship cannot be estimated. Status determination and OFL setting for Tier 3 stocks are based on a control rule framed in terms of $F_{35\%}$ and $B_{35\%}$ as proxies for F_{msy} and B_{msy}. Determining $B_{35\%}$ requires an estimate, $\bar{R}$, of mean recruitment during a period in which the stock was fished near F_{msy}. However, the appropriate time period over which to estimate $\bar{R}$ for Tanner crab, as well as the appropriate method to use to estimate it, remains unclear from the current analysis. Ideally, determining this averaging time period would be based on well-defined, objective criteria. However, even after several workshops (e.g., NMFS 2012) on this general issue over the past few years, including numerous excellent presentations and discussions, definitive guidance for estimating $\bar{R}$ in general remains lacking. Although some guidance is available, it appears insufficient for Tanner crab.

The joint uncertainties in TCSAM-estimated ln(R/MMB) and MMB (Fig. 4) indicate the model estimates of recruitment and stock size appear to be fairly unreliable prior to fertilization year 1977 or 1978 (recruitment years 1982 or 1983). Based on this, only TCSAM results subsequent to fertilization year 1977 are recommended for incorporation into further SRR studies (e.g., additional breakpoint studies, etc.). Using this time frame, it appears unlikely that any breakpoints will be identified in the SRR, but this conjecture remains to be seen. If this conjecture proves true, the nominal time period recommended for calculating average recruitment (recruitment years 1982-2012) would, coincidentally, be the same as that adopted by the SSC to calculate average recruitment (scenario R3) in Sept. 2012. However, I recommend adjusting the averaging time period by dropping the recruitment estimate associated with the final model year because the associated uncertainty in this year is always rather high relative to other recent years (Table 1).

It is worth pointing out that the costs associated with over- or under-estimating $\bar{R}$, and consequently $B_{35\%}$, are unequal in terms of setting OFL due to the sloping control rule used for Tier 3 stocks. If $\bar{R}$ is under-estimated relative to $\bar{R}_{true}$, then one obtains an overly-optimistic impression of stock status $B/[B_{35\%}]_{under}$ relative to the true stock status $B/[B_{35\%}]_{true}$ and OFL will be set too high unless B really is > $[B_{35\%}]_{true}$. Conversely, if $\bar{R}$ is over-estimated relative to $\bar{R}_{true}$, then one obtains an overly-pessimistic impression of stock status $B/[B_{35\%}]_{over}$ relative to the true stock status $B/[B_{35\%}]_{true}$ and OFL will be set too low unless B is > $[B_{35\%}]_{over}$, in which case it is also > $[B_{35\%}]_{true}$. From a conservation perspective, one cannot go wrong when over-estimating average recruitment because overfishing never occurs, but the cost is lost harvest unless $B > [B_{35\%}]_{over}$, in which case the OFL obtained using $[B_{35\%}]_{over}$ is identical to that obtained using $[B_{35\%}]_{true}$. However, one does go wrong, from both a conservation and an economic perspective if average recruitment is under-estimated and $B < [B_{35\%}]_{true}$, because the OFL is always set too high and overfishing will occur. In this situation, decision-theoretic (i.e., risk-based) approaches that incorporate loss functions that, while they may be subjectively determined a priori, are objectively applied to assessment model results should be explored as an attractive framework for estimating average recruitment for status determination and OFL setting.

Future work

While this report expands on work previously reported (CPT 2012), there remain several aspects to be examined further. These include:

- Testing the inference procedure using simulations to address uncertainty in MMB
- Applying the inference procedure to the recommended 1977-2007 fertilization year time frame
- Identifying environmental drivers, and mechanisms that might correspond to identified SRR breakpoints
- Exploring alternative stock-recruit relationships (e.g., Beverton-Holt or depensatory)
- Investigating models with more than one breakpoint

- Exploring alternative approaches to breakpoint selection, such as a risk-based approaches that incorporate a loss function reflecting the “cost” assigned to different degrees of error in estimating mean recruitment

The author looks forward to discussion and recommendations from the CPT and the SSC on this topic.

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Tables

Table 22. Time series of $F/F_{35\%}$, mature male biomass (*MMB*), recruitment (*R*) and ln(*R/MMB*) estimates from the accepted 2012 TCSAM. Coefficients of variation (CVs) are based on the model Hessian. The recruitment time series has been lagged to fertilization year, assuming a 5-year lag from fertilization to recruitment to the population tracked in the TCSAM. Values of $F/F_{35\%}$ > 0.25 are highlighted in grey.

year	F/F35%	MMB (1000's t)	cv	R (1000's)	cv	ln(R/MMB)	cv
1950	0.138	0.03	1.73	121,450	1.00	15.276	0.10
1951	0.138	0.52	1.73	126,090	0.84	12.397	0.14
1952	0.138	4.18	1.73	132,890	0.70	10.366	0.17
1953	0.138	15.78	1.72	143,000	0.57	9.112	0.21
1954	0.121	31.16	1.69	158,510	0.50	8.535	0.22
1955	0.121	43.46	1.61	183,540	0.52	8.348	0.23
1956	0.121	52.70	1.51	231,620	0.57	8.388	0.21
1957	0.121	59.75	1.38	363,160	0.57	8.712	0.18
1958	0.121	65.33	1.25	625,260	0.54	9.166	0.15
1959	0.121	70.00	1.10	867,230	0.51	9.425	0.13
1960	0.121	74.26	0.94	886,890	0.51	9.388	0.11
1961	0.121	78.61	0.76	770,280	0.50	9.190	0.10
1962	0.121	83.63	0.57	664,410	0.47	8.980	0.08
1963	0.121	90.17	0.37	602,120	0.43	8.807	0.06
1964	0.121	100.00	0.19	560,420	0.45	8.631	0.06
1965	0.121	117.65	0.14	427,600	0.36	8.198	0.05
1966	0.121	152.52	0.23	291,330	0.29	7.555	0.05
1967	0.127	199.01	0.30	289,580	0.22	7.283	0.05
1968	0.414	263.34	0.32	182,980	0.23	6.544	0.06
1969	0.413	312.85	0.33	82,263	0.37	5.572	0.09
1970	0.497	343.84	0.31	170,910	0.26	6.209	0.06
1971	0.418	357.40	0.27	392,900	0.16	7.003	0.04
1972	0.332	359.32	0.20	272,230	0.18	6.630	0.04
1973	0.276	350.15	0.12	251,580	0.18	6.577	0.03
1974	0.241	317.24	0.08	67,388	0.36	5.359	0.07
1975	0.309	275.01	0.06	13,531	1.17	3.896	0.30
1976	0.352	212.46	0.06	53,484	0.28	5.528	0.05
1977	0.733	141.90	0.07	20,990	0.49	4.997	0.10
1978	1.398	96.08	0.09	204,830	0.13	7.665	0.02
1979	1.610	62.39	0.14	172,650	0.19	7.926	0.03
1980	3.601	47.16	0.13	361,450	0.13	8.944	0.02
1981	2.506	50.71	0.09	287,010	0.16	8.641	0.02
1982	0.514	49.86	0.08	277,720	0.15	8.625	0.02
1983	0.198	39.56	0.10	200,080	0.16	8.529	0.02
1984	0.085	23.53	0.14	111,480	0.17	8.463	0.03
1985	0.186	21.52	0.10	47,418	0.25	7.698	0.03
1986	0.009	26.91	0.08	23,786	0.30	6.784	0.05
1987	0.026	40.52	0.07	18,753	0.27	6.137	0.04
1988	0.161	59.82	0.07	15,497	0.26	5.557	0.05
1989	0.293	71.57	0.07	15,210	0.25	5.359	0.05
1990	0.810	67.73	0.07	21,549	0.20	5.763	0.03
1991	1.309	61.85	0.07	24,172	0.21	5.968	0.04
1992	1.193	48.34	0.07	62,209	0.13	7.160	0.02
1993	1.915	39.46	0.07	26,331	0.20	6.503	0.03
1994	1.137	32.00	0.07	81,779	0.13	7.846	0.02
1995	0.645	23.95	0.08	47,373	0.20	7.590	0.03
1996	0.400	19.50	0.08	148,010	0.12	8.935	0.01
1997	0.297	16.70	0.08	56,599	0.21	8.129	0.03
1998	0.075	14.75	0.08	100,790	0.16	8.830	0.02
1999	0.060	14.55	0.08	198,120	0.12	9.519	0.01
2000	0.042	16.22	0.07	57,634	0.22	8.176	0.03
2001	0.045	19.86	0.07	47,145	0.23	7.772	0.03
2002	0.058	23.88	0.07	36,384	0.27	7.329	0.04
2003	0.034	29.20	0.07	40,302	0.27	7.230	0.04
2004	0.023	36.51	0.06	194,210	0.16	8.579	0.02
2005	0.025	45.40	0.06	246,700	0.17	8.601	0.02
2006	0.062	51.43	0.07	131,290	0.22	7.845	0.03
2007	0.094	56.65	0.07	32,391	0.49	6.349	0.08

Table 23. Recruitment averaging results using arithmetic-scale TCSAM recruitment estimates for the five recruitment scenarios (R1-R5) considered in the 2012 SAFE chapter (highlighted in grey), as well as other time stanzas *y*-2012 (listed by recruitment year *y*), including R6 (highlighted in blue). Coefficients of variation are based on the Hessian for the averaging method.

	Averaging Method (millions)							
year	standard		variance		covariance		process error	
	mean	cv	mean	cv	mean	cv	mean	cv
1966 (R4)	178.78	--	34.26	0.0437	3.21	0.3652	131.42	0.4884
1967	165.93	--	34.24	0.0437	3.16	0.3715	115.99	0.4026
1968	154.85	--	34.23	0.0437	3.14	0.3748	107.34	0.3583
1969	144.68	--	34.21	0.0437	3.13	0.3765	103.37	0.3417
1970	135.01	--	34.19	0.0438	3.13	0.3767	102.66	0.3302
1971 (R6)	128.05	--	34.15	0.0438	3.14	0.3756	98.89	0.3198
1972	124.07	--	34.07	0.0439	3.15	0.3744	93.46	0.3213
1973	119.93	--	33.93	0.0441	3.17	0.3718	86.71	0.3351
1974	118.31	--	33.74	0.0444	3.18	0.3717	84.38	0.3500
1975	119.26	--	33.62	0.0446	3.17	0.3726	92.67	0.3558
1976	117.86	--	33.46	0.0448	3.26	0.3629	97.82	0.3863
1977	110.22	--	33.25	0.0451	3.29	0.3608	89.88	0.3533
1978	105.60	--	33.02	0.0455	3.43	0.3481	82.11	0.3566
1979	101.30	--	32.77	0.0458	3.48	0.3450	72.80	0.4122
1980	102.33	--	32.64	0.0461	3.45	0.3482	70.97	0.4451
1981	105.10	--	32.82	0.0461	3.39	0.3553	75.54	0.4183
1982 (R3)	106.77	--	32.60	0.0466	3.31	0.3656	76.94	0.4232
1983	109.63	--	32.86	0.0468	3.25	0.3731	87.82	0.4153
1984	106.35	--	32.29	0.0477	3.74	0.3279	89.25	0.4134
1985	103.98	--	31.99	0.0482	4.55	0.2735	100.96	0.5336
1986	94.44	--	31.66	0.0487	5.75	0.2211	86.64	0.4145
1987	87.04	--	31.38	0.0492	6.85	0.1885	76.50	0.3424
1988	79.41	--	31.04	0.0497	8.19	0.1595	62.42	0.2762
1989	74.38	--	30.63	0.0504	9.01	0.1459	52.21	0.2736
1990 (R5)	72.77	--	30.12	0.0515	9.08	0.1449	48.18	0.3029
1991	73.92	--	29.81	0.0525	8.64	0.1540	49.82	0.3120
1992	76.31	--	30.11	0.0532	8.38	0.1662	53.04	0.3053
1993	79.18	--	31.36	0.0538	8.72	0.1764	56.48	0.2945
1994	82.54	--	34.72	0.0535	10.23	0.1804	60.61	0.2792
1995	86.28	--	40.90	0.0521	13.51	0.1682	64.63	0.2627
1996	90.08	--	47.21	0.0520	17.88	0.1572	69.48	0.2473
1997	94.20	--	54.21	0.0517	21.01	0.1540	74.22	0.2374
1998	96.34	--	53.06	0.0565	21.28	0.1595	77.09	0.2433
1999	101.34	--	65.29	0.0554	26.68	0.1513	82.71	0.2343
2000	102.84	--	63.06	0.0612	26.14	0.1586	84.66	0.2476
2001	107.46	--	66.24	0.0639	26.01	0.1662	91.13	0.2564
2002	103.78	--	61.43	0.0708	25.94	0.1666	85.79	0.3015
2003	108.50	--	62.17	0.0752	25.24	0.1758	91.76	0.3069
2004	109.35	--	58.70	0.0831	25.36	0.1750	96.13	0.3389
2005	98.26	--	52.15	0.0957	28.11	0.1589	77.06	0.4541
2006	104.06	--	51.12	0.1065	26.43	0.1838	83.22	0.4789
2007	113.55	--	52.42	0.1197	27.69	0.2165	92.88	0.4833
R1 ('66-'72)	515.11	--	334.78	0.1350	346.78	0.1016	346.78	0.1016
R2 ('90-'12)	287.73	--	88.10	0.0677	24.11	0.1831	252.92	0.3567

Table 24. Recruitment averaging results using log-scale TCSAM recruitment estimates for the five recruitment scenarios (R1-R5) considered in the 2012 SAFE chapter (highlighted in grey), as well as other time stanzas *y*-2012 (listed by recruitment year *y*) , including R6 (highlighted in blue). Coefficients of variation are based on the Hessian of the averaging method.

	Averaging Method (millions)							
year	standard		variance		covariance		process error	
	median	cv	median	cv	median	cv	median	cv
1966 (R4)	101.74	--	122.54	0.6068	195.93	0.6075	116.49	0.6797
1967	97.36	--	121.79	0.6068	200.08	0.6075	110.44	0.6707
1968	93.29	--	120.99	0.6068	202.09	0.6075	104.97	0.6633
1969	89.42	--	120.11	0.6068	203.03	0.6075	99.96	0.6571
1970	85.68	--	119.32	0.6068	203.24	0.6075	95.04	0.6513
1971 (R6)	82.47	--	118.29	0.6068	202.88	0.6075	90.17	0.6469
1972	79.97	--	117.17	0.6068	202.53	0.6075	87.58	0.6455
1973	77.44	--	115.16	0.6068	201.81	0.6075	82.79	0.6431
1974	75.75	--	114.25	0.6068	202.48	0.6075	78.58	0.6434
1975	75.58	--	114.50	0.6068	203.58	0.6075	81.69	0.6477
1976	73.93	--	113.87	0.6068	199.64	0.6075	84.04	0.6538
1977	70.58	--	108.42	0.6068	199.28	0.6075	78.65	0.6469
1978	67.91	--	105.44	0.6068	195.01	0.6076	75.22	0.6440
1979	65.34	--	102.50	0.6068	194.65	0.6076	67.32	0.6439
1980	65.28	--	102.84	0.6068	195.83	0.6076	65.68	0.6486
1981	68.58	--	103.00	0.6068	197.85	0.6076	67.59	0.6478
1982 (R3)	69.13	--	103.91	0.6068	201.81	0.6076	67.89	0.6507
1983	71.93	--	104.63	0.6068	202.94	0.6076	77.76	0.6615
1984	69.38	--	100.20	0.6069	189.57	0.6076	74.53	0.6598
1985	67.16	--	98.53	0.6069	164.60	0.6076	77.26	0.6709
1986	63.10	--	90.21	0.6069	127.00	0.6077	70.80	0.6584
1987	59.53	--	85.22	0.6069	99.52	0.6078	66.32	0.6511
1988	55.97	--	79.31	0.6069	66.95	0.6079	60.65	0.6418
1989	53.08	--	75.15	0.6070	50.19	0.6081	55.59	0.6369
1990 (R5)	51.39	--	73.68	0.6070	44.70	0.6083	51.56	0.6386
1991	51.58	--	74.51	0.6070	46.73	0.6084	49.72	0.6440
1992	53.52	--	76.00	0.6070	51.61	0.6085	50.66	0.6454
1993	56.40	--	78.37	0.6070	58.13	0.6085	52.87	0.6434
1994	60.37	--	81.54	0.6070	66.21	0.6086	57.42	0.6362
1995	65.17	--	85.38	0.6070	71.98	0.6086	63.64	0.6278
1996	69.56	--	90.80	0.6071	79.10	0.6086	69.29	0.6231
1997	74.31	--	95.97	0.6071	85.64	0.6086	75.28	0.6215
1998	75.19	--	101.50	0.6072	91.93	0.6087	75.28	0.6237
1999	81.04	--	109.08	0.6072	98.74	0.6087	82.79	0.6224
2000	80.98	--	114.06	0.6073	105.34	0.6088	82.00	0.6252
2001	84.68	--	121.23	0.6074	111.38	0.6088	87.62	0.6288
2002	80.49	--	115.85	0.6075	107.94	0.6090	80.54	0.6344
2003	83.37	--	122.75	0.6076	114.84	0.6091	85.11	0.6388
2004	81.63	--	126.70	0.6078	109.97	0.6093	85.91	0.6469
2005	73.07	--	103.58	0.6084	74.70	0.6101	71.68	0.6558
2006	75.58	--	112.98	0.6087	89.64	0.6106	72.12	0.6701
2007	81.77	--	128.73	0.6090	120.72	0.6111	76.31	0.6885
R1 ('66-'72)	484.08	--	390.14	0.6116	412.61	0.6093	453.51	0.6281
R2 ('90-'12)	200.60	--	243.05	0.6071	246.24	0.6077	241.80	0.6641

Table 25. Results of the breakpoint analysis, with AICc, the relative odds against the model being correct, and the Akaike weights to be used in a model averaging approach listed by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded.

break point	AICc	odds against	weights
--	30.38	10.211	0.02112
1966	33.40	46.389	0.00465
1967	33.43	47.109	0.00458
1968	33.27	43.459	0.00496
1969	32.83	34.762	0.00620
1970	32.10	24.160	0.00893
1971	32.42	28.416	0.00759
1972	33.09	39.745	0.00543
1973	33.04	38.649	0.00558
1974	26.62	1.559	0.13832
1975	28.17	3.394	0.06356
1976	31.95	22.478	0.00960
1977	31.65	19.346	0.01115
1978	32.04	23.426	0.00921
1979	32.44	28.673	0.00752
1980	32.87	35.513	0.00607
1981	31.45	17.484	0.01234
1982	31.29	16.102	0.01340
1983	29.38	6.204	0.03477
1984	27.02	1.909	0.11298
1985	25.73	1.000	0.21569
1986	26.28	1.320	0.16340
1987	28.17	3.396	0.06352
1988	30.56	11.206	0.01925
1989	33.04	38.706	0.00557
1990	34.37	75.267	0.00287
1991	34.34	74.022	0.00291
1992	34.53	81.520	0.00265
1993	33.38	45.795	0.00471
1994	33.57	50.341	0.00428
1995	34.65	86.442	0.00250
1996	33.14	40.711	0.00530
1997	34.58	83.492	0.00258
1998	34.41	76.784	0.00281
1999	34.31	73.044	0.00295
2000	32.70	32.723	0.00659
2001	34.78	92.447	0.00233
2002	34.97	101.563	0.00212

Table 26. Parameter estimates and standard deviations for the model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded.

year	α_1	std. dev.	α_2	std. dev.	β_1	std. dev.	β_2	std. dev.	$\ln(\sigma)$	std. dev.	$\tan(\rho)$	std. dev.
--	--	--	8.16	0.52	--	--	0.007	0.003	0.05	0.22	2.62	1.28
1966	11.96	3.57	7.92	0.46	0.036	0.034	0.007	0.003	-0.04	0.18	2.13	0.92
1967	10.97	2.11	7.91	0.46	0.025	0.016	0.006	0.003	-0.04	0.18	2.10	0.90
1968	9.98	1.54	7.86	0.46	0.014	0.010	0.006	0.003	-0.05	0.18	2.08	0.87
1969	9.82	1.25	7.83	0.46	0.012	0.006	0.006	0.003	-0.05	0.18	2.10	0.88
1970	10.10	1.17	7.84	0.47	0.016	0.005	0.006	0.003	-0.05	0.18	2.15	0.91
1971	9.86	1.14	7.84	0.47	0.014	0.005	0.006	0.003	-0.05	0.19	2.19	0.94
1972	9.60	1.10	7.88	0.46	0.011	0.004	0.007	0.003	-0.06	0.18	2.04	0.85
1973	9.61	1.09	7.90	0.45	0.011	0.004	0.007	0.003	-0.07	0.18	1.99	0.84
1974	9.51	1.01	8.10	0.42	0.010	0.004	0.012	0.003	-0.15	0.18	2.01	0.85
1975	9.28	0.99	8.30	0.43	0.010	0.004	0.015	0.004	-0.17	0.18	1.88	0.82
1976	9.03	1.05	8.28	0.47	0.009	0.004	0.014	0.005	-0.12	0.19	1.94	0.89
1977	8.22	1.19	8.72	0.67	0.007	0.004	0.021	0.008	-0.03	0.24	2.27	1.40
1978	6.26	1.58	9.95	1.73	0.003	0.004	0.023	0.012	0.67	0.54	11.86	13.26
1979	8.10	0.78	9.01	0.72	0.006	0.003	0.031	0.014	-0.05	0.21	2.19	1.09
1980	7.88	0.73	9.09	0.74	0.006	0.003	0.032	0.015	-0.04	0.23	2.25	1.25
1981	8.42	0.64	8.95	0.67	0.007	0.003	0.034	0.015	-0.12	0.18	1.83	0.82
1982	8.43	0.61	8.96	0.65	0.007	0.003	0.035	0.014	-0.15	0.18	1.67	0.77
1983	8.60	0.54	9.08	0.60	0.008	0.003	0.042	0.014	-0.22	0.17	1.42	0.64
1984	8.78	0.49	9.16	0.56	0.008	0.002	0.047	0.013	-0.26	0.16	1.35	0.58
1985	8.92	0.48	9.00	0.57	0.009	0.002	0.045	0.013	-0.27	0.16	1.44	0.62
1986	8.83	0.47	8.99	0.62	0.008	0.002	0.044	0.014	-0.25	0.17	1.47	0.64
1987	8.55	0.46	9.15	0.67	0.008	0.002	0.045	0.015	-0.23	0.17	1.45	0.63
1988	8.28	0.49	9.16	0.77	0.007	0.003	0.041	0.016	-0.17	0.18	1.61	0.73
1989	8.10	0.56	9.01	0.87	0.006	0.003	0.033	0.017	-0.08	0.20	1.97	0.96
1990	7.98	0.61	8.99	1.01	0.006	0.003	0.028	0.019	0.00	0.22	2.36	1.24
1991	7.96	0.62	9.10	1.07	0.006	0.003	0.030	0.021	0.02	0.22	2.47	1.27
1992	7.84	0.63	9.04	1.21	0.006	0.003	0.023	0.026	0.06	0.25	2.78	1.60
1993	8.28	0.62	9.23	1.16	0.007	0.003	0.045	0.029	0.04	0.22	2.67	1.30
1994	7.85	0.59	9.41	1.18	0.006	0.003	0.034	0.030	0.04	0.23	2.70	1.46
1995	8.25	0.61	8.93	1.10	0.007	0.003	0.036	0.031	0.05	0.22	2.62	1.29
1996	7.96	0.57	9.46	1.06	0.007	0.003	0.038	0.030	0.02	0.22	2.61	1.32
1997	8.45	0.64	8.25	1.07	0.008	0.003	0.023	0.031	0.09	0.23	2.95	1.52
1998	8.15	0.57	9.11	1.04	0.007	0.003	0.035	0.030	0.03	0.21	2.56	1.23
1999	8.17	0.57	9.18	1.06	0.007	0.003	0.036	0.030	0.04	0.21	2.63	1.27
2000	8.51	0.64	7.35	1.15	0.008	0.003	0.006	0.032	0.10	0.24	3.23	1.68
2001	8.33	0.57	7.89	1.29	0.008	0.003	0.012	0.034	0.06	0.21	2.73	1.32
2002	8.28	0.56	7.86	1.48	0.008	0.003	0.010	0.037	0.05	0.21	2.67	1.28

Figures

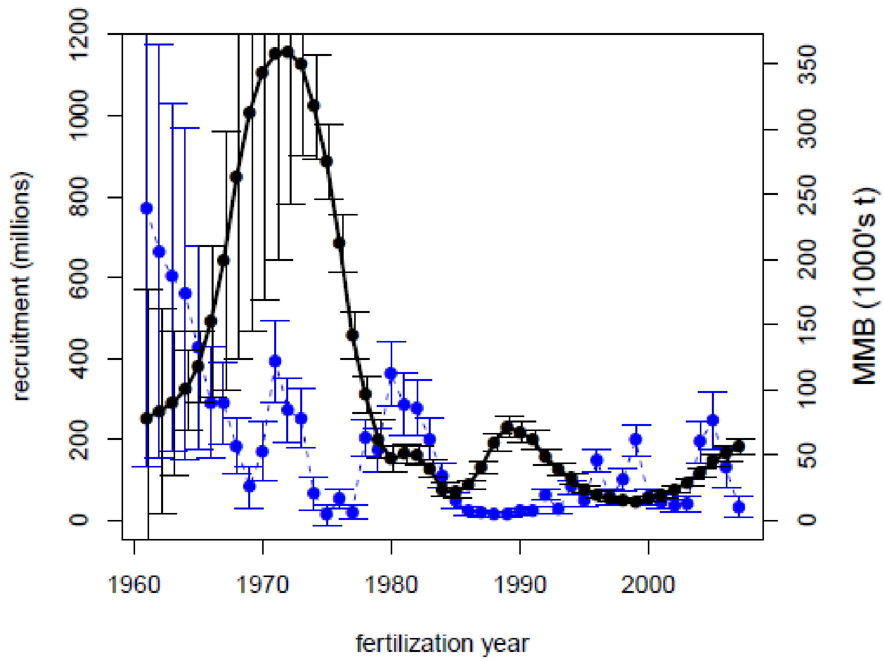


Figure 84. Time series from the accepted 2012 TCSAM of estimated MMB at mating time (black) and recruitment (blue) vs. fertilization year (1961-2007). A 5-year lag is assumed between fertilization and recruitment. Error bars represent 80% confidence intervals.

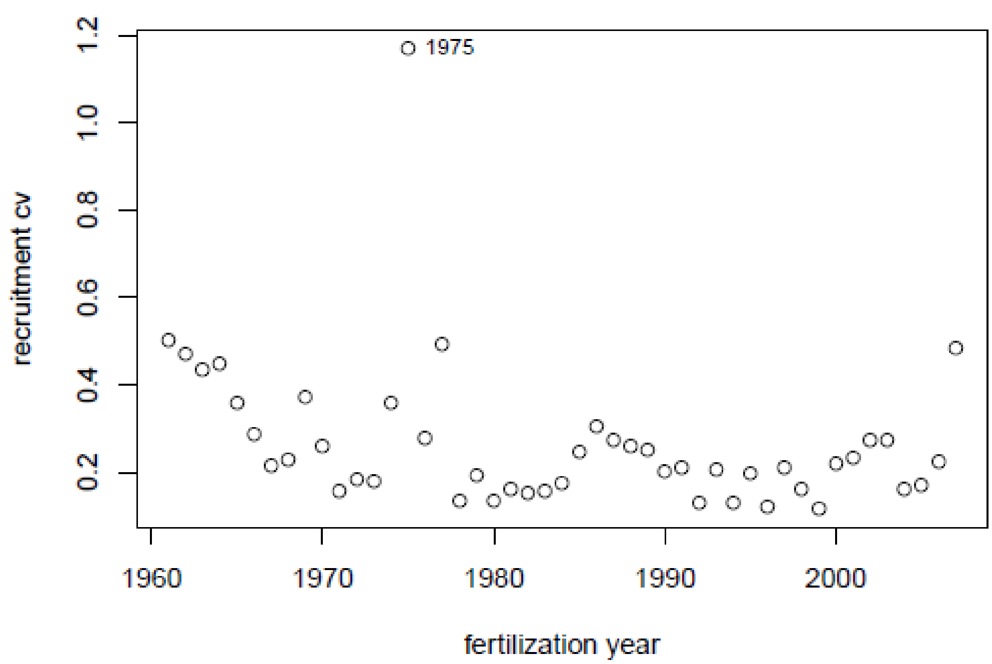


Figure 85. Time series of the CV of recruitment lagged to fertilization year. The maximum occurs in 1975.

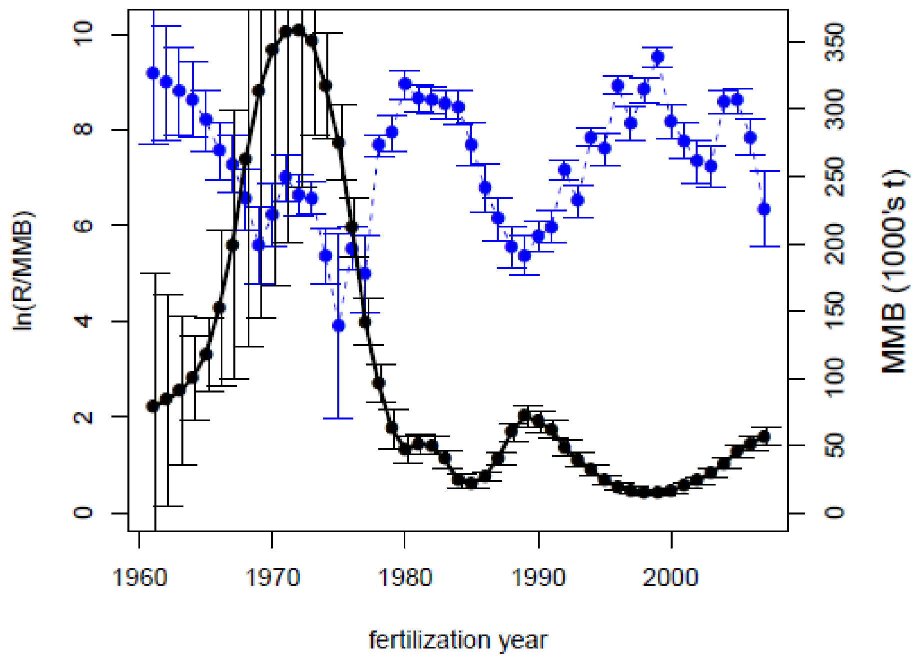


Figure 86. Time series from the accepted 2012 TCSAM of estimated *MMB* at mating time (black) and ln(*R/MMB*) (blue) vs. fertilization year (1961-2007). A 5-year lag is assumed between fertilization and recruitment. Error bars represent 80% confidence intervals.

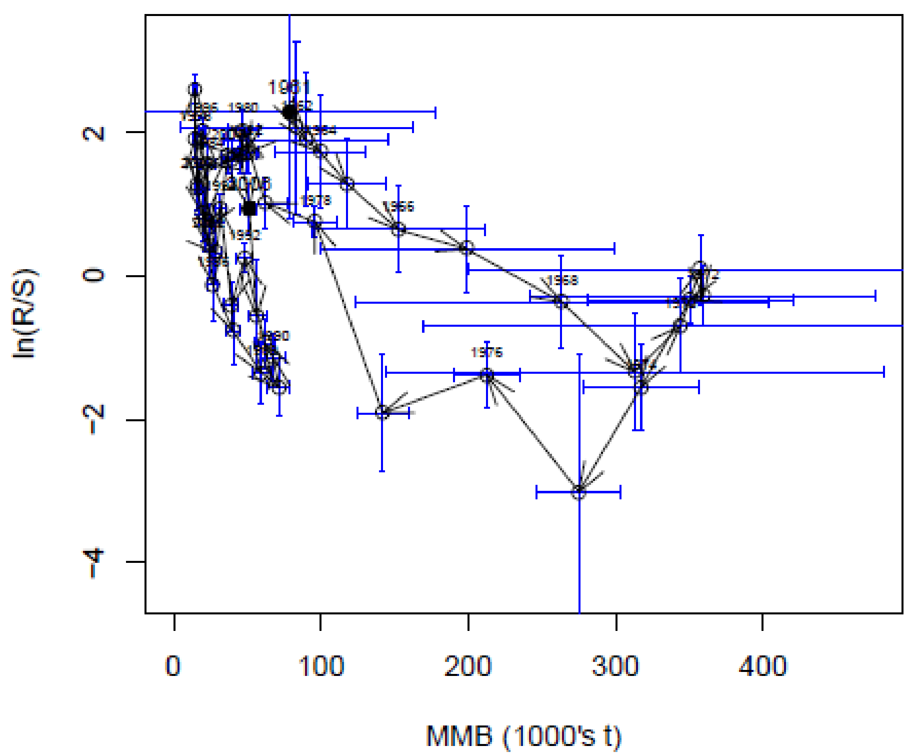


Figure 87. Ln(*R/MMB*) vs. *MMB* for fertilization years 1961-2007. Error bars represent 80% confidence intervals.

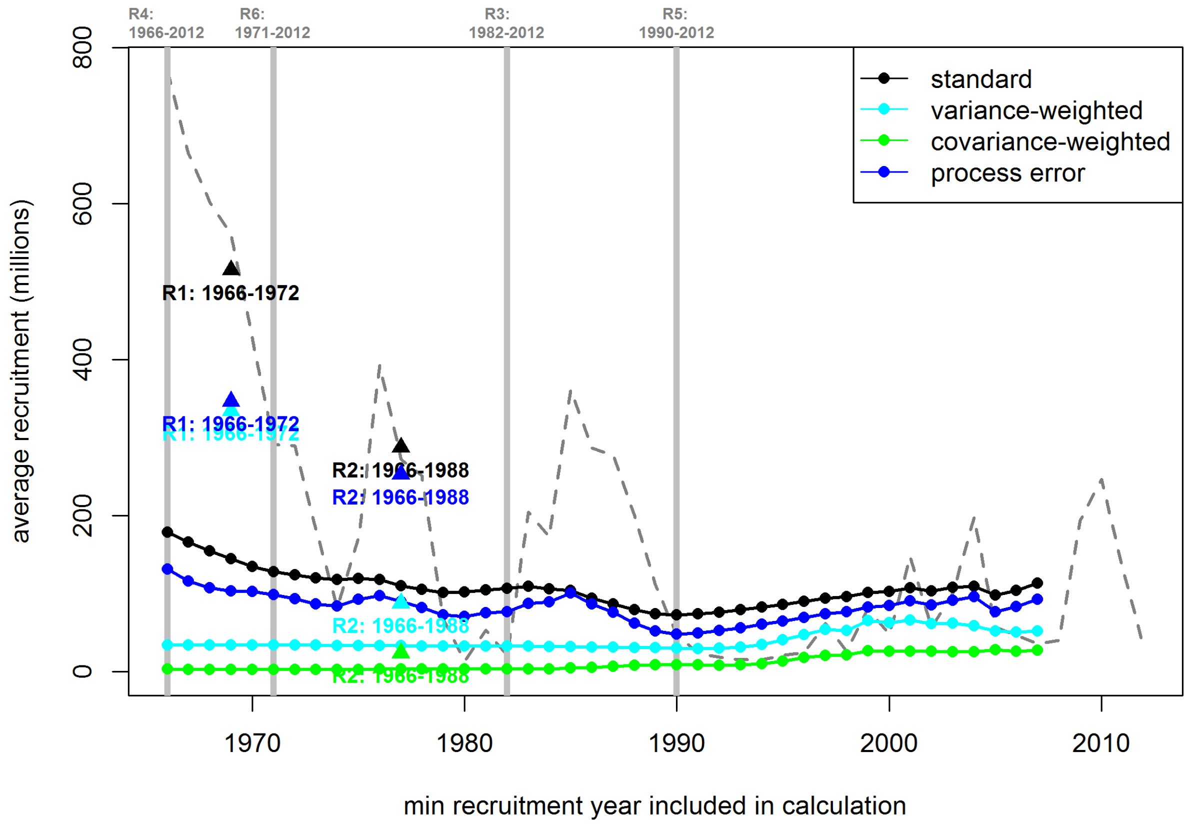


Figure 88. Estimates of *mean* recruitment using various time periods and methods for averaging the recruitment estimates (dotted grey line) from the accepted 2012 TCSAM on the arithmetic scale. Colors are used to indicate results from the four averaging methods: standard averages are plotted in black, weighted averages using the TCSAM-estimated variances are plotted in cyan, weighted averages using the TCSAM-estimated variance-covariance matrices are plotted in green, and weighted averages using the TCSAM-estimated variance-covariance matrices and estimated process error covariance matrices are plotted in blue. Values plotted as circles (and connected by colored line segments) were calculated using the time span *y*-2012, where "*y*" is the recruitment year at which the value is plotted. Values plotted as triangles were calculated using the time span indicated below the symbol. The labels R1-R6 refer to the five recruitment averaging scenarios considered in the 2012 SAFE chapter (Rugolo and Turnock, 2012) and the SSC-requested scenario (1971-2012). Note that the values for the covariance-weighted and process error-weighted methods are identical for scenario R1, so only the latter is plotted. Vertical grey lines indicate the first recruitment year included in the R3-R6 scenarios. Values are listed in Table 2.

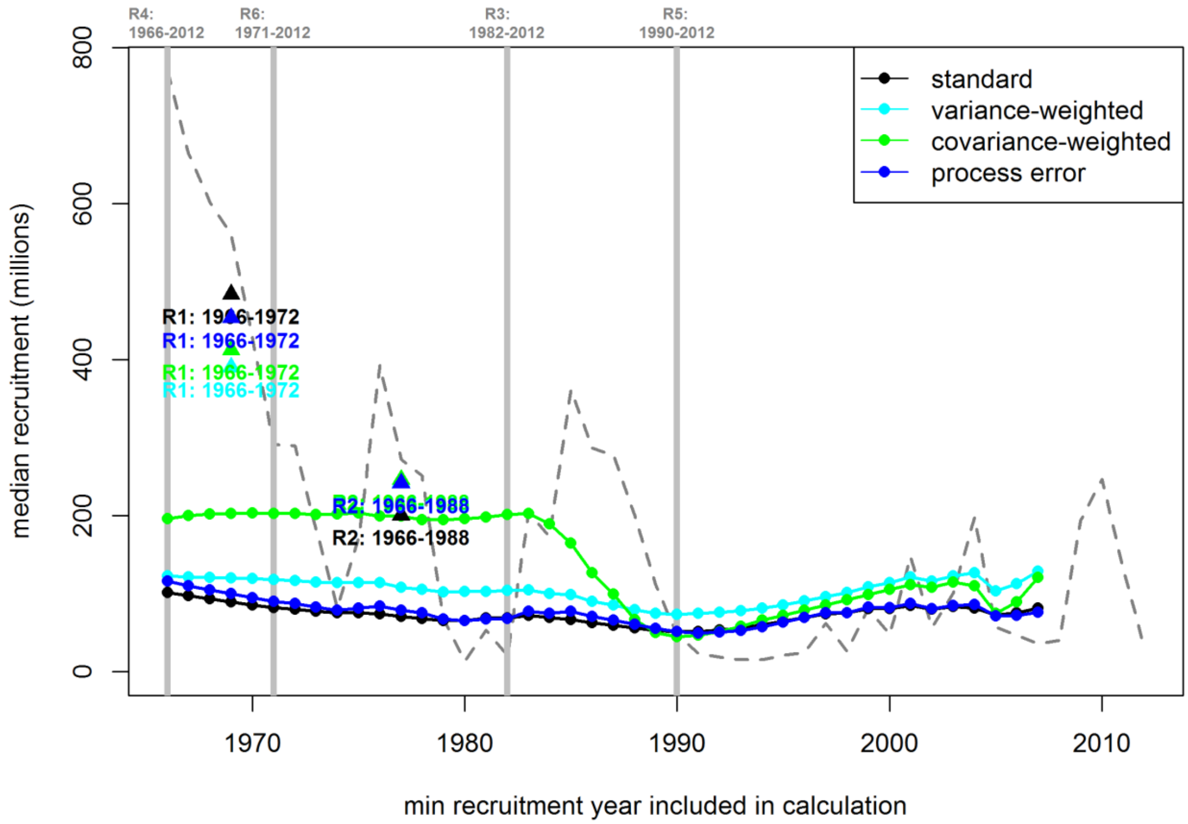


Figure 89. Estimates of *median* recruitment using various time periods and methods for averaging the recruitment estimates (dotted grey line) from the accepted 2012 TCSAM on the log scale. Colors are used to indicate results from the four averaging methods: standard averages are plotted in black, weighted averages using the TCSAM-estimated variances are plotted in cyan, weighted averages using the TCSAM-estimated variance-covariance matrices are plotted in green, and weighted averages using the TCSAM-estimated variance-covariance matrices and estimated process error covariance matrices are plotted in blue. Values plotted as circles (and connected by colored line segments) were calculated using the time span *y*-2012, where "*y*" is the recruitment year at which the value is plotted. Values plotted as triangles were calculated using the time span indicated below the symbol. The labels R1-R6 refer to the five recruitment averaging scenarios considered in the 2012 SAFE chapter (Rugolo and Turnock, 2012) and the SSC-requested scenario (1971-2012). Vertical grey lines indicate the first recruitment year included in the R3-R6 scenarios. Values are listed in Table 3.

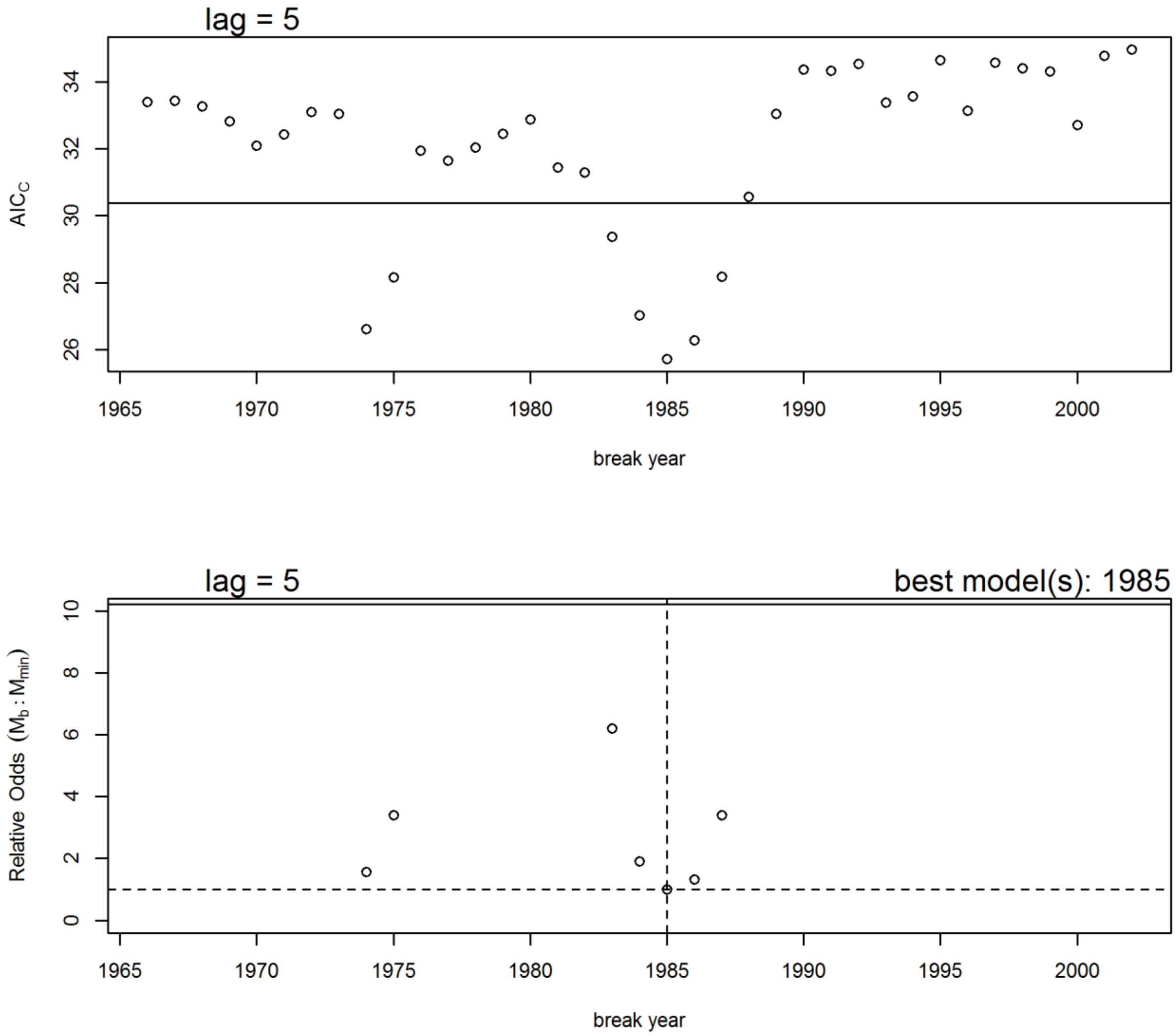


Figure 90. Results from the stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1985). Not shown are 1-breakpoint models with high odds (>10) of being incorrect.

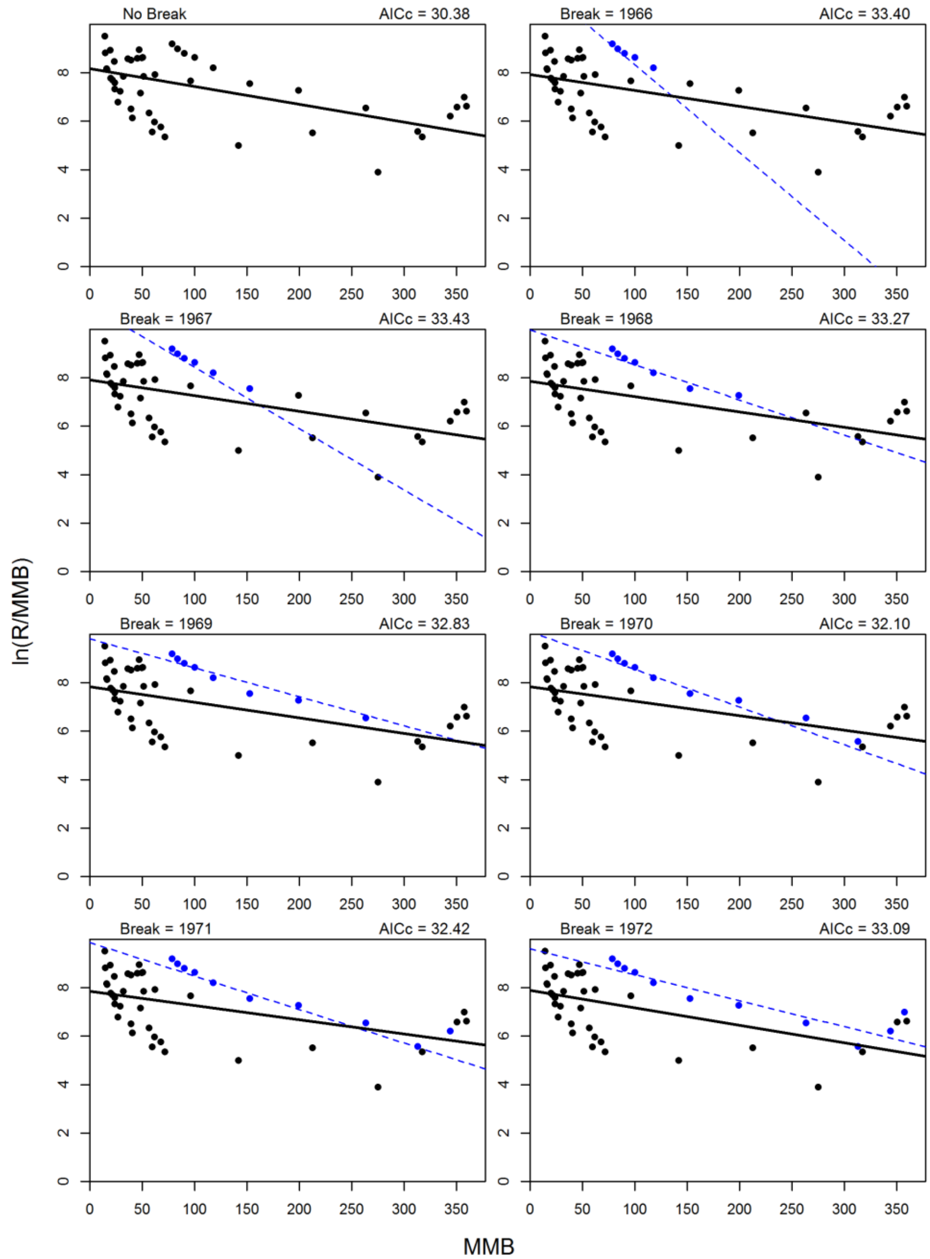


Figure 91. Fits for models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1966-2002. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in blue, whereas the post-break data and fit are shown in black.

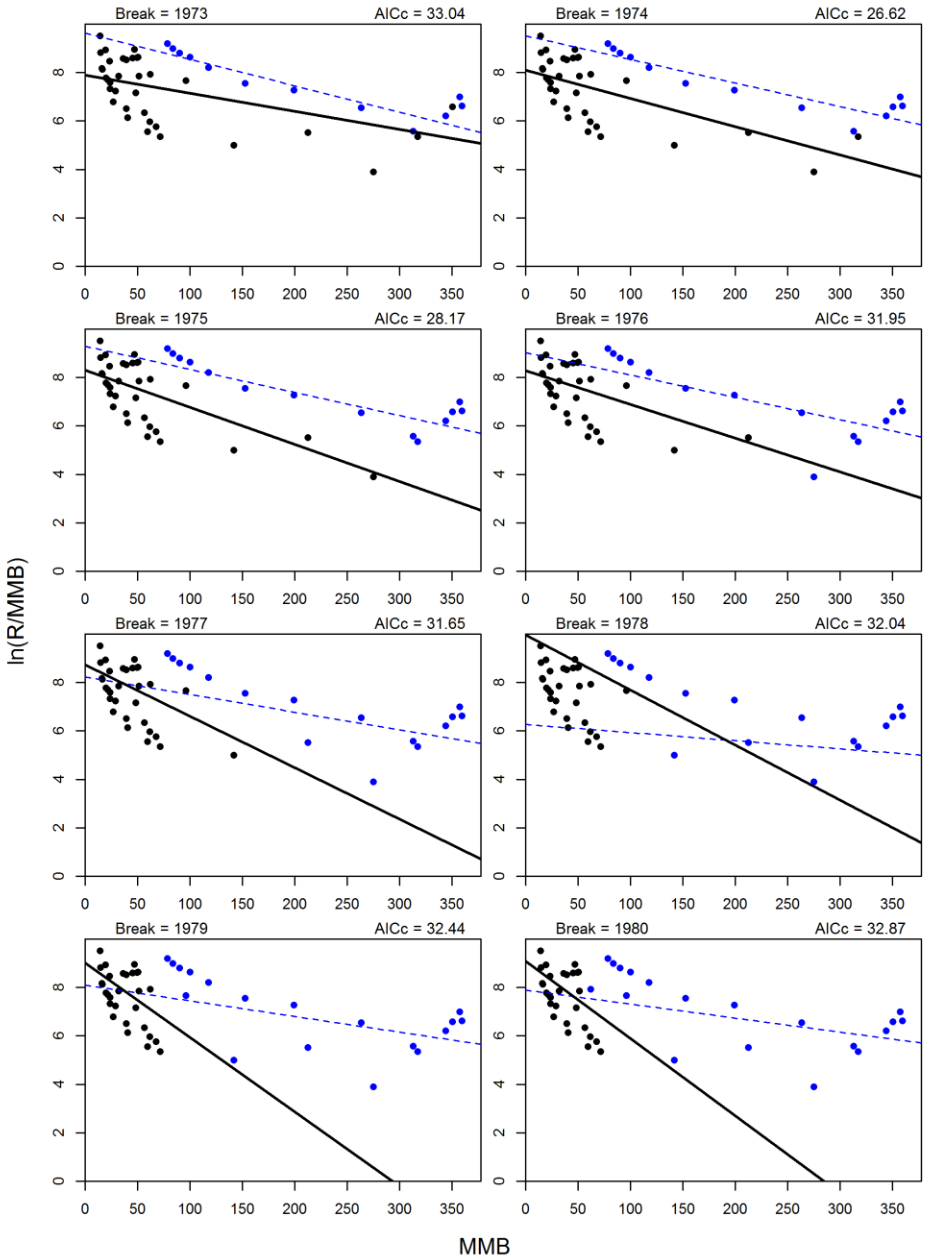
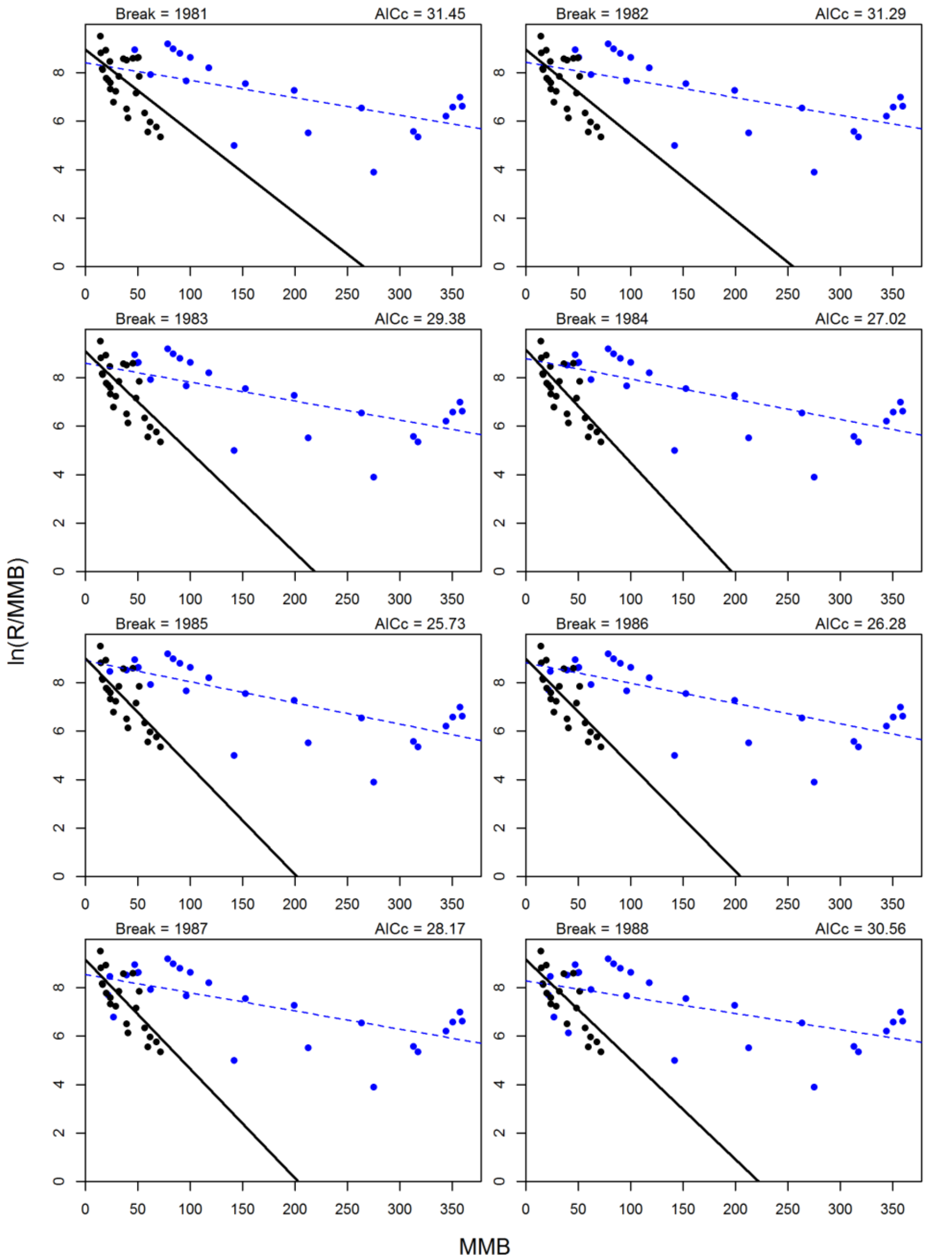


Figure 8. Continued.



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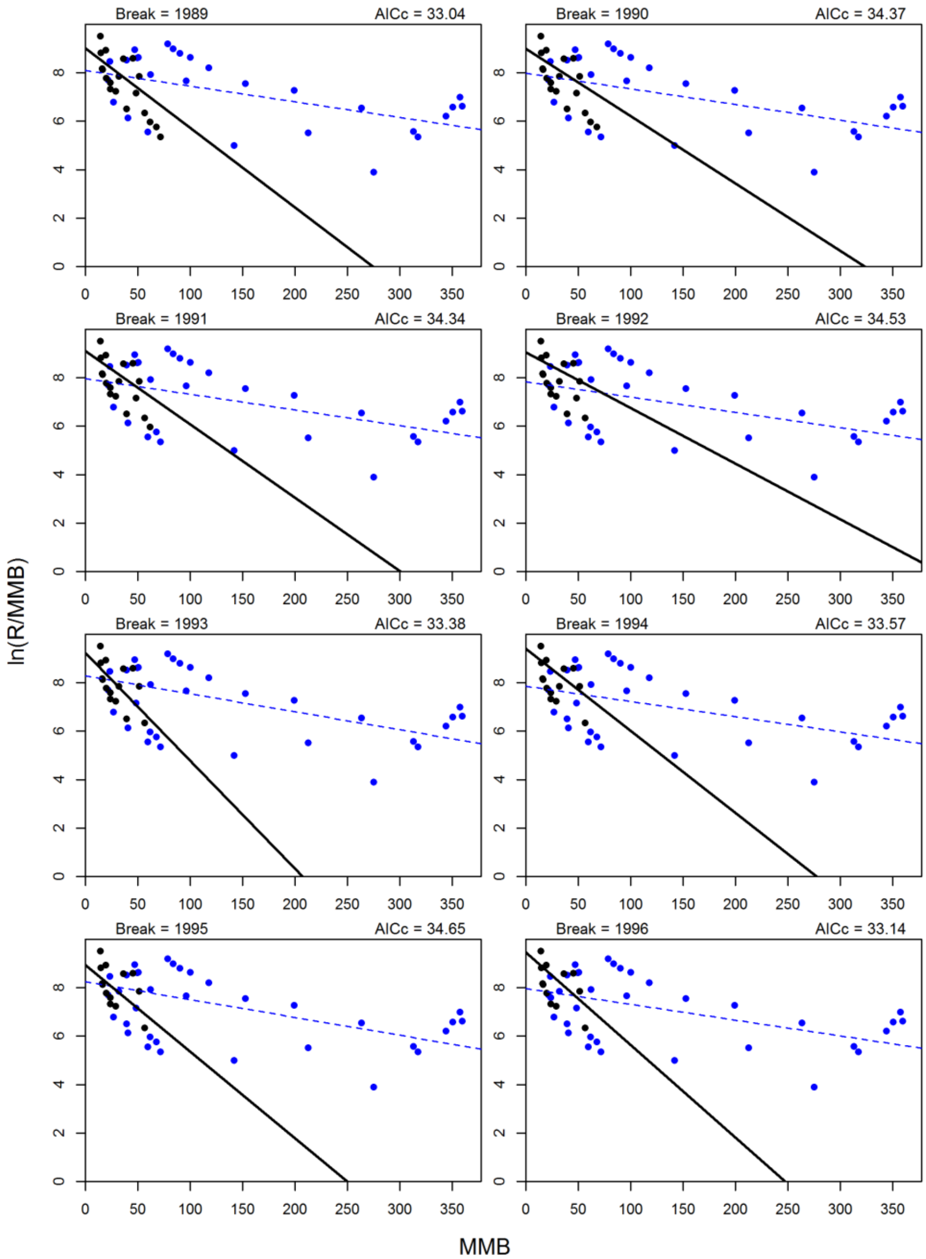

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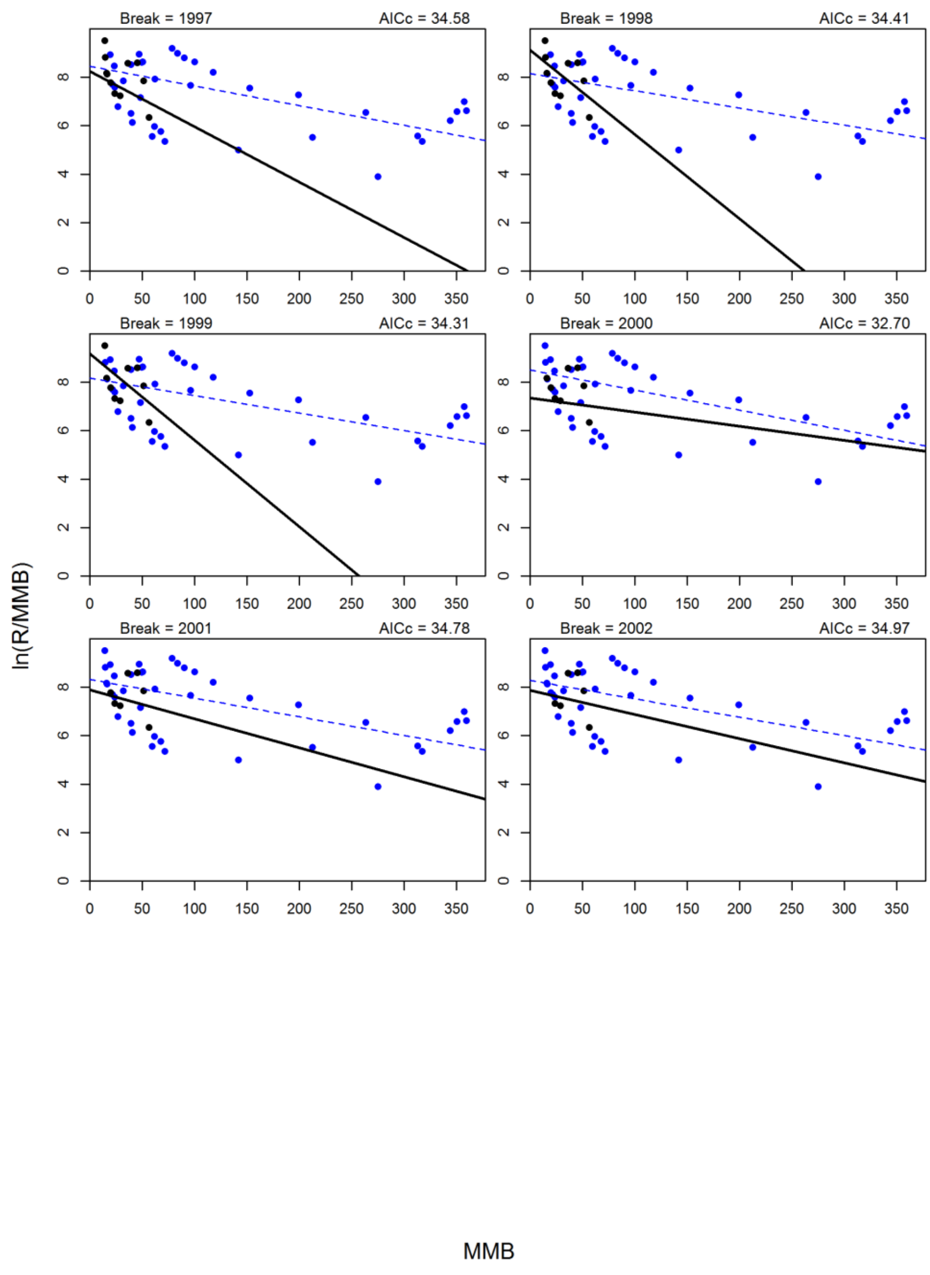


Figure 8. Continued.

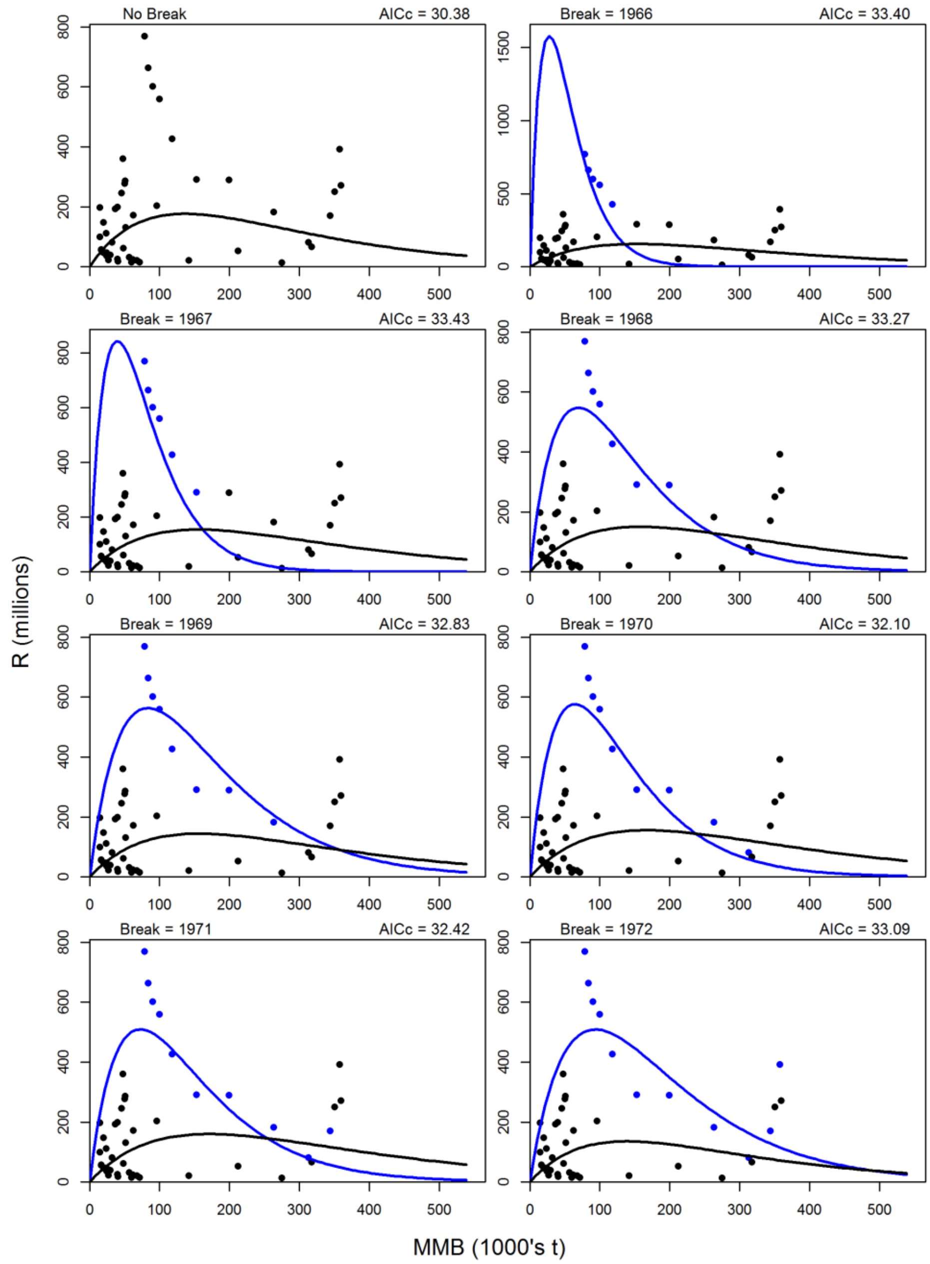


Figure 92. Fits on the arithmetic scale for models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1966-2002. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in blue, whereas the post-break data and fit are shown in black.

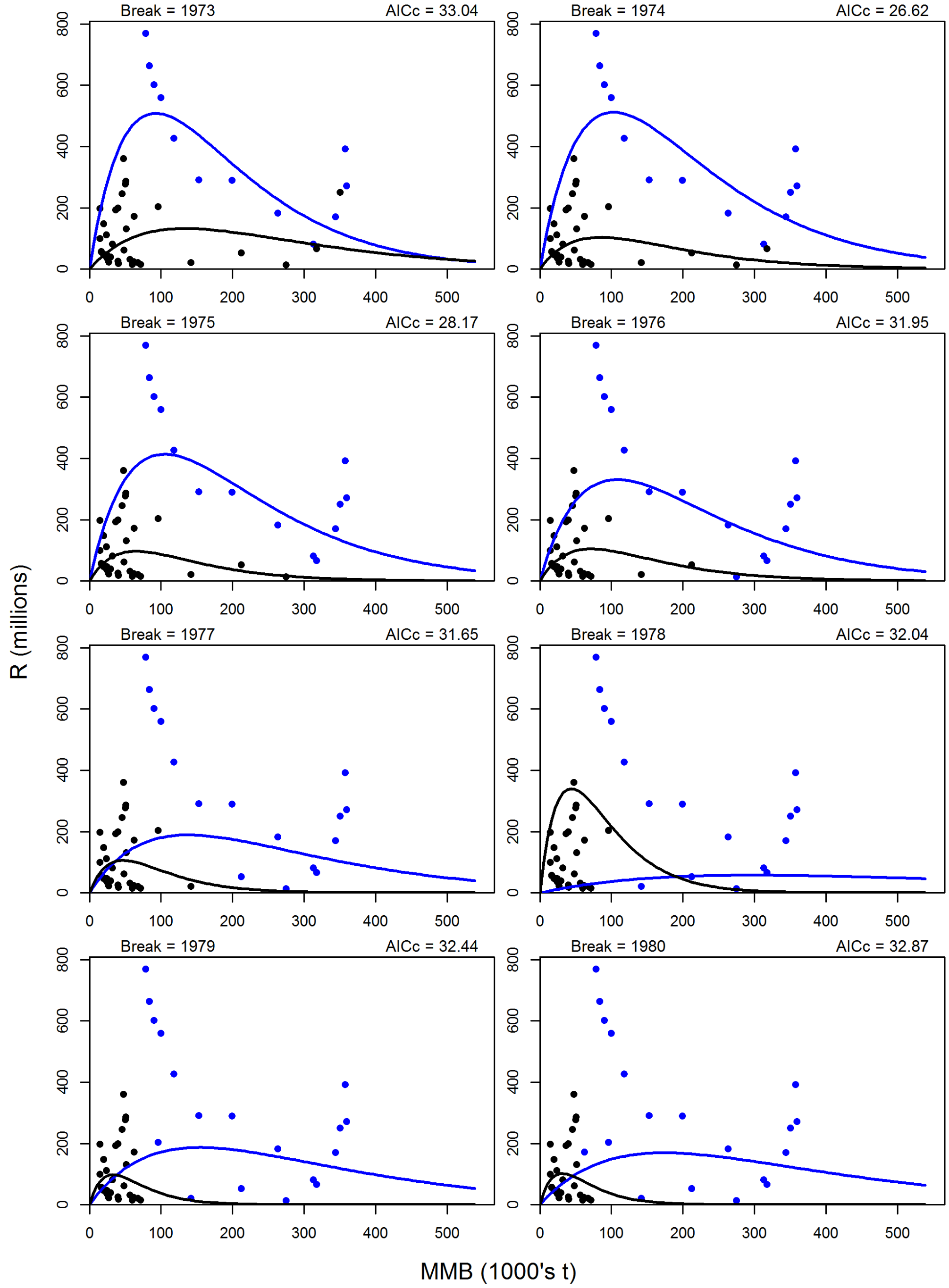


Figure 9. Continued.

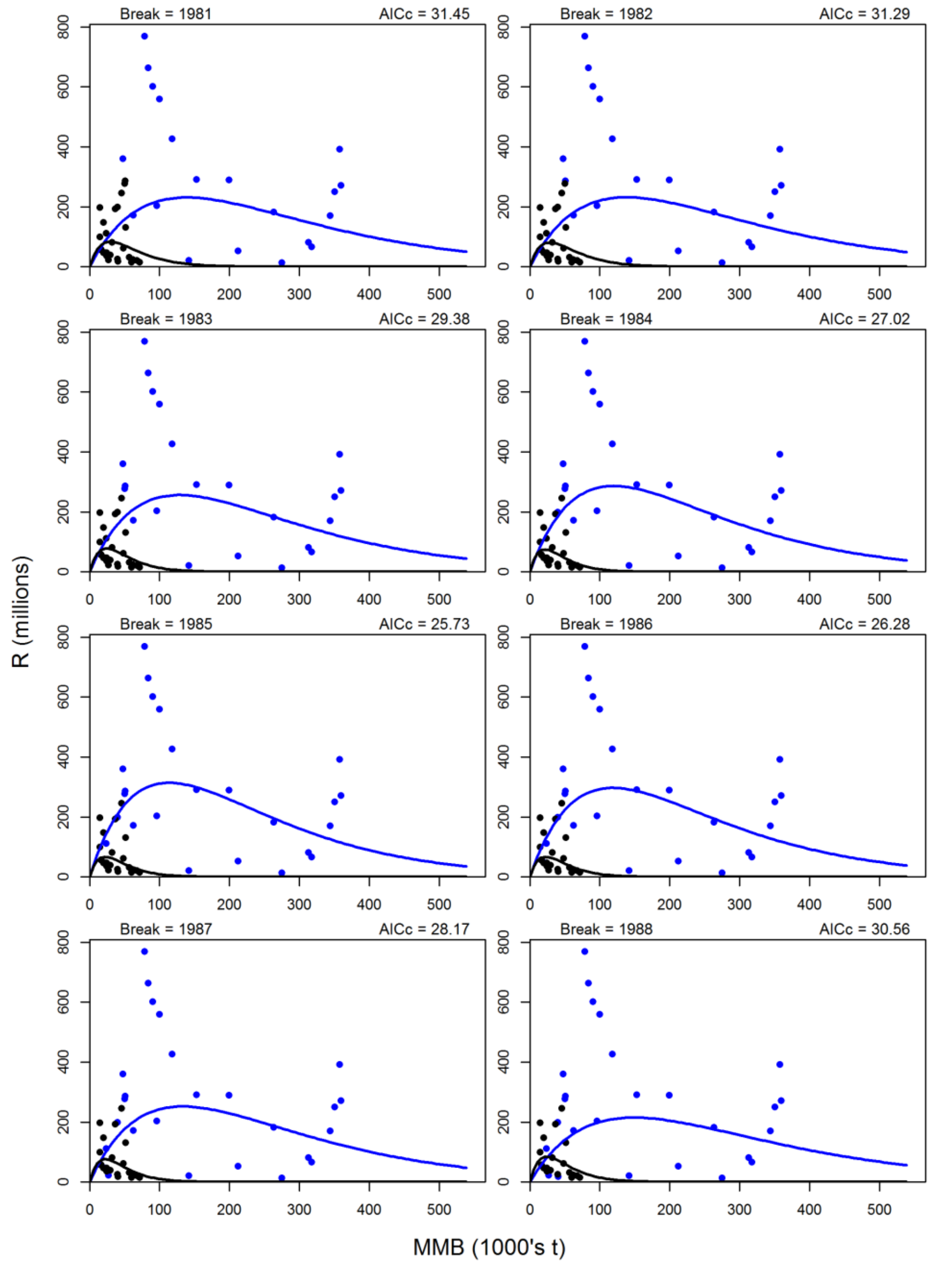
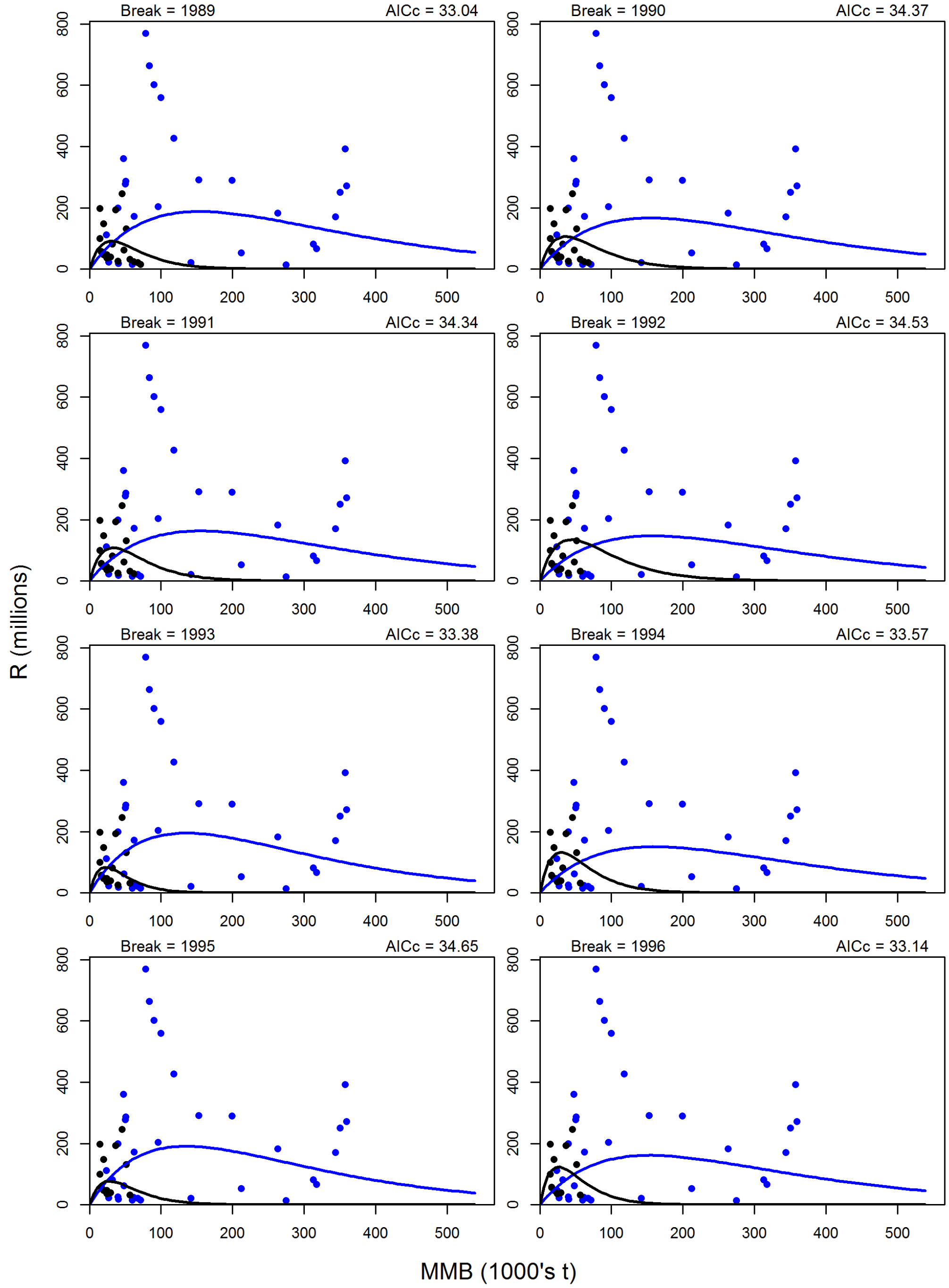


Figure 9. Continued.



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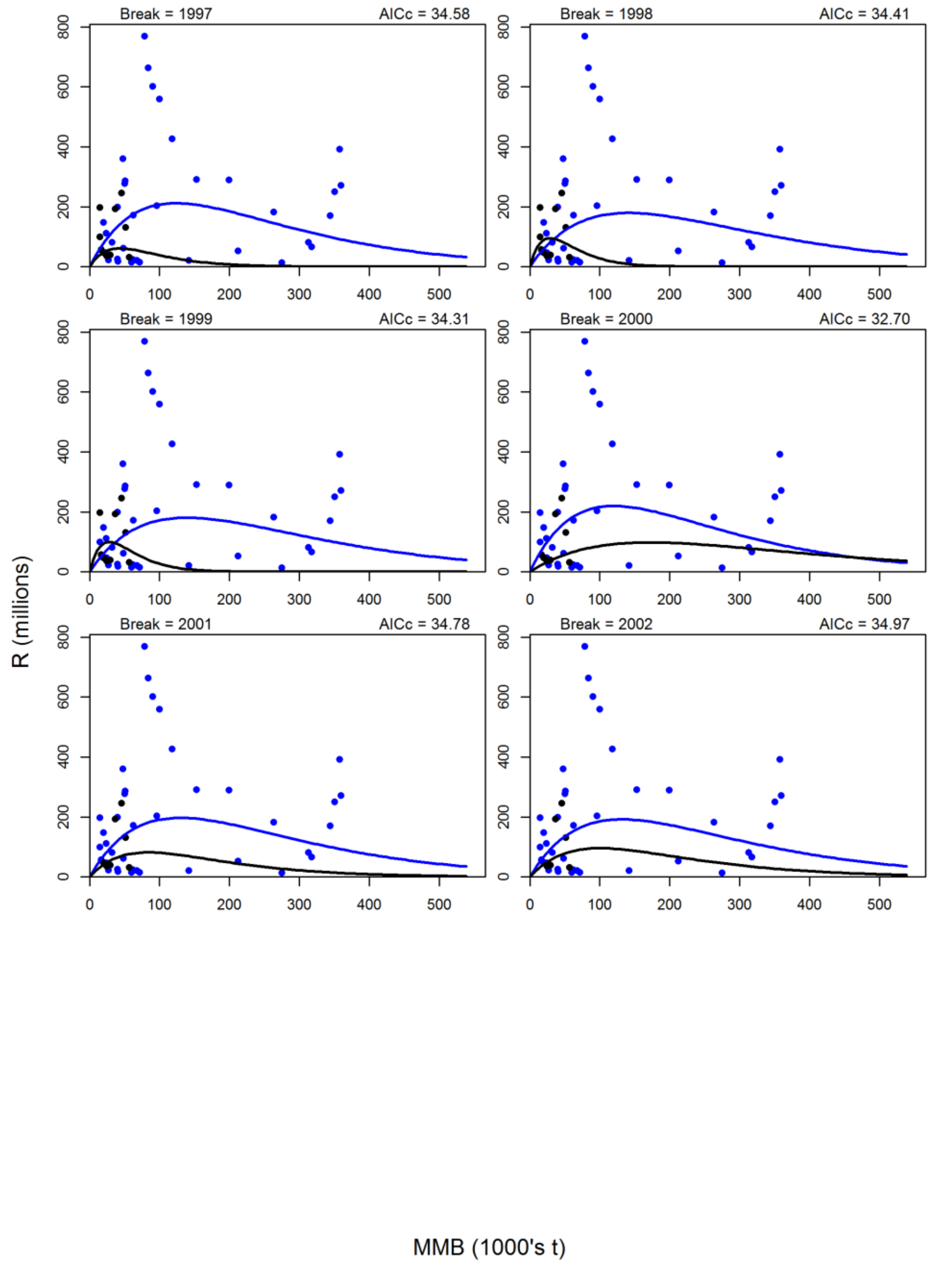

Figure 9. Continued.

2013 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Red King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

R.J. Foy
Alaska Fisheries Science Center
NOAA Fisheries

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 to current levels still low relative to the OFL.
3. Stock biomass: Stock adult biomass in recent years decreased from 2007 to 2009 and increased in in 2010 through 2013.
4. Recruitment: Recruitment indices are not well understood for Pribilof red king crab. Pre-recruits may not be well assessed with the survey but increased between 2005 and 2007 and remained low each year since 2009.
5. Management performance:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,255 (4.97)	2,754[A] (6.07)	0	0	4.2 (0.009)	349 (0.77)	
2011/12	2,571 (5.67)	2,775[B*] (6.12)	0	0	5.4 (0.011)	393 (0.87)	307 (0.68)
2012/13	2,609 (5.75)	4,025[C**] (8.87)	0	0	13.1 (0.029)	569 (1.25)	455 (1.00)
2013/14		4,679 [D**] (10.32)				903 (1.99)	718 (1.58)

All units are in t (million lbs) of crabs and the OFL is a total catch OFL for each year. The stock was above MSST in 2012/2013 and is hence not overfished. Overfishing did not occur during the 2012/2013 fishing year.

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. Basis for 2013/2014 OFL projection:

Year	Tier	B_{MSY} t (10^6 lbs)	Current MMB_{mating} t (10^6 lbs)	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}	P*
2013/14	4b	5,164 (11.38)	4,679 (10.32)	0.91	1.0	1991/1992-2012/2013	0.18	0.49

7. The OFL distribution which quantifies uncertainty was constructed using bootstrapping methods approximating the lognormal distribution. Within assessment uncertainty was included based on the 2013 survey mature male biomass CV of 0.62.

8. The ABC recommendation incorporated a σ_b of 0.4 to account for additional uncertainty, thus reducing the ABC from an ABC_{max} of 759 t (1.67 million lbs) to 718 t (1.58 million lbs).

9. Rebuilding analyses results summary: not applicable.

Summary of Major Changes:

1. Management: There were no major changes to the 2012/2013 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series were updated with 2012/2013 data. A new methodology for estimating discard catch was used for 2009/10-2012/13 replacing the previous estimates.
3. Assessment methodology: MMB was estimated with an average centered on the current year and weighted by the inverse variance.
4. Assessment results: The projected MMB increased and the OFL increased in this assessment. Total catch mortality in 2011/2012 increased substantially to 13.1 t due to increased bycatch in the yellowfin sole trawl fishery.

Responses to SSC and CPT Comments

<u>SSC comments October 2012:</u>

Specific remarks pertinent to this assessment

The fishery for red king crab in the Pribilof Islands district has been closed since 1999 due to concerns of low abundance, imprecision of biomass estimates, and pot bycatch of blue king crab, which are classified as overfished. Fishing mortality since the closure of the directed fishery has been limited to incidental catches in other crab fisheries and in Groundfish fisheries. The SSC supports the CPT recommendation to continue using the same base years as used previously (1991 to the current year) for determination of BMSY for the Pribilof Islands red king crab stock. The SSC also supports a Tier 4b designation for this stock, noting that the estimate of mature male biomass (3.30 kt) is below BMSY (5.14 kt). Unlike previous years, estimates of mature male biomass (MMB) were calculated in the assessment as a 3-year weighted moving average, centered on the current year and weighted by the inverse variance. Under the Tier 4b designation, the OFL for 2012/2013 is 0.57 kt.

The SSC agrees with the CPT recommendation to include additional uncertainty (□b = 0.4) when calculating the ABC using the P approach, resulting in an ABC of 0.46 kt. The SSC's support for this approach is based in large part on the recognition that the brief history of exploitation of this stock makes it difficult to identify an appropriate period of time suitable for establishing BMSY, such that the true distribution of the OFL is poorly known.*

The SSC supported the following CPT recommendations for the 2013 assessment: include CV's in tables of abundance estimates, include confidence intervals in the table of weighted moving average estimates of abundance, and consider the use of Kalman filter as an alternative to moving average for estimation of MMB. The SSC requests that the authors include the observation and the state equations used for the Kalman filter analysis.

Responses to SSC Comments: CVs and CIs were included in tables. The Kalman filter was not implemented this year but will be in subsequent assessment once underlying distributions for the survey variance are considered.

<u>SSC comments June 2013:</u>

Specific remarks pertinent to this assessment

none

CPT comments September 2012:

Specific remarks pertinent to this assessment

The CPT recommended the following for the 2013 assessment: include CV's in tables of abundance estimates and include CI's in the table of weighted moving averages estimates of abundance

Responses to CPT Comments: CVs and CIs were included in tables.

CPT comments May 2013:

Specific remarks pertinent to this assessment

none

Introduction

1. **Red king crabs, *Paralithodes camtschaticus*** (Tilesius, 1815)

2. **Distribution** - Red king crabs 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).

3. **Stock structure** – The information on stock structure of red king crabs in the North Pacific comes from two projects. One is based on 1,800 microsatellite DNA samples from red king crabs originating from the Sea of Okhotsk to Southeast Alaska (Seeb and Smith 2005). In the Bering Sea Aleutian Island region, 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).

4. **Life History** - Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Unlike brachyurans, 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. During copulation, 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. After copulation, eggs are fertilized 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) and estimates vary. 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 Bristol Bay red king crab females (brooding their first egg clutch) extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (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).

5. **Management history** - Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the Sate 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 2012/2013 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. Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries (see bycatch and discards section below).

Data

1. The standard survey time series data updated through 2012 and the standard groundfish discards time series data updated through 2012 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2011/2012 data.

2. a. Total catch:
   Crab pot fisheries
   Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (Tables 1 and 2), the seasons when red king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons red king crab and blue king crab were fished under the same Guideline Harvest Level (GHL). There was no GHL and therefore zero retained catch in the 2012/2013 fishing season.

   b. Bycatch and discards:
   Crab pot fisheries
   Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382) and 2010 to 2013 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

   $$\text{Weight (g)} = A * CL(mm)^B \quad (1)$$

   $$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (2)$$

   Finally, weights were the product of average weight, CPUE, and total pot lifts in the fishery. To assess crab mortalities in these pot fisheries a 50% handling mortality rate is 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. Prior to 1998 limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here.

   In 2012/2013, there were no Pribilof Islands red king crab incidentally caught in the crab fisheries (Table 3).

   Groundfish pot, trawl, and hook and line fisheries
   The 2012/2013 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 this year for Pribilof Islands red king crab, Areas 513 and 521 were included likely overestimating the catch 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 discriminated by each year's survey proportions (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 process 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" process 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 current. 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, 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 (wt crab/wt groundfish) applied to groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates at the stock area. There are instances where no observer data is available and aggregation could 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 significantly 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 (0.24 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 (Table 5). Unlike previous years no bycatch was observed in Alaska plaice fisheries in 2011/2012 or 2012/2013.

c. Catch-at-length: NA

d. Survey biomass:
The 2013 NOAA Fisheries EBS bottom trawl survey results (Daly et al. in press) are included in this SAFE report (Figure 5). Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock (Figure 6). Weight (equation 1) and maturity (equation 3) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass.

$$\text{Proportion mature male} = 1/(1 + (5.842 * 10^{14}) * e^{((CL(mm)+2.5) * -0.288)}$$
$$\text{Proportion mature female} = 1/(1 + (1.416 * 10^{13}) * e^{((CL(mm)+2.5) * -0.297)} \qquad (3)$$

Historical survey data are available from 1975 to the present (Tables 6 and 7, Figure 5). It should be noted that the survey data analyses were standardized in 1980.

In 2012, red king crab were caught at 14 of the 77 stations in the Pribilof District; 13 stations in the high-density sampling area and 1 station in the standard-density sampling area (Daly et al. in press; Figure 7). The density of legal-sized males caught at a station ranged from 66 to 3,770 crab nmi^{-2}. Legal-sized male red king crab were caught at 14 of the 77 stations in the Pribilof District with a biomass estimate (± 95% CI) of 7,567 ± 9,297 t and an abundance estimate (± 95% CI) of 1.6 ± 1.9 million crab (Figure 8). Legal-size males represented 96% of the total male biomass but were below the average of 5,430 ± 2,786 t from the previous 10 years. The majority of the legal-sized males were distributed around and to the north and east of St. Paul Island.

Mature males were encountered at 14 of the 77 stations in the Pribilof District; 13 stations in the high-density sampling area, and one station in the standard-density sampling area (Figure 8). All of the 77 mature and 5 immature males caught were measured. Two stations accounted for 81% of all mature red king crab caught (Figure 9). The biomass estimate of mature males was 7,749 ± 9,409 t and represented 99% of the total male biomass with the remaining 1% represented by 104 ± 171 t of immature male red king crab. Mature males were distributed around St. Paul Island in the nearshore shallow water stations and to the west and south of St. Paul Island (Figures 8 and 9).

The 2013 size-frequency for red king crab males shows slightly more very oldshell legal-sized males compared to 2012 (Figure 6). In 2013, 24% of the legal-sized males were new hardshell crabs and distributed to the west and south of St. Paul Island (Figure 10). Seventy five percent of the legal-sized males were in oldshell and very oldshell condition and primarily distributed to the west and south of St. Paul Island. In more recent years a small cohort of crab has moved through the stock from 120 to 175 mm but large abundances of smaller crab have not been observed since prior to 2004 (Figure 11).

The 2012 biomass estimate of mature-sized red king crab females was 663 ± 710 t and abundance was 0.4 ± 0.5 million crab, representing 100% of the total female biomass collected during the survey. A majority of the mature females were carrying uneyed embryos with 43% of the mature females in new hardshell condition. The majority of mature females with uneyed embryos were in the 130 mm to 140 mm CL size class.

The 2013 biomass estimate of mature-sized red king crab females was 169 ± 194 t and abundance was 0.1 ± 0.1 million crab, representing 100% of the total female biomass collected during the survey (Tables 6 and 7). Female biomass estimates are imprecise due to the limited number of tows with positive crab catches (Appendix), yet 2013 estimates indicate mature female biomass is considerably lower than in 2012. Approximately half of the mature females were carrying uneyed embryos with 56% of the mature females in new hardshell condition (Figure 12). Females with uneyed embryos were in the 145 mm to 160 mm CL size class. Similar to males, large cohorts of younger crab have not been observed since the mid-2000s with the survey only catching female crab around 120 mm (Figure 13).

The centers of distribution for both males and females have moved within a 40 nm by 40 nm region around St. Paul Island (Figure 14). 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.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past although is currently not in development.

Calculation of MMB

To reduce the effect of high uncertainty in the survey based area swept estimates an average biomass across 3 years centered on the current year was used to calculate the MMB in the most recent year (Table 8, Figure 15)). In addition, this average was weighted by the inverse variance of the survey biomass estimate to account for changes in variability among years. ***Therefore in this analysis the MMB was estimated by a three year moving average MMB weighted by the inverse variance.*** Figure 16 shows the three year running average of MMB_{mating} with confidence intervals and CVs used for the analyses in this SAFE. The survey time series with three year moving weighted averages for each major size class for males and females is presented in Table 8.

Calculation of the OFL

1. 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).

2. In Tier 4, Maximum Sustainable 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. In Tier 4, the fishing mortality that, if applied over the long-term, would result in MSY is approximated by F_{MSY}^{proxy}. The MSY stock size (B_{MSY}) is based on mature male biomass at mating (MMB_{mating}) which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of unknown sex ratios, a male only fishery, and the complicated female crab life

history where molting and mating occur simultaneously. The B_{MSY}^{proxy} represents the equilibrium stock biomass that provides maximum sustainable yield (MSY) to a fishery exploited at F_{MSY}^{proxy}. B_{MSY} can be estimated as the average biomass over a specified period that satisfies these conditions (i.e., equilibrium biomass yielding MSY by an applied F_{MSY}). This is also considered a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock. The current stock biomass reference point for status of stock determination is MMB_{mating}.

The mature stock biomass ratio β where $B/B_{MSY}^{prox} = 0.25$ represents the critical biomass threshold below which directed fishing mortality is set to zero (Figure 17). The parameter α determines the slope of the non-constant portion of the control rule line and was set to 0.1. Values for α and β where based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where B is greater than β includes the product of a scalar (**γ**) and M (equations 5 and 6) where the default **γ** value is 1 and M for Bering Sea red king crab is 0.18. The value of **γ** may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, the F_{OFL} control rule resulting 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}^{prox}; if current MMB at the time of mating drops below MSST, the stock is considered to be overfished.

3. Calculation of B_{MSY}^{prox}:
   The time period for establishing $B_{MSYproxy}$ was assumed to be representative of the stock being fished at an average rate near F_{MSY} fluctuating around B_{MSY}. The criteria to select the time period was based on 2011 CPT recommendations for this stock. For this assessment B_{MSY}^{prox} was calculated as the average MMB_{mating} from 1991 to current based on the observation that red king crab were relatively uncommon in the area prior to 1991 and the time series is not long enough to consider additional periods. Previously, an alternative time period was considered from 2000 to current because this time period represents the only period where the MMB oscillated relatively consistently over time without fishing pressure. However, not enough data exists to suggest a shift in productivity in the time series and there are only a few years with any exploitation. The recommendation for the entire time period was based on assessment of following established criteria:
   A. Production potential
      1) The stock does not appear to be below a threshold for responding to increased production given that increases in recruitment (120 – 134 mm males) lead to increases in adult biomass (Figure 18).
      2) An estimate of surplus production ($ASP = MMB_{t+1} – MMB_t + \text{total catch}_t$) suggested that surplus existed prior to each increase in recruitment and mature male biomass in the mid 1990s, mid 2000s, and 2010s.
      3) A climate regime shift where temperature and current structure changes are likely to impact red king crab larval dispersal and subsequent juvenile crab distribution. Subsequent to the 1978 regime shift in the North Pacific, a small increase in production of red king crab occurred in the Pribilof Islands occurred but substantial increases did not occur until the mid 1990s. There are few empirical data to identify trends that may allude to a production shift. However, further analysis is warranted to determine if subsequent climate events in the Bering Sea led to increases in production observed by the spikes in recruits (male crab 120-134 mm) /spawner (MMB) observed in the early in later years (Figure 19).
   B. Exploitation rates fluctuated during the open fishery periods from 1993 to 1998 while total catch increased quickly in 1993 before declining rapidly until the fishery was closed in 1999 (Figure 20). The current F_{MSY}^{proxy} assume F=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. However, too few years with exploitation exist for there to be a trend here.

C. No trend is apparent when comparing the ln (recruits/MMB) with exploitation on MMB.

4. 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 F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure 17) where Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current mature stock biomass (B) to $B_{MSY}{}^{proxy}$.

Stock Status Level:	F_{OFL}:	
a. $B/B_{MSY}{}^{prox} > 1.0$	$F_{OFL} = \gamma \cdot M$	(4)
b. $\beta < B/B_{MSY}{}^{prox} \leq 1.0$	$F_{OFL} = \gamma \cdot M\ [(B/B_{MSY}{}^{prox} - \alpha)/(1 - \alpha)]$	(5)
c. $B/B_{MSY}{}^{prox} \leq \beta$	$F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$	(6)

b. The MMB_{Mating} projection is based on application of M from the 2013 NMFS trawl survey (July 15) to the period of a fishery (October 15) and to mating (February 15) and the removal of estimated retained, bycatch, and discarded catch mortality (equation 7). Catch mortalities are estimated from the proportion of catch mortalities in 2012/2013 to the 2013 survey biomass.

$$MMB_{Survey} \cdot e^{-PM(sm)} - \text{(projected legal male catch OFL)} - \text{(projected non-retained catch)} \quad (7)$$

where, MMB_{Survey} is the mature male biomass at the time of the survey, $e^{-PM(sm)}$ is the survival rate from the survey to mating. PM(sm) is the partial M from the time of the survey to mating (7 months).

c. To project a total catch OFL for the upcoming crab fishing season, the F_{OFL} is estimated by an iterative solution that maximizes the projected F_{OFL} and projected catch based on the relationship of B to $B_{MSY}{}^{prox}$. B is approximated by MMB at mating (equation 7).

For a total catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the total crab biomass at the fishery (equation 8).

$$\text{Projected Total Catch OFL} = [1-e^{-Fofl}] \cdot \text{Total Crab Biomass}_{Fishery} \quad (8)$$

where $[1-e^{-Fofl}]$ is the annual fishing mortality rate.

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as:

$$\mu_{LMB} = [\text{Total LMB retained and non-retained catch}] / LMB_{Fishery} \quad (9)$$

μ_{MMB} = [Total MMB retained and non-retained catch] / $MMB_{Fishery}$ (10)

5. Recommendations:
   For ***2012/2013*** B_{MSY}^{prox}***=5,164 t of*** MMB_{mating} ***derived as the mean of 1991/1992 to 2012/2013***. The stock demonstrated highly variable levels of MMB_{mating} during these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

   Male mature biomass at the time of mating for 2013/2014 was estimated at 4,679 t for B_{MSY}^{prox}***based theinverse variance weighted survey data***. **The** B/B_{MSY}^{prox} ***=0.91 and*** F_{OFL}***=0.16.*** The biomass reference option B/B_{MSY}^{prox} is < 1, therefore the ***stock status level is b*** (equation 5). For the 2013/2014 fishery, the ***total catch OFL was estimated at 903t*** of crab and legal male catch OFL was estimated at 718 t of crab. The ***projected exploitation rates based on full retained catches up to the OFL for LMB and*** $MMB_{fishery}$ ***were both 0.17.***

   Red king crabs in the Pribilof Islands have been historically harvested with blue king crabs and are currently the dominant of the two species in this area. There are concerns as to the low reliability of survey biomass estimates and the high levels of blue king crab incidental catch mortality that would occur in a directed Pribilof Islands red king crab fishery.

Calculation of the ABC

1. 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. 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) will be considered as a recommended ABC below ABC_{max}. Additional uncertainty will be included in the application of the ABC by adding the uncertainty components as $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$.

   <u>Specification of the probability distribution of the OFL used in the ABC:</u>
   A distribution for the OFL which quantifies uncertainty was constructed using bootstrapping methods approximating the lognormal distribution. This involves generating values for *M* and annual MMB_{mating} (e.g. by assuming that MMB is log-normally distributed and *M* is normally distributed) and for each simulation calculating the OFL using the standard methods in sections 3 and 4 of the OFL Calculation section above. The OFL distribution for Pribilof Island red king crab is skewed to the right due to the patchy spatial distribution and small abundance which affects the variability of density estimates among trawl survey stations. This lognormal distribution suggests that use of the mean value (as opposed to the median) of the distribution would be appropriate as it changes with greater variability.

2. <u>List of variables related to scientific uncertainty considered in the OFL probability distribution:</u> Compared to other BSAI crab stocks, the uncertainty associated with the estimates of stock size and OFL for Pribilof Islands red king crab is high due to insufficient data and the small distribution of the stock relative to the survey sampling density. The coefficient of variation for the estimate of mature male biomass for the most recent year is 0.62 and has ranged between 0.36 and 0.79 since the 1995 peak in biomass.

3. <u>List of additional uncertainties considered for alternative σ_b applications to the ABC.</u>

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 are rather pre-specified.
- F_{msy} is assumed to be equal to γM when applying the OFL control rule while 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 1981-1988 and 1993-1999. Therefore, considerable uncertainty exists with this estimate of B_{msy}.

Given the relative amount of information available for Pribilof Island's red king crab, ***the author recommended ABC includes an additional*** σ_b ***of 0.4***.

4. Recommendations:
For 2013/2014 using the recommended B_{MSY}^{prox}, the multiplier equivalent to a P* of 0.49 was 0.84. The ***ABC***$_{max}$ ***was thus estimated to be 759 t***. Incorporating additional uncertainty by applying a σ_b of 0.4 resulted in a multiplier of 0.80 and a ***recommended ABC of 718t***.

Year	**MSST**	**Biomass (MMB_{mating})**	**TAC**	**Retained Catch**	**Total Catch**	**OFL**	**ABC**
2010/11	2,255 (4.97)	2,754[A] (5.44)	0	0	4.2 (0.009)	349 (0.77)	
2011/12	2,571 (5.67)	2,775[B*] (5.68)	0	0	5.4 (0.011)	393 (0.87)	307 (0.68)
2012/13	2,609 (5.75)	4,025[C**] (8.87)	0	0	13.1 (0.029)	569 (1.25)	455 (1.00)
2013/14		4,679[D**] (10.32)				903 (1.99)	718 (1.58)

All units are in t (million lbs) of crabs and the OFL is a total catch OFL for each year. The stock was above MSST in 2012/2013 and is hence not overfished. Overfishing did not occur during the 2012/2013 fishing year.

Notes:

A – Based on survey data available to the Crab Plan Team in September 20010 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

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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 2012/2013	0	0	0

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, 1993-2007/08 (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
1999-2012/13	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**

Table 4. Proportion by weight of the Pribilof Islands red king crab bycatch using the 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 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

Table 5. Proportion by weight of the Pribilof Islands red king crab bycatch among target species using the 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. Fisheries target species that caught blue king crab but made up less than 1% of the blue king crab bycatch across all years were not shown in the table and included halibut, sablefish, and Greenland turbot.

Crab fishing season	yellowfin sole %	Pacific cod %	flathead sole %	arrowtooth flounder %	pollock %	rockfish %	TOTAL (# crabs)
2009/2010	1	23	62	12	1 (midwater)		813
2010/2011	33	10	57		<1 (midwater)		3,026
2011/2012	39	11	41		5 (bottom)	3	2,167
2012/2013	77	3	18			1	4,517

Table 6. Pribilof Islands District red king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey with no running average.

Year	Mature Male Abundance	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Total males @ survey t	Total females @ survey t
1975/1976	0	0	0	0	0	10
1976/1977	50778	162	146	162	162	80
1977/1978	76159	116	104	0	253	120
1978/1979	367140	1228	712	1228	1228	42
1979/1980	279707	859	229	790	859	76
1980/1981	383898	1312	981	1312	1317	195
1981/1982	80928	299	250	299	299	97
1982/1983	331947	1440	1297	1440	1458	673
1983/1984	122661	518	467	486	544	216
1984/1985	64331	261	235	233	261	67
1985/1986	16823	60	54	60	60	0
1986/1987	38419	135	122	135	135	57
1987/1988	18611	53	47	53	53	25
1988/1989	66189	104	94	43	797	732
1989/1990	754994	1498	1348	854	2154	1846
1990/1991	617113	897	807	109	6815	1775
1991/1992	2435400	4335	3881	1295	4959	3860
1992/1993	1451102	3238	2825	2479	3505	2612
1993/1994	3532420	9687	7545	9017	9962	4837
1994/1995	3114248	9052	7570	7994	9600	3397
1995/1996	7098444	24282	21473	22428	24854	6199
1996/1997	555428	2323	2004	2292	2389	1456
1997/1998	1554857	6056	5124	5843	7528	1442
1998/1999	772660	2282	1814	1749	2688	1262
1999/2000	1939076	5422	4873	4394	8682	4762
2000/2001	1538502	4239	3814	3773	4393	734
2001/2002	3662559	8434	7589	5663	10714	4333
2002/2003	1891296	6916	6222	6894	6923	571
2003/2004	1470902	5280	4749	5184	5280	1644
2004/2005	811871	3563	3205	3563	3710	983
2005/2006	247739	1219	1084	1219	1272	2207
2006/2007	1370143	6762	6074	6484	6859	1406
2007/2008	1637966	7176	6458	6947	7378	2534
2008/2009	1305315	5375	4835	5022	5698	2099
2009/2010	887543	2454	2209	2088	2498	546
2010/2011	895960	3107	2795	2881	3137	468
2011/2012	1015866	3834	3450	3751	3878	817
2012/2013	1246228	4477	4025	4360	4813	663
2013/2014	1739703	7749		7567	7854	169

Table 7. Pribilof Islands District red king crab abundance CV, mature male biomass CV, legal male biomass CV, and total CVs estimated from the NMFS annual EBS bottom trawl survey data with no running average.

Year	Mature Male Abundance CV	Mature male biomass @ survey CV	Legal male biomass @ survey CV	Total male biomass @ survey CV	Total female biomass @ survey CV
1975/1976	0.00	1.00	0.00	0.00	1.00
1976/1977	1.00	1.00	1.00	1.00	0.76
1977/1978	1.00	1.00	0.00	1.00	1.00
1978/1979	0.83	0.83	0.83	0.83	1.00
1979/1980	0.37	0.39	0.42	0.39	0.72
1980/1981	0.48	0.53	0.53	0.52	0.64
1981/1982	0.57	0.58	0.58	0.58	0.78
1982/1983	0.69	0.70	0.70	0.70	0.76
1983/1984	0.59	0.53	0.52	0.55	0.48
1984/1985	0.48	0.55	0.61	0.55	0.57
1985/1986	1.00	1.00	1.00	1.00	0.00
1986/1987	0.70	0.70	0.70	0.70	1.00
1987/1988	1.00	1.00	1.00	1.00	1.00
1988/1989	1.00	1.00	1.00	0.56	0.65
1989/1990	0.93	0.91	0.85	0.77	0.69
1990/1991	0.93	0.93	1.00	0.88	0.69
1991/1992	0.79	0.80	0.81	0.80	0.60
1992/1993	0.64	0.60	0.54	0.61	0.91
1993/1994	0.92	0.92	0.92	0.92	0.72
1994/1995	0.76	0.74	0.72	0.74	0.76
1995/1996	0.42	0.43	0.44	0.43	0.51
1996/1997	0.37	0.37	0.37	0.37	0.74
1997/1998	0.57	0.62	0.64	0.54	0.57
1998/1999	0.38	0.36	0.38	0.37	0.76
1999/2000	0.58	0.67	0.70	0.58	0.86
2000/2001	0.39	0.37	0.37	0.38	0.63
2001/2002	0.85	0.79	0.70	0.83	0.99
2002/2003	0.67	0.69	0.69	0.69	0.51
2003/2004	0.68	0.66	0.65	0.66	0.91
2004/2005	0.60	0.59	0.59	0.60	0.53
2005/2006	0.59	0.59	0.59	0.57	0.78
2006/2007	0.38	0.36	0.36	0.36	0.61
2007/2008	0.42	0.39	0.39	0.40	0.52
2008/2009	0.46	0.51	0.52	0.50	0.70
2009/2010	0.69	0.64	0.62	0.64	0.55
2010/2011	0.38	0.38	0.36	0.38	0.41
2011/2012	0.63	0.65	0.65	0.64	0.73
2012/2013	0.59	0.57	0.57	0.59	0.55
2013/2014	0.59	0.62	0.63	0.61	0.58

Table 8. Three year running average weighted by inverse variance of Pribilof Islands District red king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature Male Abundance	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Total males @ survey t	Total females @ survey t
1975/1976						12
1976/1977	58589	132	118			13
1977/1978	64340	141	131		207	59
1978/1979	157147	207	183	833	501	59
1979/1980	309001	969	262	917	970	64
1980/1981	128009	461	251	448	461	96
1981/1982	107458	390	328	390	390	132
1982/1983	99871	385	325	382	386	145
1983/1984	77502	334	301	311	333	87
1984/1985	31387	107	96	105	106	84
1985/1986	30083	102	92	99	102	64
1986/1987	21323	68	61	68	68	30
1987/1988	27127	77	70	56	80	32
1988/1989	22569	65	58	48	65	27
1989/1990	79304	124	112	54	919	973
1990/1991	760737	1193	1075	138	2831	2074
1991/1992	944073	1408	1269	137	4099	2304
1992/1993	1750550	3713	3261	1813	4079	3553
1993/1994	1793250	3931	3438	2913	4293	3353
1994/1995	4359155	12392	10085	10999	13031	4592
1995/1996	604933	2576	2222	2559	2648	2150
1996/1997	635407	2648	2282	2610	2765	1641
1997/1998	660434	2393	1971	2028	2649	1389
1998/1999	909389	2592	2056	1983	3170	1444
1999/2000	969553	2804	2249	2206	3298	873
2000/2001	1683865	4613	4149	4042	4996	824
2001/2002	1664114	4700	4228	4184	4853	630
2002/2003	1753904	6242	5615	5729	6293	628
2003/2004	1038025	4385	3944	4370	4538	698
2004/2005	317776	1601	1422	1604	1646	1143
2005/2006	368055	1846	1639	1850	1896	1167
2006/2007	382339	1974	1751	1991	2019	1816
2007/2008	1415033	6452	5801	6172	6652	1817
2008/2009	1249124	3939	3545	3327	4035	702
2009/2010	973476	3139	2824	2779	3196	510
2010/2011	915420	2990	2690	2683	3033	513
2011/2012	967819	3427	3082	3193	3469	534
2012/2013	1228754	4583	3728	4467	4755	219
2013/2014	1414916	5204		5045	5595	204

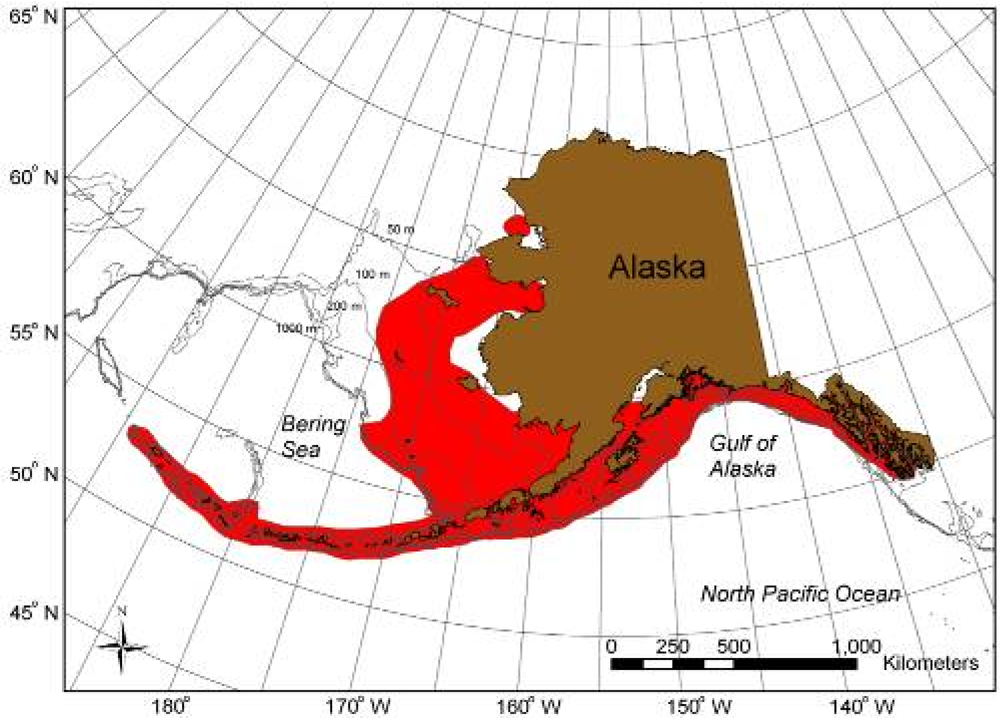


Figure 1. Red king crab distribution.

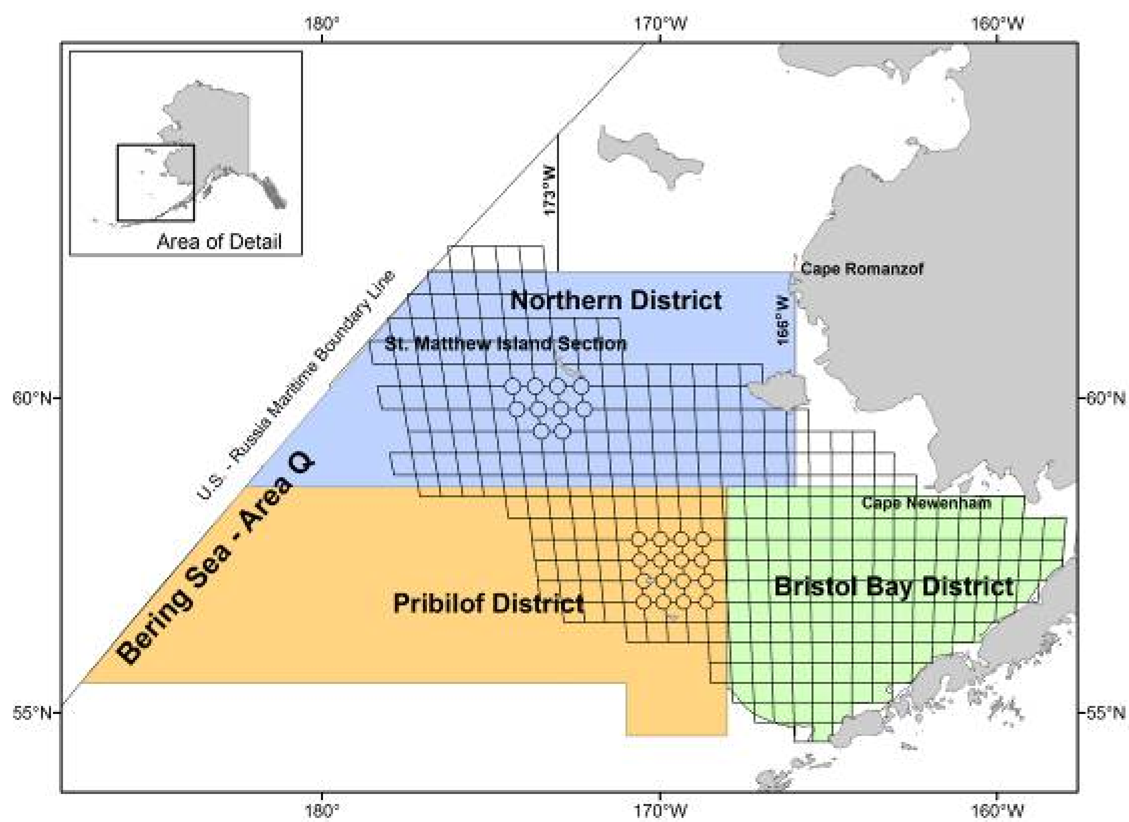


Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

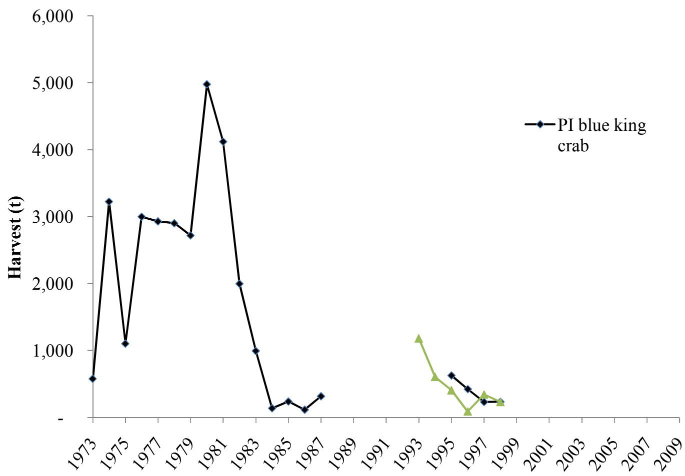


Figure 3. Historical harvests and GHLs for Pribilof Island blue (diamonds) and red king crab (triangles) (Bowers et al. 2011).

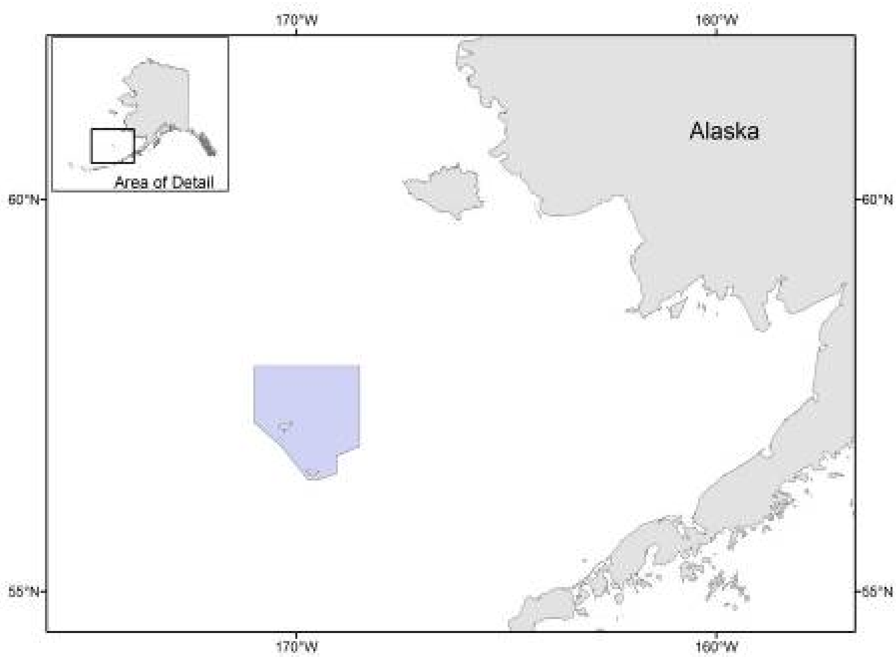


Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area.

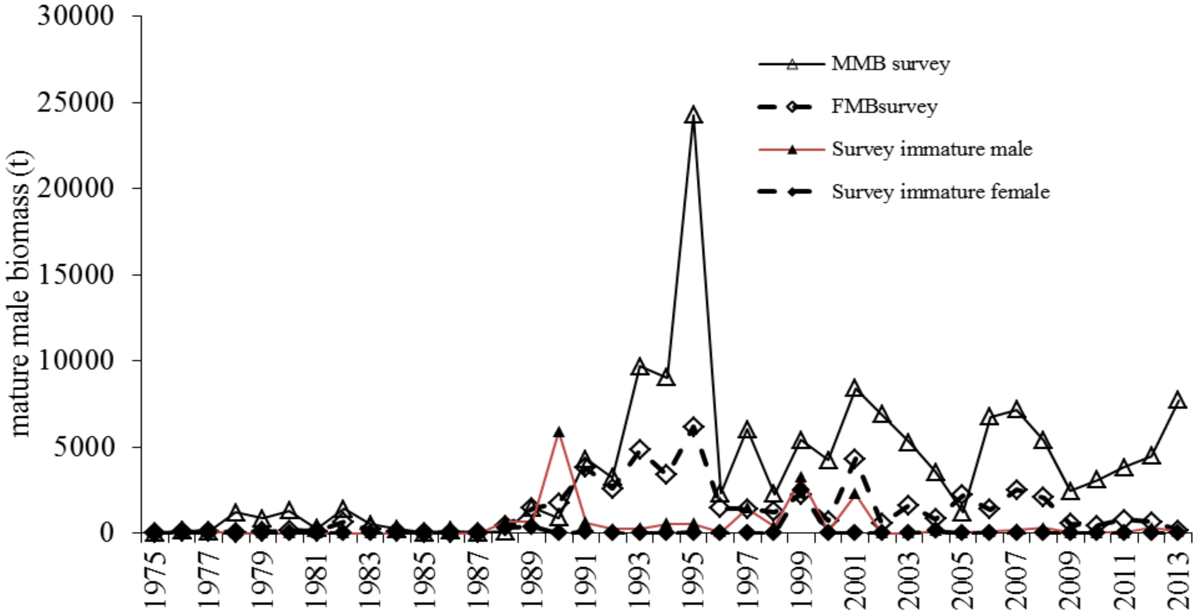


Figure 5. Time series of Pribilof Islands red king crab estimated from the NMFS annual EBS bottom trawl survey.

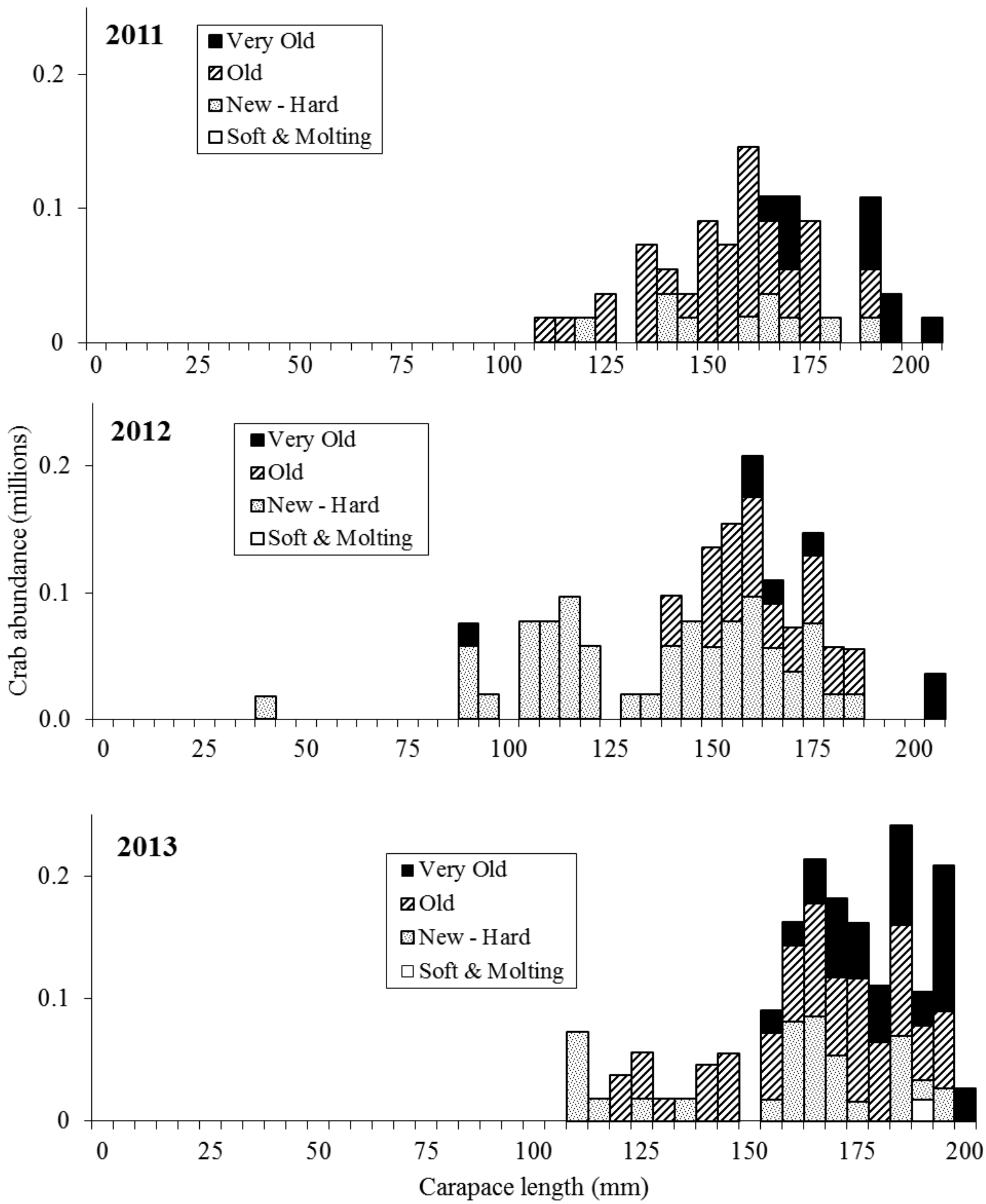


Figure 6. Distribution of Pribilof Islands red king crab in 5 mm length bins by shell condition for the last 3 surveys.

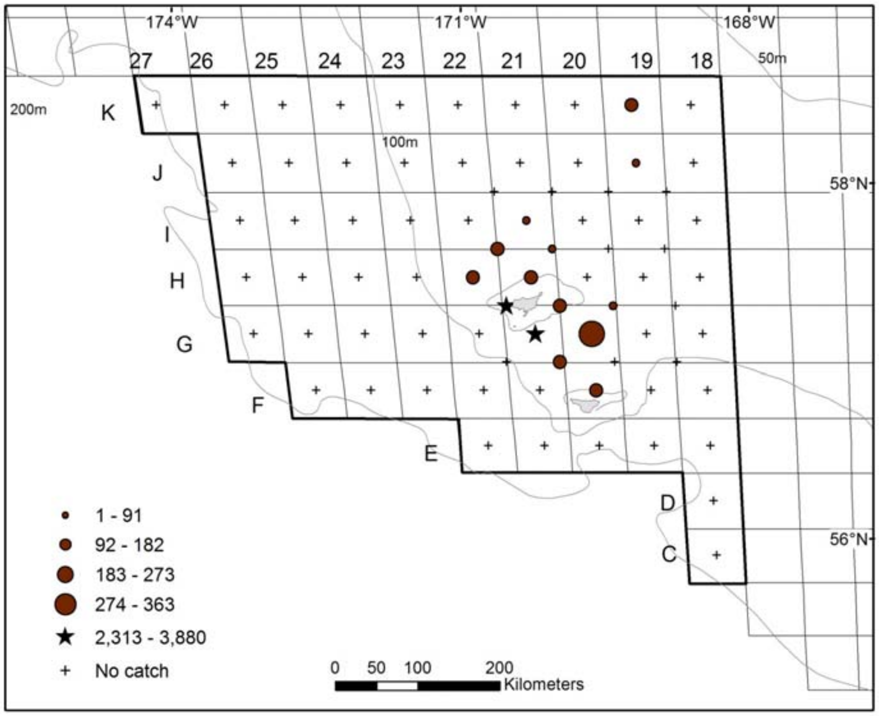


Figure 7. Total density (number nm^{-2}) of red king crab in the Pribilof District in the 2012 EBS bottom trawl survey.

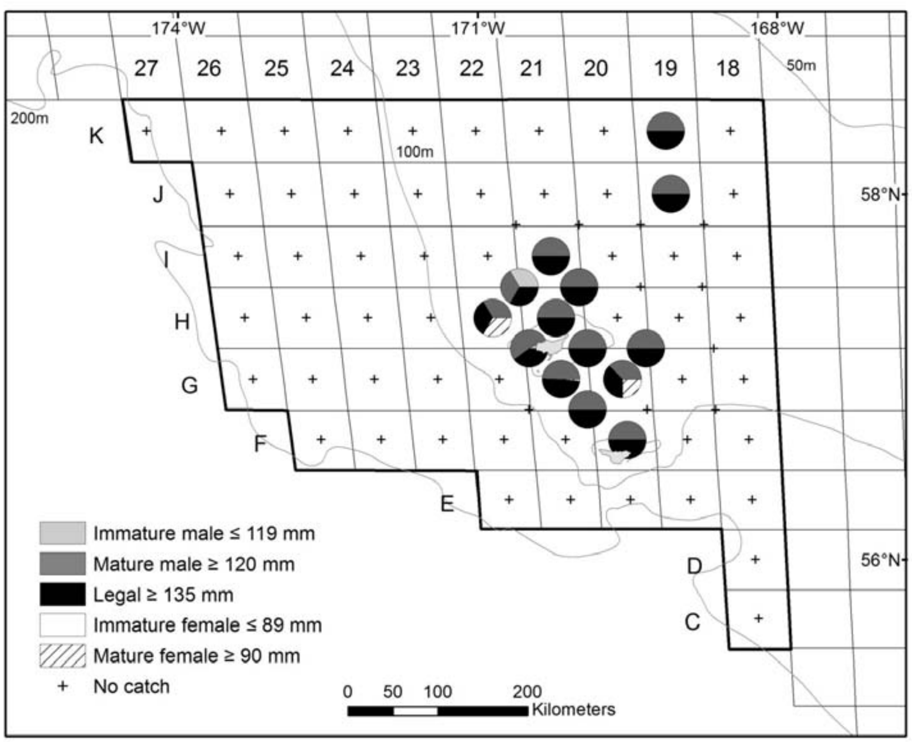


Figure 8. 2012 EBS bottom trawl survey size class distribution of red king crab in the Pribilof District.

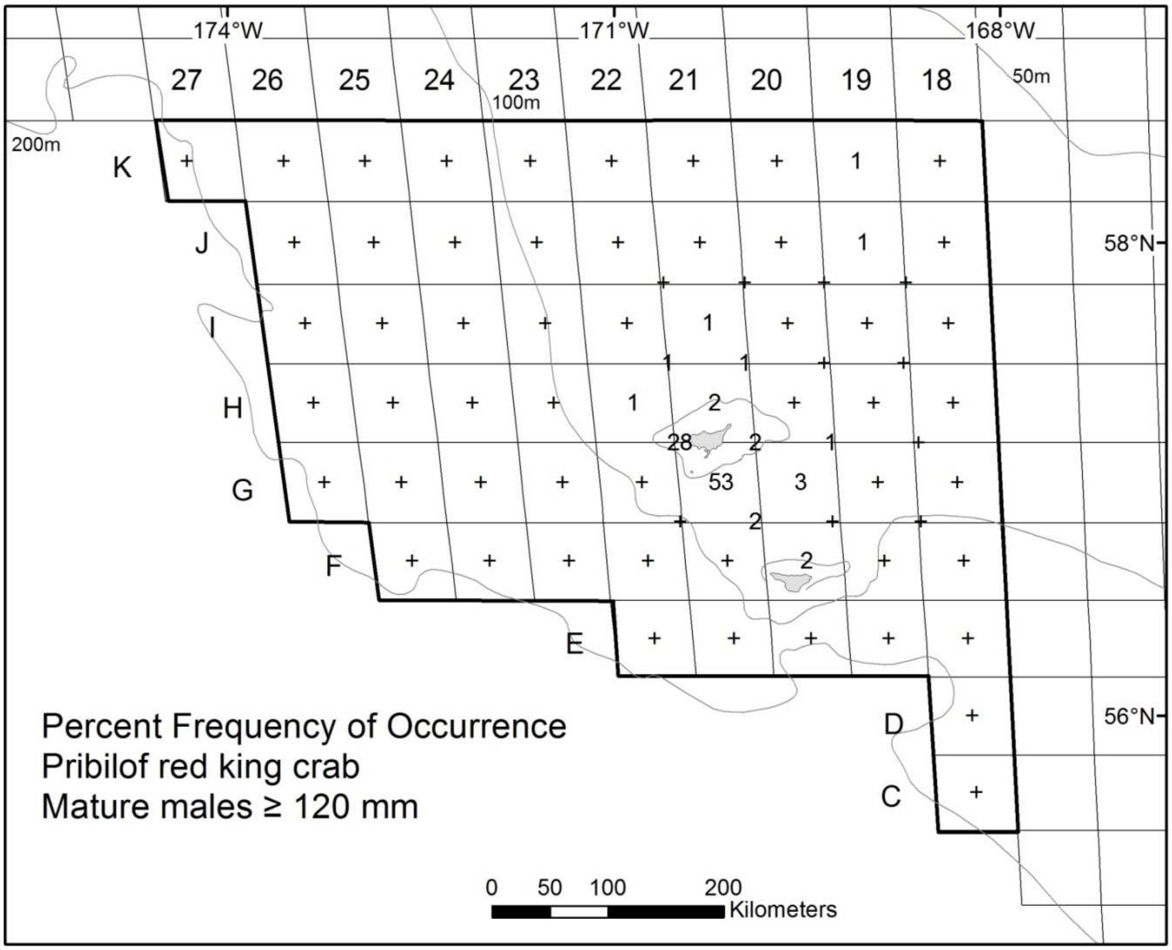


Figure 9. Percent frequency of occurrence of mature male red king crab (*Paralithodes camtschaticus*) at stations sampled in the 2013 Pribilof District.

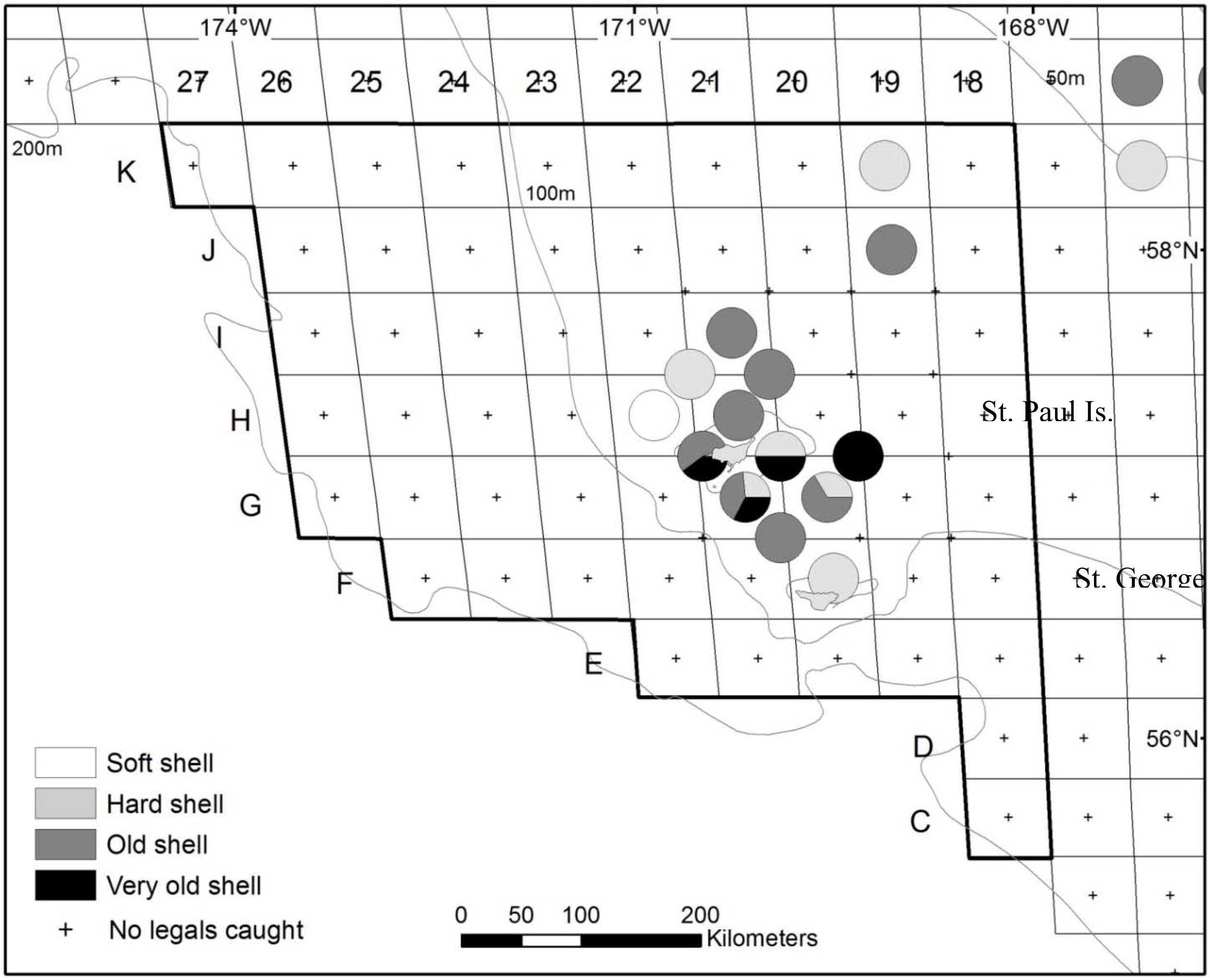


Figure 10. Distribution of legal-sized male red king crab (*Paralithodes camtschaticus*) caught at each station of the Pribilof District in 2013 and distinguished by shell condition. The outlined area depicts stations within the management district.

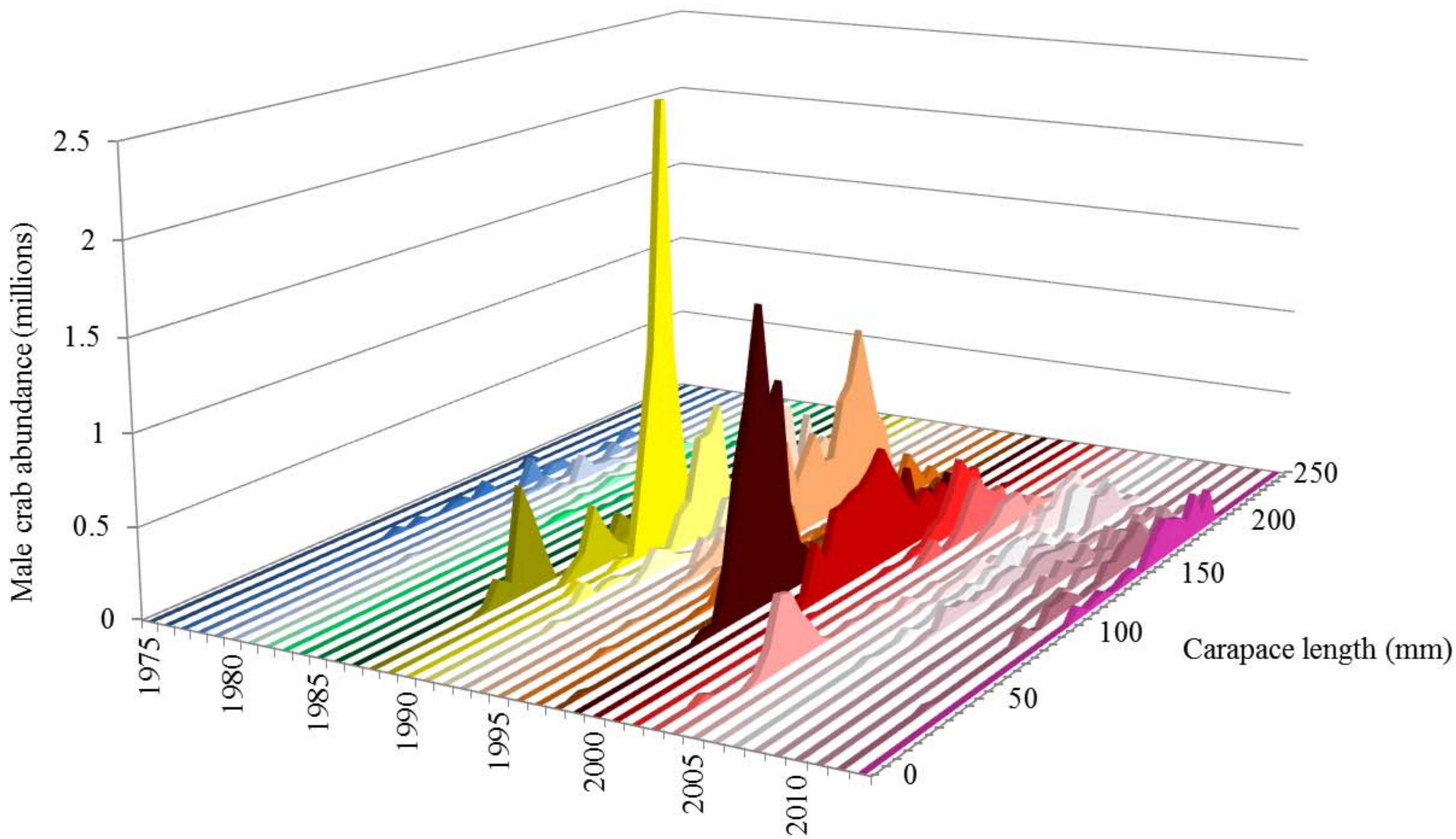


Figure 11. Size frequency by 5 mm length classes of Pribilof Islands male red king crab (*Paralithodes camtschaticus*) from 1975 to 2013.

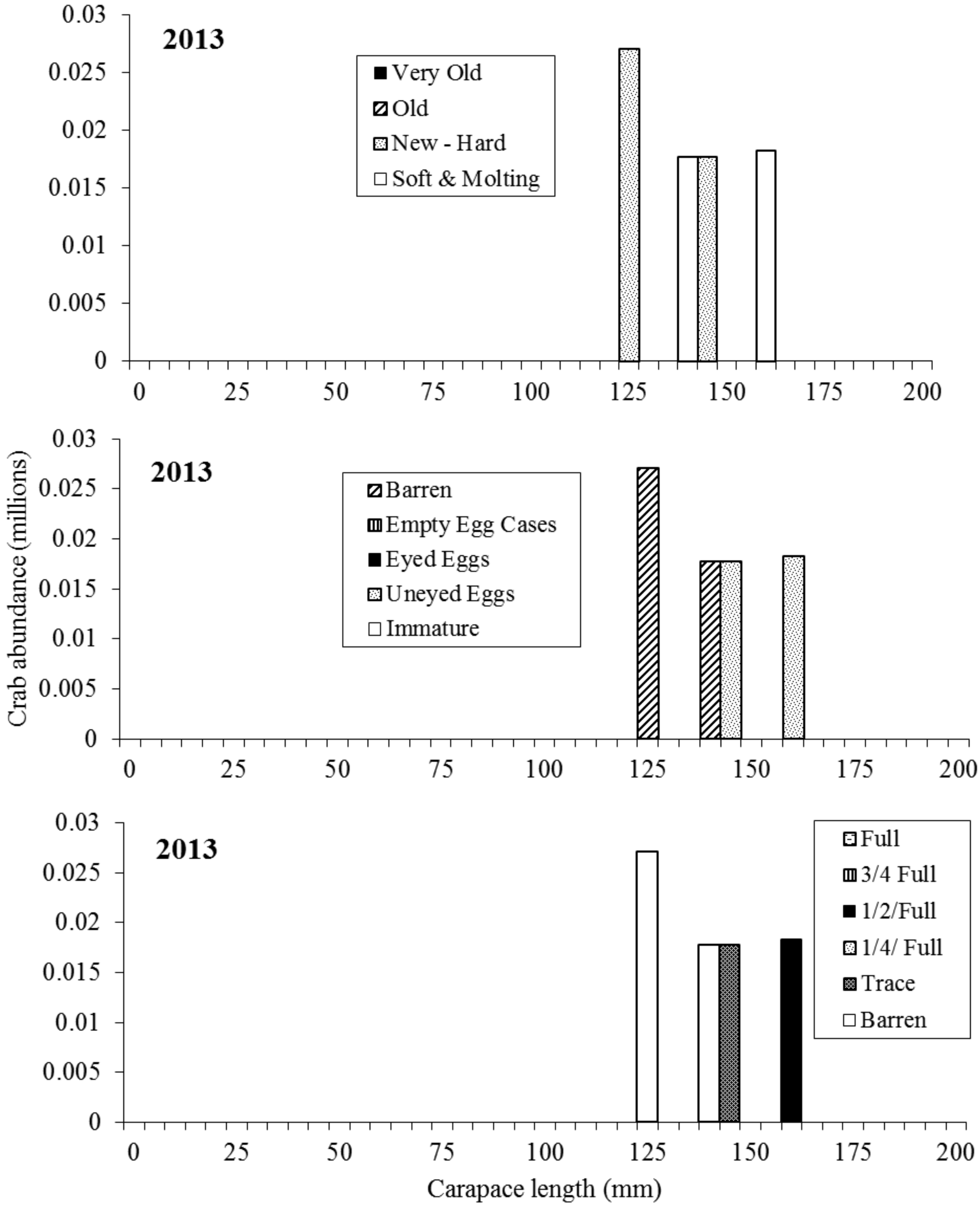


Figure 12. Size-frequency by shell condition, egg condition, and clutch fullness of Pribilof District female red king crab (*Paralithodes camtschaticus*) by 5 mm length classes in 2013.

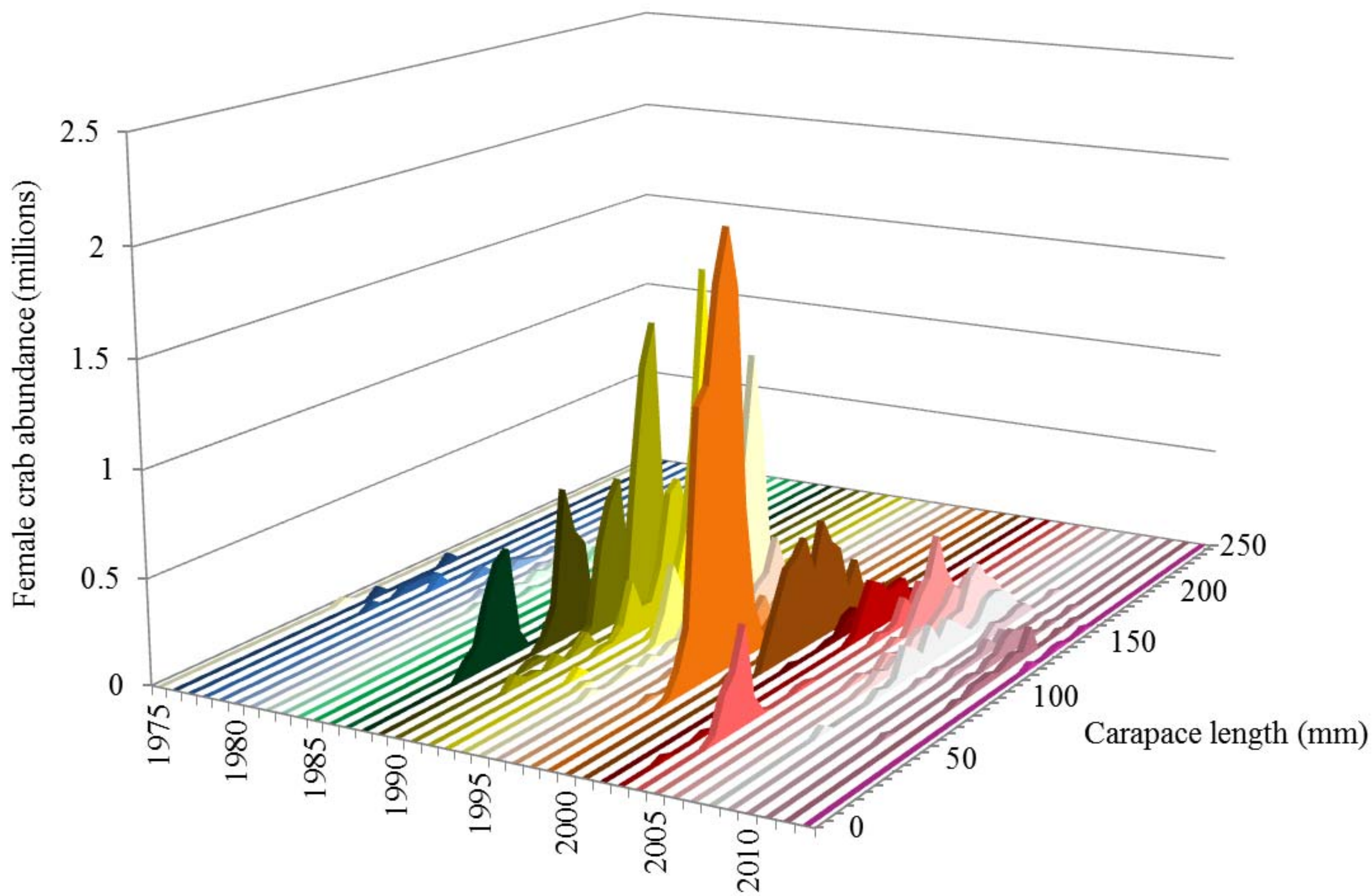
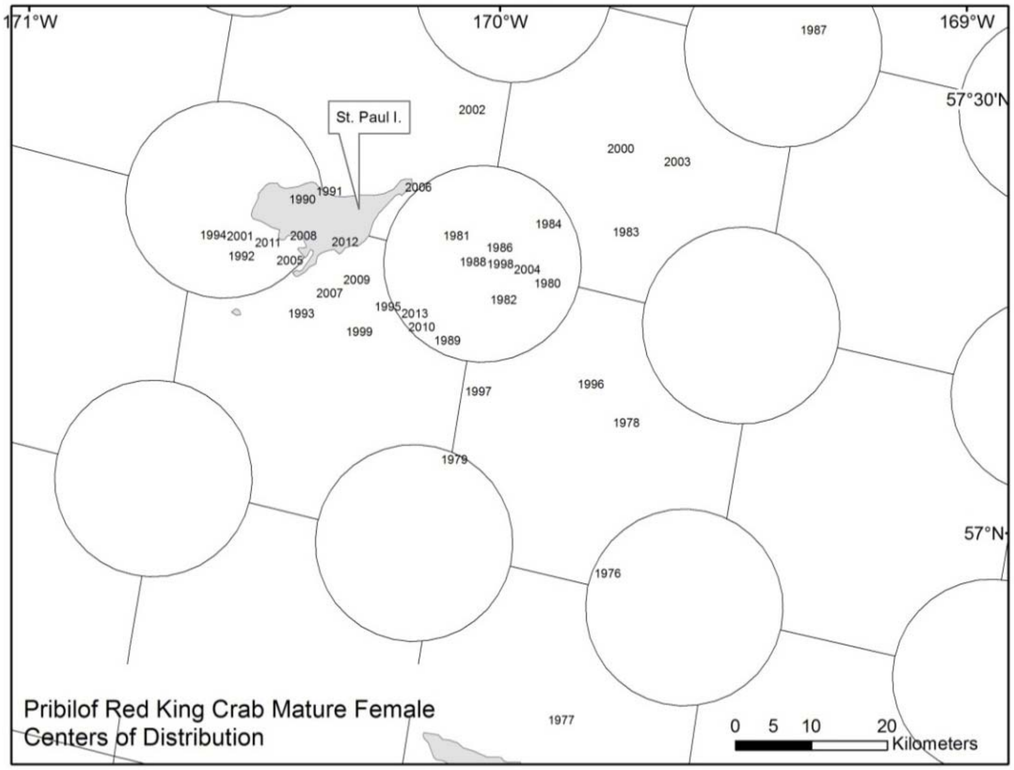


Figure 13. Size frequency by 5 mm length classes of Pribilof Islands female red king crab (*Paralithodes camtschaticus*) from 1975 to 2013.



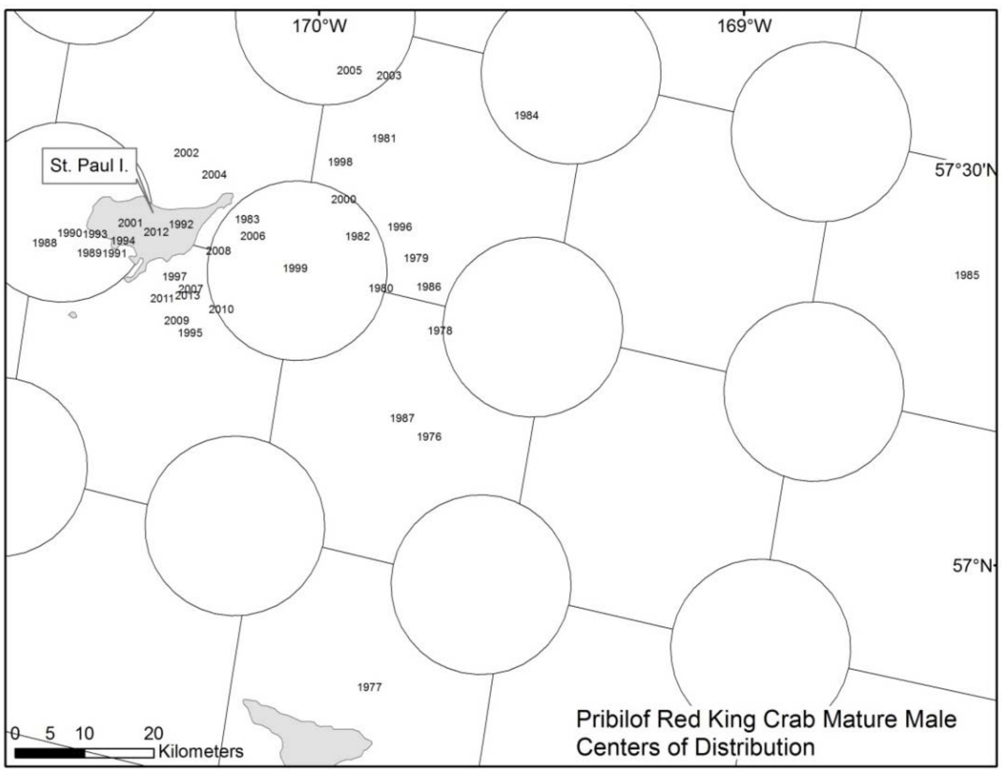


Figure 14. Centers of stock distribution of Pribilof Islands female and male red king crab (*Paralithodes camtschaticus*) from 1975 to 2013.

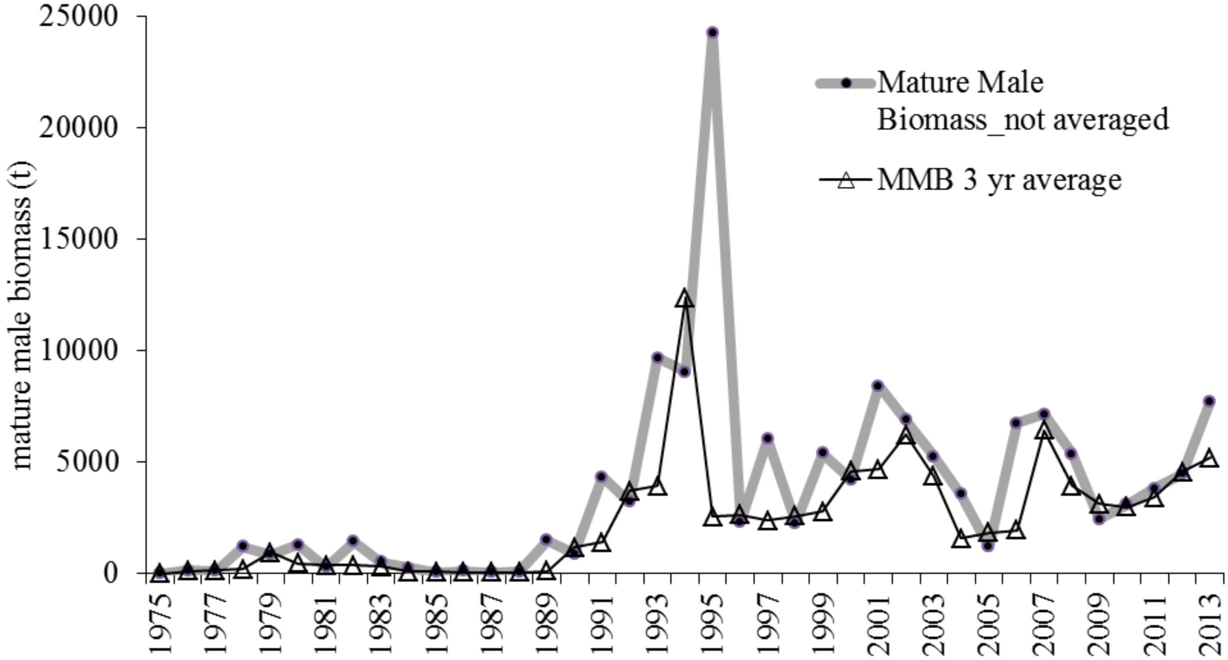


Figure 15. Mature male biomass un-weighted and average weighted by inverse variance.

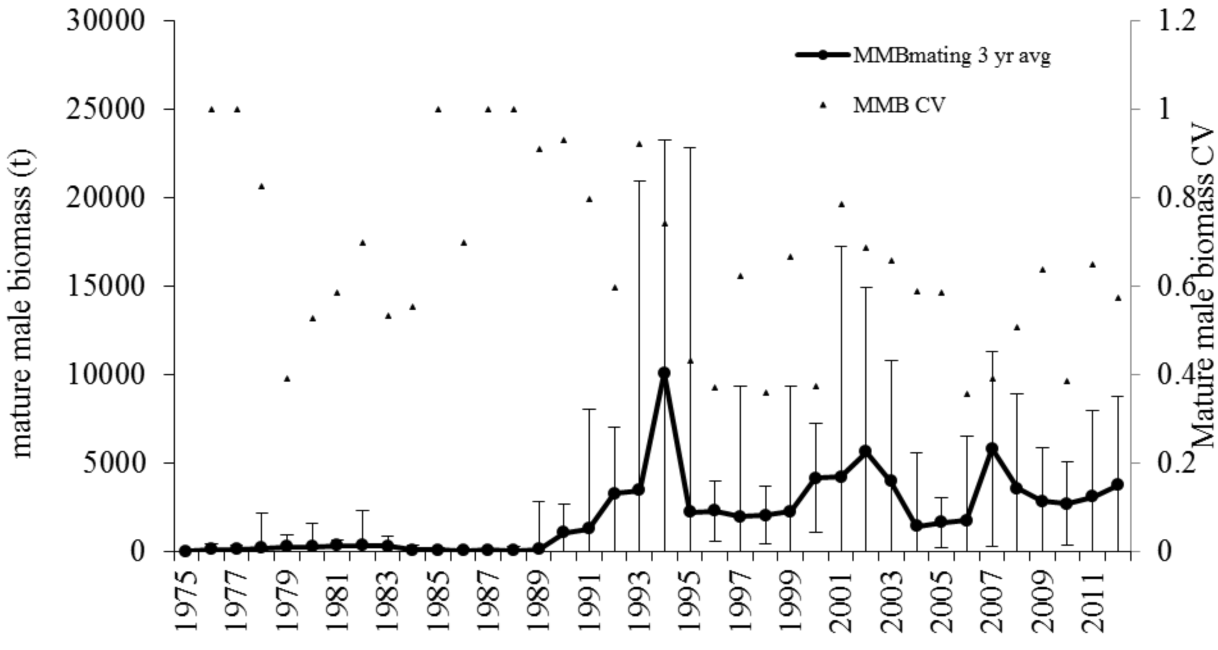


Figure 16. Time series of Pribilof Island red king crab 3 year weighted average mature male biomass (95% C.I.) and mature male biomass CV estimated from the NMFS annual EBS bottom trawl survey.

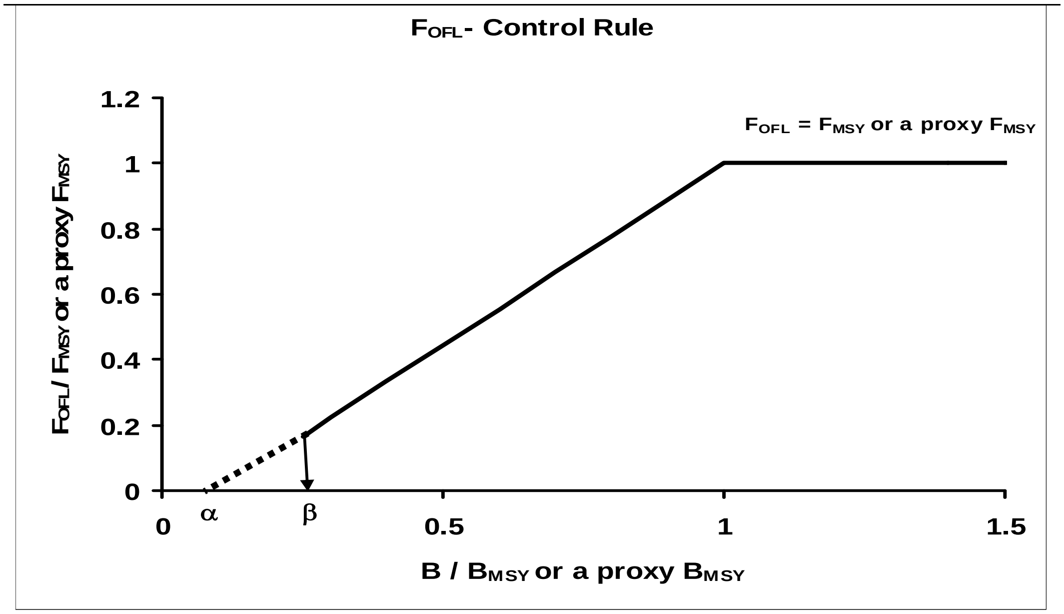


Figure 17. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

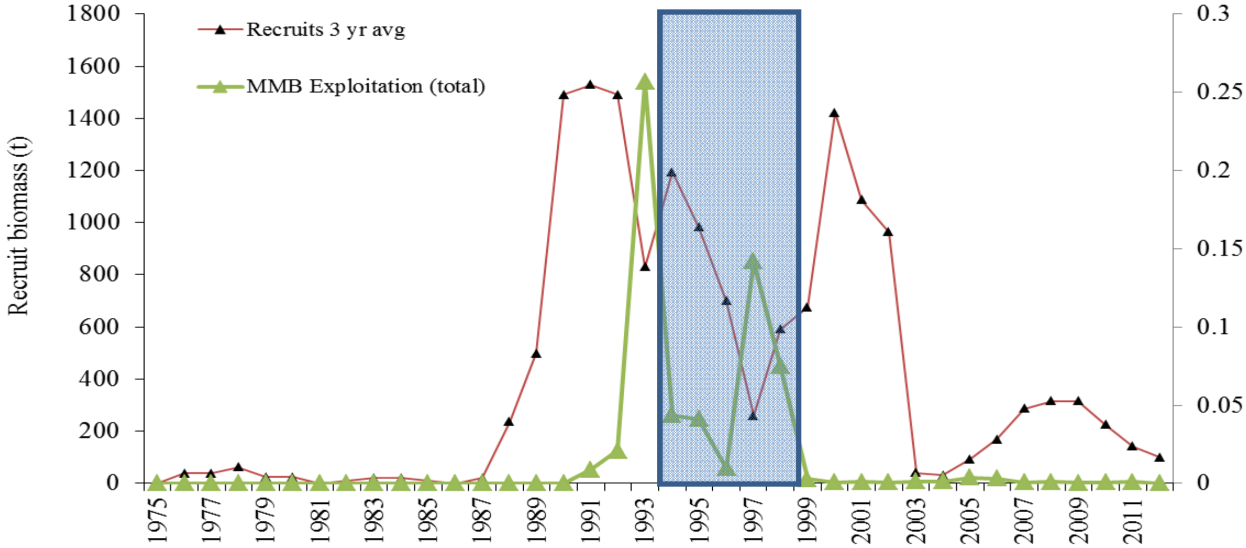


Figure 18. Time series of survey estimated recruit biomass (males 120-134 mm) and exploitation rate (based on total catch) of mature male biomass. The shaded region represents a period where commercial removals were occurring.

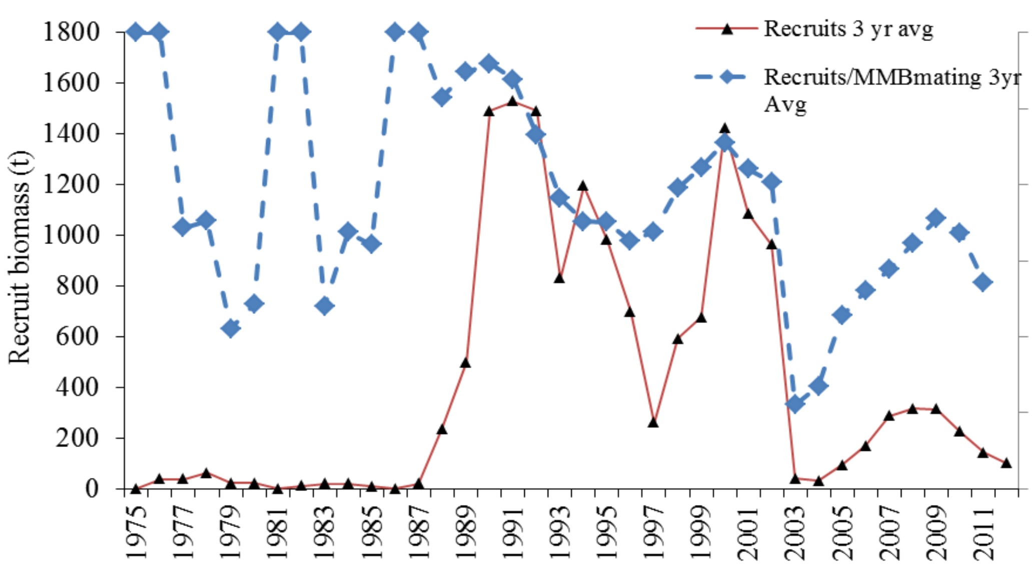


Figure 19. Time series of survey estimated recruit biomass (males 120-134 mm) and ln(Recruits/MMB). The shaded region represents a period where commercial removals were occurring.

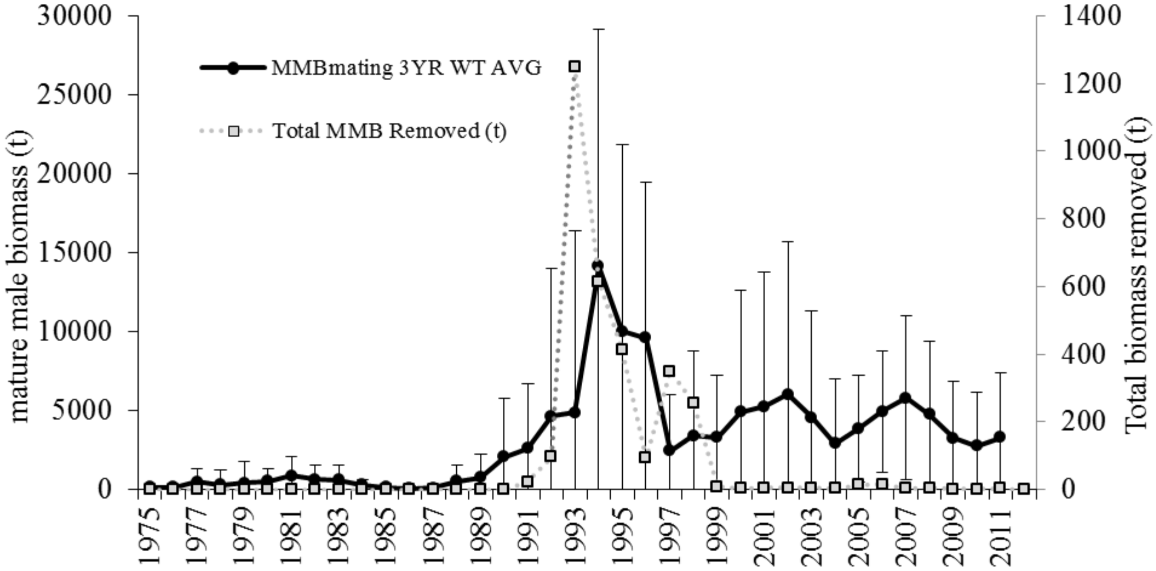


Figure 20. Time series of survey estimated Pribilof Island red king crab 3 year moving averaged mature male biomass at mating (95% C.I.) and total catch removals.

2013 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

R.J. Foy
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA

Executive Summary

1. Stock: Pribilof Islands blue king crab, *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years although a change in calculation methodology led to an increase in 2011/2012 to 0.36 t (0.0008 million lbs) and another change in calculation methodology led to an additional increase in 2012/2013.
3. Stock biomass: Stock biomass in recent years decreased between the 1995 and 2008 surveys, and continues to fluctuate with a decrease in all size classes in 2013 noting the lack of significance in any short term trends due to high uncertainty.
4. Recruitment: Recruitment indices are not well understood for Pribilof blue king crab. Pre-recruit have remained consistently low in the past 10 years although may not be well assessed with the survey.
5. Management performance:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,105 (4.64)	286 [A] (0.63)	0	0	0.18 (0.0004)	1.81 (0.004)	
2011/12	2,247 (4.95)	365 [B*] (0.80)	0	0	0.36 (0.0008)	1.16 (0.003)	1.04 (0.002)
2012/13	1,994 (4.39)	579 [C**] (1.28)	0	0	0.61 (0.0013)	1.16 (0.003)	1.04 (0.002)
2013/14		278 [D**] (0.61)				1.16 (0.003)	1.04 (0.002)

All units are tons (million pounds) of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2012/2013 and is hence overfished. Overfishing did not occur during the 2012/2013 fishing year.

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. Basis for 2013/2014 OFL projection:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
		t (10^6 lbs)	t (10^6 lbs)				yr^{-1}	
20013/14	4c	3,988 (8.79)	278 (0.61)	0.07	1.0	1980/81-1984-85 & 1990/91-1978/79	0.18	10% buffer

7. The OFL was set based on the existing control if the slope of the rule were to continue to 0 applied to the total catch. Previously a Tier 5 calculation of average catch mortalities between 1999/2000 and 2005/2006 was done to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality.
8. The ABC_{max} was calculated using a 10% buffer similar to that of the Tier 5 ABC control rule. The ABC_{max} was thus estimated to be 1.04 t.
9. Rebuilding analyses results summary: Proposed Crab FMP and regulatory amendments were submitted for review by the Secretary in early 2013 since NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014.

Summary of Major Changes:

1. Management: There were no major changes to the 2012/2013 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series were updated with 2012/2013 data. A new methodology for estimating discard catch was used for 2009/10-2012/13 replacing the previous estimates.
3. Assessment methodology: The survey biomass time series was calculated with the new area definition including an additional 20 nm strip towards the east of the Pribilof Islands District. MMB was estimated with an average centered on the current year and weighted by the inverse variance.
4. Assessment results: The projected MMB decreased substantially in this assessment and remained below the MSST. Therefore, the OFL remained low with no directed fishery. Total catch mortality in 2012/2013 was 0.61 t.

Responses to SSC and CPT Comments

<u>SSC comments October 2012:</u>

Specific remarks pertinent to this assessment

The SSC supports the CPT and author's recommendation for management of Pribilof Islands blue king crab under Tier 4c. Following the advice of the CPT, the SSC recommends a Tier 5 calculation of average catch mortalities between 1999/2000 and 2005/2006, resulting in a total catch OFL of 0.00116 kt. Similarly, the SSC supports using a 10 percent buffer for the ABC calculation, resulting in an ABCmax of 0.00104 kt. The Pribilof blue king crab stock is overfished, however overfishing did not occur during the 2011/2012 season.

The MSY stock size (BMSY) is based on mature male biomass at mating (MMBmating) which serves as an approximation for egg production. For 2011/2012, BMSYprox = 3.94 kt of MMBmating derived as the mean MMB from 1980 to 1984 and 1990 to 1997. The stock demonstrated highly variable levels of MMB during both of these periods likely leading to uncertain approximations of BMSY.
Retained catches for Pribilof Island blue king crab have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years, although a change in calculation

methodology led to an increase in 2011/12. Stock biomass decreased between the 1995 and 2008 surveys and continues to fluctuate with no significant change estimated for recent years due to the high uncertainty in estimates. Based on September 2011 CPT and SSC comments, biomass estimates are now based on a 3-year weighted average, centered on the current year and weighted by the inverse of the variance.
A revised rebuilding plan was approved by the Council in June 2012 and will soon go through final review by the Secretary of Commerce. The revised rebuilding plan closes the Pribilof Habitat Conservation Zone to Pacific cod pot fishing.

Responses to SSC Comments: None.

SSC comments June 2013:
Specific remarks pertinent to this assessment
none

CPT comments September 2012:
Specific remarks pertinent to this assessment
The stock assessment author and the CPT recommend an OFL calculation using average catch from the status quo time series. The author presented an alternative method using biomass estimates for calculating the OFL. Neither the CPT nor the author recommended using this approach given the high uncertainty surrounding this stock and the already low OFL. Uncertainty in biomass estimates could lead to an ABC of 0 and could have large management repercussions. Biologically this stock is not responsive to management measures given an already low OFL. The current method has been used since 2008 based on average catch. Before considering alternative approaches, the CPT would like to see historical groundfish bycatch data from the catch in areas database in order to more accurately assess historical catch.

Responses to CPT Comments: Now that a new bycatch estimation procedure exists for 2009-2012 based on State of Alaska stat areas the results of the catch and areas database are no longer being used.

CPT comments May 2013:
Specific remarks pertinent to this assessment
none

Introduction

1. **Blue king crabs,** *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 occur off Hokkaido in Japan, with disjunct populations occurring in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are known from 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 as far as southeastern Alaska in the Gulf of Alaska, blue king crabs are found in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). This disjunct, 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 were managed under the Bering Sea king crab Registration Area Q Pribilof District, which 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 Cape Newenham (58° 39' 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 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

3. **Stock structure** - Stock structure of blue king crabs in the North Pacific is largely unknown. To assess the potential relationship between blue king crab in the Pribilof Islands and St. Matthew, the author consulted the AFSC report entitled "Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans" by Spencer (personal communication). Per this document, aspects of blue king crab harvest and abundance trends, phenotypic characteristics, behavior, movement, and genetics will be considered. Is was also, noted that ~200 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.

   To address the potential for species interactions between blue king crab and red king crab as a potential reason for PIBKC shifts in abundance and distribution, we compared the spatial extent of both speices in the Pribilof Islands from 1975 to 2009 (Figure 1). 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 (Figure 1A). Spatially, the stations with co-occurance were all dominated by blue king crab and broadly distributed around the Pribilof Islands (Figure A). 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 max of 8 but they were equally dominated by both blue king crab ands red king crab sugggesting a direct overlap in distribution at the scale of a survey station (Figure 1A). Spatially during this time period, the red king crab dominated stations were dispersed around the Pribilof Islands (Figure B). Between 2001 and 2009 the blue king crab population has decreased dramatically while the red king crab have fluctuated (Figure 1B). Interstingly, the number of stations dominated by blue king crab is similar to those dominated by red king crab for both males and females suggesting continued competition for similar habitat (Figure 1A). Spatially the only stations dominated by blue king crab exist to the north and east of St. Paul Island (Figure C). It is noted that although the blue king crab protection measures also afford protection for the red king crab in this region, the red king crab stocks continue to fluctuate even considering 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). Red king crab are annual spawners with relatively higher fecundity and smaller sized (*ca.* 1.0 mm) eggs. 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 and 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 once 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 (NOAA 2005).

Longevity is unknown for the 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 (Figure 5). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season with an associated increase in effort to 110 vessels (ADF&G 2008). Following 1995, declines in the stock resulted in a closure from 1999 to present. The Pribilof blue king crab stock was declared overfished in September of 2002 and the Alaska Department of Fish and Game developed a rebuilding harvest strategy as part of the North

Pacific Fishery Management Council's (NPFMC) comprehensive rebuilding plan for the stock. 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 (NOAA 1995). Guideline harvest level (GHL) was 10 percent of the abundance of mature male or 20 percent of the number of legal males (ADF&G 2006).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 6) 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.

Blue king crab in the Pribilof District can occur as bycatch in the following crab fisheries: the eastern Bering Sea snow crab (*Chionoecetes opilio*), the eastern Bering Sea Tanner crab (*Chionoecetes bairdi*), the Bering Sea hair crab (*Erimacrus isenbeckii*), and the Pribilof red and blue king crab. In addition, blue king crab are caught in flatfish, sablefish, halibut, pollock, and Pacific cod fisheries.

Data

1. The standard survey time series data including an additional 20 nm strip on the eastern portion of the Pribilof District was updated through 2013 and the updated groundfish discards time series data through 2012 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2012/2013 data.

2. a. Total catch:
<u>Crab pot fisheries</u>
Retained pot fishery catches (live and deadloss landings data) are provided for 1973/1974 to 2012/2013 (Table 1), including the 1973/1974 to 1987/1988 and 1995/1996 to 1998/1999 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons blue king crab and red king crab were fished under the same GHL. There was no total allowable catch (TAC) and therefore zero retained catch in the 2012/2013 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. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was calculated from length frequency tables where the CL (mm) was converted to g using equation 1. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000329, B=3.175; females: A=0.114389, B=1.9192) and 2010 to 2011 (males and females: A=0.000508, B=3.106). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * CL(mm)^B \quad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (2)$$

Finally, weights were the product of average weight, CPUE, and total pot lifts in the fishery. To assess crab mortalities in these pot fisheries a 50% handling mortality rate is applied to these estimates.

Historical non-retained catch data are available from 1996/1997 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, limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here.

In 2012/2013, there were no Pribilof Islands blue king crab incidentally caught in crab fisheries (Table 2).

Groundfish pot, trawl, and hook and line fisheries

The 2012/2013 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 this year for Pribilof Islands blue king crab, only Area 513 was included. It is noted that in these earlier years groundfish non-retained crab catches for Pribilof Islands blue king crab may exist in Area 521 (and other areas) but the large number of St. Mathew Section Northern District blue crab in Area 521 would overestimate the blue king crab caught in groundfish fisheries. 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 discriminated by each year's survey proportions (Table 2). Prior to 1991data are only available in INPFC reports. Between 1991 and December 2001 bycatch was estimated using the "blend method". The blend process 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" process 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 current. 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, 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 (wt crab/wt groundfish) applied to groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates at the stock area. There are instances where no observer data is available and aggregation could 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 in the newly defined Pribilof stock are resulted in significantly different estimates of red king crab bycatch biomass in 2009/2010-2012/2013 (Tables 2- 3). In 2012/2013, using the new estimation method, 0.82 t of male and female blue king crab were caught in fixed gear (0.16 t) and trawl (0.67 t) gear groundfish fisheries. The targeted species in these fisheries were Pacific cod (*Gadus macrocephalus*) (19%), yellowfin sole (*Limanda aspera*) (78%), and flathead sole (*Hippoglossoides elassodon*) (3%) fisheries (Table 3). The catch was in non-pelagic trawls (81%) and longline (19%) fisheries. There was no bycatch attributed to pot fisheries. (Table 4). The discrepancy between the old and new methods highlights the problems attributing non –observed vessels from outside the stock boundaries. The analyses in this document use only the new method for 2009/2010 through 2012/2013 catch data.

c. Catch-at-length: NA

d. Survey biomass:
The 2013 NMFS EBS bottom trawl survey results (Daly et al. in press) are included in this SAFE report for the new Pribilof Islands blue king crab stock area definition (Tables 5 and 6, Figure 7). This new area was defined as a result of the new rebuilding plan and the concern that crab outside of the Pribilof District were not being accounted for in the assessment. The addition of the 20 nm strip resulted in a small effect on the time series. Annual differences between the previous time series and the new time series ranged from 0 to 9% (Figure 8). Abundance estimates of male and female crab are assessed for 5 mm length bins with shell condition for total abundances for each EBS stock (Figure 9 and 10). Weight (equation 1) and maturity (equation 3) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass.

Proportion mature male = $1/(1 + (3.726 * 10^{15}) * e^{((CL(mm)+2.5) * -0.332)}$

Proportion mature female = $1/(1 + (8.495 * 10^{13}) * e^{((CL(mm)+2.5) * -0.332)}$ (3)

Historical survey data are available from 1975 to the present (Tables 5 and 6). It should be noted that the survey data analyses were standardized in 1980.

Blue king crab were caught at 6 of the 77 stations in the Pribilof District; 6 stations in the high-density sampling area and zero stations in the standard-density sampling area in 2013 (Figure 11). Legal-sized males were caught at two stations north of St. George Island with a density of 62 to 219 crab nmi^{-2} (Appendix, Figures 11 and 12). The 2013 biomass estimate (± 95% CI) of legal-sized males was 190 ± 280 t and abundance was 0.07 ± 0.11 million crab, representing 38% of the total male abundance and well below the average of 1,222 ± 687 t for the previous 20 years.

Blue king crab mature males were caught at 2 of the 77 stations in the Pribilof District; 2 stations in the high-density sampling area and zero stations in the standard-density sampling area and 100% of the six mature males and three immature males caught were measured (Figure 12). One station accounted for 85% of the mature males in the survey (Figure 13). The mature male biomass estimate of 250 ± 391 t represents 94% of the total male biomass with 15 ± 28 t of immature male blue king crab estimated in the Pribilof District. All male blue king crab were captured in the Pribilof District north of St. George Island.

Six mature female blue king crab were caught in the Pribilof District high-density sampling area which extrapolated to a biomass estimate of 131 ±210 t and an abundance estimate of 0.11 ± 0.18 million crab, and represents 79% of the total female biomass. Immature female blue king crab were caught at three stations northeast of St. Paul Island in the Pribilof District high-density sampling area with a biomass estimate of 35 ± 45 t. Estimates of female biomass are imprecise due to the preference of these crab for rocky habitat which is difficult to sample with bottom trawls. Three of the six mature female blue king crab sampled in the Pribilof District were brooding eyed embryos, two had empty egg cases, and one was barren (Figure 14). The mature females with embryos had 75% full clutches. Female cohorts were apparent early in the time series been captured by the survey since the mid-2000s (Figure 15).

The centers of distribution for both males and female blue king crab are located within a 40 nm by 40 nm region east of St. Paul Island (Figure 16). The center of the blue king crab distribution moved to within 20 nm of the northeast side of St. Paul Island as the population abundance decreased in the 1980's before moving easterly the 1990's. Since then, the centers of distribution have been located at the northeastern edge of the distribution. In 2013, mature male and female centers of distribution were located approximately 20 nm south of St. Paul Island.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past although is currently not in development.

Calculation of MMB

To reduce the effect of high uncertainty in the survey based area swept estimates an average biomass across 3 years centered on the current year was used to calculate the MMB in the most recent year (Table 7, Figure 17). In addition, this average was weighted by the inverse variance of the survey biomass estimate to account for changes in variability among years. ***Therefore in this analysis the MMB was estimated by a three year moving average MMB weighted by the inverse variance.*** Figure 18 shows the three year running average of MMB_{mating} with confidence intervals and CVs used for the analyses in this SAFE. The survey time series with three year moving weighted averages for each major size class for males and females is presented in Table 7.

Calculation of the OFL

1. 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).

2. In Tier 4, 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. In Tier 4, the fishing mortality that, if applied over the long-term, would result in MSY is approximated by F_{MSY}^{proxy}. The MSY stock size (B_{MSY}) is based on mature male biomass at 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. The B_{MSY}^{proxy} represents the equilibrium stock biomass that provides maximum sustainable yield (MSY) to a fishery exploited at F_{MSY}^{proxy}. B_{MSY} can be estimated as the average biomass over a specified period that satisfies these conditions (i.e., equilibrium biomass yielding MSY by an applied F_{MSY}). This is also considered a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock. The current stock biomass reference point for status of stock determination is MMB_{mating}.

   The mature stock biomass ratio β where B/B_{MSY}^{prox} = 0.25 represents the critical biomass threshold below which directed fishing mortality is set to zero (Figure 19). The parameter α determines the slope of the non-constant portion of the control rule line and was set to 0.1. Values for α and β where based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where *B* is greater than β includes the product of a scalar (**γ**) and *M* (equations 5 and 6) where the default **γ** value is 1 and M for Bering Sea blue king crab is 0.18. The value of **γ** may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

   Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, the F_{OFL} control rule resulting 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}^{prox}; if current MMB at the time of mating drops below MSST, the stock is considered to be overfished.

3. Calculation of B_{MSY}^{prox}:
   The time period for establishing $B_{MSYproxy}$ was assumed to be representative of the stock being fished at an average rate near F_{MSY} fluctuating around B_{MSY}. The criteria to select the time period was based on 2011 CPT recommendations for estimating B_{MSY}. Previously, B_{MSY}^{prox} for Pribilof Islands blue king crab was calculated as the average MMB_{mating} from 1980 to 1984 and 1990 to 1997 to avoid time periods of low abundance possibly caused by high fishing pressure. In the previous assessment, an alternative time period from 1975 to 1979 was also considered because it represents the only period where a fishery was occurring where exploitation and MMB oscillated relatively consistently over time. During the remainder of the time series, the stock was either dropping under high exploitation or recovering during a no fishing period. This alternative time period was chosen by the CPT but the SSC recommended staying with the original time series. Considerations for choosing the time series 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 = MMB_{t+1} – 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. 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).

B. Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Figure 20) while total catch increased until 1980 before the fishery was closed in 1987 and increased again in 1995 before again closing in 1999 (Figure 22). The current F_{MSY}^{proxy} assume F=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 ln (recruits/MMB) dropped suggesting that exploitation rates at the levels of MMB present were not sustainable.

4. 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 F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure 19) where Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

Stock Status Level:	F_{OFL}:	
a. $B/B_{MSY}^{prox} > 1.0$	$F_{OFL} = \gamma \cdot M$	(4)
b. $\beta < B/B_{MSY}^{prox} \leq 1.0$	$F_{OFL} = \gamma \cdot M\ [(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(5)
c. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$	(6)

b. The MMB_{mating} projection is based on application of M from the 2013 NMFS trawl survey (July 15) to mating (February 15) and the removal of estimated retained, bycatch, and discarded catch mortality (equation 7). Catch mortalities are estimated from the proportion of catch mortalities in 2010/2011 to the 2011 survey biomass.

$$MMB_{survey} \cdot e^{-PM(sm)} – \text{(projected legal male catch OFL)-(projected non-retained catch)} \qquad (7)$$

where, MMB_{survey} is the mature male biomass at the time of the survey, $e^{-PM(sm)}$ is the survival rate from the survey to mating. PM(sm) is the partial M from the time of the survey to mating (8 months).

c. To project a total catch OFL for the upcoming crab fishing season, the F_{OFL} is estimated by an iterative solution that maximizes the projected F_{OFL} and projected catch based on the relationship of B to B_{MSY}^{prox}. B is approximated by MMB at mating (equation 7).

For a total catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the total crab biomass at the fishery (equation 8).

Projected Total Catch OFL = $[1 – e^{-Fofl}]$ · Total Crab $Biomass_{fishery}$ (8)

where $[1 – e^{-Fofl}]$ is the annual fishing mortality rate.

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as:

μ_{LMB} = [Total LMB retained and non-retained catch] / $LMB_{fishery}$ (9)

μ_{MMB} = [Total MMB retained and non-retained catch] / $MMB_{fishery}$ (10)

5. Specification of the retained catch portion of the total catch OFL:
   a. For a retained catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the legal crab biomass at the fishery (equation 11).

   Projected Retained Catch OFL = $[1 – e^{-Fofl}]$ · Legal Crab $Biomass_{Fishery}$ (11)

   where $[1 – e^{-Fofl}]$ is the annual fishing mortality rate.

6. Recommendations:
   For 2012/2013, *B_{MSY}^{prox} = 3,988t of MMB_{mating} derived as the mean MMB from 1980 to 1984 and 1990 to 1997*. The stock demonstrated highly variable levels of MMB during both of these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

   MMB_{mating} for 2013/2014 was estimated at 278 t for B_{MSY}^{prox}. The B/B_{MSY}^{prox} ratio corresponding to the biomass reference is 0.07. B/B_{MSY}^{prox} 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 2005/2006. This period was after a targeted fishery and did not include the most recent changes to the groundfish fishery that led to increased blue king crab bycatch. ***The author recommended OFL for 2013/2014 based on an average catch mortality is 1.16 t***. In 2012, an alternative to establish a biomass based OFL based on the existing control rule was applied to MMB and B_{MSY}^{prox} to derive an $F_{OFL} \leq F_{MSY}$ which was then applied to the total blue king crab biomass. This method was not preferred by either the CPT or SSC.

Calculation of the ABC

1. 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) will be considered as a recommended ABC below ABC_{max}. Additional uncertainty will be included in the application of the ABC by adding

the uncertainty components as $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$. For a Tier 5 stock a constant buffer of 10% is applied to the OFL.

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 2005/2006 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality.

2. List of variables related to scientific uncertainty considered in the OFL probability distribution:
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 distribution 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 0.75 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 are rather pre-specified.
- F_{msy} is assumed to be equal to γM when applying the OFL control rule while 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}.

Given the relative amount of information available for Pribilof Island's blue king crab, the author recommended ABC would include an additional σ_b of 0.4.

4. Recommendations:
   For 2013/2014, $F_{directed}$ = 0 and the total catch OFL based on catch biomass would maintain the conservation needs with this stock and acknowledge the existing non-directed catch mortality. In that case the ***ABC_{max}* based on a 10% buffer of the average catch between 1999/2000 and 2005/2006 would be 1.04 t.**

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,105 (4.64)	286 [A] (0.63)	0	0	0.18 (0.0004)	1.81 (0.004)	
2011/12	2,247 (4.95)	365 [B*] (0.80)	0	0	0.36 (0.0008)	1.16 (0.003)	1.04 (0.002)
2012/13	1,994 (4.39)	579 [C**] (1.28)	0	0	0.61 (0.0013)	1.16 (0.003)	1.04 (0.002)
2013/14		278 [D**] (0.61)				1.16 (0.003)	1.04 (0.002)

All units are tons (million pounds) of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2012/2013 and is hence overfished. Overfishing did not occur during the 2012/2013 fishing year.

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

Rebuilding Analyses

Rebuilding analyses results summary: Proposed Crab FMP and regulatory amendments were submitted for review by the Secretary in early 2013 since NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014.

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Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly, ADF&G, personal communications).

Year	Catch (count)	Catch (t)	Avg CPUE (legal crab count/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	0
1989/1990	0	0	0
1990/1991	0	0	0
1991/1992	0	0	0
1992/1993	0	0	0
1993/1994	0	0	0
1994/1995	0	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 to 2012/2013	0	0	0

Table 2. Non-retained total catch 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 the catches. Groundfish fishery data is not available prior to 1991/1992 and ADF&G catch data is not available prior to 1996/1997 (Bowers et al. 2011; D. Pengilly, ADF&G; J. Mondragon, NMFS). ***2012 calculation of bycatch using AKRO catch in areas database in areas 513, 514, 517, 521, 523, and 524 that overlap with the newly defined Pribilof Islands blue king crab district. ** NEW 2013 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the newly defined Pribilof Islands blue king crab district.**

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male non-retained (t)	Sublegal male (t)	Female (t)	All fixed (t)	All Trawl (t)
1991/1992				0.03	4.96
1992/1993				0.44	48.63
1993/1994				0.00	27.39
1994/1995				0.02	5.48
1995/1996				0.05	1.03
1996/1997	0.00	0.40	0.00	0.02	0.05
1997/1998	0.00	0.00	0.00	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	0.00	0.00	0.00	0.06	0.02
2001/2002	0.00	0.00	0.00	0.42	0.02
2002/2003	0.00	0.00	0.00	0.04	0.24
2003/2004	0.00	0.00	0.00	0.17	0.18
2004/2005	0.00	0.00	0.00	0.41	0.00
2005/2006	0.00	0.00	0.05	0.18	1.07
2006/2007	0.00	0.00	0.05	0.07	0.06
2007/2008	0.00	0.00	0.05	2.00	0.11
2008/2009	0.00	0.00	0.00	0.07	0.38
2009/2010	0.00	0.00	0.00	0.17	0.43
****2009/2010**				**1.04**	**0.17**
2010/2011	0.00	0.09	0.00	0.07	0.02
****2010/2011**				**0.05**	**0.05**
2011/2012	0.00	0.00	0.00	0.02	0.10
****2011/2012**				**0.06**	**0.01**
***2011/2012**				**0.35**	**0.01**
****2012/2013**	0.00	0.00	0.00	**0.08**	**0.535**

Table 3. Proportion by weight of the Pribilof Islands blue king crab bycatch among target species. Between 2003/2004 and 2011/2012 crab fishing seasons the data are from area 513 only. ****Years in bold use the new 2013 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the newly defined Pribilof Islands blue king crab district.** Fisheries target species that caught blue king crab but made up less than 1% of the blue king crab bycatch across all years were not shown in the table and included pollock-bottom trawl, pollock-midwater trawl, halibut, and arrowtooth flounder.

	yellowfin sole	Pacific cod	flathead sole	rocksole	sablefish		TOTAL (# crabs)
Crab fishing season	%	%	%	%	%		
2003/2004	47	22	31				252
2004/2005		100					259
2005/2006		97	3				757
2006/2007	54	20		26			96
2007/2008	3	96	1				2,950
2008/2009	77	23					295
2009/2010	51	39	10				487
****2009/2010**	**4**	**92**	**2**		**2**		**3,147**
2010/2011		86	14				256
****2010/2011**		**59**	**38**		**<1**	**3**	**128**
2011/2012		26		74			117
****2011/2012**		**99**			**<1**	**<1**	**67**
****2012/2013**	**78**	**19**	**3**		**<1**		**406**

Table 4. Proportion by weight of the Pribilof Islands blue king crab bycatch from area 513 among gear types between 2003/2004 and 2011/2012 crab fishing seasons. ***2012 calculation of bycatch using AKRO catch in areas database in areas 513, 514, 517, 521, 523, and 524 that overlap with the Pribilof Island District. **Years in bold use the new 2013 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the newly defined Pribilof Islands blue king crab district.**

Crab fishing season	hook and line %	non-pelagic trawl %	pot %	pelagic trawl %	TOTAL (# crabs)
2003/04	21	79	0		252
2004/05	99	1	0		259
2005/06	18	3	79		757
2006/07	20	20	0		96
2007/08	1	3	95		2,950
2008/09	23	77	0		295
2009/10	21	61	18		487
****2009/10**	**4**	**9**	**87**	**<1**	**3,147**
2010/11	4	14	83		256
****2010/11**	**29**	**38**	**33**	**<1**	**128**
2011/12	22	78	0		117
***2011/12**	**95**	**2**	**0**	**3**	**494**
**2011/12	**94**	**6**	**0**	**<1**	**67**
**2012/13	**19**	**81**	**0**	**0**	**406**

Table 5. Pribilof Islands District blue king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey with no running average. These data are estimated using the new stock boundaries established in 2012 which included a 20 nm column to the east of the previous stock boundary definition.

Year	Mature Male Abundance	Mature male biomass @ survey t	Mature male biomass @ mating t	Legal Male biomass @ survey t	Total male biomass @ survey t	Total female biomass @ survey t
1975/1976	14955818	33862	29432	24037	41292	12172
1976/1977	3568103	9573	5752	8585	13333	5770
1977/1978	13043983	38756	32093	36706	42137	13572
1978/1979	6140638	15798	11450	12291	18315	6492
1979/1980	5232918	12974	9081	10843	14275	4097
1980/1981	5432065	14253	8075	12163	16050	63713
1981/1982	3921734	10744	5735	9686	13014	9911
1982/1983	2344203	6691	4113	6241	7740	9376
1983/1984	1851301	4919	3478	4069	5795	10248
1984/1985	674376	1761	1452	1446	1860	2580
1985/1986	428076	959	635	687	995	523
1986/1987	480198	1368	1120	1340	1372	2431
1987/1988	903180	2659	2089	2529	2833	913
1988/1989	237868	766	690	766	921	717
1989/1990	239948	752	677	752	1914	1746
1990/1991	1738237	3259	2934	1549	5376	3811
1991/1992	2014086	4266	3839	3025	5521	2776
1992/1993	1935278	3995	3573	2761	5635	2649
1993/1994	1875500	4144	3718	2913	5136	2092
1994/1995	1263447	3028	2724	2491	3578	4858
1995/1996	3139328	7753	6379	6365	8616	4843
1996/1997	1712015	4221	3394	3522	4899	5585
1997/1998	1201296	2940	2425	2515	3288	3028
1998/1999	967097	2545	2061	2283	3175	2182
1999/2000	617258	1573	1414	1297	1719	2868
2000/2001	725050	1902	1712	1588	2005	1462
2001/2002	522239	1454	1309	1329	1533	1817
2002/2003	225476	618	557	588	618	1401
2003/2004	228897	638	575	610	656	1307
2004/2005	47905	97	87	44	130	123
2005/2006	91932	313	281	313	610	847
2006/2007	50638	137	124	115	210	558
2007/2008	100295	254	228	170	417	257
2008/2009	18256	42	37	42	235	672
2009/2010	248626	452	407	170	684	625
2010/2011	138787	322	290	202	420	440
2011/2012	165525	461	415	399	461	37
2012/2013	272233	644	579	459	809	237
2013/2014	104361	250		190	265	166

Table 6. CVs for Pribilof Islands District blue king crab abundance, mature biomass, legal male biomass, and totals estimated based on the NMFS annual EBS bottom trawl survey with no running average. These data are estimated using the new stock boundaries established in 2012 which included a 20 nm column to the east of the previous stock boundary definition.

Year	Mature Male Abundance	Mature males @ survey CV	Legal Males @ survey CV	Total males @ survey CV	Total females @ survey CV
1975/1976	0.50	0.50	0.50	0.48	0.64
1976/1977	0.42	0.41	0.42	0.47	0.89
1977/1978	0.74	0.77	0.78	0.73	0.87
1978/1979	0.50	0.56	0.64	0.51	0.72
1979/1980	0.27	0.26	0.25	0.27	0.44
1980/1981	0.32	0.30	0.28	0.31	0.89
1981/1982	0.17	0.17	0.17	0.17	0.45
1982/1983	0.18	0.19	0.19	0.17	0.67
1983/1984	0.19	0.18	0.17	0.19	0.78
1984/1985	0.23	0.23	0.25	0.23	0.38
1985/1986	0.28	0.27	0.28	0.26	0.45
1986/1987	0.31	0.30	0.31	0.30	0.90
1987/1988	0.41	0.41	0.41	0.40	0.53
1988/1989	0.51	0.53	0.53	0.46	0.47
1989/1990	0.62	0.64	0.64	0.55	0.50
1990/1991	0.44	0.42	0.38	0.43	0.37
1991/1992	0.36	0.39	0.45	0.37	0.38
1992/1993	0.42	0.42	0.45	0.43	0.46
1993/1994	0.31	0.31	0.30	0.30	0.40
1994/1995	0.34	0.35	0.35	0.34	0.44
1995/1996	0.54	0.54	0.54	0.56	0.42
1996/1997	0.28	0.27	0.27	0.28	0.49
1997/1998	0.29	0.28	0.27	0.29	0.41
1998/1999	0.25	0.25	0.25	0.25	0.39
1999/2000	0.33	0.34	0.35	0.33	0.47
2000/2001	0.30	0.30	0.31	0.30	0.46
2001/2002	0.71	0.73	0.76	0.73	0.72
2002/2003	0.47	0.51	0.52	0.51	0.78
2003/2004	0.39	0.40	0.41	0.39	0.73
2004/2005	0.56	0.58	1.00	0.46	0.50
2005/2006	0.71	0.71	0.71	0.59	0.61
2006/2007	0.57	0.60	0.70	0.46	0.67
2007/2008	0.85	0.80	0.73	0.66	0.71
2008/2009	1.00	1.00	1.00	0.80	0.70
2009/2010	0.73	0.71	0.60	0.70	0.82
2010/2011	0.48	0.46	0.48	0.52	0.60
2011/2012	0.79	0.84	0.89	0.84	0.67
2012/2013	0.80	0.74	0.64	0.79	0.64
2013/2014	0.86	0.80	0.75	0.75	0.65

Table 7. Three year weighted (inverse variance) running average of Pribilof Islands District blue king crab abundance, mature biomass, and legal male biomass based on the NMFS annual EBS bottom trawl survey.

Year	Mature Male Abundance	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Mature females @ survey t
1975/1976	3999214	10821	6349	9865	3194
1976/1977	4200609	11280	6580	10247	3508
1977/1978	4234074	11020	6650	9579	3502
1978/1979	5517339	13598	9534	11191	3206
1979/1980	5404179	13645	8781	11402	3103
1980/1981	4311444	11615	6445	10304	3466
1981/1982	2898311	8353	4940	7783	8586
1982/1983	2300630	6214	4129	5253	8625
1983/1984	1017736	2686	2205	2291	2805
1984/1985	614303	1401	950	1030	636
1985/1986	508803	1223	852	925	647
1986/1987	475461	1133	772	853	590
1987/1988	369370	1165	1010	1153	558
1988/1989	278353	901	818	902	589
1989/1990	261166	879	792	931	633
1990/1991	362449	1250	1126	1206	1057
1991/1992	1897982	3766	3385	1941	1908
1992/1993	1930678	4139	3713	2897	1733
1993/1994	1550754	3575	3210	2714	1767
1994/1995	1547448	3632	3265	2816	2267
1995/1996	1521470	3713	3185	3085	4694
1996/1997	1428799	3480	2851	2952	3565
1997/1998	1136930	2943	2396	2590	2283
1998/1999	838049	2166	1865	1848	2239
1999/2000	752767	1948	1713	1639	1737
2000/2001	648723	1696	1526	1422	1740
2001/2002	336836	954	859	905	1490
2002/2003	237187	658	592	628	1447
2003/2004	72140	138	124	71	127
2004/2005	67024	134	120	70	142
2005/2006	52721	119	107	68	147
2006/2007	60960	171	154	147	309
2007/2008	29890	67	60	67	316
2008/2009	23986	57	51	70	308
2009/2010	28621	69	61	80	419
2010/2011	154495	357	322	195	26
2011/2012	153347	364	327	238	40
2012/2013	139469	337	482	259	40
2013/2014	128996	309		241	110

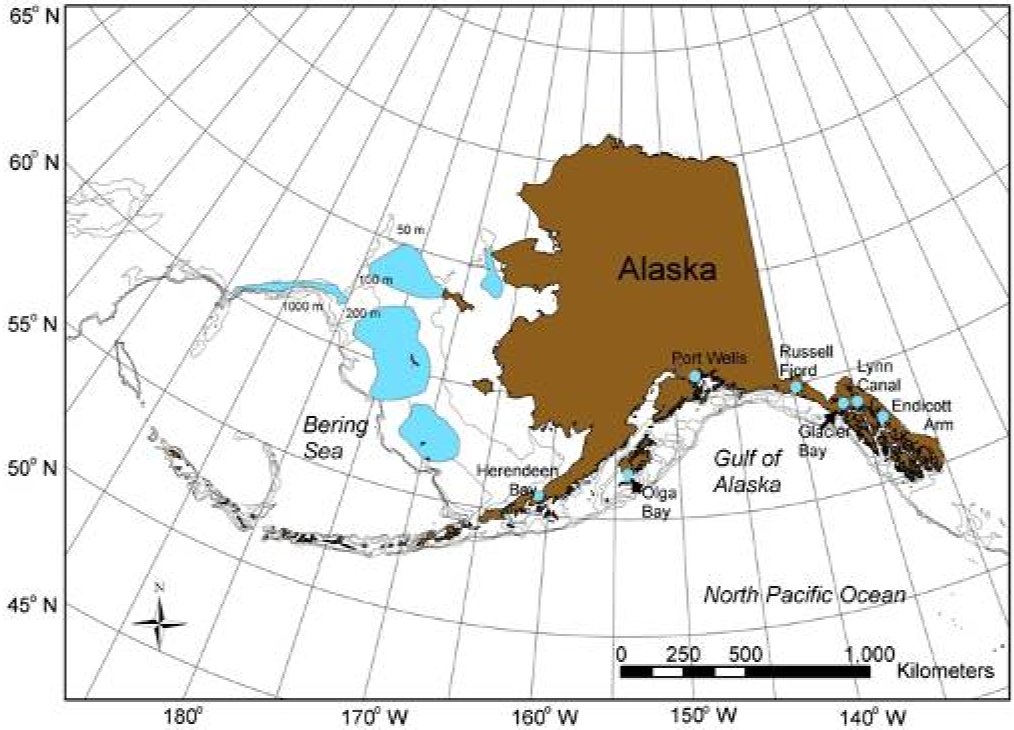

Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

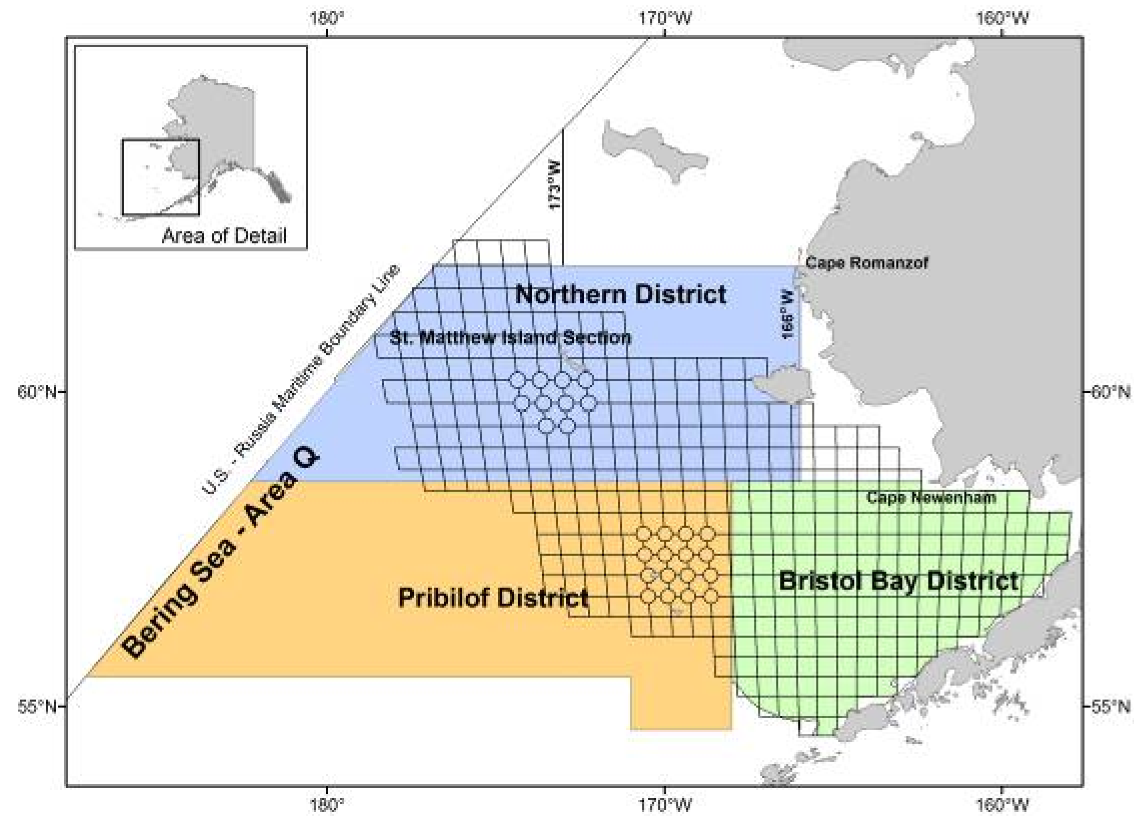

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District. This figure does not show the additional 20 nm strip considered this year for biomass and catch data in the Pribilof District.

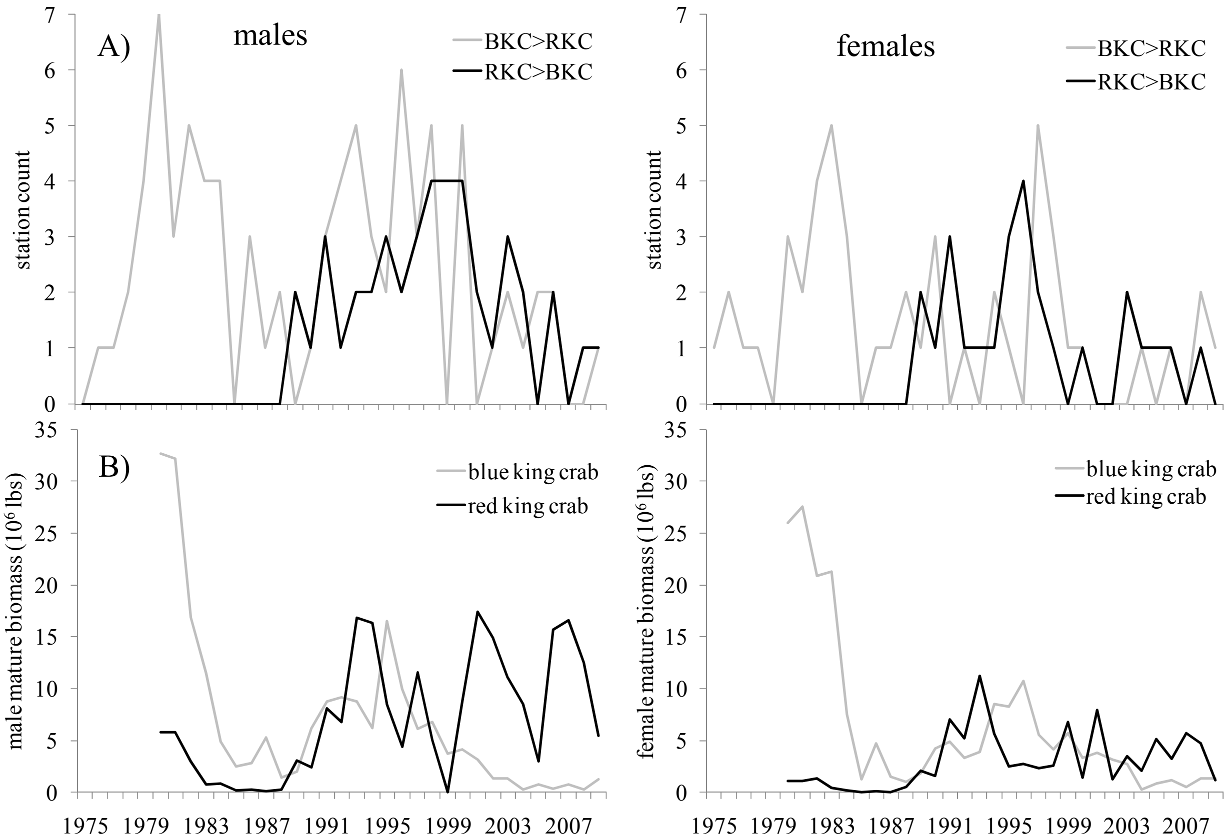

Figure 1. Time series of overlap between blue king crab and red king crab for males and females in the eastern Bering Sea showing A) the number of stations with blue king crab (BKC) or red king crab (RKC) as the dominant species and B) the mature biomass of both species.

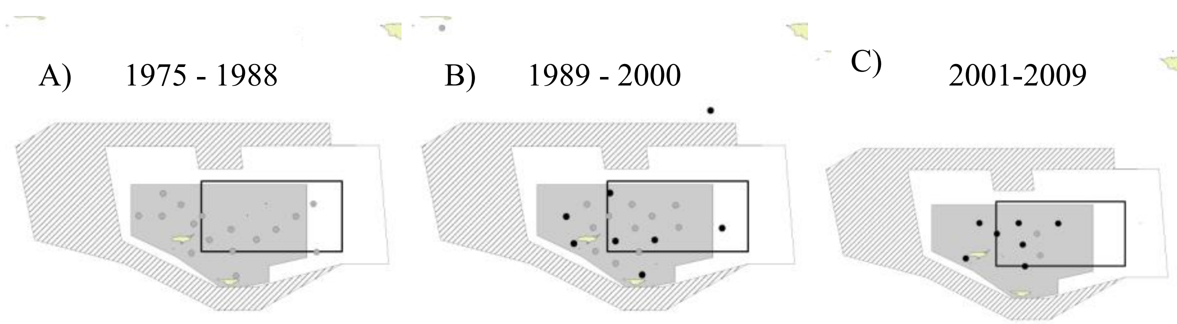

Figure 4. Spatial distribution of stations where there is overlap between blue king crab and red king crab males showing the dominant species (blue king crab=gray circles; red king crab=black circles) corresponding to time periods of major changes in biomass of both species.

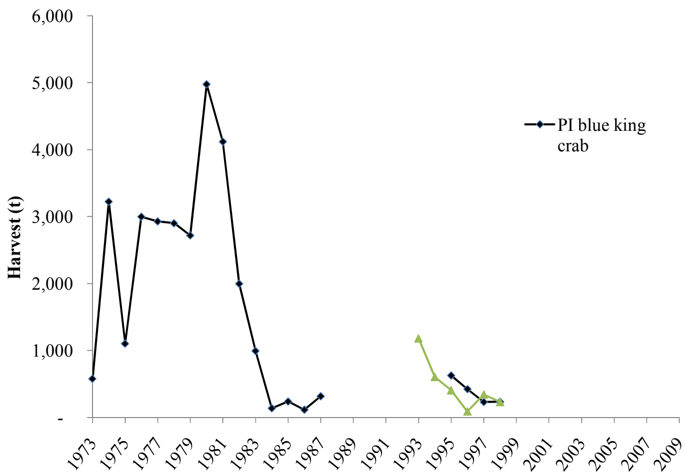

Figure 5. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

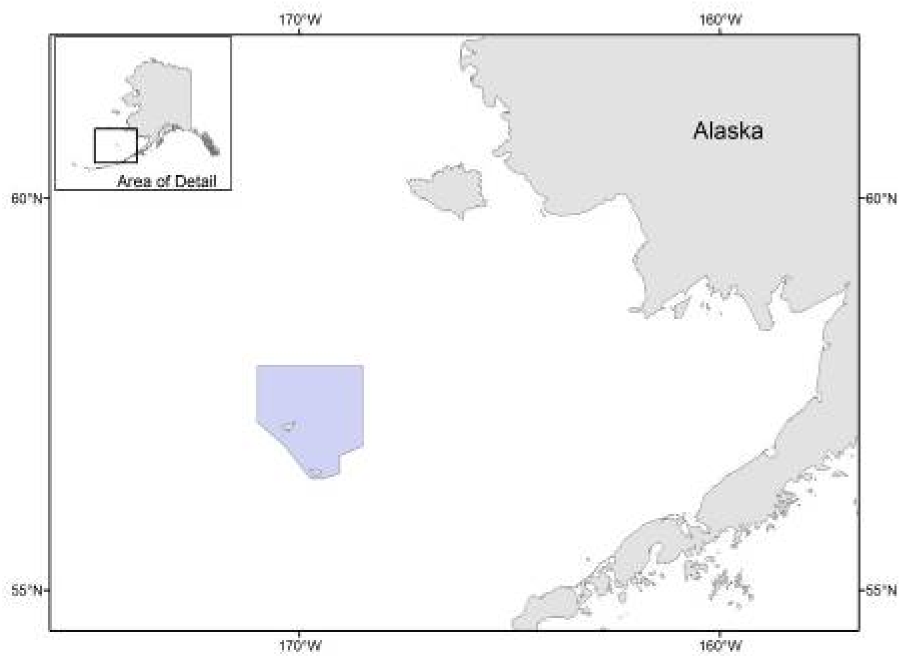

Figure 6. The shaded area shows the Pribilof Islands Habitat Conservation area. Trawl fishing is prohibited year-round in this zone.

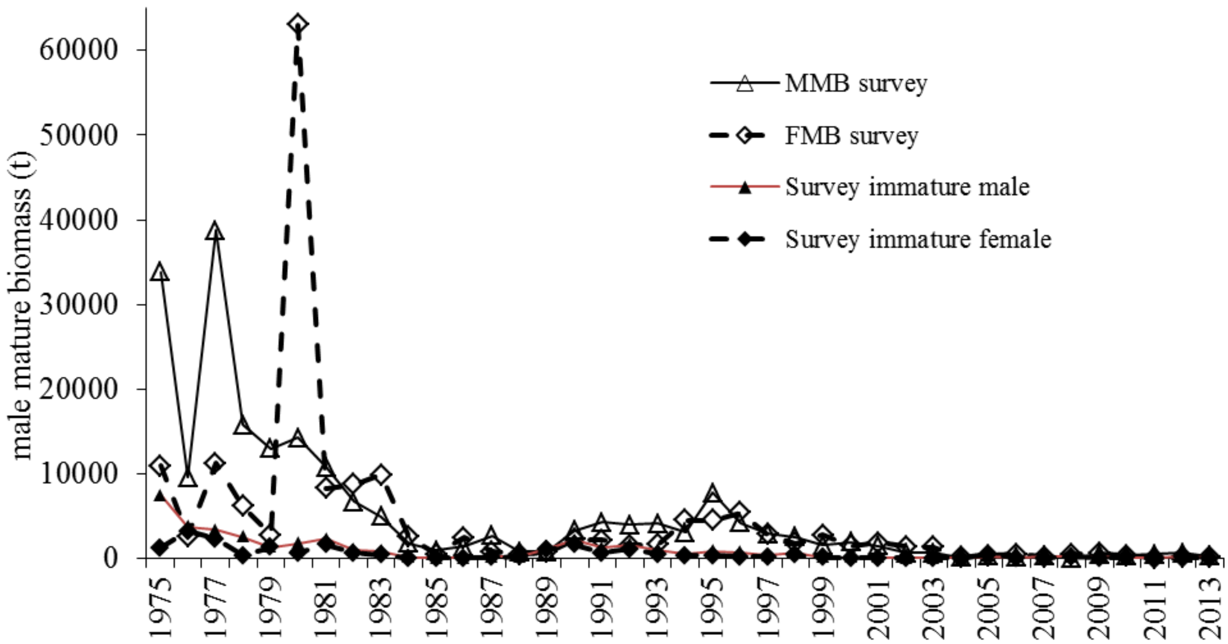

Figure 7. Time series of Pribilof Islands blue king crab estimated from the NMFS annual EBS bottom trawl survey.

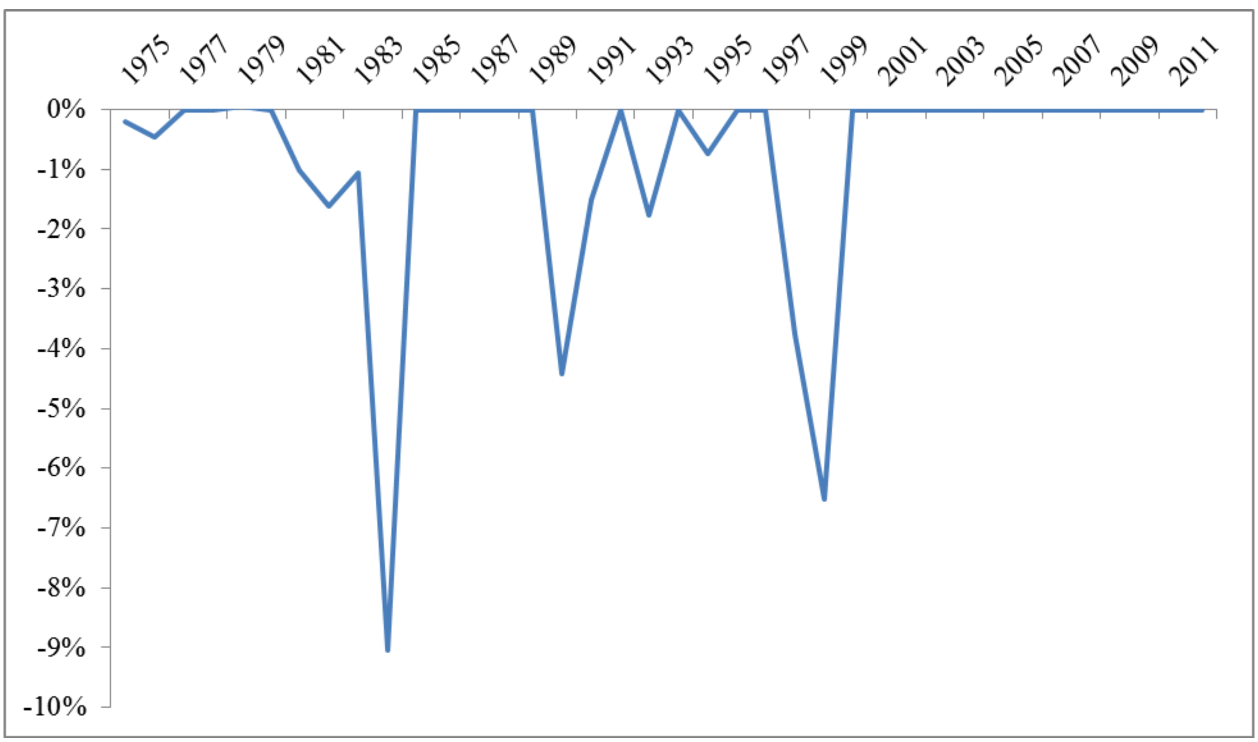

Figure 8. Percent change in MMB between the previous survey biomass estimate and the new estimate which includes an additional region 20 nm on the eastern edge of the Pribilof District.

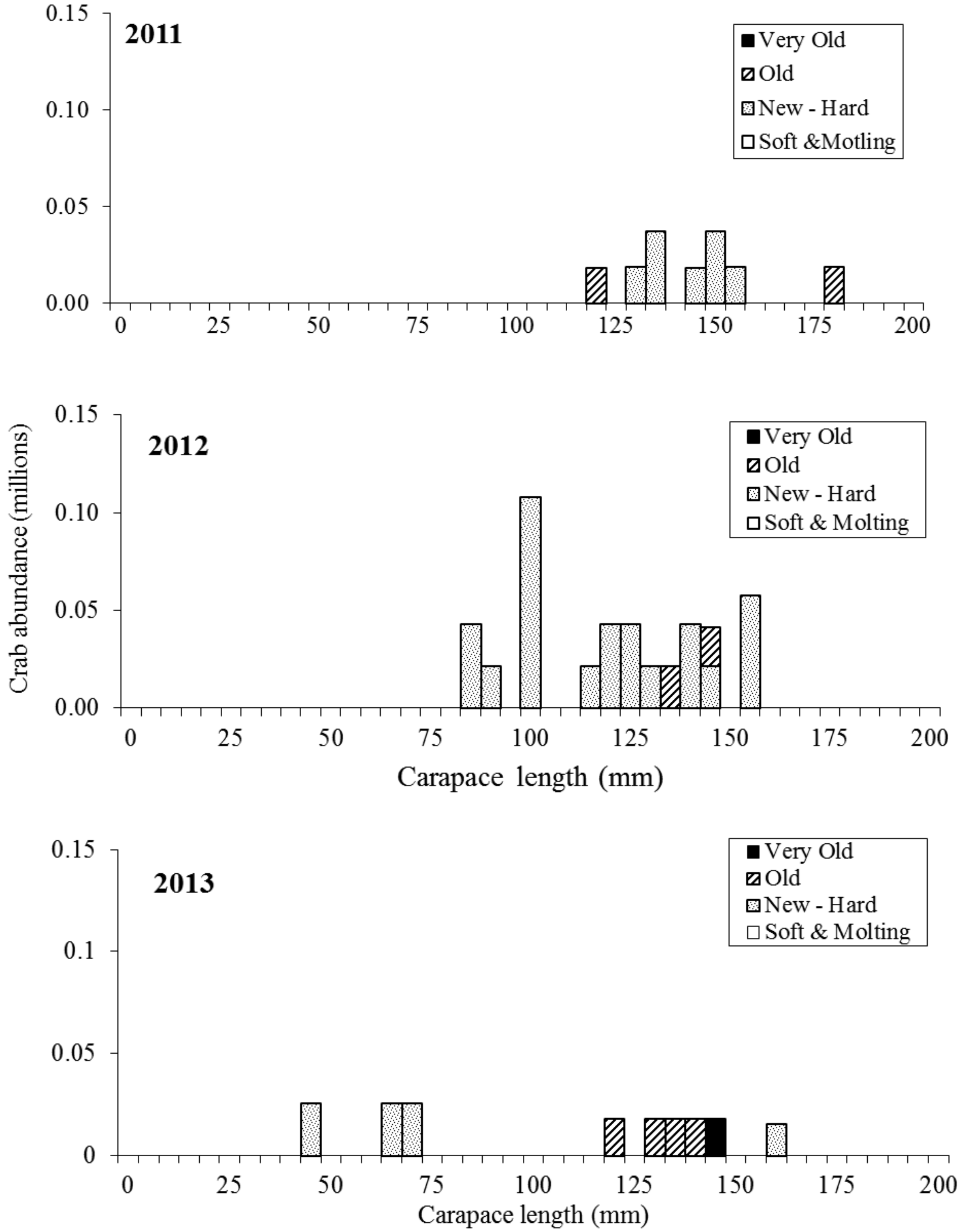

Figure 9. Distribution of Pribilof Island blue king crab in 5 mm length bins by shell condition for the last 3 surveys.

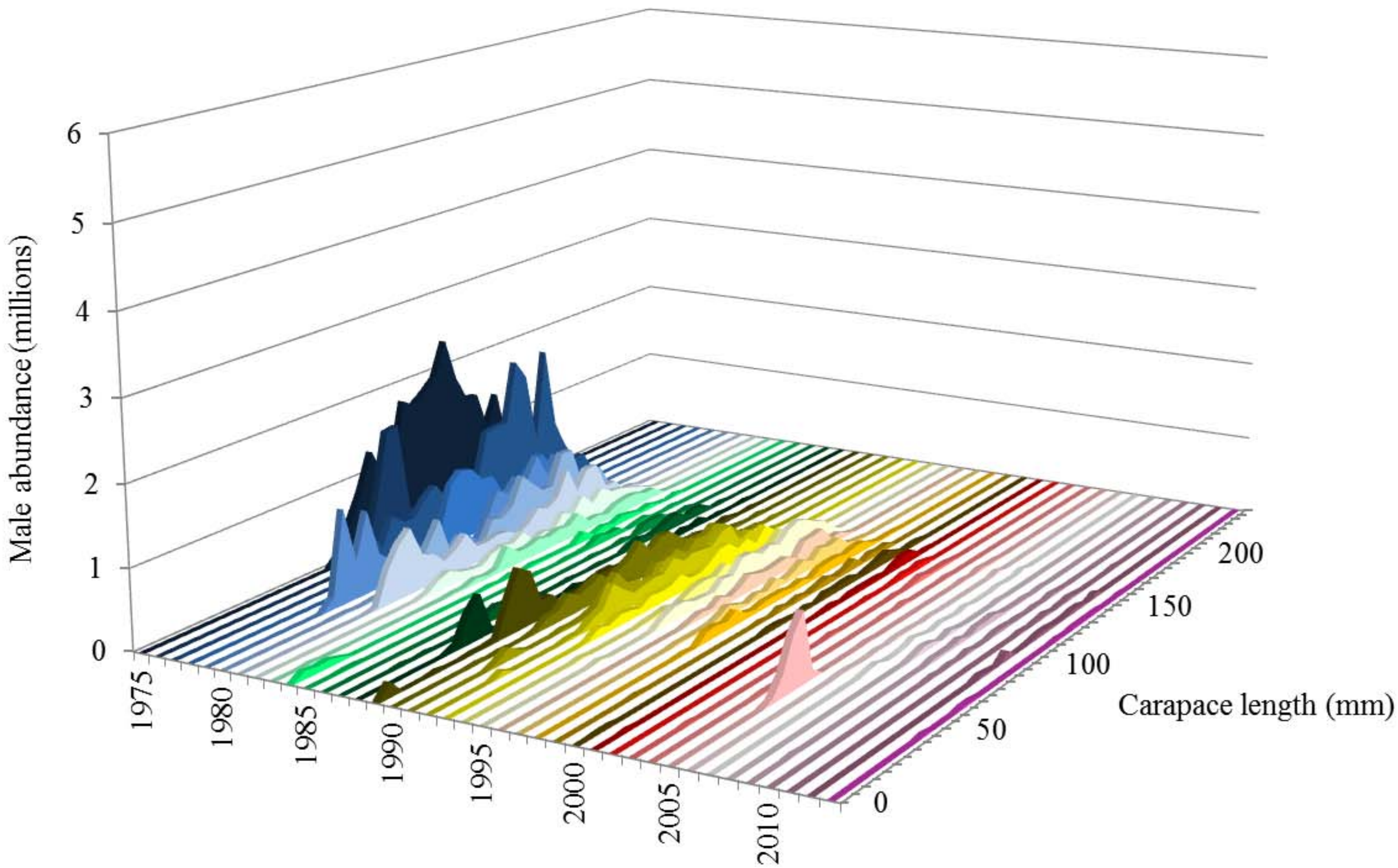

Figure 10. Size frequency by 5 mm length classes of Pribilof Islands male blue king crab (*Paralithodes camtschaticus*) from 1975 to 2013.

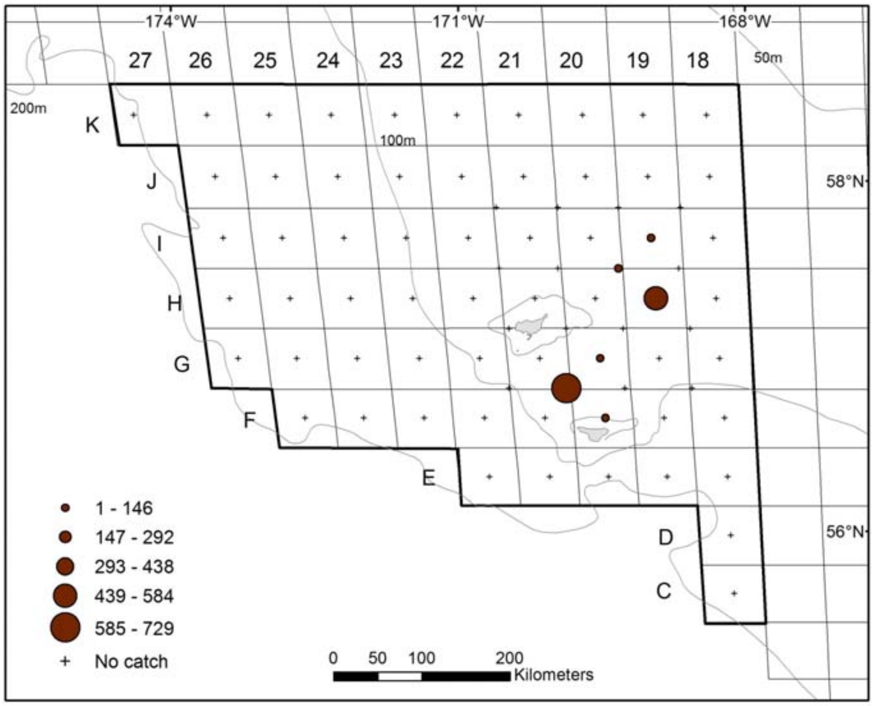

Figure 11. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2013 EBS bottom trawl survey.

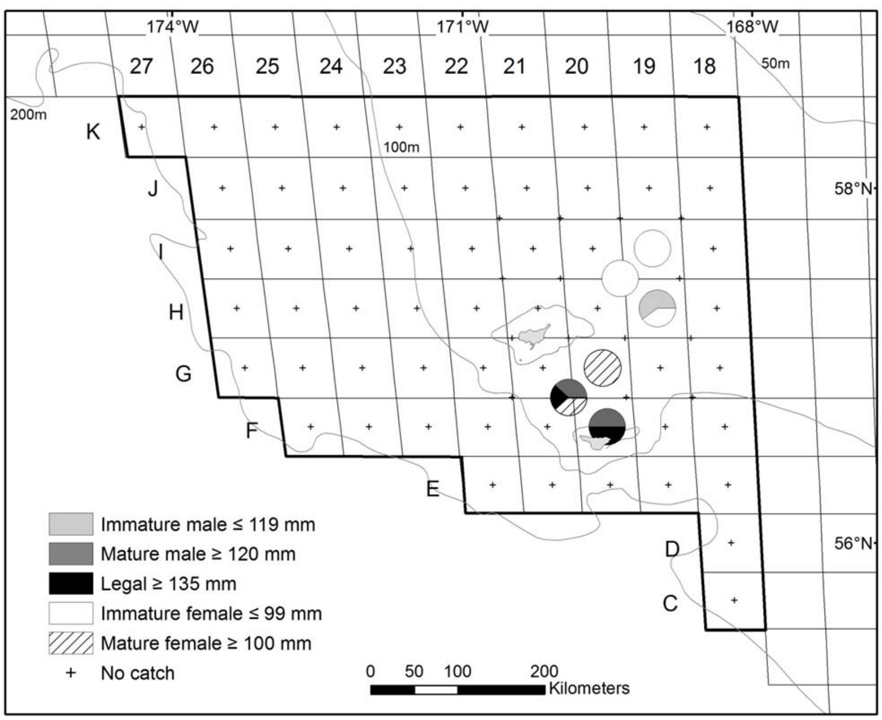

Figure 12. 2013 EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

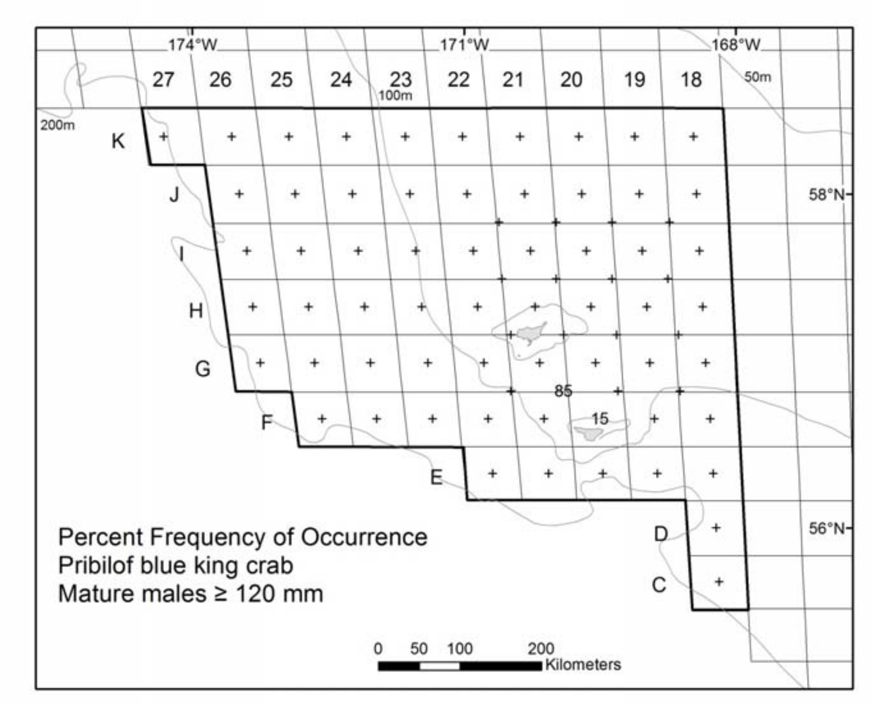

Figure 13. 2013 EBS bottom trawl survey frequency of occurrence of mature male blue king crab in the Pribilof District

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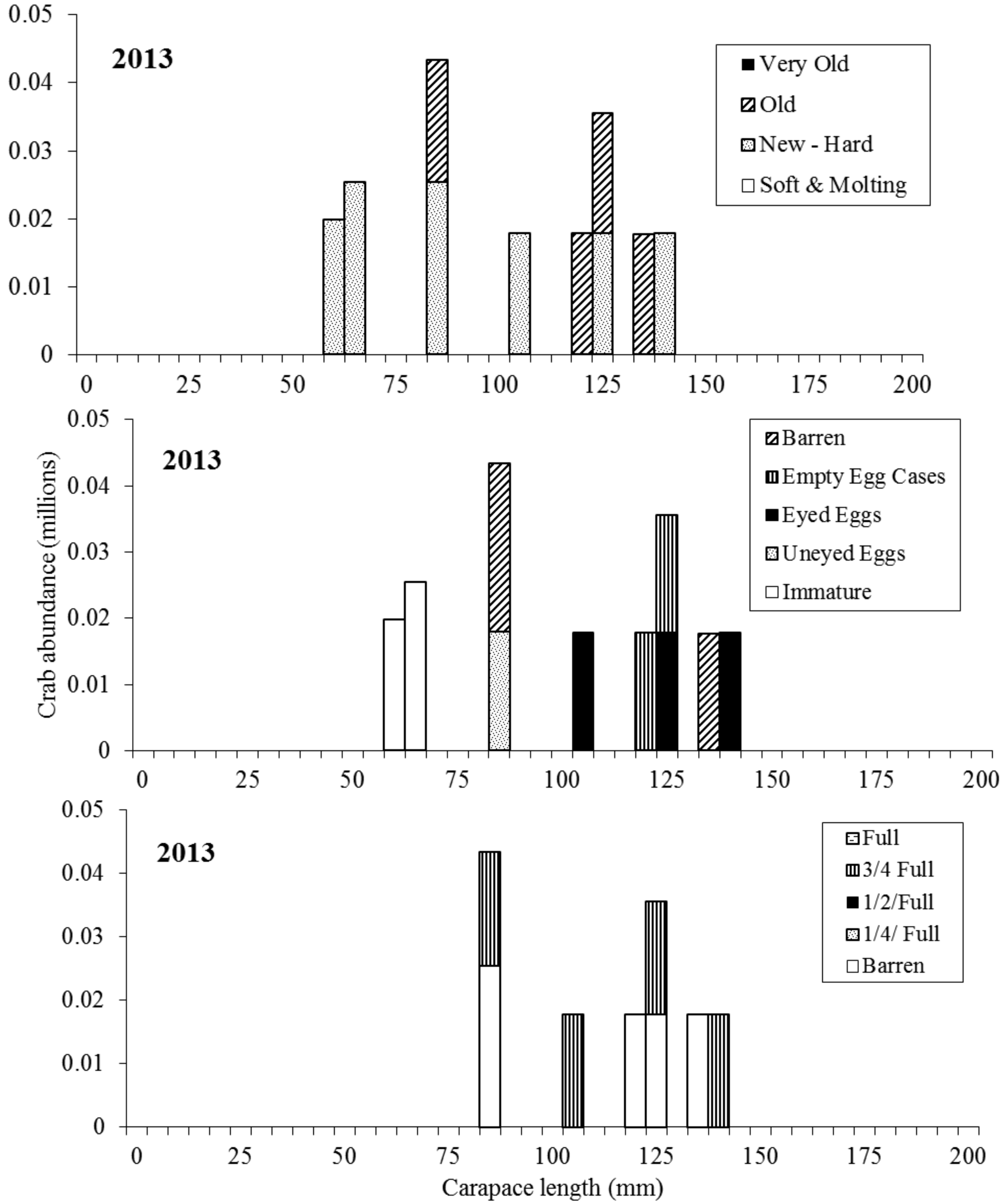


Figure 14. Size-frequency by shell condition, egg condition, and clutch fullness of Pribilof District female blue king crab (*Paralithodes platypus*) by 5 mm length classes in 2013.

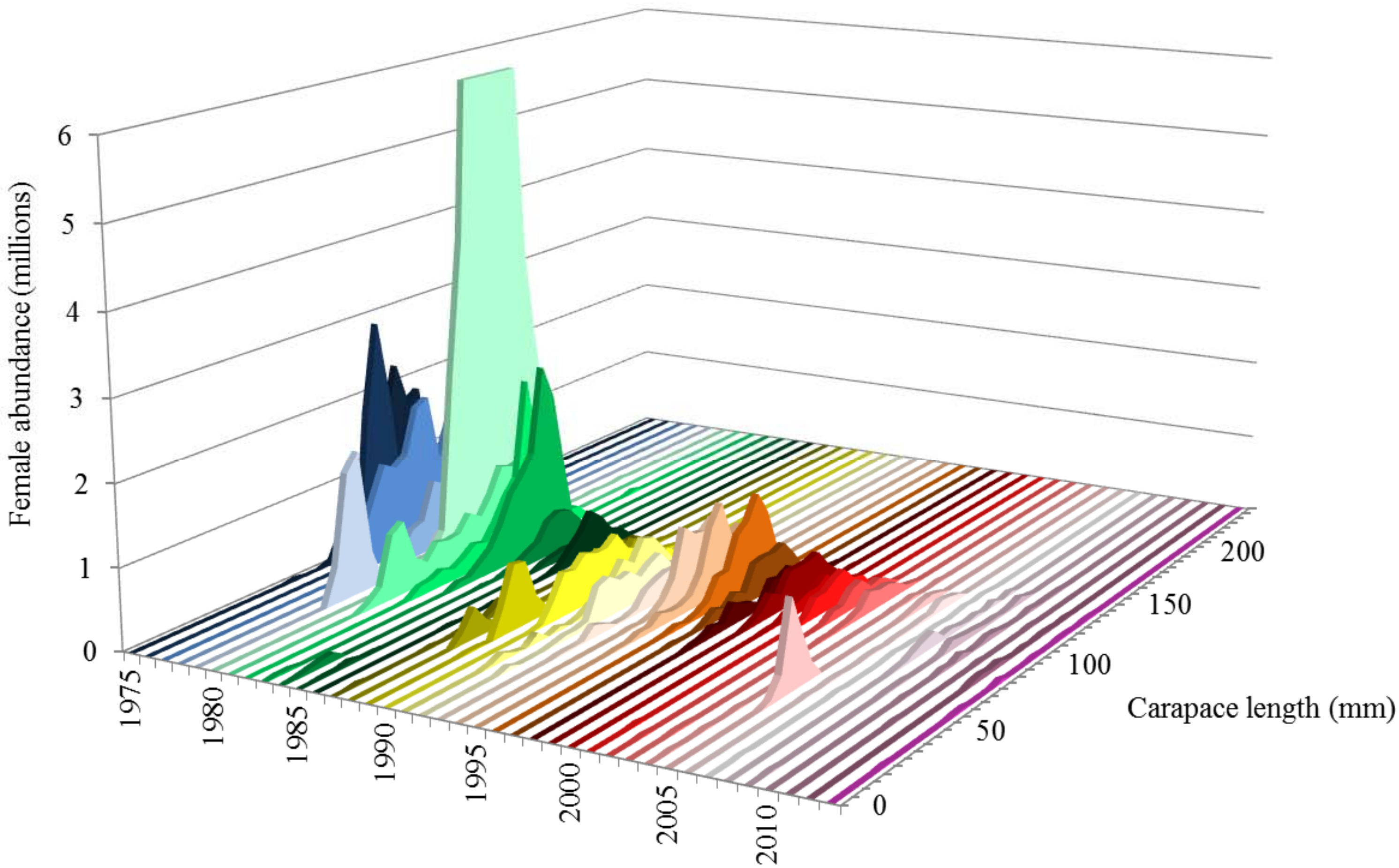


Figure 15. Size frequency by 5 mm length classes of Pribilof Islands female blue king crab (*Paralithodes camtschaticus*) from 1975 to 2013.

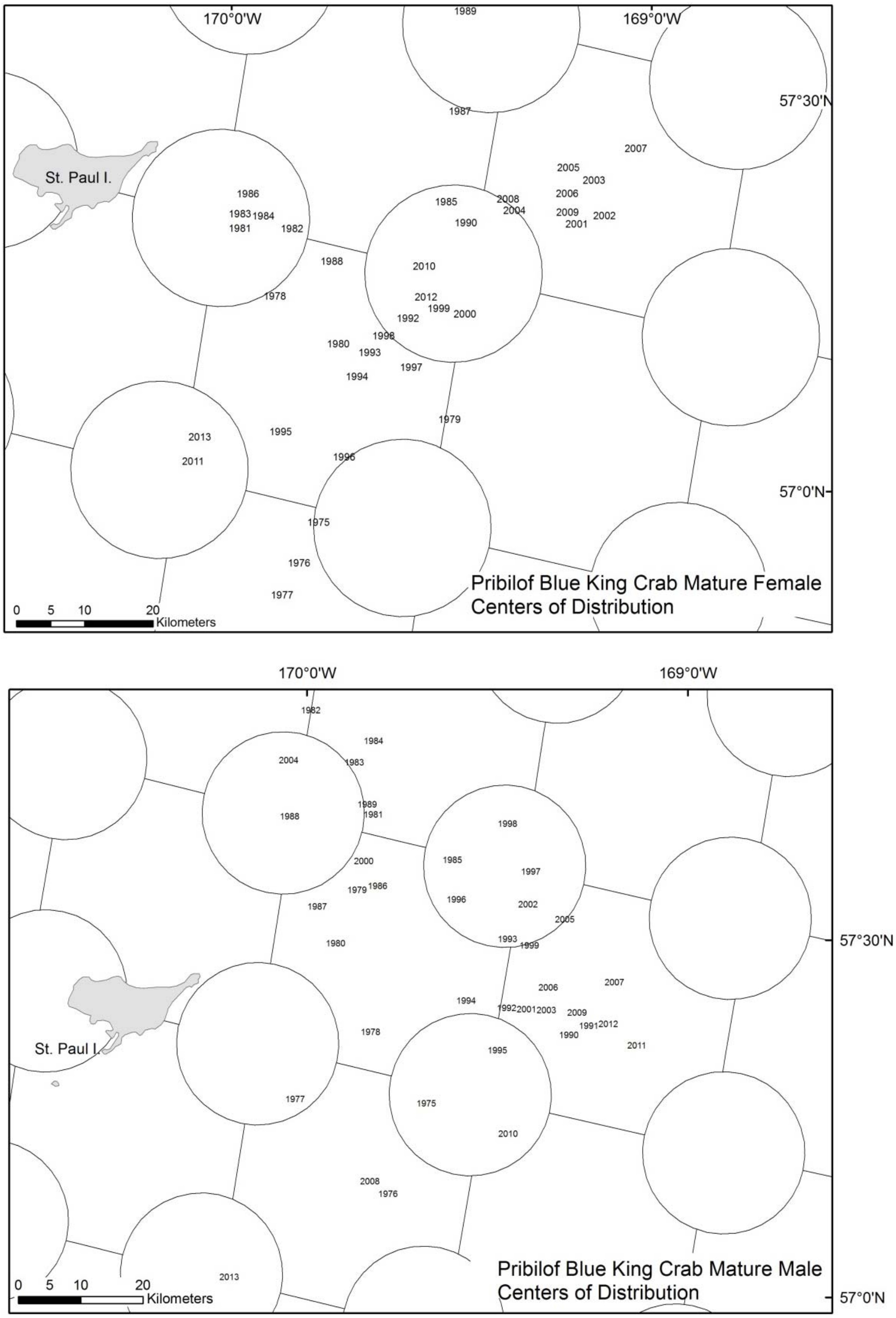


Figure 16. Centers of stock distribution of Pribilof Islands female and male blue king crab (*Paralithodes platypus*) from 1975 to 2013.

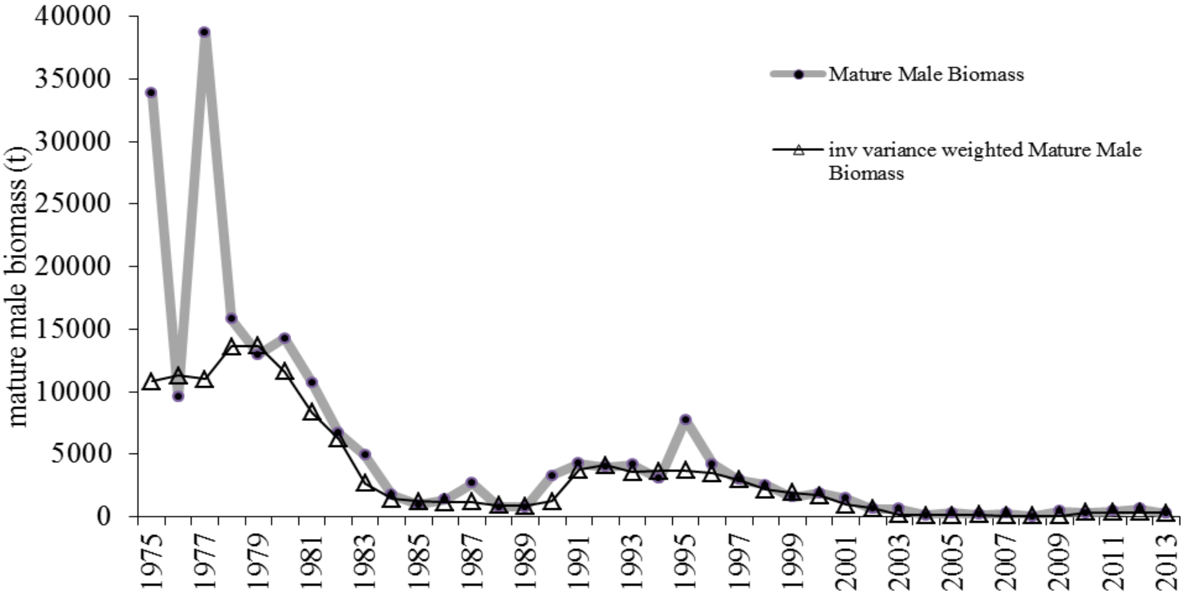


Figure 17. Time series comparison of MMB and the three year running average MMB at the time of the survey.

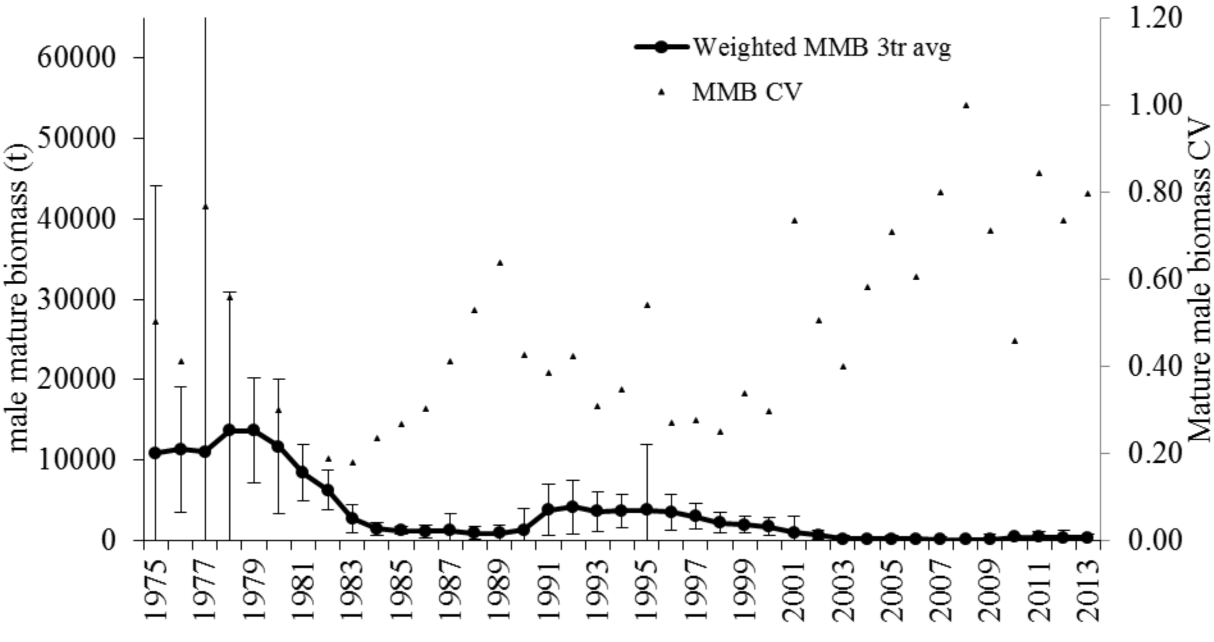


Figure 18. Time series of Pribilof Island blue king crab 3 year moving averaged mature male biomass (95% C.I.) and mature male biomass CV estimated from the NMFS annual EBS bottom trawl survey.

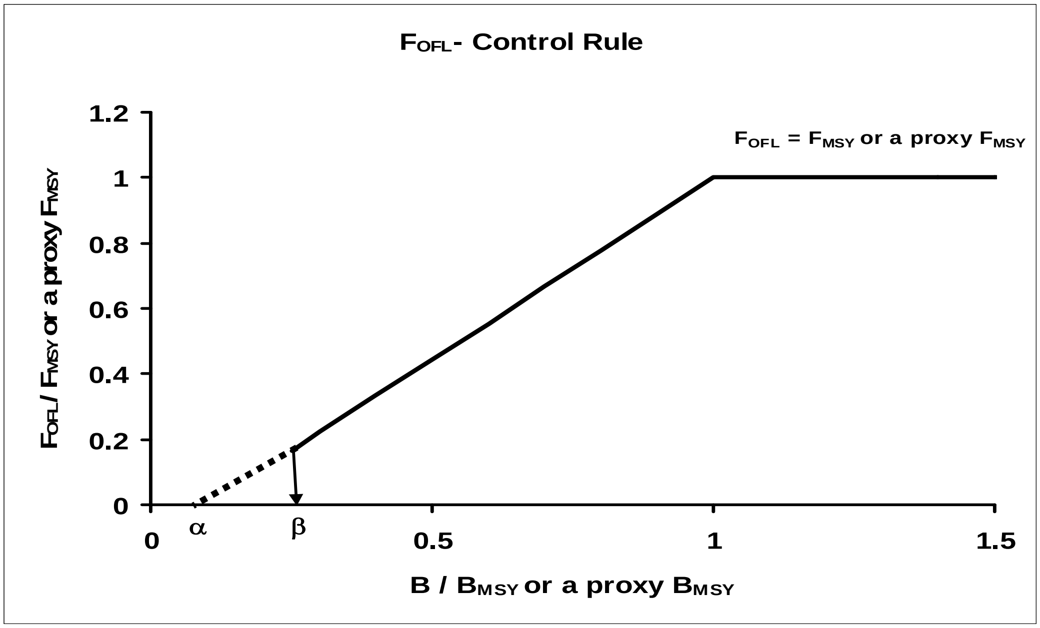


Figure 19. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

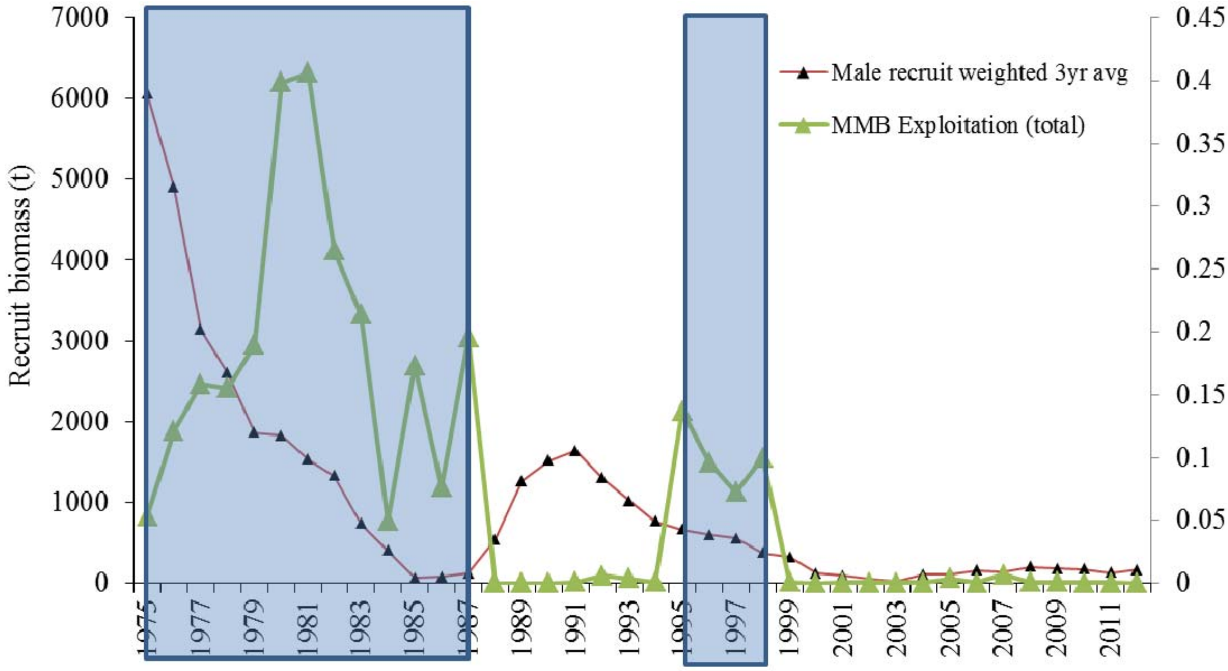


Figure 20. Time series of survey estimated recruit biomass (males 120-134 mm) and exploitation rate (based on total catch) of mature male biomass. The shaded region represents a period where commercial removals were occurring.

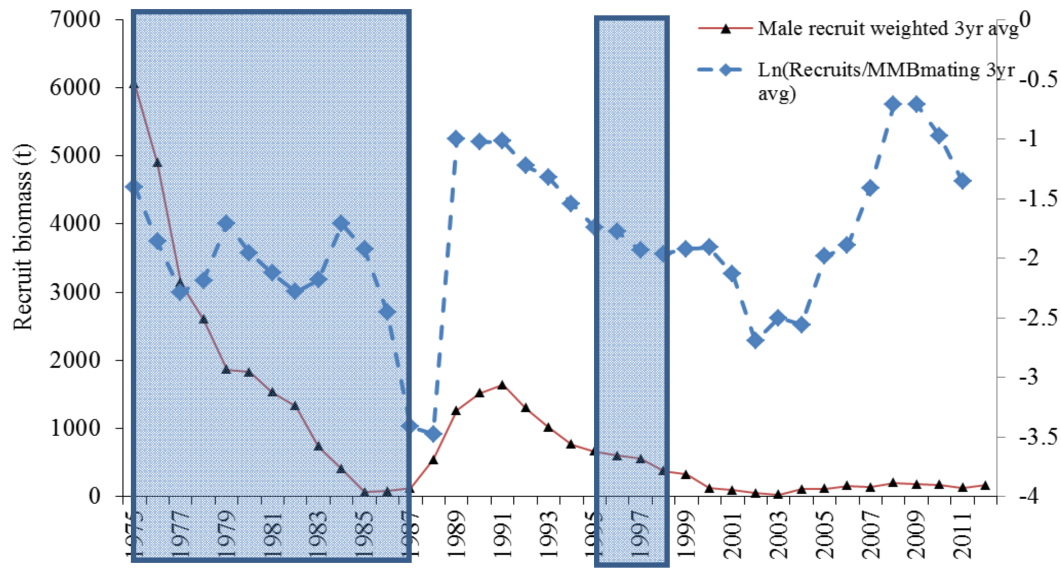


Figure 21. Time series of survey estimated recruit biomass (males 120-134 mm) and ln(Recruits/MMB). The shaded region represents a period where commercial removals were occurring.

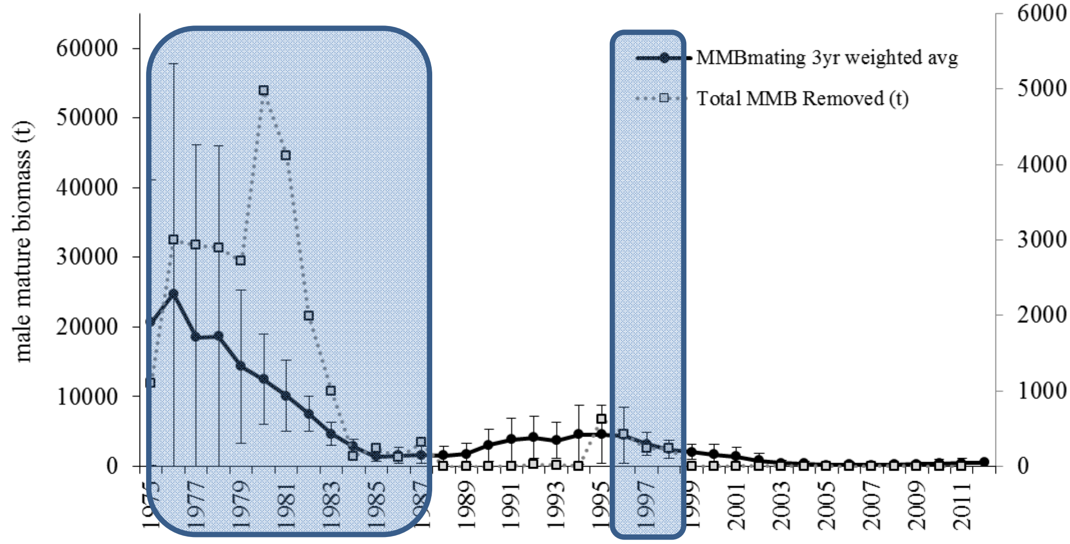


Figure 22. Time series of survey estimated Pribilof Island blue king crab 3 year moving averaged mature male biomass at mating (95% C.I.) and total catch removals.

BACKTESTING and CURRENT-YEAR FORECAST (NOWCAST) RESULTS

Fig. 1a: Gold king crab VAR(3) model and data 1991-2012 with three price series based on COAR wholesale values for gold king crab (plot), TPIS king crab import price index, and TPIS king crab export price index. The regression runs through 2013 with 90% 1-step forecasts for 2011 and 2012, where the latter is conditioned on Jan-July 2013 average values for TPIS series. The expected values of each forecast are represented by squares in the forecast intervals for each year. All values are in 2012 dollars per pound.

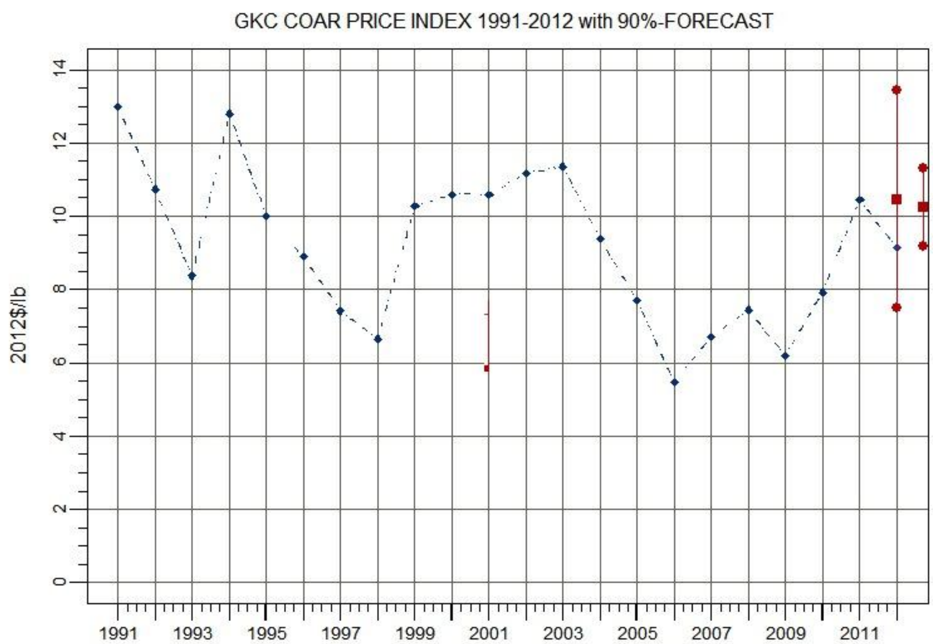


Fig. 1b: Red king crab VAR(3) model and data 1991-2012 with three price series based on COAR wholesale values for red king crab (plot), TPIS king crab import price index, and TPIS king crab export price index. The regression runs through 2013 with 90% 1-step forecasts for 2011 and 2012 where the latter is conditioned on Jan-July 2013 average values for TPIS series. The expected values of each forecast are represented by squares in the forecast intervals for each year. All values are in 2012 dollars per pound.

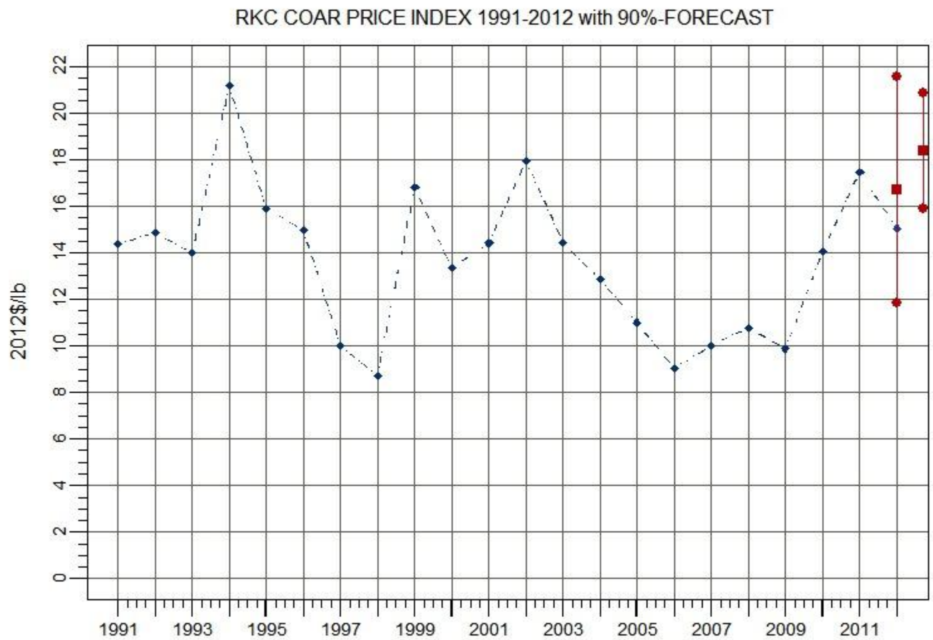
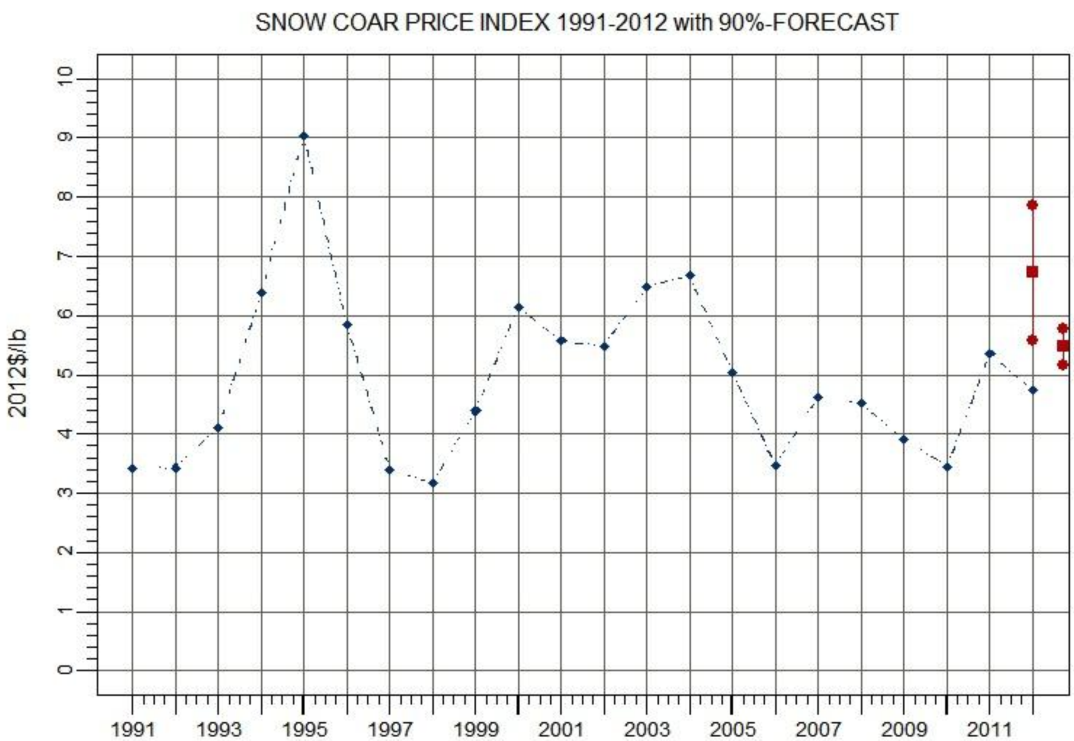


Fig. 1c: Snow crab VAR(3) model and data 1991-2008 with three price series based on COAR wholesale values for snow crab (plot) TPIS snow crab import price index, and TPIS snow crab export price index. The regression runs through 2013 with 90% 1-step forecasts for 2011 and 2012 where the latter is conditioned on Jan-July 2013 average values for TPIS series. The expected values of each forecast are represented by squares in the forecast intervals for each year. All values are in 2012 dollars per pound.



2013 Saint Matthew Island Blue King Crab Stock Assessment

William Gaeuman, ADF&G, Kodiak
Sept 2013

Executive Summary

1. Stock: Blue king crab, *Paralithodes platypus,* Saint Matthew Island, 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. The TAC was increased to 1.600 million pounds (725.7 t) in 2010/11 and to 2.359 million pounds (1,151 t) in 2011/12, but reported catches again fell short at 1.264 million pounds (573.3 t; 79% of the TAC) and 1.881 million pounds (853.2 t; 80% of the TAC), respectively. In 2012/13, by contrast, harvesters landed 99% of a reduced TAC of 1.630 million pounds (739.4 t), though fishery efficiency, at about 10 crab per pot, was little changed from what it had been in each of the previous three years. Total male discard mortality in the 2012/13 directed fishery is estimated from ADF&G crab-observer data at 0.193 million pounds (87.5 t), assuming 20% handling mortality. Male bycatch mortality in the 2012/13 groundfish fisheries is estimated from NMFS observer data at 0.001 million pounds (0.5 t), and an additional estimated 0.0004 million pounds (0.2 t) of male biomass was removed from the stock as bycatch in the 2012/13 Bering Sea snow crab fishery.

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 have generally increased in recent years, with 2011 estimated mature male biomass at 21.07 million pounds (9,557 t; CV 0.53), the second highest in the 36-year time series used in this assessment. However, survey estimated mature male biomass decreased to 12.46 million pounds (5,652 t; CV 0.33) in 2012 and to 4.459 million pounds (2,203 t; CV 0.22) in 2013. Although the 2013 value is still higher than the post-collapse low of 2.812 million pounds (1,275 t; CV 0.36) reported in 2005, both the low value and the apparent downward trend give reason for concern.

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 entering 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 marks a three-year exponential decline and is the lowest since 2005. The 2013 estimate is based on 14 captured animals (compared to 29 in 2012) from the 56 survey stations currently used to assess the SMBKC stock.

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. In 2012/13, ADF&G crab observers in the Bering Sea snow crab fishery additionally recorded some unusual bycatch of 59 male blue king crab in 20 sample pots from ADF&G statistical areas 745830 and 745900

southwest of St. Matthew Island; however, as fishery data indicate that only around 5.7% of all pots were fished in these two statistical areas, a reasonable estimate of SMBKC male bycatch mortality in the 2012/13 Bering Sea snow crab fishery is 11,888 lb × 0.057 × 0.5 = 339 lb, assuming 50% mortality. Including this amount for modeling purposes in the estimate of groundfish bycatch mortality yields an estimated 2012/13 SMBKC total male catch of 1.616 + 0.193 + (0.0011 + 0.0004) = 1.811 million pounds (821.2 t), which is comfortably below the 2012/13 OFL of 2.24 million pounds (1,020 t) so that no declaration of overfishing is warranted. On the other hand, the low 2013 survey estimate of stock biomass, along with the declining trends in both stock biomass and (model) recruitment, raises concern that the stock may be approaching an overfished condition. See table below. (Biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL[a]	ABC
2009/10	3.4 (1,500)	12.76 (5,790)	1.167 (529.3)	0.461 (209)	0.53 (240)	1.72 (780)	-
2010/11	3.4 (1,500)	14.77 (6,700)	1.600 (725.7)	1.264 (573)	1.41 (639)	2.29 (1,040)	-
2011/12	3.4 (1,500)	11.09 (5,030)	2.539 (1,151)	1.881 (853)	2.10 (953)	3.74 (1,700)	3.40 (1,540)
2012/13	4.0 (1,800)	6.29[b] (2,850)	1.630 (739.4)	1.616 (733)	1.81 (821)	2.24 (1,020)	2.02 (916)
2013/14	3.4[c] (1,500)	6.64[d] (3,010)	TBD	TBD	TBD	1.24[e] (562)	1.10[e,f] (501)

[a] Total male catch OFL.
[b] Fall 2013 base-model estimate.
[c] Fall 2013 base-model estimate using the reference period 1978/79 – 2012/13.
[d] Fall 2012 base-model projection assuming OFL catch.
[e] From Fall 2013 base model.
[f] As described in §G with P* = 0.49 and 10% buffer.

6. Basis for the OFL: 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 period, and current CPT/SSC guidance recommends using the the full assessment time frame, 1978/79 – 2012/13, as the default reference period. Under the author-recommended base-model configuration that procedure results in an estimated 2013/14 B_{MSY} proxy of 6.756 million pounds (3,060 t). The F_{MSY} proxy is taken equal to the assumed 0.18 yr^{-1} instantaneous natural mortality (NPFMC 2007). See table below. (Biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality	P^*
2009/10	4a	6.95 (3,150)	12.76 (5,790)	1.84	$0.18yr^{-1}$	1	1989/90 – 2009/10	$0.18yr^{-1}$	-
2010/11	4a	6.86 (3,110)	15.29 (6,940)	2.23	$0.18yr^{-1}$	1	1989/90 – 2009/10	$0.18yr^{-1}$	-
2011/12	4a	6.85 (3,110)	15.80 (7,167)	2.31	$0.18yr^{-1}$	1	1989/90 – 2009/10	$0.18yr^{-1}$	0.49
2012/13	4a	7.93 (3,560)	12.41 (5,629)	1.56	$0.18yr^{-1}$	1	1978/79 – 2011/12	$0.18yr^{-1}$	0.49
2013/14	4b	6.76 (3,060)	6.639[a] (3,010)	0.98	$0.18yr^{-1}$	1	1978/79 – 2012/13	$0.18yr^{-1}$	0.49

[a] Fall 2013 base-model projection assuming OFL catch.

7. Distribution of the OFL: It is recognized that the use of the assessment methodology to compute the OFL involves substantial inherent uncertainty by virtue of, among other things, its dependence on estimated quantities as key inputs. Accordingly, the calculated OFL may be

viewed as a random variable with an associated probability distribution. Following recommendations developed during the Jan 2012 NPFMC crab modeling workshop, the model associated standard error of the logarithm of the estimated OFL is used to specify a probability distribution to quantify some of this uncertainty and to facilitate determination of the ABC. Details are provided in §G of this document.

8. Basis for the ABC: For determining an acceptable biological catch (ABC) and hence the annual catch limit (ACL), current instructions are to require that P[ABC > OFL] = P* with P* = 0.49. Implementation of this requirement to determine a maximum ABC relies on the assigned OFL probability distribution and is described in §G. To account for additional sources of uncertainty, and in keeping with past CPT and SSC guidance, the author recommends that the ABC be set at no more than 90% of the maximum value.

9. Summary of rebuilding analyses: The stock was declared rebuilt in 2009.

$$P[ABC > OFL] = P^*;\ P^* = 0.49;\ ABC = \lambda\widehat{OFL}; \log\left(\widehat{OFL}\right) \sim N(\log(OFL)\,,\sigma)$$

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.

Changes in Assessment Methodology
This assessment employs the 3-stage length-based assessment model first presented in May 2011 and accepted by the CPT in May 2012. The model was developed as an alternative to a similar 4-stage model used prior to 2011. For 2013 the author has presented four additional model configurations to go with the seven considered for 2012. In addition, biomass has replaced abundance as the trawl-survey index used in model estimation, though this change has little practical impact on model behavior.

Changes in Assessment Results
There are no major changes in assessment results at this time.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

- Fall 2012 CPT
  Comments: *The team would strongly encourage authors to follow the TOR in so much as it is applicable to individual assessments and encourages authors to seek internal review to improve the quality of the documents. The team requests that a meeting occur between the PT chairs, Council staff, RO staff and the heads of the respective agencies to discuss the need to improve the quality of the assessment documents being reviewed by the team on an annual basis.*

  Response: Noted. The author will review the TOR and take other measures to ensure the assessment document is clear, informative, and appropriately structured.

- Fall 2012 SSC
  Comments: No new recommendations.

  Response: NA

- Spring 2013 CPT
  Comments: No new recommendations.
  Response: NA

- Spring 2013 SSC
  Comments: No new recommendations.
  Response: NA

CPT and SSC Comments Specific to SMBKC Stock Assessment

- Fall 2012 CPT
  Comments: *The assessment author was commended for the elegance and simplicity of the model and the efforts to make the model understandable without getting lost in the details. The CPT discussed diagnostic tools and how one size doesn't fit all, noting that the utility of a particular diagnostic will vary among assessments. It may be useful to add something similar to Table 6 with residual values and number of estimated parameters to indicate how much of the residual variance is explained by different alternatives. The serial autocorrelation in the residual patterns from the all model scenarios indicate something happened about 10 years ago, and the CPT suggested looking at retrospective estimates of Q for stage 2 crab in May 2013. For May 2013 the CPT also requests that the author explore a model alternative that merges characteristics of models B and C, perhaps allowing flexibility in M while bounding Q.*

  One potential contributor to misspecification is the growth transition matrix, and the CPT suggested exploring whether additional information could be used to inform this matrix. The current matrix allows crabs from stage 1 to grow to stage 2 and then to stage 3 (all with a probability of 1 each year) but does not allow crab to grow from stage 1 to stage 3. The author is also encouraged to evaluate the use of biomass instead of abundance as the way to summarize the survey data.

Response: The author has included additional information along the lines of that suggested regarding last year's Table 6 (Table 8 in this document) for use in model selection. As Q (trawl-survey catchability) is fixed at 1 rather than model estimated, no retrospective estimates of this quantity are available. However, 2013 base-model retrospective estimates of stage-1 and stage-2 selectivity parameters are shown in Figure 21 of this document, and retrospective estimates of other model parameters are readily available. For this assessment, the author has presented two models additional model configurations, B1:C and B2:C, that merge models B1 and B2 with model C. Models T and TC presented in this document make use of an alternative presumably more biologically plausible transition matrix motivated by the author's review of Otto and Cummisky's (1990) work on Pribilof and St. Matthew Island blue king crab molting frequency and growth increment, and the author hopes to go forward with more in depth work on this matter in the future.

- Fall 2012 SSC

  Comments: *The SSC offers the following remarks to the assessment author. There is significant improvement in model evaluation. The SSC agrees with the Crab Plan Team on the need to develop diagnostic tools to understand and improve model performance (e.g., residual plots). For 2013, the SSC concurs with the Crab Plan Team that the author should explore an alternative model that merges characteristics of model B and model C, perhaps allowing two different Ms (one for 10 years ago and one for the recent 10 years). In addition, the SSC recommends that the author should fix the seed in the simulation, as it can help future reviewers to repeat and verify the simulation results. The Crab Plan Team offered some additional comments to the author, with which the SSC concurs. In addition, the SSC identified an important research need to investigate the annual molting frequency (and growth increment) with pre-molt size.*

  Response: The author has addressed most of these matters already in his previous response to Fall 2013 CPT comments and notes here only that, so far as he is aware, choice of random seed is not relevant for this particular model and manner of model estimation.

- Spring 2013 CPT

  Comments: *The base model and six alternative scenarios were addressed in the Fall 2012 SAFE chapter. These included different weighting on likelihood components, fixing or estimating various trawl survey selectivity parameters, and fixing or estimating natural mortality (M). Bill intends to repeat these scenarios in the fall 2013 for re-consideration by the CPT and SSC, and to add a seventh alternative scenario requested by the CPT and SSC that combines features of two of the six models. This seventh scenario merges aspects of scenarios B and C (as described in the Fall 2012 SAFE chapter) and incorporates two time periods for M.*

  Response: The author has presented hybrid B-C models, B1:C and B2:C. These allow M to vary by year around a geometric mean of 0.18 yr^{-1}. These results could inform further work of the type suggested by the CPT regarding two time periods for M, and the author is open to further guidance on how to proceed in regard to this matter.

- Spring 2013 SSC
  Comments: No new recommendations.
  Response: NA

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 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 its lithodid cousins the golden or brown 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). Mature females have a biennial ovarian cycle and 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 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. 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 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

[1] NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

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 1999 ADF&G pot survey, as well as 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.

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 crab per pot lift. The TAC was increased to 1.600 million pounds in 2010/11 and to 2.359 million pounds in 2011/12, with similarly low CPUEs and reported catches again falling short at 1.264 million pounds (79% of the TAC) and 1.881 million pounds (80% of the TAC), respectively. CPUE remained around 10 crab per pot during the 2012/13 season, but harvesters landed 99% (1.616 million pounds) of the 1.630-million-pound TAC.

Though historical observer data are limited, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high in past years, 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 2012; 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 historically observed in the eastern Bering Sea snow crab fishery, and ADF&G crab observers recorded 57 male blue king crab in sampled pot lifts during the 2012/13 fishery in two ADF&G statistical areas southwest of St. Matthew Island. More typically, however, bycatch of blue king crab in the Bering Sea snow crab fishery has been negligible. During the three previous seasons, for example, observers recorded a total of 3 blue king crab in a combined 6,023 sampled pot lifts. 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 4).

[2] D. Pengilly, ADF&G, pers. comm.

D. Data

Summary of New Information
Data used in this assessment have been updated to include the most recently available fishery and survey numbers.

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; Table 1); results from the annual NMFS eastern Bering Sea trawl survey (1978-2013; Table 2); results from the triennial ADF&G SMBKC pot survey (every third year 1995-2010; Table 3); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13; Table 4); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2012/13; 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 Foy and Armistead (2012); 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, e.g. Figure 4. Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2011). 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
Other relevant data sources, including assumed population and fishery parameters, are discussed in Appendix A, which gives a detailed description of the assessment model.

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 more 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 ≥ 120 mm CL and newshell ≥ 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), with the slightly narrower stage-3 size range intended to buttress the model assumption that all stage-3 crab transition to stage 4 after one year[3].

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. The author proposed an alternative 3-stage model 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 for use a slightly revised and better documented version of the alternative model.

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+. This consolidation was heavily 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 (ADMB Project 2009) is presented in technical Appendix A to this report. Basic model code was previously provided to the CPT in May 2012 and is available upon request from the author[4].

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[3] J. Zheng, ADF&G, pers. comm.
[4] william.gaeuman@alaska.gov

Model Selection and Evaluation

For the 2013 assessment, ten alternative model configurations, denoted Tbase, A1, A2, A3, B1, B2, C, TC, B1:C, and B2:C were examined along with the base-model configuration described in detail in Appendix A. With the exception of Tbase and TC, these alternatives were designed to address CPT and SSC requests and recommendations subsequent to the 2012 assessment. By comparison with the alternatives, the base-model configuration is characterized by 1) trawl and pot-survey index component weights both equal to unity; 2) separate estimated parameters for stage-1 and stage-2 trawl-survey selectivity, with stage-3 selectivity equal to survey catchability assumed equal to unity; 3) natural mortality model estimated in 1998/99 and otherwise fixed at 0.18 yr^{-1}; and 4) stage-1 to stage-2 and stage-2 to stage-3 transition probabilities both fixed at 1.0. The ten alternative model configurations differ from the base model in one or at most two of these features.

Model configurations A1, A2, and A3 reflect different weighting schemes for the trawl and pot-survey indices, with the added difference that, following Francis (2011), configuration A2 makes no use of the pot-survey data whatsoever: both pot-survey abundance index and pot-survey composition data components are assigned weights of zero. Model configurations B1 and B2 differ from the base model and from each other in how trawl-survey stage selectivities are parametrized. These configurations were introduced in Fall 2012 to address implausibly high estimates of stage-1 and, particularly, stage-2 selectivities under the other model configurations.

Configuration C modifies the base model to allow natural mortality M to vary across pre-assessment years according to $\log(M_t) = \log(0.18yr^{-1}) + \eta_t$, with the η_t subject to a moderate quadratic penalty $8.0\frac{\sum \eta_t^2}{2}$ and the constraint $\sum \eta_t = 0$. The purpose of this modification was to give the model more year-to-year flexibility as a way of improving its fit to the data, especially to the trawl-survey composition data. Models B1:C and B2:C are the obvious hybrid models and were introduced for this 2013 assessment in response to recent CPT and SSC recommendations. Within model estimation of 1998/99 natural mortality to account for an hypothesized anomalous mortality event (Zheng and Kruse 2002) proved a useful strategy in the context of the previous SMBKC stock assessment model (2010 SAFE), and this author previously verified in terms of conventional likelihood theory the utility of including this one extra parameter in the current base model (2012 SAFE). For these reasons, this strategy was again deployed in the base model and all other non-C model configurations.

Finally, model configurations Tbase and TC are presented at the author's initiative to investigate the effect on model behavior of using a different and presumably more biologically realistic stage-transition matrix. In these two models the matrix $\begin{bmatrix} 0.3 & 0.7 & 0 \\ 0 & 0.5 & 0.5 \\ 0 & 0 & 1 \end{bmatrix}$ replaces the stage-transition matrix $\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$ employed in all other model configurations. So, for example, in any given year, instead of 100%, only 70% of stage-1 crab molt and grow into stage-2 crab, with the other 30% remaining in stage 1, whether or not they molt. The alternative transition matrix is motivated by the work of Otto and Cummiskey (1990) on Pribilof and St. Matthew Island blue king crab molting and growth. The following table summarizes all eleven model configurations examined for this assessment.

Model configurations examined for the 2013 SMBKC stock assessment. Configurations Tbase and TC employ an alternative stage-transition matrix in model population dynamics. See text for details.

	survey-index objective function weight		trawl-survey selectivity parametrization			
model	trawl-survey	pot-survey	stage 1	stage 2	stage 3	yearly natural mortality[a]
base	1.0	1.0	s1	s2	Q = 1	0.18 yr^{-1}
Tbase	1.0	1.0	s1	s2	Q = 1	0.18 yr^{-1}
A1	1.0	0.5	s1	s2	Q = 1	0.18 yr^{-1}
A2	1.0	0[c]	s1	s2	Q = 1	0.18 yr^{-1}
A3	0.5	1.0	s1	s2	Q = 1	0.18 yr^{-1}
B1	1.0	1.0	s1	s2	s2	0.18 yr^{-1}
B2	1.0	1.0	s1	Q = 1	s2	0.18 yr^{-1}
C	1.0	1.0	s1	s2	Q = 1	estimated, with geometric mean 0.18 yr^{-1}
TC	1.0	1.0	s1	s2	Q = 1	estimated, with geometric mean 0.18 yr^{-1}
B1:C	1.0	1.0	s1	s2	s2	estimated, with geometric mean 0.18 yr^{-1}
B2:C	1.0	1.0	s1	Q = 1	s2	estimated, with geometric mean 0.18 yr^{-1}

[a] In all non-C models, a separate parameter is used to estimate M in 1998/99 .
[b] Model A2 excludes **all** pot-survey data, i.e. index and composition data component weights are both set to zero.

Base-model ADMB parameter estimates, standard errors, and estimated correlations are given in Tables 6 and 7. As already observed, notably problematic are the implausibly high estimates of stage-1 and 2 trawl-survey selectivites. Another concern with the base model, evident in Figure 6, is its poor fit to the trawl-survey composition data, particularly in the last decade or so of the time series, possibly indicative of an important change in stock dynamics or distribution. Choice of alternative model configurations examined for this assessment, as for the 2012 assessment, has been largely driven by these two concerns. Another concern about the base model, and one that is undoubtedly linked to the first, is the biologically unrealistic default stage transition matrix determining model population dynamics, and alternative model configurations Tbase and TC represent the author's attempt to address it.

Table 8 and Figures 7 – 15 facilitate basic comparison of the different model configurations with respect to these concerns and in terms of important measures of model behavior. Figures 7, 8, and 9 show model fits to trawl and pot-survey indices, and Figures 10 – 15 display key model outputs with respect to management decisions. Table 8 makes clear that estimation of trawl-survey selectivity parameters is generally problematic. Among model configurations using the base-model default stage-transition matrix only configuration B1 leads to what might immediately be considered plausible values. For the others, stage-2 estimates, in particular, are unreasonably high. The exception is model B2 and its variant B2:C. These models assume stage-2 selectivity equal to unity, leading to a dome-shaped selectivity curve and questionably low estimates of stage-3 selectivity that ultimately result in what are likely inflated estimates of stock MMB and B_{MSY} (Table 8; Figures 12 and 13). By contrast, the two model configurations Tbase and TC, which make use of a more biologically defensible stage-transition matrix, yield considerably more appealing results in this regard.

Model fit to trawl-survey composition data is likewise generally problematic, with the base-model residual pattern exhibited in Figure 6 fairly typical across model configurations. Other than B2, which is suspect for other reasons, C-type model configurations that allow yearly variation in natural mortality tend to do better, with TC affording what might be judged the most satisfactory fit to the trawl-survey stage-proportion data (Figure 16). Judged by Table 8 and Figures 7 – 9, these model configurations offer a better fit to the data generally, and they do so based on a pattern of yearly mortality deviations that are remarkably small except for a few years in the latter part of the time series, again suggestive of some fundamental change subsequent to the 1998/99 stock decline (Figures 13 and 14).

In Fall 2012 CPT discussion of model selection, model configurations B1 and C were each proposed as potential alternatives to the base model. It was noted that B1 led to more plausible estimates of trawl-survey selectivity, whereas C provided a better fit to the data, especially the trawl-survey composition data. However, as no clear preference emerged, the CPT at that time opted to go with the base model as the default. In the author's view, similar considerations point to model configurations B1, C, TC, and Tbase as the most reasonable candidates for replacing the base model for use in the 2013 assessment. The difference this time around is the introduction of an alternative stage-transition matrix in configurations Tbase and TC that not only makes these models more structurally appealing from a biological perspective but also enables them to deliver more reasonable estimates of trawl-survey selectivity. That said, there is, on the one hand, some statistical evidence in Table 8 that model C is in fact to be preferred over model TC, and, on the other, none to suggest that model Tbase should be preferred over the base model. Moreover, whereas biological plausibility clearly deserves a major role in these matters, mere plausibility is insufficient on its own. In this instance, the author believes that more work is needed to develop a properly credible biologically appropriate stage-transition matrix before adopting it for assessment use. This again leaves models B1 and C as the potential alternatives to the base model, and as there is again no compelling reason to prefer either of these to the other given the weaknesses of each, the author recommends using the base model for this 2013 assessment. Whereas the fit of model B1

Results

Additional results are presented for the base-model, as the author-recommended choice for use in the Fall 2013 SMBKC stock assessment. As was previously noted, the high estimates of trawl-survey stage-1 and stage-2 selectivity (0.95 and 1.38 relative to Q = 1; Table 6) are a concern, as is the poor fit to the trawl-survey stage-proportion data (Figure 6). Despite these pathologies, however, in the author's view there is no compelling reason to prefer one of the competing alternative models, and by comparison with the alternatives base-model results generally seem reasonable overall. This was also the conclusion reached by the CPT in 2012.

In addition to results already mentioned, Figure 17 displays standardized residuals of base-model fits to the pot-survey and crab-observer stage-proportion data. The three components of 2012/13 fishing mortality are shown in Figure 18. Figure 19 provides a plot of estimated directed-fishery fishing mortality against estimated mature male biomass at time of mating, and Figure 20 shows a 12-year retrospective plot of trawl-survey model-male (90mm+ CL) biomass. Notable in this Figure is that the different trajectories are vertically ordered consistent with the sequence of terminal years, and that this ordering reverses itself following the large overall decline from 1998 to 1999, so that the trajectories with the more recent terminal years tend to be associated with the highest estimates of biomass before the decline but the lowest following it. This same general pattern occurs also for model-estimated mature male biomass (not shown). Figure 21 shows 2013 base-model retrospective estimates of trawl-survey stage-1 and stage-2 selectivities.

Whereas actual sample sizes (number of measured crab) range between 38 and 385 for the trawl-survey (Table 2) and are generally much higher for both the pot-fishery (Table 3) and pot-survey (Table 4) data, model effective sample sizes are set at 100 for the pot-fishery and pot-survey and are typically equal to, and never exceed, 50 for the trawl-survey. (See Appendix A for further details.) Despite a great deal of experimentation in the choice of model effective samples sizes, a satisfactory fit to the trawl-survey composition data in particular proved elusive. Methods such as iterative reweighting using estimated effective sample size were not attempted; however, estimated effective samples sizes were computed and are plotted against survey year for the trawl-survey (Figure 22). A plot of these values against model effective sample size, all but four of which are equal to 50, is less than enlightening and was omitted. Estimated effective sample sizes ranged from 64.4 to 1,946.9 for the pot-survey composition data (6 years) and from 32.5 to 399.8 for the pot-fishery composition data (13 years).

F. Calculation of The OFL

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 (2012 SAFE), and only a Tier 4 analysis is presented here, with development of a Tier 3 approach deferred subject to CPT/SSC recommendations until the behavior of the new assessment model is better understood. 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

$$a)\quad F_{OFL} = F_{MSY},\ when\ \ B/B_{MSY} > 1;$$

$$b)\quad F_{OFL} = F_{MSY}\,(B/B_{MSY} - \alpha)/(1-\alpha),\ when\ \ \beta < B/B_{MSY} \le 1;$$

$$c)\quad F_{OFL} < F_{MSY}\ with\ directed\ \ fishery\ F = 0,\ when\ \ B/B_{MSY} \le \beta\,,$$

where B is quantified as mature-male biomass at mating MMB_{mating}, with time of mating assigned a nominal date of Feb 15. Note that as B is itself 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. This approach is consistent with that used under the previous model-based SMBKC stock assessment methodology (e.g. 2010 SAFE).

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978/79 – 2012/13, 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 $\beta = 0.25$. With these specifications and letting F_{OFL} determine directed-fishery fishing mortality, under the author recommended base-model configuration the B_{MSY} proxy is 6.76 million pounds, and case b) of the control rule obtains, resulting in a Tier 4b 2013/14 total male catch OFL of 1.24 million pounds with $F_{OFL} = F_{MSY} = 0.18$ yr^{-1}. The retained catch component of the OFL is 1.20 million pounds. Complete partitioning of the OFL under the base-model configuration is given in Table 9.

G. Calculation of The ABC

For determining an acceptable biological catch (ABC), and hence the annual catch limit (ACL), current recommendations are to require that $P[ABC > OFL] = P^*$, with P^* = 0.49. As implemented here, the maximum ABC is set equal to $\lambda \times ofl$, where *ofl* is the Tier 4 model-calculated overfishing level from the control rule and the multiplier λ is determined by the probability statement $P[\lambda\widehat{OFL} > OFL] = P^*$, under the assumptions that $OFL = median(\widehat{OFL})$ and $\log(\widehat{OFL}) \sim N(\log(OFL), \sigma)$, where σ is the ADMB-reported standard error of $\log(\widehat{OFL})$ from the model. With this set up, $P^* = P\left[\lambda\widehat{OFL} > OFL\right] = 1 - \Phi(-\frac{\log(\lambda)}{\sigma})$, so that

$\log(\lambda) = -\sigma\Phi^{-1}(1 - P^*)$ and $\lambda = \exp(\sigma\Phi^{-1}(P^*))$.

For the base model, this procedure yields $\lambda = \exp\left(0.2714\Phi^{-1}(0.49)\right) = 0.99$ and a maximum ABC of $\lambda \times ofl$ = 0.99 × 1.24 = 1.23 million pounds. To account for additional sources of uncertainly and in keeping with past CPT and SSC guidance, the author recommends that the ABC be set at no more than 90% of the maximum value. In this instance, the use of an additional 10% buffer leads to a provisional author-recommended ABC of 1.10 million pounds.

H. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

I. Data Gaps and Research Priorities

In Fall 2012 the SSC identified an important research need to investigate SMBKC annual molting frequency (and growth increment) as a function of pre-molt size. As the currently specified base-model transition matrix, requiring all stage-1 and 2 crab to transition in each year to stages 2 and 3, respectively, is likely unrealistic, the author concurs with this recommendation. For this assessment he has explored the use of a more biologically plausible transition matrix based on his review of Otto and Cummiskey's 1990 work on molting frequency and growth increment of Pribilof and St. Matthew Island blue king crab. For the future, the author plans to look at historical ADF&G SMBKC tagging data as a possible basis for extending their efforts with the goal of formulating a credible biologically motivated model transition matrix.

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Table 1. The 1978/79 – 2011/12 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

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Harvest number/pot lifts.
[d] Harvest weight/harvest number, in pounds.
[e] Average CL of retained crab in millimeters, from dockside sampling of delivered crab.

Table 2. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lb). Total number of captured male crab $\geq$ 90 mm CL is also given. Source: J.Zheng, ADF&G; R.Foy, NMFS.

	abundance					biomass		
year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total	CV	mature male (105mm+ CL)	cv	number of crab
1978	2.384	2.268	1.764	6.416	0.46	11.876	0.39	163
1979	2.939	2.225	2.223	7.388	0.44	12.864	0.39	187
1980	2.539	2.456	2.867	7.861	0.57	16.724	0.47	188
1981	0.477	1.233	2.346	4.055	0.36	12.833	0.40	140
1982	1.713	2.495	5.987	10.194	0.38	30.748	0.32	269
1983	1.078	1.663	3.363	6.104	0.34	17.921	0.28	231
1984	0.410	0.499	1.478	2.387	0.24	7.684	0.19	104
1985	0.381	0.376	1.124	1.881	0.22	5.750	0.22	93
1986	0.206	0.457	0.377	1.039	0.44	2.578	0.39	46
1987	0.325	0.631	0.715	1.671	0.32	4.060	0.29	71
1988	0.410	0.816	0.957	2.183	0.30	5.693	0.24	81
1989	2.164	1.158	1.792	5.115	0.37	9.675	0.25	211
1990	1.053	1.031	2.338	4.422	0.32	11.955	0.26	170
1991	1.135	1.680	2.236	5.052	0.36	12.255	0.25	198
1992	1.074	1.382	2.291	4.746	0.33	12.649	0.20	220
1993	1.521	1.828	3.276	6.626	0.26	16.959	0.16	324
1994	0.883	1.298	2.257	4.438	0.18	11.696	0.18	211
1995	1.025	1.188	1.741	3.953	0.19	9.843	0.17	178
1996	1.238	1.891	3.064	6.193	0.25	17.112	0.24	285
1997	1.165	2.228	3.789	7.182	0.35	20.143	0.33	296
1998	0.660	1.661	2.849	5.170	0.34	15.054	0.36	243
1999	0.223	0.222	0.558	1.003	0.24	2.871	0.18	52
2000	0.282	0.285	0.740	1.307	0.30	3.795	0.31	61
2001	0.419	0.502	0.938	1.859	0.28	5.064	0.26	91
2002	0.111	0.230	0.640	0.981	0.30	3.311	0.32	38
2003	0.449	0.280	0.465	1.194	0.56	2.483	0.32	65
2004	0.247	0.184	0.562	0.993	0.45	2.705	0.29	48
2005	0.319	0.310	0.501	1.130	0.41	2.812	0.36	42
2006	0.917	0.642	1.240	2.798	0.36	6.494	0.36	126
2007	2.518	2.020	1.193	5.730	0.40	9.157	0.35	250
2008	1.352	0.801	1.457	3.609	0.36	7.354	0.29	167
2009	1.573	2.161	1.410	5.144	0.27	10.189	0.26	251
2010	3.927	3.253	2.458	9.638	0.58	17.948	0.37	385
2011	1.693	3.215	3.252	8.160	0.59	21.073	0.53	315
2012	0.705	1.967	1.808	4.483	0.36	12.461	0.33	193
2013	0.335	0.452	0.807	1.593	0.22	4.459	0.22	74

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
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

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)	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

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.

	bycatch		
year	trawl[a]	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	1.7	18.3	10.5
2010/11	0.1	7.5	3.8
2011/12	0.0	1.8	0.9
2012/13	0.8	1.0	1.1

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gea

Table 6. Base-model parameter estimates and standard errors. Ranges are given for log recruit and log fishing mortality deviations.

parameter	estimate	standard error
1998/99 natural mortality	0.91	0.133
pot-survey proportionality constant	4.97	0.412
trawl-survey stage-1 selectivity	0.95	0.066
trawl-survey stage-2 selectivity	1.38	0.085
pot-survey stage-1 selectivity	0.39	0.062
pot-survey stage-2 selectivity	1.03	0.125
pot-fishery stage-1 selectivity	0.44	0.044
pot-fishery stage-2 selectivity	0.76	0.063
log initial stage-1 abundance	7.65	0.182
log initial stage-2 abundance	7.30	0.242
log initial stage-3 abundance	7.37	0.237
mean log recruit abundance	6.62	0.046
mean log recruit abundance deviations (34)	[-1.77, 1.27]	[0.104, 0.330]
mean log directed fishing mortality	-1.27	0.059
log directed fishing mortality deviations (24)	[-3.27, 1.31]	[0.084, 0.253]
mean log GF trawl fishing mortality	-10.60	0.228
log GF trawl fishing mortality deviations (21)	[-1.60, 1.77]	[0.698, 0.731]
mean log GF fixed-gear fishing mortality	-9.32	0.220
log GF fixed-gear fishing mortality deviations (21)	[-2.28, 2.48]	[0.688, 0.702]

Table 7. Base-model ADMB primary parameter correlations. Does not include those for recruit and fishing mortality deviations.

index	parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1998/99 M	1													
2	PS Q	-0.32	1												
3	TS s1 selectivity	-0.27	0.13	1											
4	TS s2 selectivity	-0.23	0.13	0.44	1										
5	PS s1 selectivity	-0.11	-0.27	0.07	0.06	1									
6	PS s2 selectivity	-0.11	-0.41	0.06	0.06	0.20	1								
7	PF s1 selectivity	-0.12	-0.08	0.06	0.07	0.10	0.12	1							
8	PF s2 selectivity	-0.03	-0.15	0.01	0.00	0.07	0.10	0.48	1						
9	log initial N1	-0.03	0.01	0.07	0.07	0.01	0.01	0.03	0.03	1					
10	log initial N2	-0.03	0.01	0.14	0.00	0.01	0.01	0.02	0.02	0.08	1				
11	log initial N3	-0.09	0.05	0.25	0.28	0.03	0.02	0.04	0.03	-0.04	-0.23	1			
12	mean log PF F	-0.09	0.32	-0.19	-0.16	-0.06	-0.09	-0.31	-0.36	-0.17	-0.15	-0.42	1		
13	mean log recruits	0.49	-0.59	-0.36	-0.33	-0.09	-0.05	0.02	0.15	-0.12	-0.10	-0.18	-0.28	1	
14	mean log GFT F	-0.07	0.19	0.05	0.06	0.00	-0.01	-0.03	-0.05	0.01	0.01	0.02	0.12	-0.23	1
15	mean log FGF F	-0.07	0.20	0.05	0.06	0.00	-0.01	-0.03	-0.05	0.01	0.01	0.02	0.12	-0.23	0.07

Table 8. Key base and alternative model quantities.

	model estimated trawl-survey selectivity			survey-index RMSE		objective function		management quantities (10^6 lb)		
model	stage 1	stage 2	stage 3	trawl	pot	min[a]	K[b]	Bmsy[c]	OFL[d]	MMBmating[e]
base	0.95	1.38	Q = 1	1.58	6.64	3,733	119 - 4	6.756	1.241	6.639
Tbase	0.57	0.69	Q = 1	1.66	6.91	3,735	119 - 4	8.498	1.173	8.012
A1	0.94	1.37	Q = 1	1.60	6.97	3,703	119 - 4	6.711	1.324	6.927
A2	0.92	1.34	Q = 1	1.66	NA	3,148	116 - 4	6.672	1.475	7.699
A3	1.01	1.46	Q = 1	2.01	6.73	3,715	119 - 4	7.404	1.219	6.910
B1	0.72	Q = 0.85		1.52	6.53	3,745	119 - 4	7.622	1.882	9.893
B2	0.66	Q = 1	0.48	1.60	6.41	3,710	119 - 4	13.085	2.210	12.092
C	0.90	1.33	Q = 1	1.24	3.04	3,673	154 - 5	6.073	0.732	4.963[f]
TC	0.54	0.66	Q = 1	1.27	3.13	3,698	154 - 5	7.777	0.723	6.196[f]
B1:C	0.92	Q = 1.31		1.58	2.63	3,701	154 - 5	4.551	0.562	3.845[f]
B2:C	0.69	Q = 1	0.56	1.36	3.47	3,693	154 - 5	10.641	1.451	8.978[f]

[a] ADMB minimized objective function value.
[b] Number of model "parameters" – number of zero-sum constraints.
[c] Average 1978-2012 model MMBmating.
[d] Tier 4 assuming Fmsy = 0.18 yr^{-1}.
[e] Model projected 2014 value assuming OFL catch.
[f] Assuming M = 0.18 yr^{-1} in 2013/14.

Table 9. Partitioning of the OFL. Catches are in millions of pounds, with metric ton equivalents in parentheses.

			OFL				
			directed fishery		groundfish bycatch mortality		
year	tier	F_{OFL} (yr^{-1})	retained	discard mortality	trawl	fixed gear	total male
2010/11	4a	0.18	1.90 (862)	0.263 (119)	0.003 (1)	0.038 (17)	2.29 (1,040)
2011/12	4a	0.18	3.36 (1,520)	0.296 (134)	0.001 (0.5)	0.009 (4)	3.74 (1,700)
2012/13	4a	0.18	2.14 (971)	0.095 (43)	0.0002 (0.1)	0.0009 (0.4)	2.24 (1,020)
2013/14	4b	0.18	1.20 (544)	0.044 (20)	0.0002 (0.09)	0.0007 (0.3)	1.24 (562)

[a] From Fall 2013 base-model configuration.

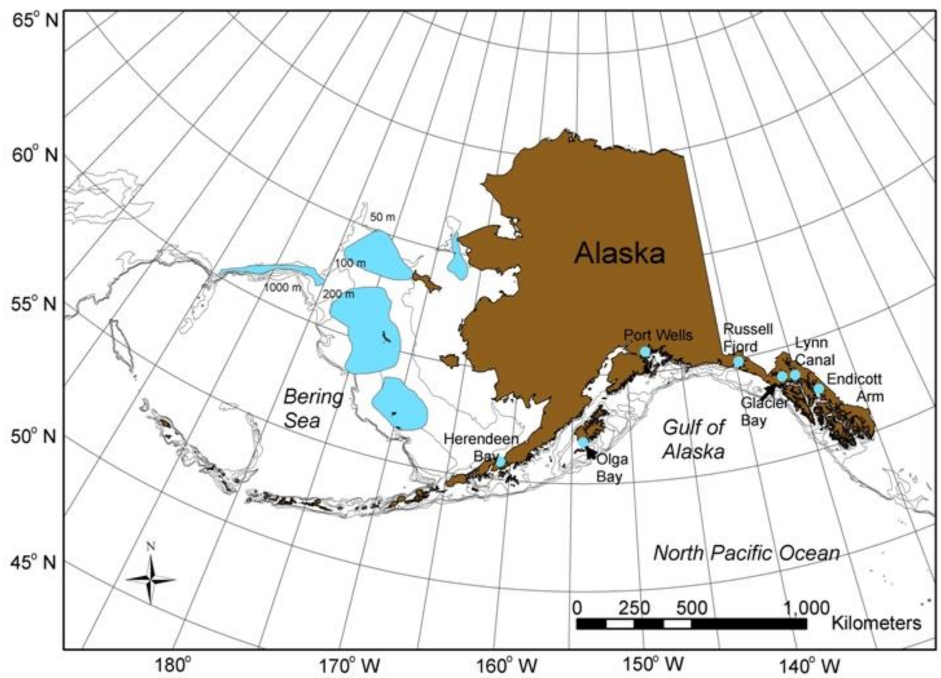


Figure 1. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

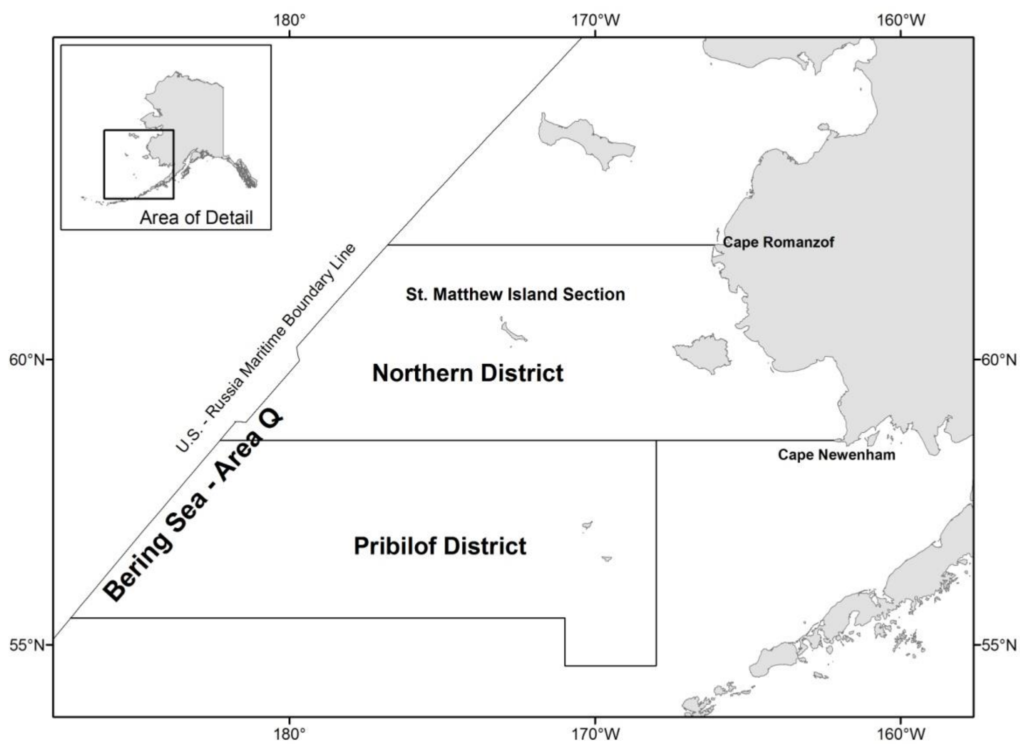


Figure 2. King crab Registration Area Q (Bering Sea).

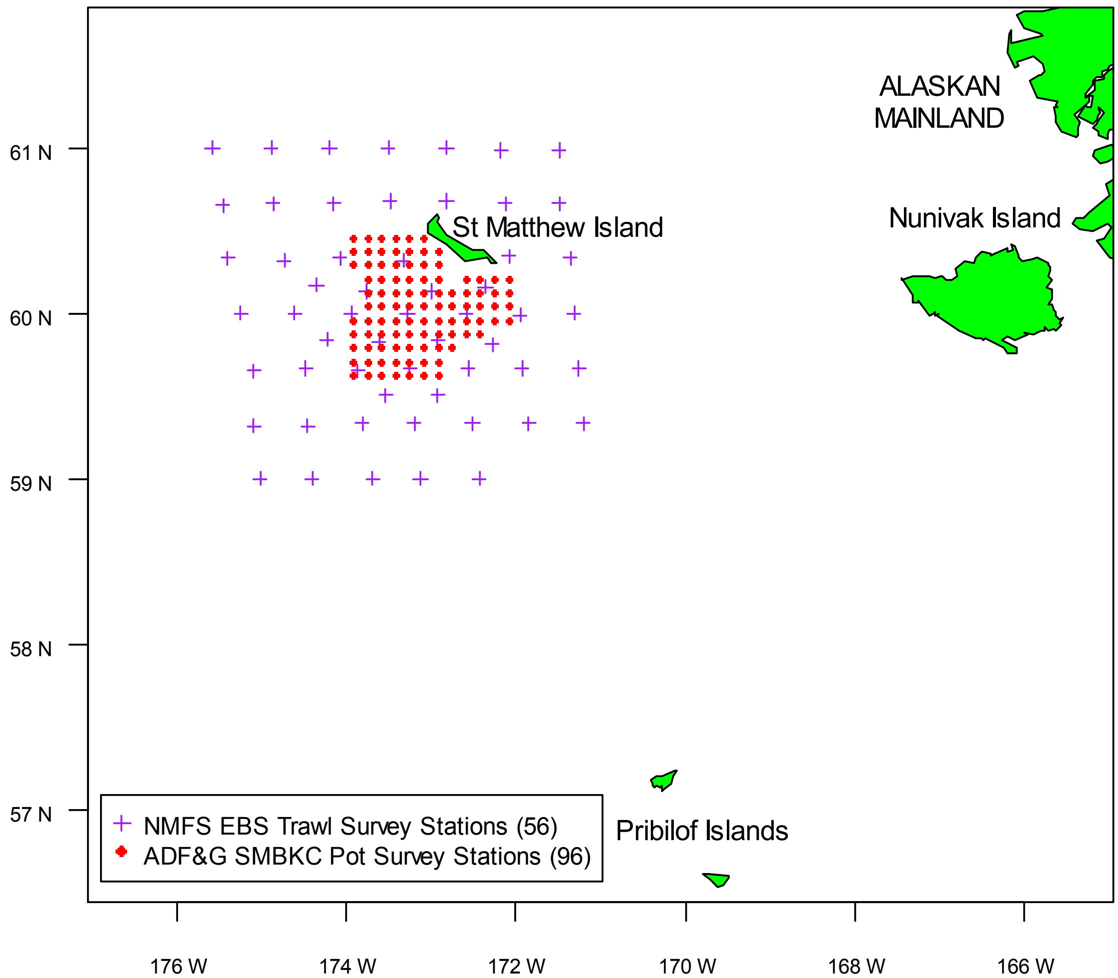


Figure 3. Trawl and pot-survey stations used in the SMBKC stock assessment.

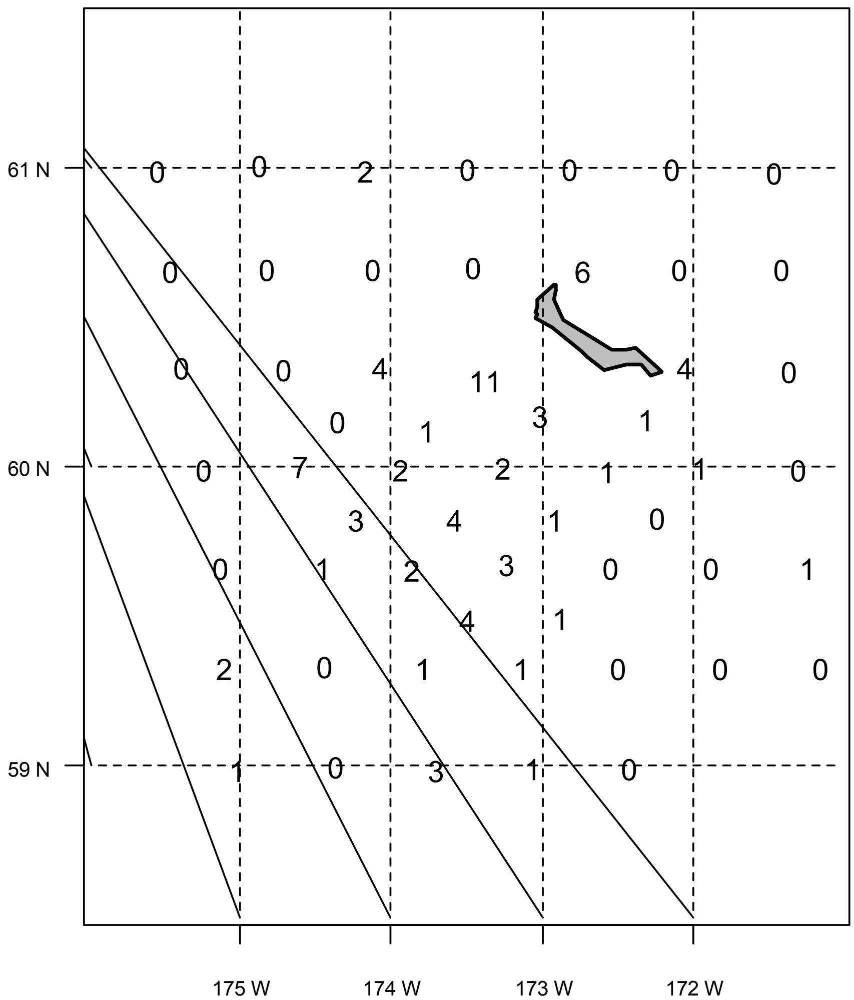


Figure 4. Catches of male blue king crab measuring at least 90 mm CL from the 2013 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island is not represented in the ADF&G pot-survey data used in the assessment.

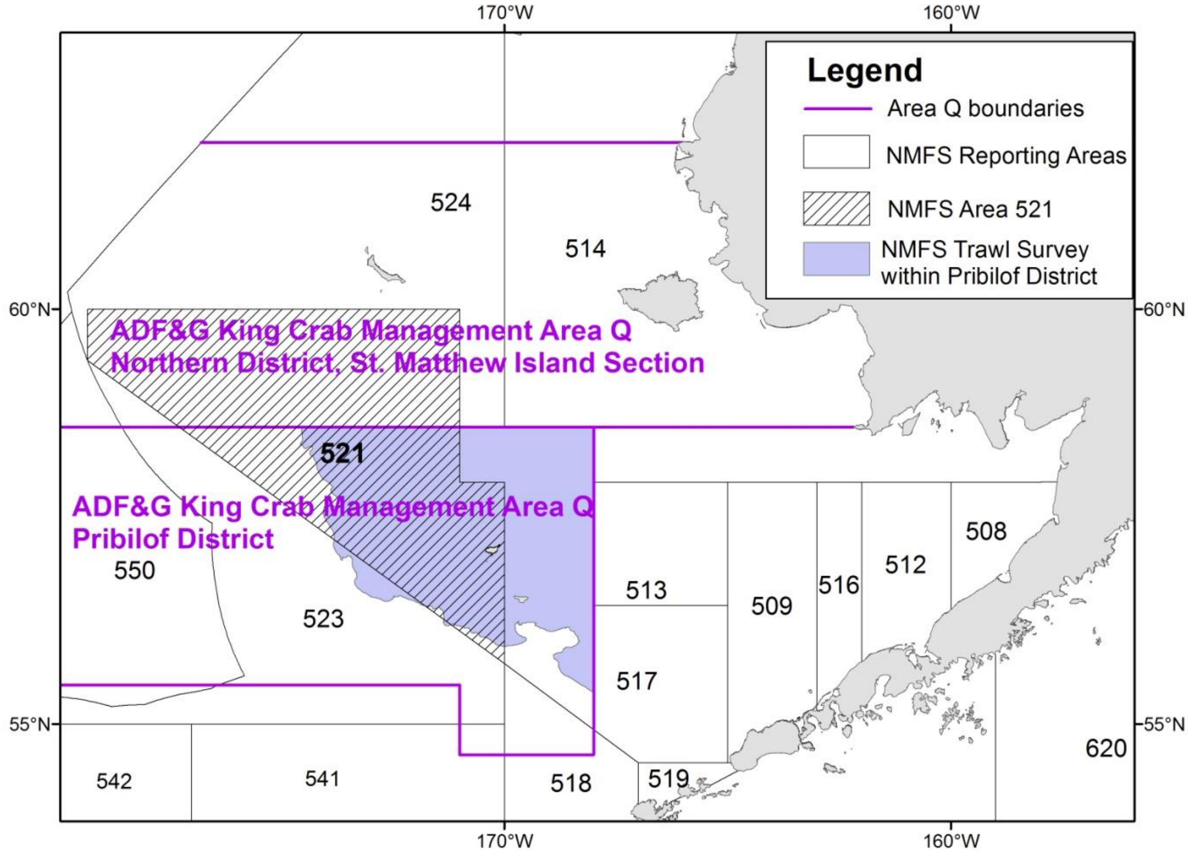
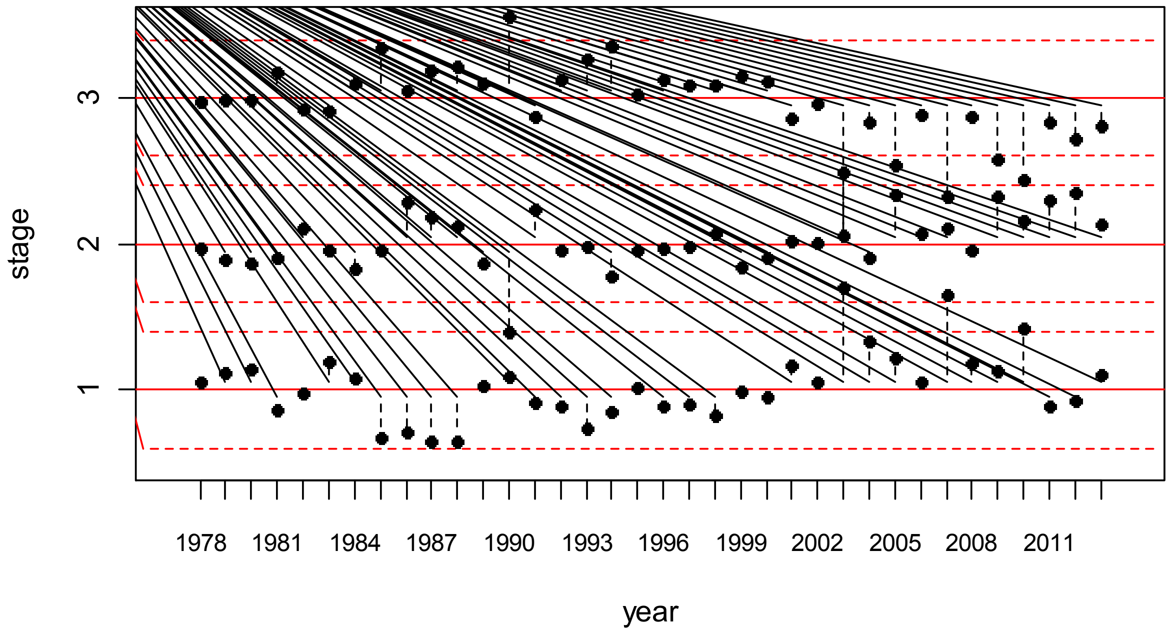


Figure 5. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.



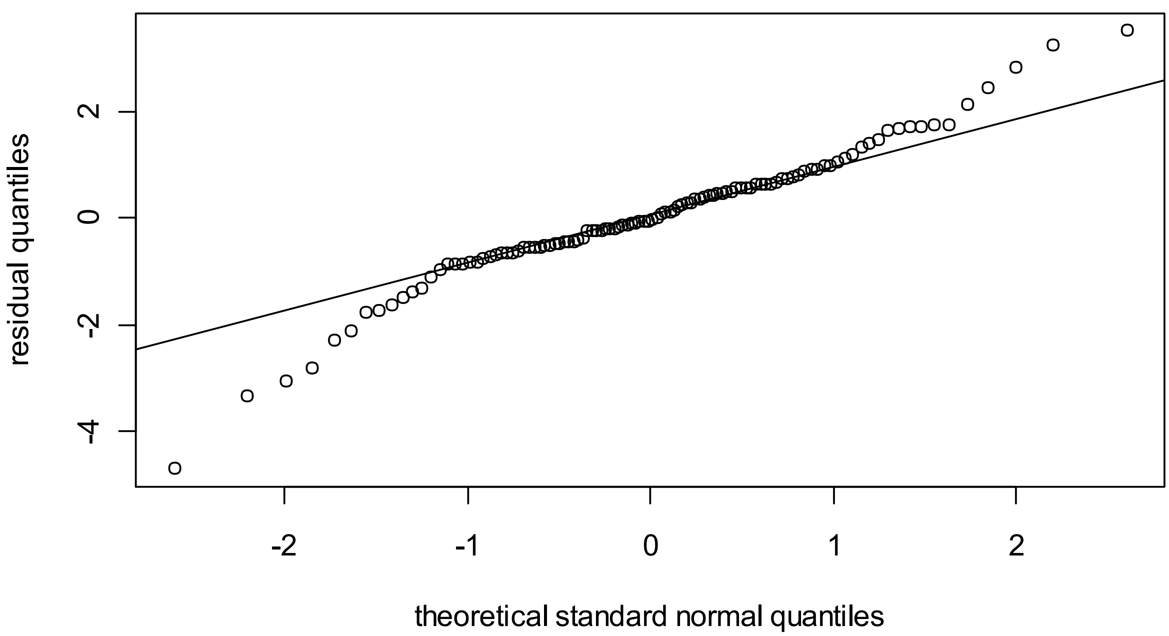


Figure 6. Base-model trawl-survey stage-proportion standardized residuals and normal qq-plot.

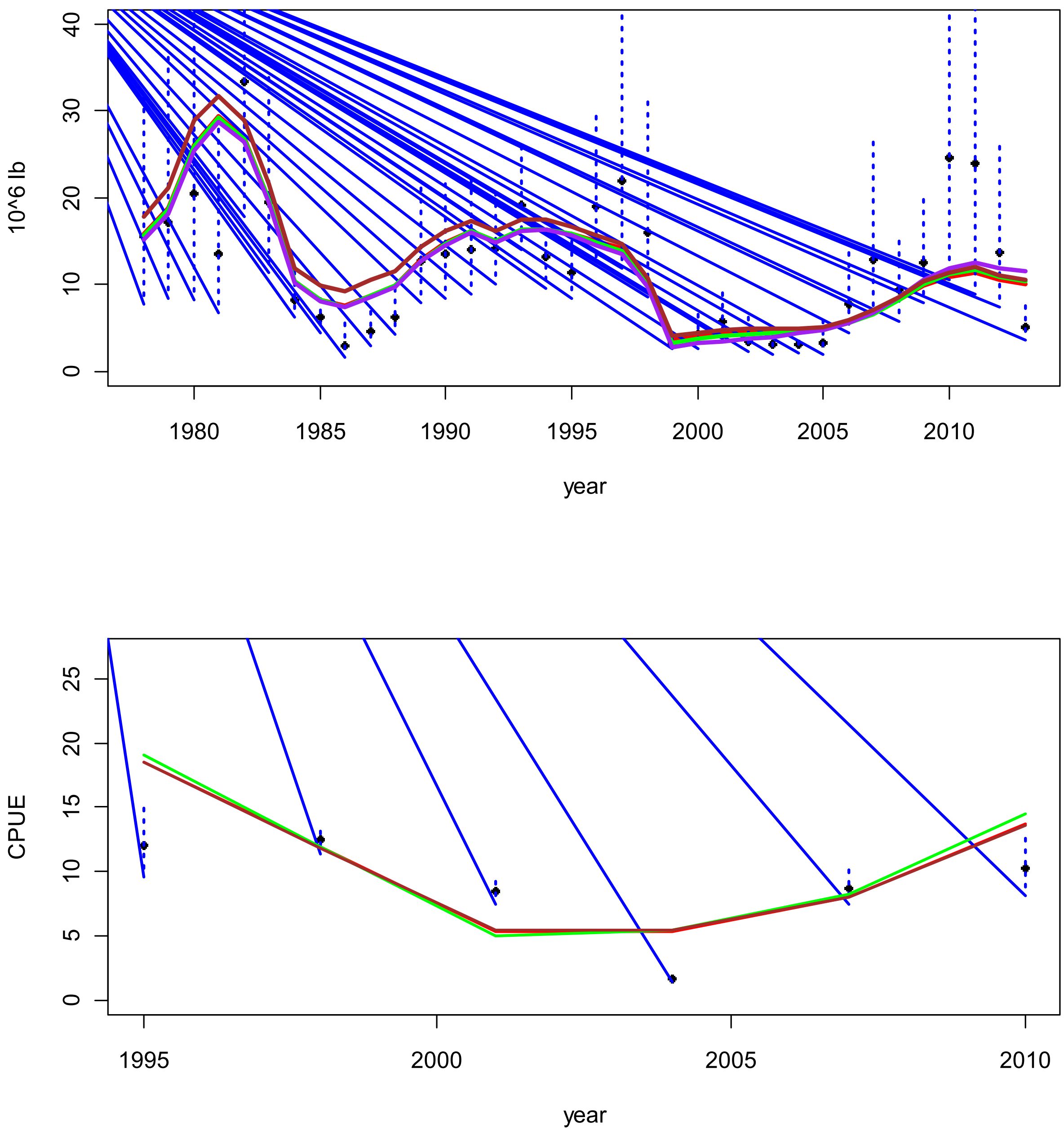
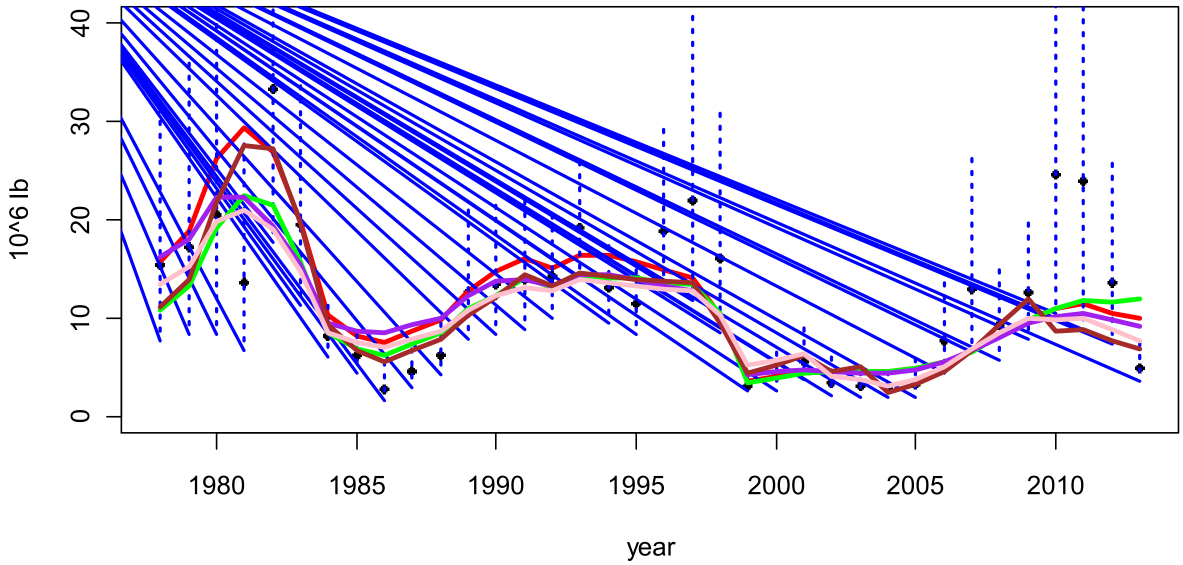


Figure 7. Model fits to trawl (top panel) and pot-survey indices (points) for base model (red) and model configurations A1 (green), A2 (purple), and A3 (brown). Note that model A2 makes no use of pot-survey data so no results for that model are displayed in the lower panel.



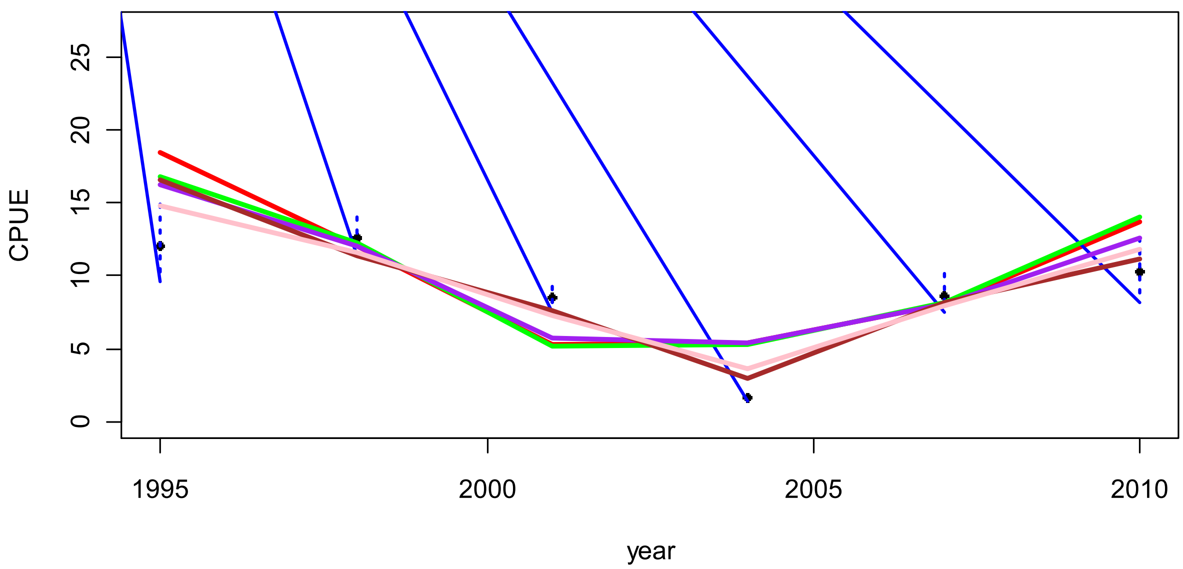


Figure 8. Model fits to trawl (top panel) and pot-survey indices (points) for base model (red) and model configurations B1 (green), B2 (purple), B1:C (brown), and B2:C (pink).

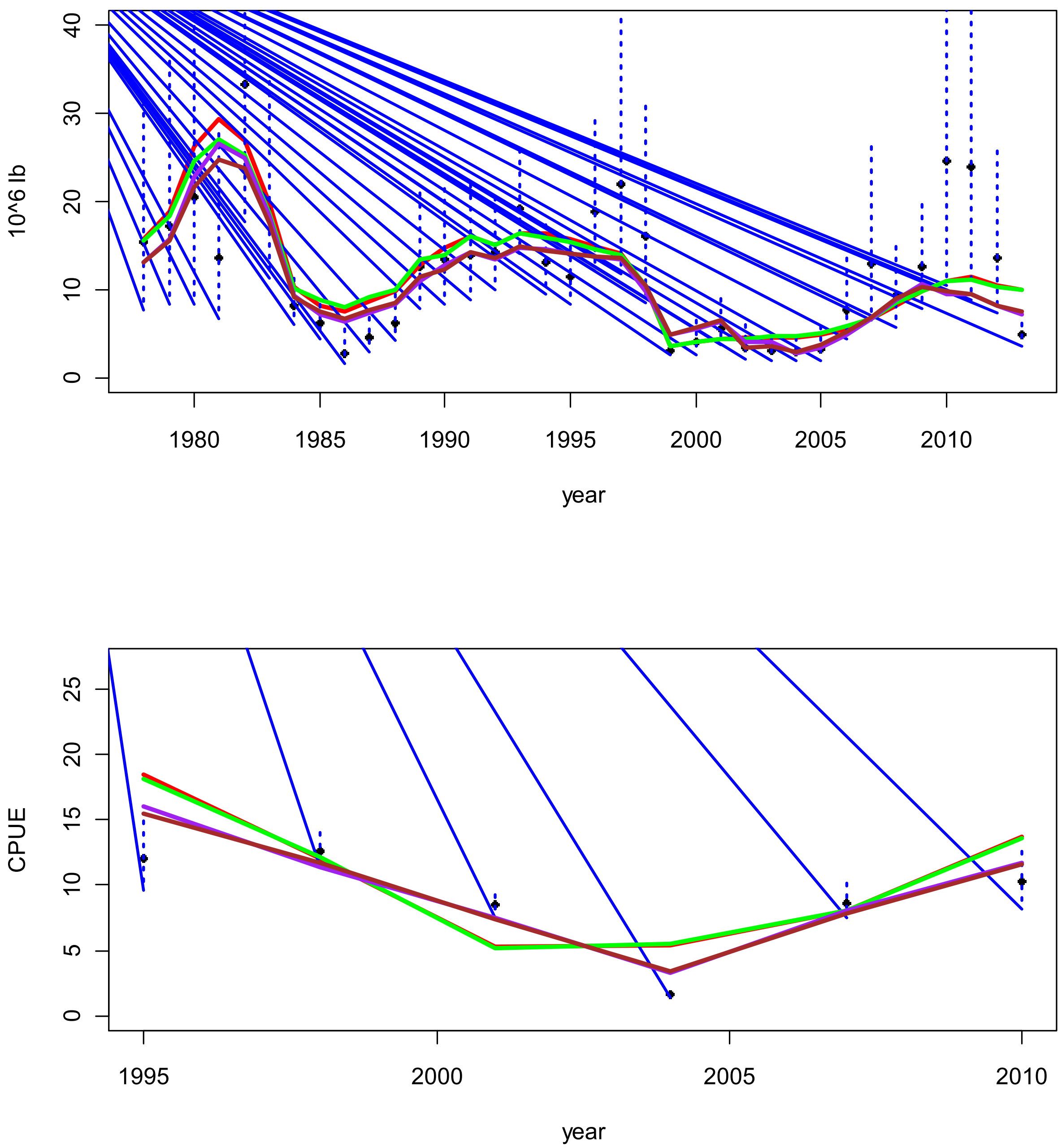
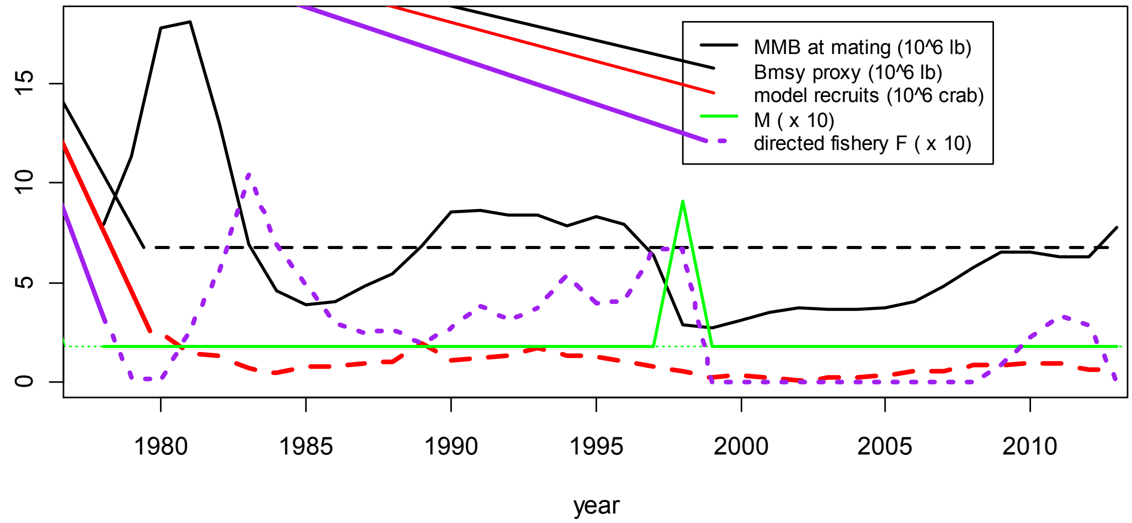


Figure 9. Model fits to trawl (top panel) and pot-survey indices (points) for base model (red) and model configurations Tbase (green), C (purple), and TC (brown).



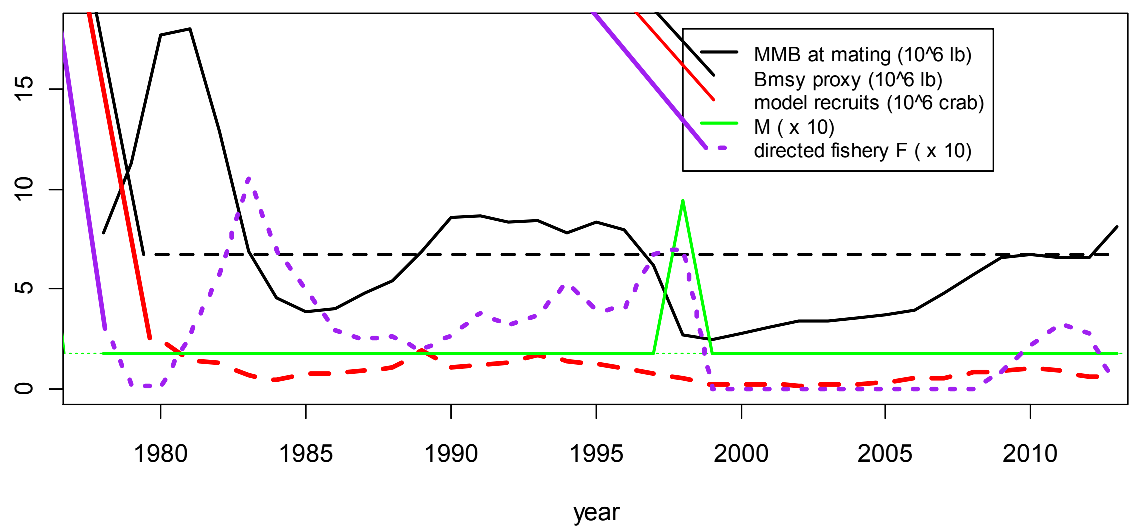
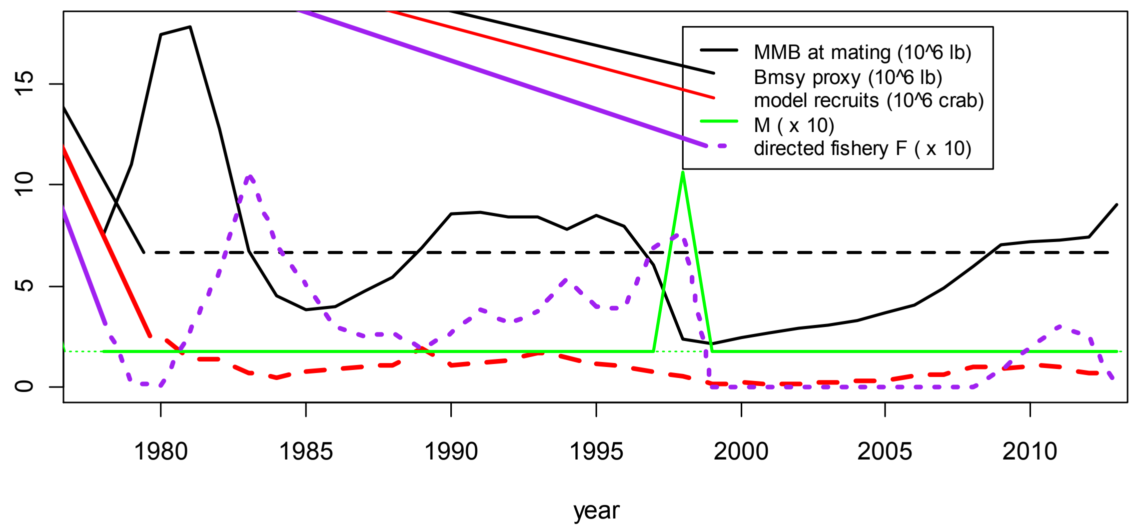


Figure 10. Base-model (top) and model A1 key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



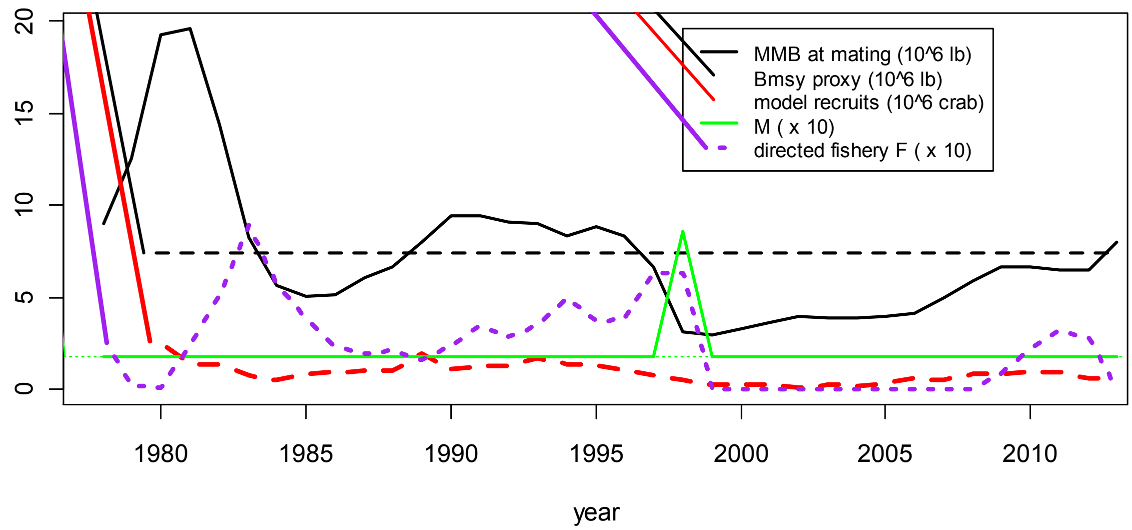
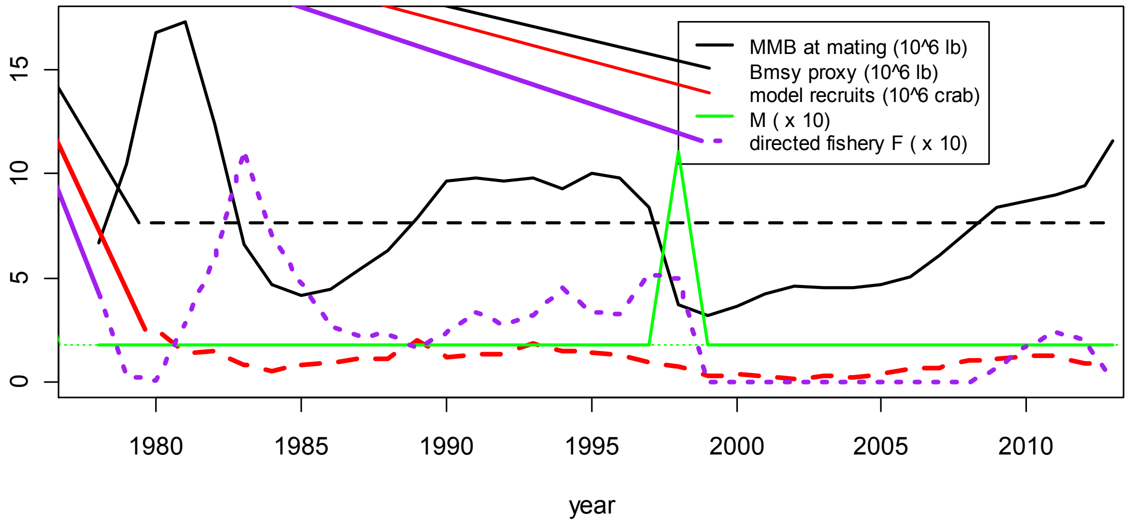


Figure 11. Model A2 (top) and A3 key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



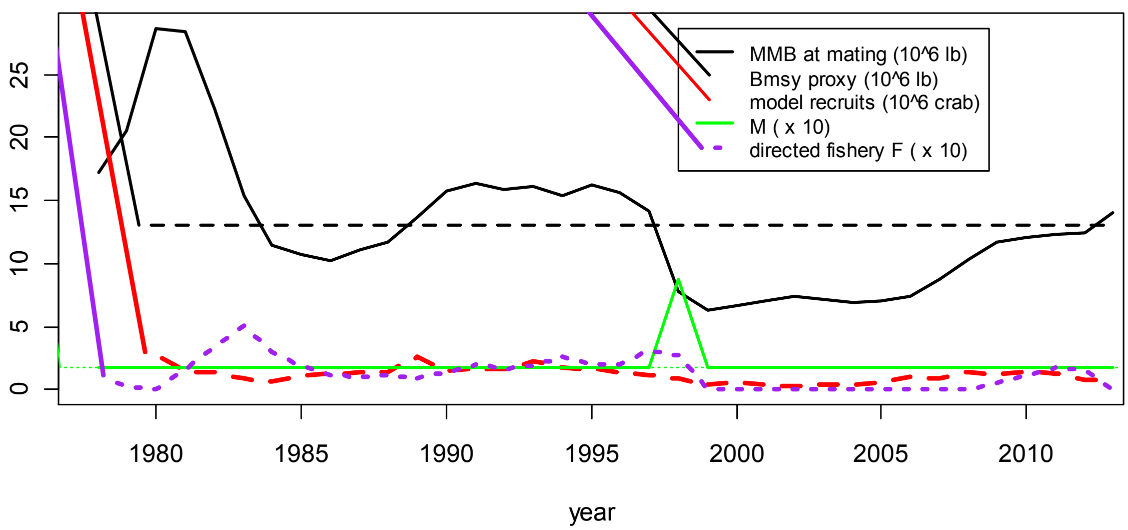
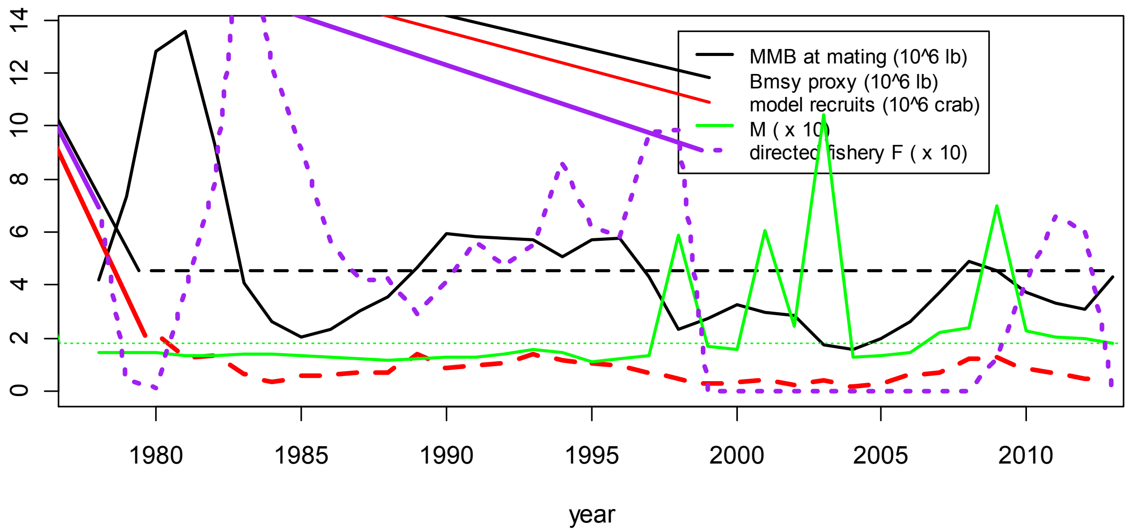


Figure 12. Model B1 (top) and B2 key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



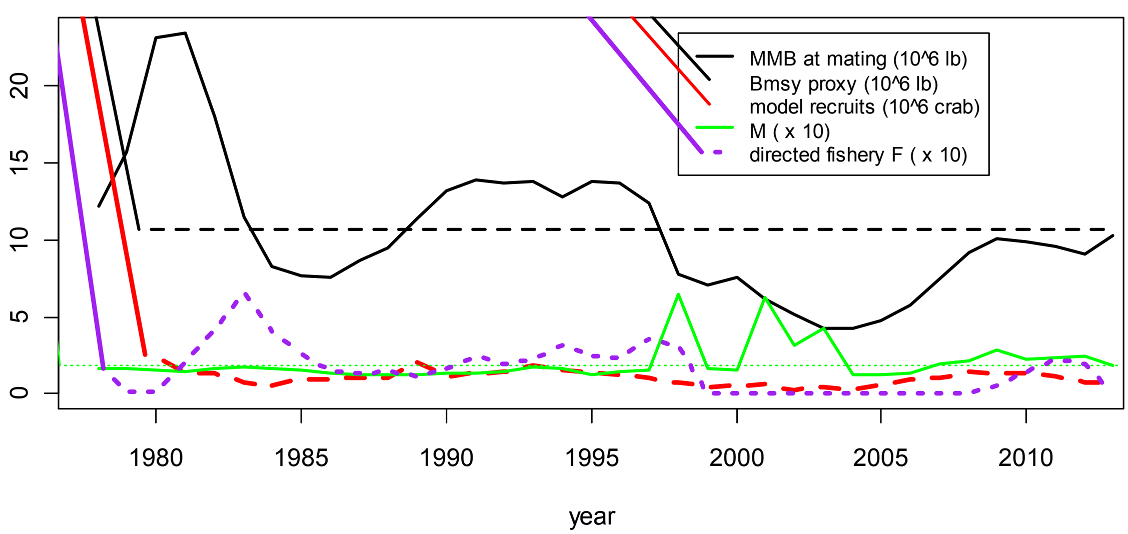
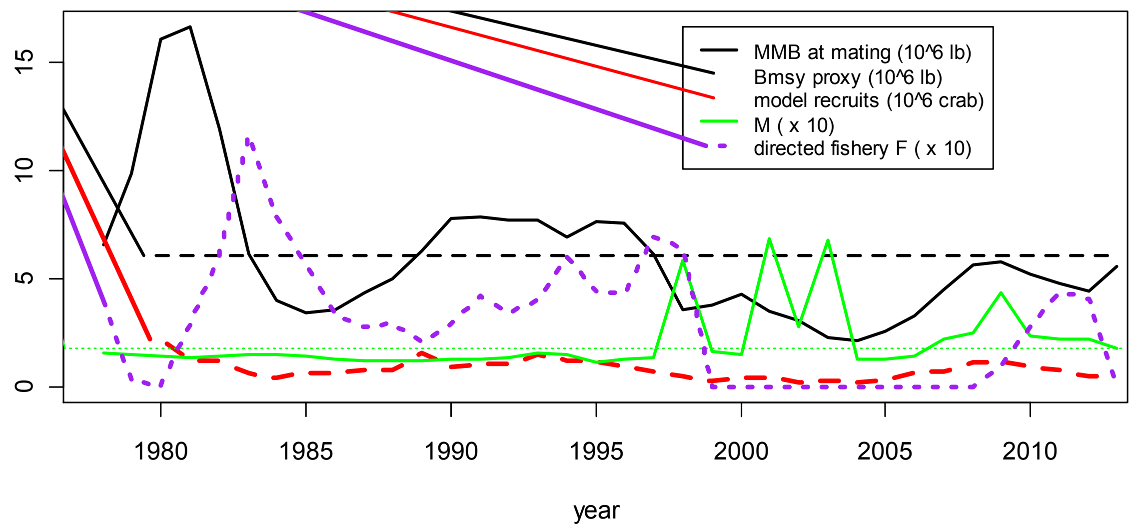


Figure 13. Model B1:C (top) and B2:C key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



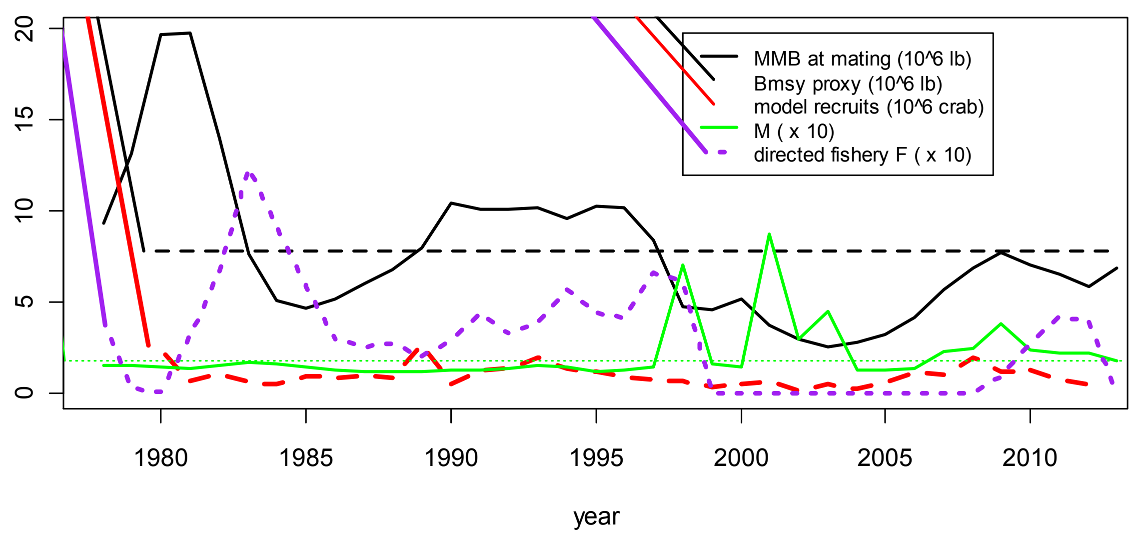
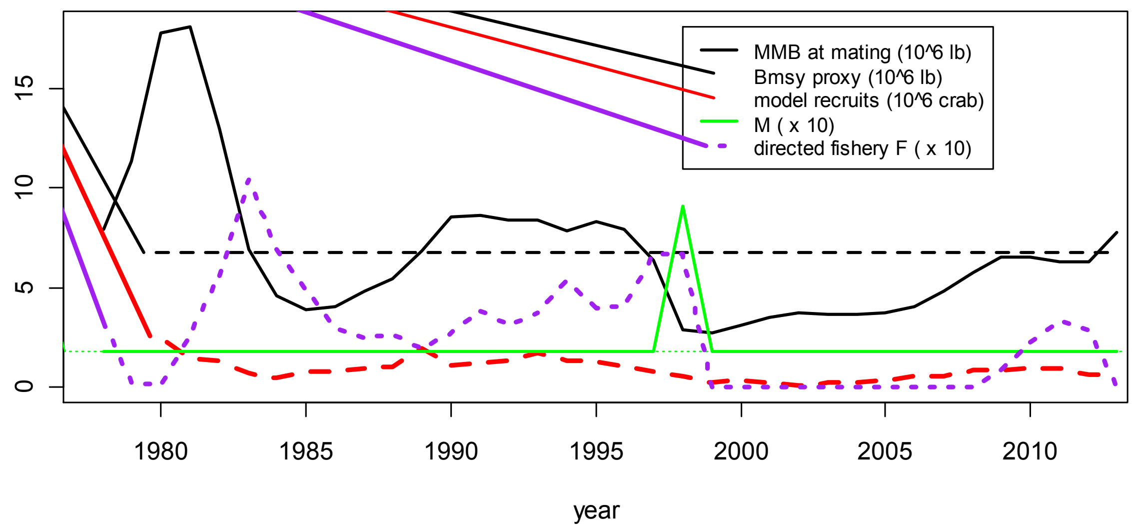


Figure 14. Model C (top) and TC key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



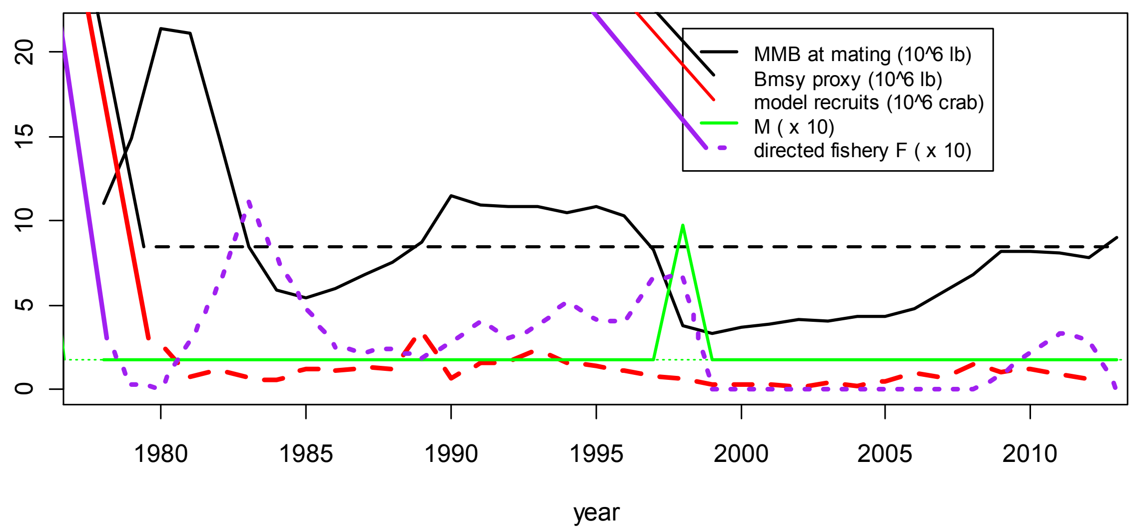
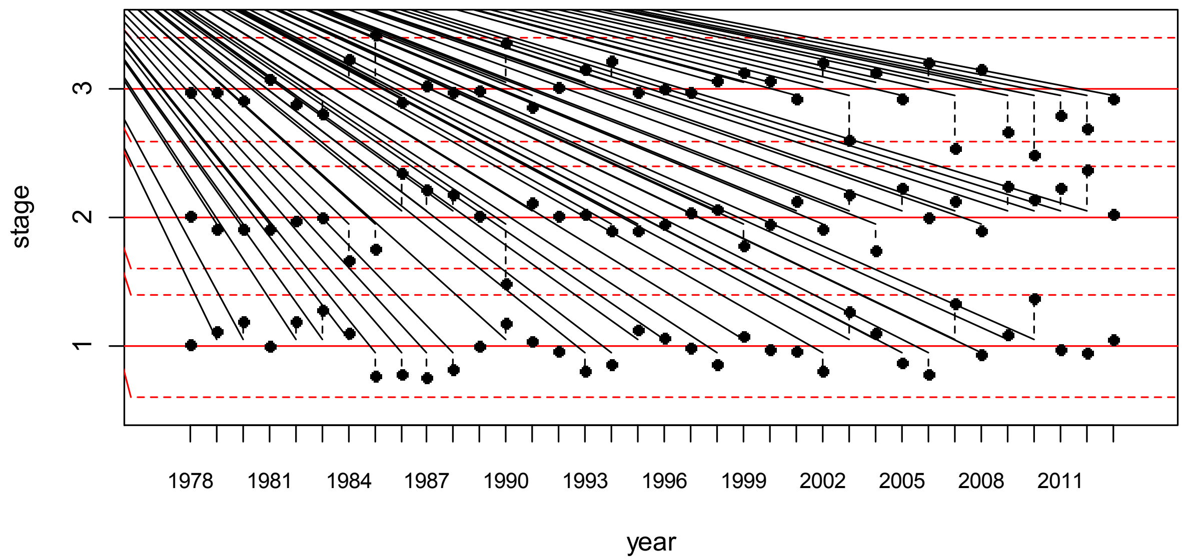


Figure 15. Base-model (top) and model Tbase key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



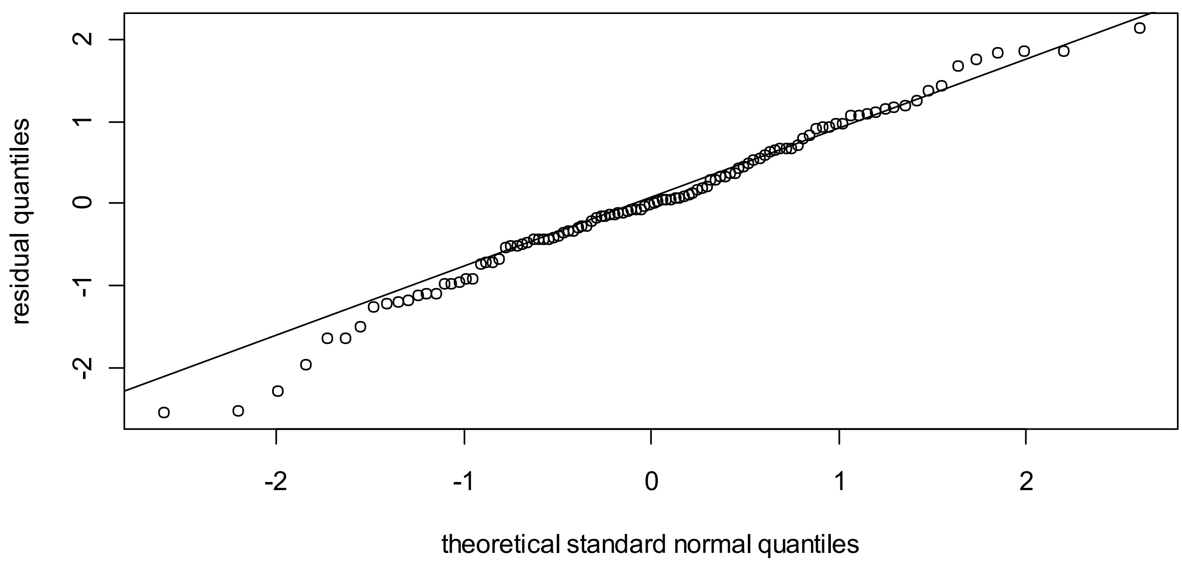
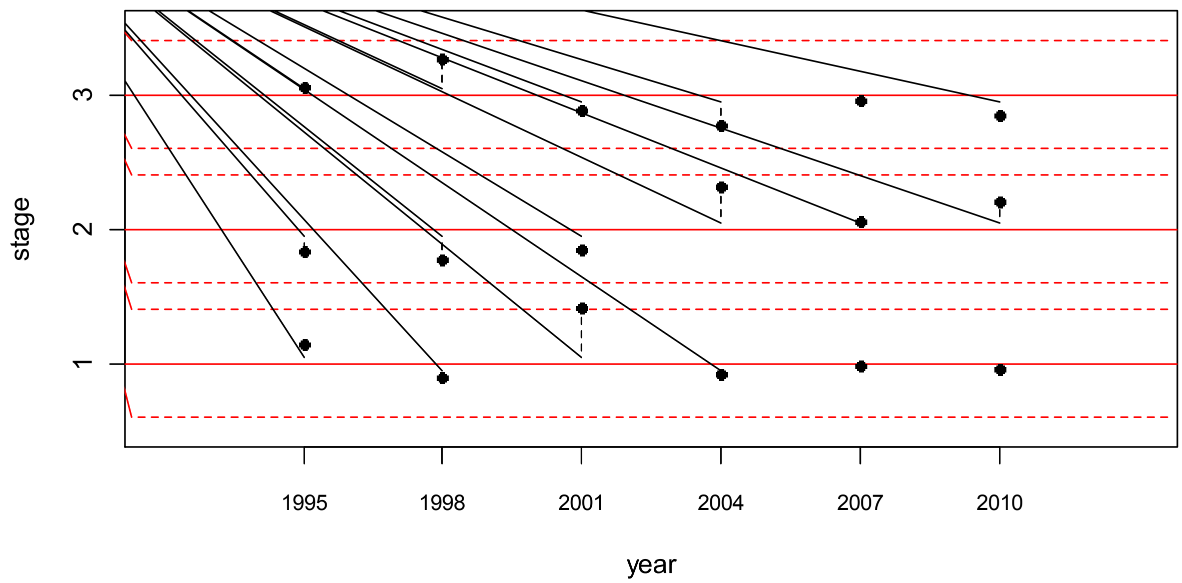


Figure 16. Model TC trawl-survey stage-proportion standardized residuals and normal qq-plot. This display should be compared against Figure 6.



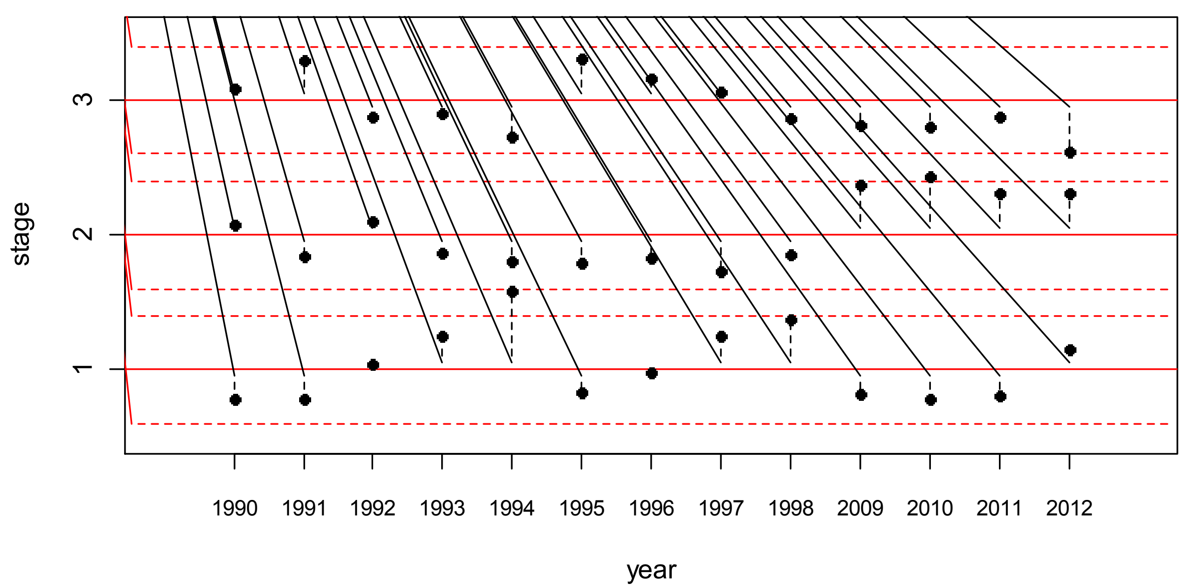


Figure 17. Base-model pot-survey (top panel) and crab-observer composition data standardized residuals.

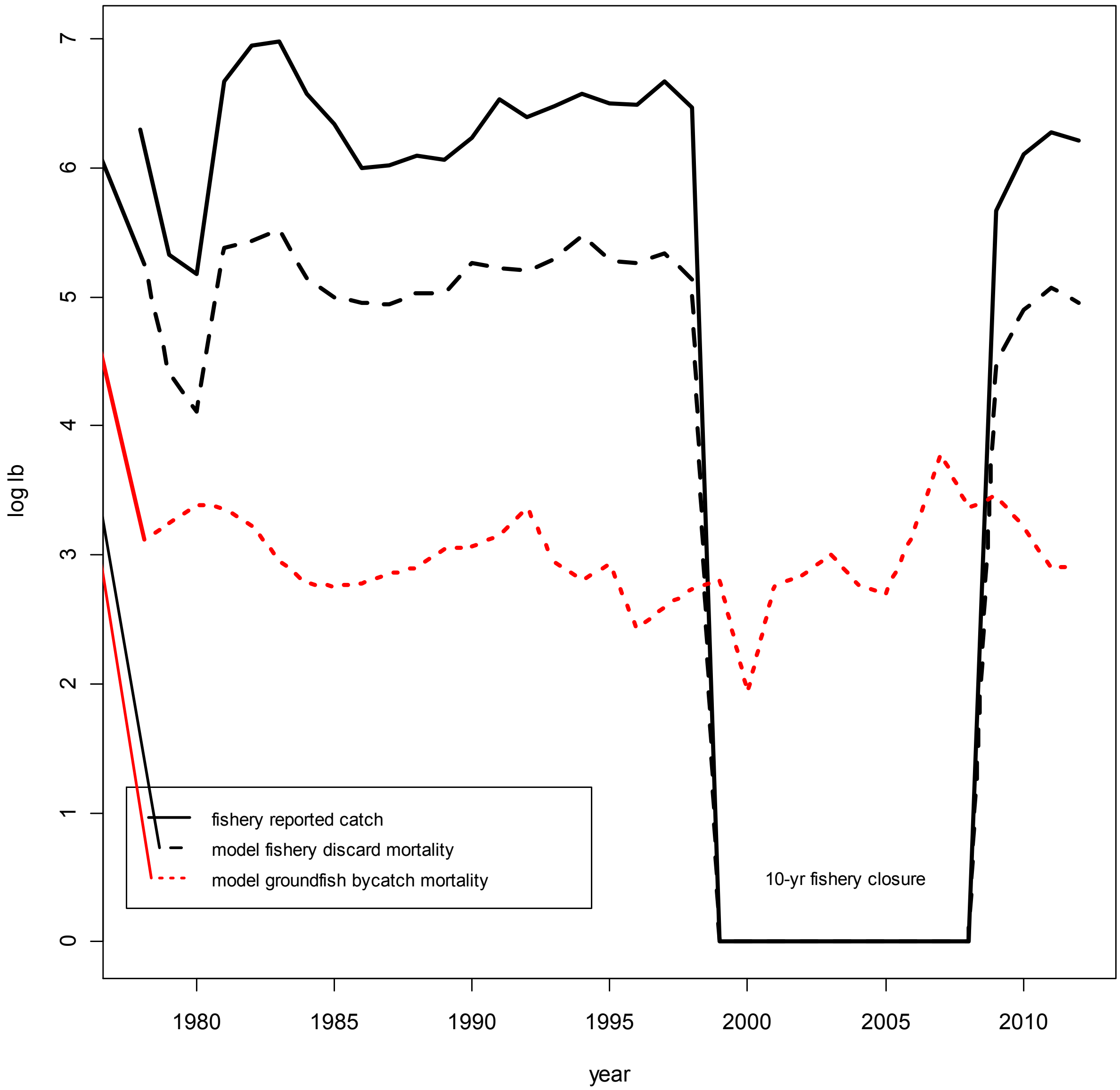


Figure 18. Components of SMBKC fishing mortality biomass for the years 1978/79 – 2012/13. Note logarithmic scale on the vertical axis.

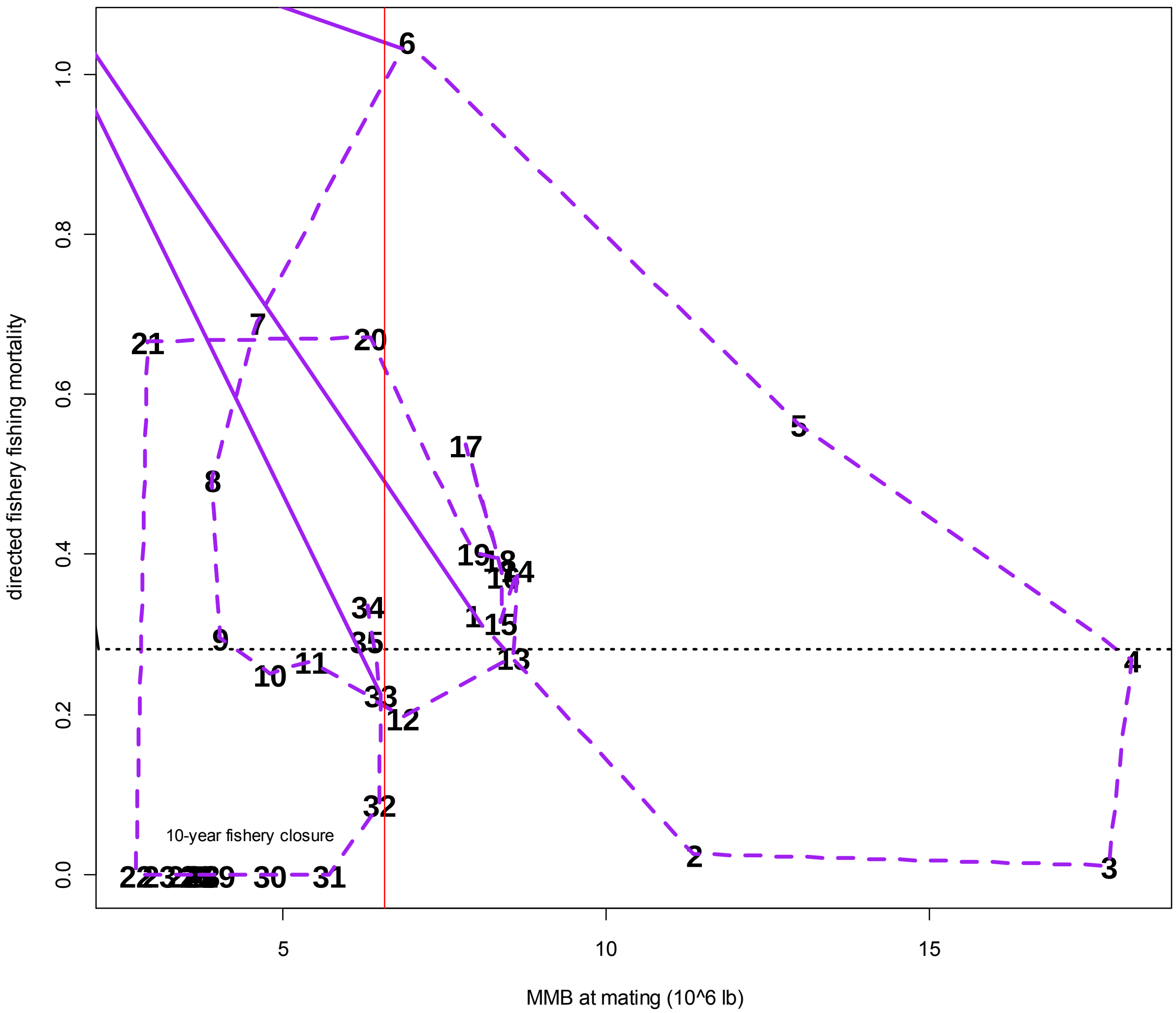


Figure 19. Base-model directed-fishery fishing mortality versus mature male biomass at time of mating for fishery years 1978/79 - 2012/13. Dotted horizontal line indicates model estimated geometric mean fishing mortality over years with a fishery. Vertical red line indicates model estimated B_{MSY} = average MMB_{MATING}.

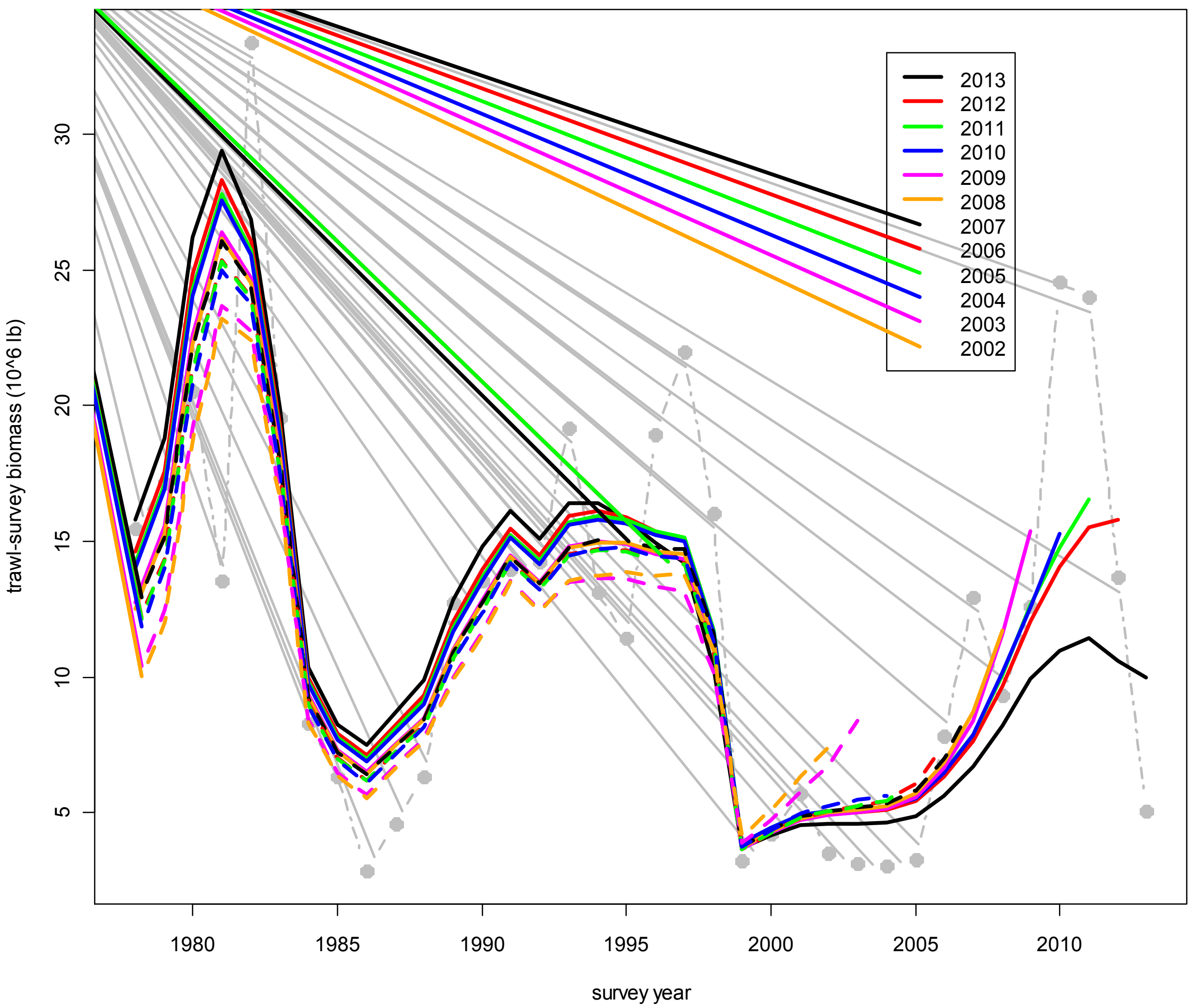


Figure 20. Retrospective plot of trawl-survey model-male (90mm+ CL) biomass for 2013 base-model configuration and terminal years 2002 – 2013. Estimates are based on all available data up to and including terminal-year trawl and pot surveys. Grey dotted line and points represent trawl-survey area-swept estimates.

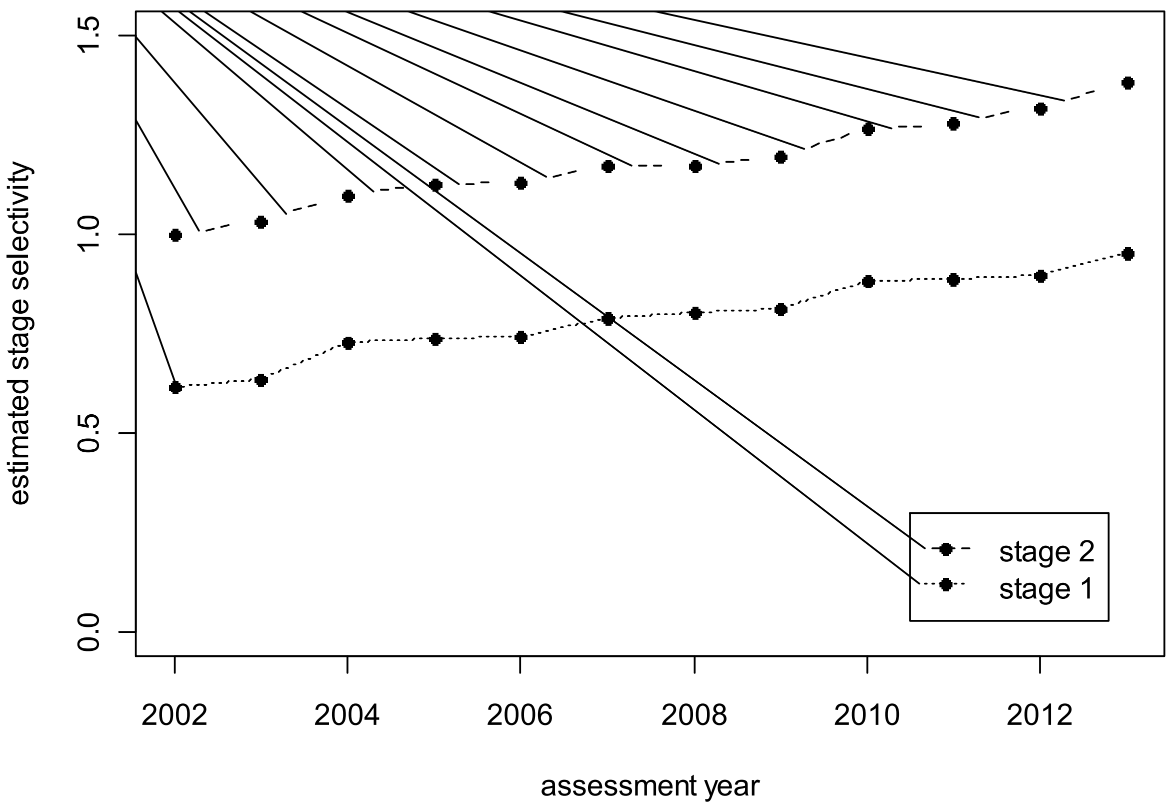


Figure 21. Retrospective 2013 base-model estimates of trawl-survey stage-1 and stage-2 selectivity for assessment years 2002 through 2013.

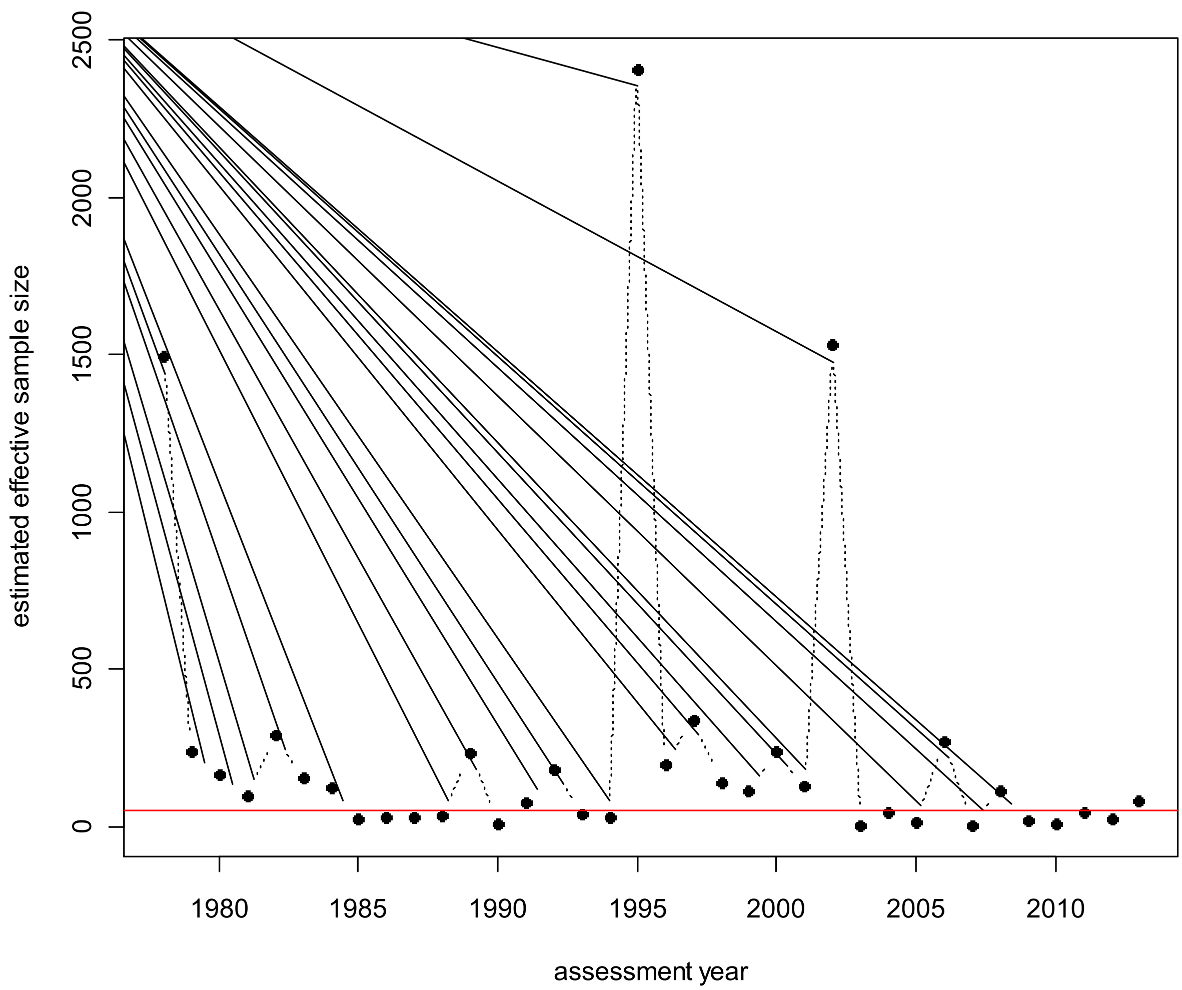


Figure 22. Trawl survey estimated effective sample size. The red line indicates the maximum model effective sample size (50).

Appendix A: SMBKC Stock Assessment 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 105mm 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. Differences characterizing alternative model scenarios considered in this document are described under **Model Selection and Evaluation** of §G. It is to be noted that for this 2013 assessment, biomass has replaced abundance as the trawl-survey index used in base-model estimation.

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 $\boldsymbol{N}_t = [\, N_{1,t}, N_{2,t}, N_{3,t} \,]^T$ 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 $\boldsymbol{N}^{new}{}_{t+1} = [\, N^{new}{}_{1,t+1}, 0, 0 \,]^T$ 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. (In the event of nontrivial bycatch mortality with another fishery, as in 2012/13, it is 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

$$\boldsymbol{R}_t^{gt} = \frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gt} \qquad \text{[A4]}$$

$$\boldsymbol{R}_t^{gf} = \frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \qquad \text{[A5]}$$

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

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \qquad \text{[A6]}$$

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 of Chilton and Foy (2010) 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 2009/10-2012/13	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2013	NMFS EBS trawl survey
ADFG pot-survey abundance index (CPUE) and CV	Triennial 1995-2010	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2013	NMFS EBS trawl survey

ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2010	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2012/13	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2012/13	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2012/13	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 length-to-weight relationship of Chilton and Foy (2010), 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

Base-model estimated parameters 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. Note, in particular, that under all model configurations examined for this assessment, stage 1 to 2 and stage 2 to 3 transition probabilities are assumed equal to 1.0, consistent with Otto and Commiskey (2009).

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. Base-model estimated parameters.

Parameter	Number
Log initial stage abundances	3
1998/99 natural mortality	1
Pot-survey “catchability”	1
Stage 1 and 2 Trawl-survey selectivities	2
Stage 1 and 2 Pot-survey selectivities	2
Stage 1 and 2 Directed-fishery selectivities	2
Mean log recruit abundance	1
Log recruit abundance deviations	35[a]
Mean log directed-fishery mortality	1
Log directed-fishery mortality deviations	25[a]
Mean log groundfish trawl fishery mortality	1
Log groundfish trawl fishery mortality deviations	22[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	22[a]
Total	119

[a] Subject to zero-sum constraint.

Table 3. Base-model fixed parameters.

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 lb	Chilton and Foy (2010) length-weight equation applied to stage size-interval midpoints.
Stage-3 mean weight	depends on year	Fishery-reported average retained weight from fish tickets, or its average.
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 $\geq$ 90mm 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 number	Lognormal	$-\lambda_1 0.5 \sum [\log(c_t + 0.001) - \log(C_t + 0.001)]^2$
Trawl-survey biomass index	Lognormal	$-\lambda_2 0.5 \sum [\frac{\ln(b_t^{ts}) - \ln(B_t^{ts})}{\ln(1 + \widehat{cv}_t^{ts\,2})}]^2$
Pot-survey abundance index	Lognormal	$-\lambda_3 0.5 \sum [\frac{\ln(a_t^{ps}) - \ln(A_t^{ps})}{\ln(1 + \widehat{cv}_t^{ps\,2})}]^2$
Trawl-survey stage proportions	Multinomial	$\lambda_4 \sum neff_t^{ts} (\boldsymbol{p}_t^{ts})^T \ln(\boldsymbol{P}_t^{ts} + 0.01)$
Pot-survey stage proportions	Multinomial	$\lambda_5 \sum neff_t^{ps} (\boldsymbol{p}_t^{ps})^T \ln(\boldsymbol{P}_t^{ps} + 0.01)$
Directed-fishery stage proportions	Multinomial	$\lambda_6 \sum neff_t^{df} (\boldsymbol{p}_t^{df})^T \ln(\boldsymbol{P}_t^{df} + 0.01)$

Groundfish trawl mortality biomass	Lognormal	$-\lambda_7 \sum [\ln(b_t^{gt}) - \ln(B_t^{gt})]^2$
Groundfish fixed-gear mortality biomass	Lognormal	$-\lambda_8 \sum [\ln(b_t^{gf}) - \ln(B_t^{gf})]^2$
$\ln(N_{1,t}^{new})$ 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 $\sum \Delta_t = 0$

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 base-model scenario. The weight of 1,000 applied to the lognormal fishery catch-number component (λ_1) corresponds to a coefficient of variation of approximately 3% for the fishery estimate of catch number. 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 1.0 weights on the lognormal groundfish bycatch mortality biomass components (λ_7 and λ_8) correspond to implied CVs of about 130%, which this author judges 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 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 the base-model 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. Base-model objective-function weighting scheme.

Objective-Function Component	Weight λ_j
Legal retained-catch number	1000
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	1.0
Groundfish fixed-gear mortality biomass	1.0
Log model recruit-abundance deviations	1.25
Log directed fishing mortality deviations	0.001
Log groundfish trawl fishing mortality deviations	1.0
Log groundfish fixed-gear fishing mortality deviations	1.0

6. Estimation

The model was implemented using the software AD Model Builder (ADMB Project 2009), with parameter estimation by automatic differentiation and minimization of the model objective function. Standard errors and estimated parameter correlations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.

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Norton Sound Red King Crab Stock Assessment for the fishing year 2014

Toshihide Hamazaki[1] and Jie Zheng [2]
Alaska Department of Fish and Game Commercial Fisheries Division
[1]333 Raspberry Rd., Anchorage, AK 99518-1565
Phone: 907-267-2158
Email: Toshihide.Hamazaki@alaska.gov
[2]P.O. Box 115526, Juneau, AK 99811-5526
Phone : 907-465-6102
Email : Jie.Zheng@alaska.gov

Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. Summer commercial fishery started in 1977, and its catch quickly 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. As the crab population rebounds, retained catches have been increasing. For past several years, retained catch is around 0.4 million pounds.

3. Stock Biomass. Estimated mature male biomass (MMB) shows an increasing trend since 1997, and an historic low in 1982 following a crash from the peak in 1977. However, uncertainty in historical biomass is great, which is in part by infrequent trawl surveys (every 3 to 5 years) and limited winter pot survey.

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 lbs.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	1.56[A]	5.44	0.40	0.42	0.46	0.73[A]	
2011/12	1.56[B]	4.70	0.36	0.40	0.43	0.66[B]	0.59
2012/13	1.78[C]	4.59	0.47	0.47	0.47	0.53[C]	0.48
2013	2.06[D]	5.00	0.50	0.35*	0.35*	0.58[D]	0.52
2013/14	2.18[E]	3.72	TBD	TBD	TBD	0.39[E]	0.36

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Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	0.71^{A}	2.47	0.18	0.19	0.21	0.33^{A}	
2011/12	0.71^{B}	2.13	0.16	0.18	0.20	0.30^{B}	0.27
2012/13	0.80^{C}	2.08	0.21	0.21	0.21	0.24^{C}	0.22
2013	0.62^{D}	2.16	0.23	0.16^{*}	0.16^{*}	0.26^{D}	0.24
2013/14	0.99^{E}	1.69	TBD	TBD	TBD	0.18^{E}	0.16

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2010
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2011
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2012
D-Calculated from the assessment reviewed by the Crab Plan Team in May 2013
E-Calculated from the assessment reviewed by the Crab Plan Team in Sept 2013
* - As of Sept 09 2013
Conversion to Metric ton: 1 Metric ton = 2.024 × 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
2010/11	4a	3.12	5.44	1.7	0.18	1983-2010	0.18		
2011/12	4a	2.97	4.70	1.6	0.18	1983-2011	0.18	0.9	0.59
2012/13	4a	3.51	4.25	1.2	0.18	1980-2012	0.18	0.9	0.48
2013	4a	4.12	5.00	1.2	0.18	1980-2013	0.18	0.9	0.52
2013/14	4a	4.36	3.72	0.9	0.15	1980-2014	0.18	0.9	0.36

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2010/11	4a	1.42	2.47	1.7	0.18	1983-2010	0.18		
2011/12	4a	1.35	2.18	1.6	0.18	1983-2011	0.18	0.9	0.27
2012/13	4a	1.59	1.93	1.2	0.18	1980-2012	0.18	0.9	0.22
2013	4a	1.86	2.27	1.2	0.18	1980-2013	0.18	0.9	0.24
2013/14	4a	2.00	1.69	0.9	0.15	1980-2014	0.18	0.9	0.16

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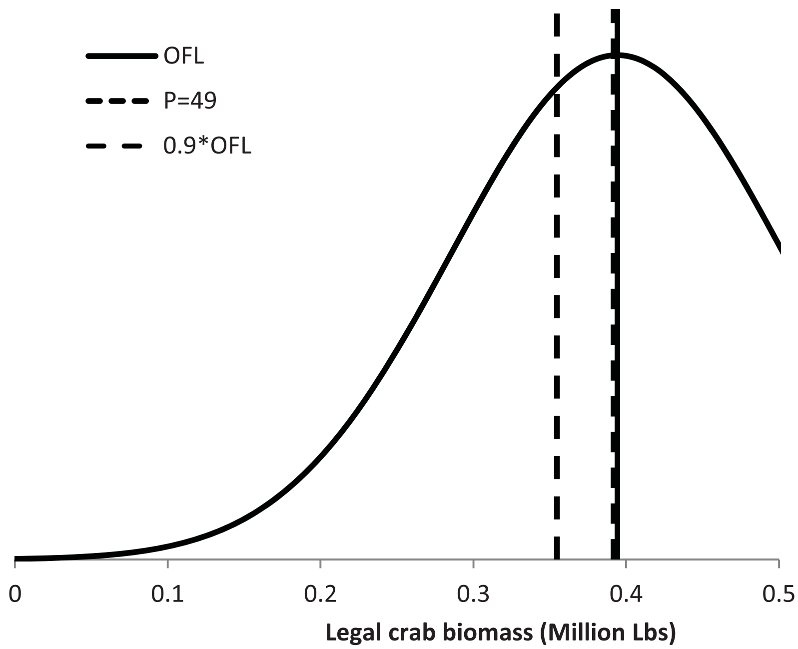
6. Probability Density Function of the OFL



OFL profile. CV of the OFL was assumed to be 0.2.

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 in 2011.

For 2014 fishery, we chose 90% OFL (10% Buffer) which was 0.355 million lb

8. A summary of the results of any rebuilding analyses.
   N/A

A. Summary of Major Changes in 2013

1. Changes to the management of the fishery**:**

In March 2012, the board of fish adopted a revised GHL: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lbs; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lbs; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lbs; and (3) ≤ 15% of legal male when estimated legal biomass >3.0 million lbs.

2. Changes to the input data
    a. Data update: 2013 summer commercial fishery, 2012/2013 winter commercial and subsistence catch.
    b. New Data: 2013 summer commercial fishery observer data, standardized commercial catch CPUE and CV.
    c. Revised data: 1976-1991 NMFS survey NSRKC crab abundance estimates were revised based on original survey data.
    d. Inclusion of the historical winter total subsistence catch data. In previous model, only winter retained subsistence catch data were used, in which it was assumed no discards mortality from winter subsistence catch. This revised model incorporates winter discards mortality.

3. Changes to the assessment methodology:

    Following major modeling modification was made:

    a. Changing modeling schedule from July 01- June 30 to Feb 01 to Jan 30 schedule
    b. Inclusion of winter commercial and subsistence discards. The number and length composition of the winter commercial catch discards were estimated from the model. Discards from the winter subsistence fishery was estimated as total subsistence catch minus total retained subsistence catch. Total catch data are not available for 1978-1983. Total catch (and thus discards) of those years were estimated by multiplying average Total/retained catch ratio for 1984-2013 (average total/retained ratio = 1.6).

       Discards of all winter subsistence catch was assumed to be males of length classes 1 and 2. In reality, subsistence catch and discards include females; however, because female proportion was very small, their catches were ignored.

4. Changes to the assessment results.
    a. Calculation of retained OFL and ABC are for both winter (subsistence + commercial) and summer commercial catches.

B. Response to SSC and CPT Comments

CPT Review April 30 – May 3, 2013

The team had the following comments:
Additional items to be addressed in the future include the following.

- Future model runs should examine variation in M.

  Author response:

  Estimation of M from the model was 0.3 with standard deviation of 8.9 (CV=2966%). Profile analyses were not successful because the model failed to converge for some value of M. Further, M was correlated with molting probability: low M = high molting probability for older length class (i.e., crab grows fast), and high M = low molting probability (i.e., crab grows slow). No empirical studies exist to support either case is more likely. Further investigations is needed.

- *Future runs should compare the parameter value estimates for NSRKC and those for BBRKC. For example, are molting probabilities similar? Are there tagging data that can be used to inform molting probability?*

  Author response:

  Comparison of parameter value estimates with BBRKC can be valid, assuming that life-history characteristics of NSRKC are similar to the BBRKC. However, we contend that the assumption is wrong. For instance, the maximum CL of male BBRKC reaches > 165 mm (maximum size 227mm), and males are assumed to mature at CL of 120 mm (Zheng and Siddeek 2012). On the other hand, the maximum CL of male NSRKC is around 130mm, and males are assumed to mature at CL of 94mm. By BBRKC standard, NEARLLY ALL NSRKC is considered immature, which obviously is incorrect. Molting probability of BBRKC from 65 to 125 mm is greater than 60% (Zheng and Siddeek 2012), which is reasonable considering that they are immature. On the other hand, molting probability of BBRKC the older length class (> 155mm) goes down to < 25%. If we assume that CL class of > 120mm of NSRKC corresponds to > 155mm of BBRKC, > 55% molting probability of CL > 120mm NSRKC seems unreasonably high.

- *The stock assessment author should verify that the assessment document follows the terms of reference for crab stock assessment documents.*

  Implemented.

- *Plots of recruitment for the different models should be included.*

  Implemented.

- List the bounds for each parameter and evaluate which parameters might be hitting bounds.

  Implemented.

- When plotting model runs, always include the base model for comparison.

  Implemented.

- Include the discussion of model runs in the main document, not as an appendix.

  Implemented.

- Be sure that the figures are titled consistently. In the current document, “total crab abundance” actually means “total male crab abundance” (figures in Appendix D are very confusing and mislabeled) and “Trawl survey legal abundance” actually means “total legal abundance” (Figure 4b) – correct all throughout,

  Implemented.

- Be sure that data in tables and figures are consistent.

  Implemented.

- Equation 24 is missing the additional variance term.

  Corrected

- Figures all need unique figure numbers.

  This was largely due to the fact that two separate documents (SAFE assessment report, and Standardization of CPUE report) were combined as a single document at the time of publication.

- All pages must be numbered sequentially, and all pages must have page numbers for ease of review and discussion by the team.

  Implemented.

SSC Review on June 3-5, 2013

SSC's agreed with all CPT's reviews, and no further comments were provided.

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 with 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 migrates between deeper offshore waters during molting/feeding and inshore shallow waters during the mating period. Timing of the inshore mating migration is unknown; but is assumed to be during March-June. Offshore migration is considered to begin in May-July. 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. Timing of molting is unknown; however, is considered to occur in late August – September, based on increase catches of fresh-molted crabs in later fishing season (August- September).
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) (Menard et al. 2011). The majority of red king crab are harvested by the summer commercial fisheries, whereas the majority of the winter harvest is in the subsistence fishery occurring near the coast (Table 2).

   <u>Summer Commercial Fishery</u>

   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 crabs of ≥ 5 inch carapace.

Not all Norton Sound area is open for commercial fisheries. Since beginning of the commercial fisheries in 1977, inland waters near Nome area has been closed for summer commercial crab fishery, possibly to protect crab nursery grounds (Figure 2). Extent of closed water changed throughout history.

<u>CDQ Fishery</u>

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. It is possible that the fishery starts BEFORE determination of OFL and ABC.

<u>Winter Commercial Fishery</u>

Winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. Approximately 10 permit holders participated in this fishery harvesting, on average 2,500 crabs during 1978-2009; however, during 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

Subsistence crab fishery has been occurring for a long time; however, its harvest is available since 1977/78 winter period. The majority of subsistence crab fishery mainly occurs during winter using hand lines and pots through the nearshore ice. Average annual winter subsistence harvest was 5,400 crabs (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).

Summer subsistence crab fishery harvest has been monitored since 2004 with average harvest of 712 crabs per year. Since this harvest is very small, 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. Since 1999, 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 lbs; (2) ≤ 5% of legal male abundance when the estimated legal biomass falls within the range 1.5-2.5 million lbs; and (3) ≤ 10% of legal male when estimated legal biomass >2.5 million lbs.

In 2012 the Alaska Board of Fisheries adopted a revised GHL: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lbs; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lbs; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lbs; and (3) ≤ 15% of legal male when estimated legal biomass >3.0 million lbs.

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 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°W line.
1998	Community Development Quota (CDQ) allocation into effect
1999	Guideline Harvest Limit (GHL) into effect
2000	North Pacific License Limitation Program (LLP) 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	Board of fisheries adopted a revised GHL

7. Summary of the history of the $B_{MSY.}$

   NSRKC is a Tier4a crab stock. Direct estimation of the B_{MSY} is not possible. B_{MSY} is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on a belief that PDO shift occurred in 1976-77 could have changed the productivity.

D. Data

1. Summary of new information:
   1. Historical total catch of winter subsistence fishery. Data have been available but have not been incorporated into the model.
2. Available survey, catch, and tagging data

Data	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11	Abundance and proportion by length and shell condition	3,5, Figure 3
Winter pot survey	81-87, 89-91,93,95-00,02-12	Proportion by length and shell condition	6, Figure 3
Summer commercial fishery	76-90,92-13	Harvest, effort, standardized CPUE, and proportion by length and shell condition	1,4, Figure 3
Summer commercial Observer	87-90,92,94, 2012-2013	Proportion by length and shell condition (sub-legal only)	7, Figure 3
Winter commercial and subsistence fishery	76-13	The Number of crab harvested and retained (No length composition was recorded)	2, Figure 3
Tagging	80-13	Used to create a growth increment matrix	8

Data available but not used for assessment

Data	Years	Data Types	Reason for not used
Summer pot survey	80-82,85	Abundance and proportion by length and shell condition	Uncertainties on how estimates were made.
Summer preseason survey	95	Proportion by length and shell condition	Just one year of data

1. Summer commercial fishery and winter commercial and subsistence catch, (ADF&G 1976-2011) (Tables 1 and 2).

2. Length composition of discards of sublegal males (observer data) from the summer fishery (ADF&G 1987-90, 1992, 1994, 2012) (Table 7). The survey was opportunistic, and the number of crab discarded was not recorded. Continuation of summer commercial

discards observer data depend upon future funding. No information on winter commercial catch discards. Total number of discards from winter subsistence catch is available (Table 2).

3. In Norton Sound, no other crab, groundfish, or shellfish fisheries exist.

	Fishery	Data availability
Directed pot fishery (males)	Summer commercial Winter commercial/subsistence	summer commercial winter subsistence
Directed pot fishery (females)		Little
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

4. Catch at length data for summer commercial fisheries (Table 4).

5. Survey abundance estimates:

Triennial trawl surveys were conducted by the NMFS (1976-1991, 2010) and by the ADF&G (1996-2011) (Table 3). The NMFS survey was conducted using the 83-112 Eastern Otter Trawl, whereas the ADF&G survey was conducted using the 400 Eastern Otter Trawl. In both surveys, survey design was based on 10×10nm square, except for the NMFS survey in 2010 where survey grid was 20×20nm. Abundance of crabs were estimated by area-swept methods (Alverson and Pereyra 1969). Historical NMFS trawl survey abundance was re-estimated from the original raw data in 2013.

Summer pot survey was conducted in 1980-82 and 1985. However, the data were dropped out of the assessment model by a recommendation of the CPT in 2013. The main reason was the lack of original data to verify the abundance estimates.

3. Other miscellaneous data: None.
4. Growth-per-molt (Table 8), estimated from tagging data (1991-2007).
5. Proportion of legal size crab, estimated from trawl survey data (Table 5).

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).

In 2010 the model was modified with 1) M =0.18, 2) include summer commercial discards mortality, 3) weight of fishing effort = 20, 4) the maximum effective sample size for commercial catch and winter surveys = 100, and 5) M of the last length class = 0.288.

In 2012, the model was modified with 1) M of the last length class = 0.648, 2) the maximum effective sample size for commercial catch and winter surveys = 50, and 3) weight of fishing effort = 50.

In 2013, after the modeling workshop, the model was modified with 1) replace likelifhood 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, and 4) reduce the maximum effective sample size for commercial catch and winter surveys = 20.

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. Instantaneous natural mortality *M* is 0.18 for all length classes, except for the last length group (> 123mm) where M =0.648 (0.18 × 3.6) (Zheng et al. 1998). 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 CPT. The assumption of the higher M for the last length group is based not on biological data, but rather 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 (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).

   iii. 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.

iv. 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 a belief (but no empirical data) that very large crab less representative in near shore area where the winter surveys occur. This assumption improves the model fit and reduces the bias in the bubble plot.

v. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class 5 and 6. It has two curves: before 1993, 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 legal crab with CW < 5.0 are discarded, one can argue that the catch selectivity changed in 2005. However, the model was not able to accurately estimate parameters for 2005-2013. Hence, selectivity for both 1993-2004 and 2005-2013 were combined.

vi. Winter commercial and subsistence fishery selectivity and length-shell conditions are the same as those of the winter pot survey. All winger commercial and subsistence harvests occur after February 1st.

Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No data exists about length composition of crab harvested in commercial and subsistence fishery. 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.

vii. Growth increments are is a function of length and are constant over time.

viii. Molting probabilities are an inverse logistic function of length for males.

ix. A summer fishing season for the directed fishery is short.

x. Discards handling mortality of all fishery is assumed 20%. No empirical estimate is available.

xi. Annual retained catch is measured without error.

xii. All legal size crabs (≥ 4-3/4 inch CW) are taken to the commercial dock.

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.

xiii. All sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.

xiv. Length compositions have a multinomial error structure, and abundance has a log-normal error structure.

h. Changes of assumptions since last assessment:

Discards mortality of the winter commercial and subsistence fisheries is 20%.

i. Code validation. Model code is reviewed at CPT modeling workshop in 2013, and is available from the authors.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

Following model modifications were made:

1. Shift modeling time period from July 1st - June 30th to Feb 1st - Jan 31st. This modeling configuration considers that winter fisheries occur prior to summer fisheries.

2. Inclusion of winter commercial and subsistence discards mortality.

We did not evaluate various model configurations, but evaluated the influence of observer data. For this, we evaluated

a. Full data
b. Without 2013 observer data

b. Evaluation of alternative models results

Log-likelihood

	Total	Trawl survey abundance	Standardized CPUE	Trawl Length Composition	Winter Pot Length Composition	Commercial Catch Length Composition	Recruitment	Observer Length Composition
Full Data	28.86	5.85	-22.35	9.79	14.36	14.45	0.34	6.24
Without 2013 Observer data	26.70	5.84	-22.62	9.89	14.26	13.83	0.30	5.18

c. Search for balance:

d. Convergence status and convergence criteria

e. Table & plot of the sample sizes (See Figures 4a, 4b)

f. Parameter estimates (See Tables 10, 11).

Parameter estimates of the two models are very similar. Notable difference is the shape of trawl size selectivity (Figures 5a b). While full data model showed trawl selectivity increasing from 0.7 to 1.0 as length class increased (Figure 5a), the reduced data model showed constant 1.0 selectivity for all length classes.

g. Description of criteria used to evaluate the model.

Selection of the best model in this case, depends on reliability of data obtained in 2013.

In 2013, commercial fishery opened on July 3 because of low meat fill observed in crabs collected during the spring tagging survey. Once opened, very low catch rates persisted for the first three weeks. Considering that crabs have not moved to offshore, the ADF&G opened waters normally closed to commercial fishing (3 nmiles inward of the closure line) in order to increase harvest efficiency. However, this did not increase the catch rate and cpue. The season was extended by emergency order when it became apparent the GHL would not be met by the regulatory closure date of September 3. As of this writing (September 9 2013), fishery has not been closed yet. (Fishery closed on September 13 2013; however, all data have not been finalized).

Observer data were collected from as many as fishermen as possible. However, the observer data are limited to fishermen who 1) have a boat large enough to have an observer safely, 2) are willing to have an observer on board, and 3) are accessible by the observers. However, the estimates seem reliable because the estimates did not differ from systematic survey conducted by the ADF&G. Furthermore, composition of retained crab lengths from the observer data were similar to that from the commercial catches measured at the dock.

h. Residual analysis.

RMSE was calculated as

$$RMSE = \sqrt{\tfrac{1}{n}\sum(\ln(obs) - \ln(pred))^2}$$

Indices	Full data	without 2013 observer data
Trawl survey	0.268	0.267
CPUE	0.464	0.461

QQ plots, histograms of residuals, and plot of predicted vs. residual were provided for trawl abundance and commercial catch standardized CPUE (Figure 11)

i. Evaluation of the model

Projection of the two data models were almost identical, except for 2012 (Figures 7a 7b). The full data model resulted in high recruitment and thus high projected legal biomass, whereas the second model (without 2013 observer data) showed decline of projected legal biomass. In the absence of data suggesting high recruitment and projected biomass (which will be verified in 2014 when trawl survey will be conducted), **the CPT recommends to adopt the 2nd model (i.e., without 2013 observer data).**

4. Results

1. List of effective sample sizes and weighting factors (Figure 4a b)

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 overtime.

Following weights were used

Data	Weighting Factor
Recruitment	0.01

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 (Table 10, 11, Figure 5).

Most of parameters were estimated with CV of around 30%. Notable exception was recruitment parameter for 1977-1979, 1998, 2003, 2012, 2013 (log_R_{77}, log_R_{78}, log_R_{79}, log_R_{98}, log_R_{03}, log_R_{12}, log_R_{13}), trawl selectivity parameter (log_ϕ_{st} and log_ω_{st}), and winter pot survey selectivity (log_ω_{sw}). For 1978 and 1979, estimates were close to zero reflecting extremely low proportion of < 94mm crab observed in 1979 trawl survey (Table 5, Figure 3, 4). The high CVs for those selectivity parameters are an artifact because the estimated selectivity was 1.0 for those cases. In asymptotic logistic function, multitudes of parameter combinations can result in 1.0, so that model was not able to converge into single parameter.

b. Abundance and biomass time series (Figure 6, 7, 8).

Fits of the both scenarios to trawl survey data are similar. Exception is 2013.

c. Recruitment time series (Table 12 and Figure 6).

d. Time series of catch/biomass (Table 3, Figure 9, 10)

3. Graphs of estimates.

   a. Molting probability and trawl/pot selectivity (Figure 5)

   b. Trawl survey abundance and model abundance (Figure 6)

   c. Estimated male abundances (recruits, legal, and total) (Figure 7)

   d. Estimated mature male biomass (Figure 8)

   e. Time series of catch standardized cpue (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 (Figure 9, 11)

   b. Model fits to survey numbers (Figure 6, 11).
   The majority of model estimated abundances of total crabs were within the 95% confidence interval of the survey observed abundance, except for 1976 and 1979, where model estimates was higher than the observed abundance.

   c. Fits of catch proportions by lengths (Figures).

   d. Model fits to catch and survey proportions by length (Figure 12, 13, 14, 15, 16).

   e. Marginal distribution for the fits to the composition data: (Figure 13).

   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:

Indices	Full data	without 2013 observer data
Trawl survey	0.268	0.267
CPUE	0.464	0.461

   h. QQ plots and histograms of residuals (Figure 11).

5. Retrospective and prospective analyses.

   Not provided

6. Uncertainty and sensitivity analyses.

F. Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is currently placed in Tier 4 (NPFMC 2007). 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 capture the essential population dynamics. Whereas tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous M, the estimates for the Norton Sound red king crab stock uncertain. Survey biomass is based on triennial trawl surveys with CVs ranging 15-42% (Table 4). The natural mortality of 18% adopted by the CPT (2010) is based on Bristol Bay red king crab with the maximum age 25 and the 1% rule (Zheng 2005); however, no data are available to support the assumption of a maximum age 25 for the Norton Sound red king crab.

The OFL is estimated by the F_{MSY} proxy, B_{MSY} proxy, and estimated legal male abundance and biomass:

$$F_{OFL} = \gamma\, M, \quad when\ B / B_{MSY^{prox}} > 1, \tag{1}$$

$$F_{OFL} = \gamma\, M\, (B / B_{MSY^{prox}} - 0.1) / 0.9, \quad when \quad 0.25 < B / B_{MSY^{prox}} \le 1, \tag{2}$$

$$F_{OFL} = bycatch\ mortality\ \&\ directed\ \ fishery\ F = 0, \quad when\ B / B_{MSY^{prox}} \le 0.25, \tag{3}$$

where B is a mature male biomass (MMB), B_{MSY} proxy is average mature male biomass over a specified time period. $M = 0.18$ and $\gamma = 1$.

For Norton Sound red king crab, MMB is defined as CL > 94 mm.

OFL was calculated for retained catch and total male catch. The retained OFL is based on legal crab biomass catchable to summer commercial pot fisheries (*Legal_B*). However, because the projected model biomass is Feb 1st, projected legal biomass on July 1st was calculated as: Projected legal abundance (Feb 1st) × Natural mortality (from Feb 1st to July 1st) × Commercial pot selectivity × Proportion of legal crab per length class × Average lb per length class. Note that this projection does not include winter harvests, so that the retained OFL can is both winter and summer catch combined.

$$Legal\_B = \sum_l (N_{s,l,} + O_{s,l,}) S_{s,l} L_l wm_l = \sum_l (N_{w,l,} + O_{w,l,}) \exp(-0.417 M_l) S_{s,l} L_l wm_l$$

$$OFL_{retained} = (1 - \exp(-F_{OFL})) Legal\_B$$

The total male OFL is

$$OFL_{totalmales} = OFL_{retained} + (1 - \exp(-F_{OFL})) \sum_l (N_{s,l,} + O_{s,l,}) S_{s,l} (1 - L_l) wm_l\ hm$$

where $N_{w,l}$ and $O_{w,l}$ are winter abundance and $N_{s,l}$ and $O_{s,l}$ are summer abundances of newshell and oldshell crabs in length class l in the terminal year, -0.417 is a proportion of year between Feb 1st and July 1st, 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.

For the selection of the B_{MSY} proxy, default data used are survey MMB. However, for the Norton Sound red king crab stock, only available survey MMB data are triennial trawl surveys. Instead, we used the *model estimated* MMB for calculation of B_{MSY} proxy from 1980 to present.

Predicted legal male and mature male biomass in 2014 are:

Legal male biomass:

2.83 million lb with a standard deviation of 1.18 million lb.

Mature male biomass:

3.72 million lb with a standard deviation of 4.37 million lb.

B_{MSY} proxy was calculated as an average MMB during 1980-2014 periods.

4.36 million lb

Since projected MMB for 2014 (3.72) was less than B_{MSY} proxy (4.36), or B/B_{MSY} = 0.85, F_{OFL} calculation was based on the equation (2),

$$F_{OFL} = \gamma\, M\, (B / B_{MSY^{prox}} - 0.1) / 0.9, \quad when \quad 0.25 < B / B_{MSY^{prox}} \leq 1,$$

F_{OFL} = 0.18(0.85 – 9.1)/0.9 = 0.15

Retained OFL for legal male crab is

$$OFL_{retained} = (1 - \exp(-F_{OFL}))Legal\_B$$

OFL = 3.72(1-exp(-0.15)) = 0.394 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 2013 as follows:

Tier 4 crab stocks

Calculation of a distribution for the OFL for Tier 4 stocks involves repeating four steps (detailed below). The aim is to have the median of the distribution for the OFL equal the point estimate (so that P*=0.5 implies that the ABC equals to the point estimate of the OFL). The proposed steps are: (a) Sample current MMB from a normal distribution with mean given by the point estimate of current MMB and CV equal to the sampling CV. (b)The B_{MSY} proxy is the average MMB over a pre-specified set of years. Uncertainty in the B_{MSY} proxy only accounts for uncertainty in MMB for the years for which it is assumed the stock was "at B_{MSY}" and not uncertainty in the years concerned. For each of the years used when defining the B_{MSY} proxy, sample MMB from a distribution with mean given by its point estimate and CV equal to the sampling CV. The pseudo B_{MSY} proxy is then the average of the samples values. (c)Sample *M* from a normal distribution with mean equal to the assumed *M* and CV equal to an assumed CV (e.g. 0.2). (d)Compute the OFL. Form a cumulative distribution for the OFL from the sampled values. Find the median of this distribution. Using normal quantiles to rescale the distribution so that the median equals the OFL (similar to a bias-corrected bootstrap).

For the Norton Sound red king crab, calculation of OFL was based on summer commercial retained legal male biomass. For calculation of the ABC, default percentile is P* = 49; however, for the Norton Sound Stock the NPFMC adopted 10% buffer of OFL (i.e., ABC = 0.9×OFL) in 2012.

Retained ABC for legal male crab is 90% of OFL

ABC = 0.9OFL
ABC = 0.9*0.394 = 0.355 million lb.

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

The major data gap that hinder this year's OFL/ABC calculation 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, location of females during summer.

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Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2013. Bold type shows data used for assessment model.

Year	Guideline Harvest Level (lbs) [b]	Commercial Harvest (lb) [a, b] Open Access	CDQ	Total Number Harvest	Vessels	Permits	Landings	Total Pots Registered	Pulls	ST CPUE	SD	Season Length Days	Dates	Mid-day from July 1
1977	[c]	0.52		**195,877**	7	7	13		5,457	**NA**	**NA**	60	[c]	**0.03**
1978	3.00	2.09		**660,829**	8	8	54		10,817	**1.55**	**0.36**	60	6/07-8/15	**0.03**
1979	3.00	2.93		**970,962**	34	34	76		34,773	**3.01**	**0.23**	16	7/15-7/31	**0.063**
1980	1.00	1.19		**329,778**	9	9	50		11,199	**1.60**	**0.22**	16	7/15-7/31	**0.063**
1981	2.50	1.38		**376,313**	36	36	108		33,745	**1.97**	**0.27**	38	7/15-8/22	**0.093**
1982	0.50	0.23		**63,949**	11	11	33		11,230	**0.66**	**0.19**	23	8/09-9/01	**0.14**
1983	0.30	0.37		**132,205**	23	23	26	3,583	11,195	**0.12**	**0.26**	3.8	8/01-8/05	**0.093**
1984	0.40	0.39		**139,759**	8	8	21	1,245	9,706	**1.10**	**0.23**	13.6	8/01-8/15	**0.107**
1985	0.45	0.43		**146,669**	6	6	72	1,116	13,209	**1.17**	**0.24**	21.7	8/01-8/23	**0.132**
1986	0.42	0.48		**162,438**	3	3		578	4,284	**0.42**	**0.22**	13	8/01-8/25	**0.153**
1987	0.40	0.33		**103,338**	9	9		1,430	10,258	**1.28**	**0.44**	11	8/01-8/12	**0.118**
1988	0.20	0.24		**76,148**	2	2		360	2,350	**0.74**	**0.33**	9.9	8/01-8/11	**0.115**
1989	0.20	0.25		**79,116**	10	10		2,555	5,149	**1.76**	**0.72**	3	8/01-8/04	**0.096**
1990	0.20	0.19		**59,132**	4	4		1,388	3,172	**2.02**	**0.34**	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	**0.31**	**0.33**	2	8/01-8/03	**0.093**
1993	0.34	0.33		**115,913**	14	20	208	560	7,063	**1.01**	**0.10**	52	7/01-8/28	**0.09**
1994	0.34	0.32		**108,824**	34	52	407	1,360	11,729	**0.89**	**0.06**	31	7/01-7/31	**0.044**
1995	0.34	0.32		**105,967**	48	81	665	1,900	18,782	**0.47**	**0.05**	67	7/01-9/05	**0.066**
1996	0.34	0.22		**74,752**	41	50	264	1,640	10,453	**0.54**	**0.08**	57	7/01-9/03	**0.096**
1997	0.08	0.09		**32,606**	13	15	100	520	2,982	**0.92**	**0.10**	44	7/01-8/13	**0.101**
1998	0.08	0.03	0.00	**10,661**	8	11	50	360	1,639	**0.87**	**0.13**	65	7/01-9/03	**0.088**
1999	0.08	0.02	0.00	**8,734**	10	9	53	360	1,630	**0.89**	**0.12**	66	7/01-9/04	**0.101**
2000	0.33	0.29	0.01	**111,728**	15	22	201	560	6,345	**1.29**	**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	**0.67**	**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	**1.27**	**0.06**	77	6/15-9/03	**0.074**
2003	0.25	0.25	0.01	**93,638**	25	43	236	960	8,494	**0.92**	**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	**1.35**	**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	**1.28**	**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	**1.36**	**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	**1.08**	**0.05**	52	6/15-8/17	**0.063**
2008	0.41	0.36	0.03	**143,337**	23	30	248	920	8,721	**1.41**	**0.05**	73	6/23-9/03	**0.063**
2009	0.38	0.37	0.03	**143,485**	22	27	359	920	11,934	**0.89**	**0.04**	98	6/15-9/20	**0.1**
2010	0.40	0.39	0.03	**149,822**	23	32	286	1,040	9,698	**1.26**	**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	**1.68**	**0.06**	33	6/28-7/30	**0.038**
2012	0.47	0.44	0.03	**161,113**	29	29	289	1,200	10,041	**1.34**	**0.05**	72	6/29-9/08	**0.077**
2013[d]	0.50	0.33	0.02	**117,733**	36	33			12,738	**0.70**	**0.04**	69	7/3-9/08	**0.077**

[a] Deadloss included in total. [b] Millions of pounds. [c] Information not available. [d] Preliminary as of 9/08 fishery has not been closed.

Table 2. Historical winter commercial and subsistence red king crab fishery, Norton Sound Section, eastern Bering Sea, 1977-2013. Bold typed were used for 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	1999/2000	10	**3,045**	1999/2000	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	30	**22,641**	2012/13	149	140	67	**21,524**	**7,622**

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**

Table 4. Summer commercial catch size/shell composition. 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[a]	4203	0	0	0.0052	0.2427	0.3624	0.3084	0	0	0.0005	0.0159	0.0402	0.0247

[a]: Fishery has not been closed yet, preliminary as of Sept 08 2013

Table 5. Summer Trawl Survey size/shell composition

		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

Table 6. Winter pot survey size/shell composition

		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+
1981/82	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	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	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	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	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	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	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	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	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	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	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	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	1582	0.2297	0.2351	0.1189	0.1568	0.1216	0.0676	0	0	0	0.0189	0.027	0.0243
1997/98	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	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	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													
2001/02	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	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	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	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	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	160	0.1486	0.2095	0.3784	0.1419	0.0473	0	0	0	0.0068	0.0203	0.0405	0
2007/08	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	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	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	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	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, 2012-2013 observer survey (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[a]	1457	0.5148	0.2711	0.1997	0.0110	0	0	0.0007	0.0007	0.0021	0	0	0

[a]: Fishery has not been closed yet, preliminary as of Sept 08 2013

Table 8. Growth matrix (proportion of crabs molting from a given pre-molt carapace length range into post-molt length ranges) for Norton Sound male red king crab. Length is measured as mm CL. Results are derived from mark-recapture and winter tagging data from 1980 to 2007.

Pre-molt Length Class	Post-molt Length Class 74-83	84-93	94-103	104-113	114-123	124+
74-83	0	0.33	0.67	0	0	0
84-93	0	0	0.56	0.44	0	0
94-103	0	0	0	0.76	0.24	0
104-113	0	0	0	0.18	0.61	0.21
114-123	0	0	0	0	0.33	0.67
124+	0	0	0	0	0	1.00

Table 9. Estimated selectivities, molting probabilities, and proportions of legal crabs by length (mm CL) class for Norton Sound male red king crab

Full data

Length Class	Legal Proportion	Mean weight (lb)	Selectivity				Molting Probability
			Summer Trawl	Winter Pot	Summer Fishery		
					77-92	93-13	
74 - 83	0.00	0.854	0.70	0.56	0.15	0.06	1.00
84 - 93	0.00	1.210	0.77	1.00	0.25	0.15	0.93
94 - 103	0.26	1.652	0.84	1.00	0.40	0.35	0.87
104 - 113	0.97	2.187	0.91	1.00	0.63	0.67	0.81
114 - 123	0.99	2.825	1.00	1.00	1.00	1.00	0.75
124+	1.00	3.697	1.00	0.36	1.00	1.00	0.70

Without 2013 Observer data

Length Class	Legal Proportion	Mean weight (lb)	Selectivity				Molting Probability
			Summer Trawl	Winter Pot	Summer Fishery		
					77-92	93-13	
74 - 83	0.00	0.854	1.00	0.60	0.14	0.03	1.00
84 - 93	0.00	1.210	1.00	1.00	0.22	0.10	0.93
94 - 103	0.26	1.652	1.00	1.00	0.37	0.31	0.87
104 - 113	0.97	2.187	1.00	1.00	0.61	0.69	0.81
114 - 123	0.99	2.825	1.00	1.00	1.00	1.00	0.75
124+	1.00	3.697	1.00	0.36	1.00	1.00	0.70

Table 10. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

Parameter	Lower	Upper
log_q_1	-32.5	8.5
log_q_2	-32.5	10.0
log_N_{76}	2.0	15.0
R_0	2.0	12.0
$log\_\sigma_R^2$	-20.0	20.0
a_1	-5.0	5.0
a_2	-5.0	5.0
a_3	-5.0	5.0
a_4	-5.0	5.0
a_5	-5.0	5.0
r	0.5	0.9
log_α	-5.5	-2.0
log_β	0.55	10.0
log_ϕ_{st}	-10.0	-1.0
log_ω_{st}	0.51	10.0
log_ϕ_{sw}	-10.0	10.0
log_ω_{sw}	3.9	5.5
Sw_6	0.1	1.0
log_ϕ_1	-5.0	-1.0
log_ω_1	3.9	7.5
log_ϕ_2	-5.0	-1.0
log_ω_2	3.9	7.5
w_t	0.0	6.0
q	0.1	1.0

Table 11. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

	Full data		Without 2013 Observer data	
name	Estimate	std.dev	Estimate	std.dev
log_q_1	-7.137	0.220	-7.128	0.222
log_q_2	-6.769	0.118	-6.781	0.118
log_N_{76}	9.050	0.204	9.045	0.206
R_0	6.393	0.233	6.332	0.304
$log\_\sigma_R^2$	1.112	0.541	1.181	0.583
log_R_{77}	-2.740	3.385	-2.696	3.428
log_R_{78}	-2.440	1.629	-2.357	1.630
log_R_{79}	-0.583	1.267	-0.695	1.518
log_R_{80}	1.168	0.401	1.242	0.452
log_R_{81}	0.448	0.461	0.523	0.494
log_R_{82}	0.594	0.498	0.648	0.535
log_R_{83}	1.036	0.397	1.084	0.444
log_R_{84}	0.532	0.461	0.616	0.493
log_R_{85}	0.745	0.443	0.827	0.503
log_R_{86}	0.465	0.420	0.527	0.463
log_R_{87}	0.068	0.421	0.143	0.461
log_R_{88}	0.336	0.393	0.392	0.438
log_R_{89}	0.046	0.419	0.097	0.473
log_R_{90}	-0.456	0.477	-0.366	0.535
log_R_{91}	-0.518	0.560	-0.507	0.654
log_R_{92}	-1.120	0.839	-1.280	0.953
log_R_{93}	-0.337	0.483	-0.122	0.489
log_R_{94}	-0.437	0.506	-0.461	0.565
log_R_{95}	-0.084	0.376	-0.006	0.420
log_R_{96}	0.298	0.405	0.332	0.453
log_R_{97}	0.625	0.337	0.702	0.387
log_R_{98}	-2.204	1.398	-2.105	1.398
log_R_{99}	-0.602	0.657	-0.567	0.694
log_R_{00}	0.336	0.399	0.390	0.445
log_R_{01}	0.280	0.354	0.350	0.401
log_R_{02}	0.525	0.431	0.592	0.472
log_R_{03}	-0.962	1.162	-0.882	1.157
log_R_{04}	-0.004	0.461	0.033	0.503
log_R_{05}	0.657	0.324	0.725	0.377
log_R_{06}	0.106	0.474	0.141	0.515
log_R_{07}	0.714	0.332	0.785	0.382
log_R_{08}	0.542	0.383	0.598	0.431
log_R_{09}	-0.087	0.451	-0.011	0.486
log_R_{10}	-0.157	0.435	-0.133	0.481
log_R_{11}	0.027	0.609	0.259	0.626
log_R_{12}	2.068	1.091	0.000	6.977
log_R_{13}	2.068	1.091	0.000	6.977
a_1	-0.339	1.779	-0.342	1.780
a_2	1.291	1.235	1.296	1.235
a_3	1.837	1.145	1.843	1.145
a_4	2.119	1.130	2.118	1.129
a_5	1.397	1.190	1.393	1.190

r1	0.613	0.055	0.578	0.058
log_α	-4.626	0.320	-4.616	0.326
log_β	0.739	17.991	0.550	0.420
log_ϕ_{st}	-4.721	70.665	0.507	2208.300
log_ω_{st}	9.755	42.960	3.707	9236.400
log_ϕ_{sw}	0.640	79.778	0.626	465.420
log_ω_{sw}	4.361	0.132	4.360	1.344
Sw_6	0.359	0.103	0.362	0.104
log_ϕ_1	-3.071	0.250	-2.995	0.359
log_ω_1	7.211	711.440	7.163	0.321
log_ϕ_2	-2.260	0.358	-1.981	0.284
log_ω_2	4.689	0.068	4.663	0.038
log_w^2_t	0.061	0.024	0.060	0.023
q	0.659	0.129	0.658	0.129

Table 12. Annual abundance estimates (million crabs) and mature male biomass (MMB, million lbs) for Norton Sound red king crab estimated by length-based analysis from 1976-2014 (Full data)

Full data

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 74 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	1.432	7.842	6.410	4.805	1.245	11.460	3.106	14.171	3.418
1977	1.816	7.795	5.979	5.250	1.076	13.762	2.872	15.028	3.060
1978	0.361	5.719	5.357	4.561	0.756	12.669	2.236	14.028	2.114
1979	0.073	3.670	3.597	3.361	0.467	9.665	1.449	10.087	1.459
1980	0.320	2.160	1.840	1.776	0.320	5.342	0.993	5.462	1.008
1981	1.841	3.033	1.192	1.060	0.224	3.241	0.683	3.466	0.769
1982	1.205	2.922	1.717	1.016	0.263	2.532	0.683	3.698	0.914
1983	1.186	3.270	2.085	1.555	0.356	3.814	0.888	4.708	1.069
1984	1.761	4.025	2.264	1.753	0.394	4.474	1.013	5.338	1.202
1985	1.250	3.990	2.740	2.015	0.448	5.158	1.156	6.377	1.396
1986	1.362	4.148	2.786	2.229	0.493	5.811	1.291	6.755	1.475
1987	1.114	3.952	2.838	2.253	0.482	5.989	1.302	6.977	1.470
1988	0.773	3.522	2.749	2.255	0.457	6.087	1.253	6.926	1.376
1989	0.898	3.347	2.450	2.094	0.403	5.797	1.132	6.405	1.220
1990	0.733	2.993	2.260	1.875	0.340	5.242	0.971	5.894	1.052
1991	0.469	2.510	2.041	1.716	0.289	4.801	0.824	5.353	0.883
1992	0.403	2.134	1.731	1.513	0.234	4.297	0.673	4.672	0.707
1993	0.247	1.699	1.452	1.270	0.181	3.667	0.527	3.979	0.556
1994	0.433	1.511	1.078	0.962	0.141	2.804	0.411	3.005	0.428
1995	0.434	1.365	0.931	0.754	0.109	2.148	0.314	2.447	0.346
1996	0.581	1.448	0.867	0.683	0.102	1.857	0.276	2.168	0.310
1997	0.847	1.804	0.957	0.715	0.106	1.875	0.276	2.281	0.328
1998	1.180	2.416	1.236	0.889	0.123	2.264	0.309	2.846	0.404
1999	0.265	1.958	1.694	1.208	0.146	3.031	0.372	3.846	0.428
2000	0.325	1.793	1.467	1.309	0.147	3.484	0.389	3.761	0.414
2001	0.835	2.023	1.188	1.041	0.123	2.936	0.343	3.190	0.384
2002	0.883	2.185	1.302	0.968	0.117	2.636	0.311	3.195	0.368
2003	1.083	2.547	1.464	1.094	0.122	2.843	0.315	3.465	0.348
2004	0.397	2.133	1.735	1.282	0.137	3.275	0.340	4.038	0.473
2005	0.602	2.088	1.487	1.282	0.174	3.403	0.443	3.755	0.480
2006	1.176	2.545	1.369	1.113	0.153	3.036	0.416	3.470	0.459
2007	0.823	2.459	1.636	1.165	0.149	3.026	0.397	3.816	0.466
2008	1.258	2.942	1.684	1.321	0.156	3.410	0.406	4.023	0.474
2009	1.174	3.135	1.961	1.443	0.157	3.704	0.410	4.575	0.467
2010	0.700	2.839	2.138	1.636	0.159	4.201	0.415	5.049	0.495
2011	0.580	2.532	1.952	1.627	0.172	4.318	0.451	4.873	0.497
2012	0.663	2.351	1.687	1.427	0.152	3.913	0.418	4.357	0.448
2013	4.485	5.985	1.501	1.220	0.175	3.359	0.436	3.833	0.593
2014						3.745	1.548	7.934	5.824

Without 2013 Observer data

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 74 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	1.428	7.801	6.373	4.770	1.240	11.371	3.088	14.079	3.406
1977	1.830	7.780	5.951	5.221	1.077	13.675	2.866	14.941	3.062
1978	0.351	5.713	5.362	4.565	0.754	12.653	2.226	14.015	2.104
1979	0.073	3.672	3.599	3.364	0.467	9.665	1.445	10.084	1.456
1980	0.271	2.116	1.845	1.781	0.320	5.349	0.994	5.470	1.009
1981	1.854	3.021	1.167	1.054	0.224	3.233	0.681	3.427	0.765
1982	1.208	2.925	1.717	1.019	0.263	2.535	0.683	3.696	0.918
1983	1.175	3.267	2.092	1.562	0.359	3.830	0.894	4.724	1.078
1984	1.733	4.003	2.270	1.765	0.399	4.504	1.023	5.358	1.213
1985	1.257	3.994	2.737	2.027	0.453	5.190	1.167	6.386	1.404
1986	1.384	4.176	2.793	2.236	0.496	5.830	1.299	6.774	1.484
1987	1.111	3.976	2.865	2.275	0.493	6.038	1.322	7.035	1.511
1988	0.775	3.550	2.775	2.283	0.477	6.157	1.295	6.992	1.420
1989	0.891	3.365	2.474	2.118	0.418	5.864	1.170	6.472	1.259
1990	0.721	3.000	2.279	1.898	0.351	5.305	0.999	5.952	1.079
1991	0.474	2.524	2.049	1.730	0.292	4.846	0.836	5.389	0.890
1992	0.386	2.127	1.741	1.522	0.234	4.325	0.676	4.702	0.712
1993	0.206	1.656	1.450	1.274	0.180	3.684	0.526	3.985	0.552
1994	0.491	1.541	1.050	0.949	0.140	2.783	0.408	2.957	0.423
1995	0.414	1.361	0.947	0.751	0.108	2.134	0.310	2.464	0.347
1996	0.583	1.456	0.873	0.695	0.104	1.882	0.279	2.182	0.312
1997	0.825	1.792	0.966	0.725	0.107	1.901	0.278	2.306	0.331
1998	1.189	2.423	1.234	0.897	0.125	2.288	0.312	2.854	0.406
1999	0.262	1.965	1.703	1.217	0.147	3.056	0.373	3.871	0.430
2000	0.318	1.790	1.472	1.314	0.148	3.499	0.391	3.776	0.415
2001	0.826	2.015	1.189	1.045	0.124	2.949	0.344	3.197	0.385
2002	0.883	2.186	1.302	0.974	0.117	2.651	0.311	3.202	0.368
2003	1.084	2.554	1.470	1.101	0.122	2.860	0.315	3.480	0.349
2004	0.396	2.143	1.747	1.295	0.139	3.307	0.344	4.068	0.479
2005	0.588	2.084	1.496	1.292	0.175	3.429	0.445	3.780	0.483
2006	1.179	2.549	1.371	1.121	0.154	3.060	0.419	3.484	0.461
2007	0.801	2.447	1.647	1.177	0.150	3.057	0.399	3.844	0.469
2008	1.262	2.944	1.682	1.328	0.157	3.431	0.408	4.030	0.474
2009	1.163	3.133	1.970	1.453	0.157	3.729	0.410	4.598	0.469
2010	0.700	2.845	2.144	1.647	0.160	4.232	0.417	5.071	0.498
2011	0.560	2.520	1.960	1.635	0.172	4.341	0.453	4.895	0.498
2012	0.764	2.447	1.683	1.431	0.152	3.927	0.418	4.359	0.449
2013	0.646	2.212	1.566	1.250	0.185	3.420	0.453	3.953	0.635
2014						2.835	1.180	3.719	4.369

Table 13. Summary of catch and estimated bycatch/discards (million lbs) for Norton Sound red king crab. Assumed average crab weight is 2.5 lbs for the winter commercial catch and 2.0 lbs for the subsistence catch.

Full data

Year	*Summer com*	*Winter com*	*Winter Sub*	*discards Summer*	*discards Winter Sub*	*discards Winter com*	*Total*	*Catch/ MMB*
1977	0.52	0.000	ND	0.0071	ND	0.0000		
1978	2.09	0.024	0.025	0.0202	0.0153	0.0001	2.175	0.155
1979	2.93	0.001	0.000	0.0128	0.0003	0.0000	2.944	0.292
1980	1.19	0.000	0.000	0.0048	0.0003	0.0000	1.195	0.219
1981	1.38	0.000	0.001	0.0333	0.0004	0.0000	1.415	0.408
1982	0.23	0.000	0.003	0.0094	0.0016	0.0000	0.244	0.066
1983	0.37	0.001	0.021	0.0107	0.0128	0.0000	0.416	0.088
1984	0.39	0.002	0.022	0.0117	0.0094	0.0000	0.435	0.082
1985	0.43	0.003	0.017	0.0114	0.0048	0.0000	0.466	0.073
1986	0.48	0.005	0.014	0.0101	0.0074	0.0001	0.517	0.076
1987	0.33	0.003	0.012	0.0061	0.0033	0.0000	0.354	0.051
1988	0.24	0.001	0.005	0.0036	0.0017	0.0000	0.251	0.036
1989	0.25	0.001	0.012	0.0034	0.0036	0.0000	0.270	0.042
1990	0.19	0.009	0.024	0.0028	0.0090	0.0001	0.235	0.040
1991	0	0.010	0.015	0.0000	0.0039	0.0001	0.029	0.005
1992	0.07	0.019	0.023	0.0008	0.0066	0.0001	0.120	0.026
1993	0.33	0.004	0.002	0.0028	0.0002	0.0000	0.339	0.085
1994	0.32	0.014	0.008	0.0029	0.0016	0.0001	0.347	0.115
1995	0.32	0.019	0.011	0.0045	0.0047	0.0001	0.359	0.147
1996	0.22	0.004	0.003	0.0039	0.0025	0.0000	0.233	0.108
1997	0.09	0.000	0.001	0.0022	0.0017	0.0000	0.095	0.042
1998	0.03	0.002	0.017	0.0008	0.0234	0.0000	0.073	0.026
1999	0.02	0.007	0.015	0.0005	0.0062	0.0001	0.049	0.013
2000	0.3	0.008	0.011	0.0026	0.0082	0.0001	0.330	0.088
2001	0.28	0.003	0.001	0.0036	0.0002	0.0000	0.288	0.090
2002	0.25	0.006	0.004	0.0055	0.0059	0.0000	0.271	0.085
2003	0.26	0.017	0.008	0.0060	0.0098	0.0002	0.301	0.087
2004	0.34	0.001	0.002	0.0063	0.0012	0.0000	0.351	0.087
2005	0.4	0.005	0.008	0.0044	0.0050	0.0001	0.423	0.113
2006	0.45	0.000	0.002	0.0078	0.0017	0.0000	0.462	0.133
2007	0.31	0.008	0.021	0.0073	0.0215	0.0001	0.368	0.096
2008	0.39	0.014	0.019	0.0079	0.0183	0.0002	0.449	0.112
2009	0.4	0.012	0.010	0.0091	0.0044	0.0001	0.436	0.095
2010	0.42	0.012	0.014	0.0074	0.0039	0.0001	0.457	0.091
2011	0.4	0.008	0.013	0.0049	0.0051	0.0001	0.431	0.088
2012	0.47	0.023	0.018	0.0056	0.0081	0.0002	0.525	0.120
2013	0.35	0.057	0.018	0.0121	0.0278	0.0004	0.465	0.121

Without 2013 Observer data

Year	*Summer com*	*Winter com*	*Winter Sub*	*discards Summer*	*discards Winter Sub*	*discards Winter com*	*Total*	*Catch/ MMB*
1977	0.52	0.000	ND	0.0069	ND			
1978	2.09	0.024	0.025	0.0188	0.0153	0.0013	2.174	0.155
1979	2.93	0.001	0.000	0.0121	0.0003	0.0000	2.943	0.292
1980	1.19	0.000	0.000	0.0044	0.0003	0.0000	1.195	0.218
1981	1.38	0.000	0.001	0.0332	0.0004	0.0000	1.415	0.413
1982	0.23	0.000	0.003	0.0089	0.0016	0.0000	0.244	0.066
1983	0.37	0.001	0.021	0.0102	0.0128	0.0002	0.415	0.088
1984	0.39	0.002	0.022	0.0112	0.0094	0.0002	0.435	0.081
1985	0.43	0.003	0.017	0.0107	0.0048	0.0003	0.466	0.073
1986	0.48	0.005	0.014	0.0098	0.0074	0.0005	0.517	0.076
1987	0.33	0.003	0.012	0.0058	0.0033	0.0002	0.354	0.050
1988	0.24	0.001	0.005	0.0034	0.0017	0.0001	0.251	0.036
1989	0.25	0.001	0.012	0.0033	0.0036	0.0001	0.270	0.042
1990	0.19	0.009	0.024	0.0026	0.0090	0.0006	0.235	0.039
1991	0	0.010	0.015	0.0000	0.0039	0.0007	0.030	0.006
1992	0.07	0.019	0.023	0.0008	0.0066	0.0012	0.121	0.026
1993	0.33	0.004	0.002	0.0023	0.0002	0.0002	0.339	0.085
1994	0.32	0.014	0.008	0.0023	0.0016	0.0007	0.347	0.117
1995	0.32	0.019	0.011	0.0040	0.0047	0.0011	0.360	0.146
1996	0.22	0.004	0.003	0.0031	0.0025	0.0004	0.233	0.107
1997	0.09	0.000	0.001	0.0017	0.0017	0.0000	0.094	0.041
1998	0.03	0.002	0.017	0.0006	0.0234	0.0003	0.073	0.026
1999	0.02	0.007	0.015	0.0004	0.0062	0.0007	0.049	0.013
2000	0.3	0.008	0.011	0.0022	0.0082	0.0007	0.330	0.087
2001	0.28	0.003	0.001	0.0028	0.0002	0.0001	0.287	0.090
2002	0.25	0.006	0.004	0.0044	0.0059	0.0005	0.271	0.085
2003	0.26	0.017	0.008	0.0048	0.0098	0.0018	0.301	0.086
2004	0.34	0.001	0.002	0.0054	0.0012	0.0001	0.350	0.086
2005	0.4	0.005	0.008	0.0037	0.0050	0.0005	0.422	0.112
2006	0.45	0.000	0.002	0.0061	0.0017	0.0000	0.460	0.132
2007	0.31	0.008	0.021	0.0060	0.0215	0.0008	0.367	0.095
2008	0.39	0.014	0.019	0.0063	0.0183	0.0016	0.449	0.111
2009	0.4	0.012	0.010	0.0074	0.0044	0.0012	0.435	0.095
2010	0.42	0.012	0.014	0.0062	0.0039	0.0013	0.457	0.090
2011	0.4	0.008	0.013	0.0042	0.0051	0.0008	0.431	0.088
2012	0.47	0.023	0.018	0.0047	0.0081	0.0016	0.525	0.120
2013	0.35	0.057	0.018	0.0043	0.0278	0.0041	0.461	0.117

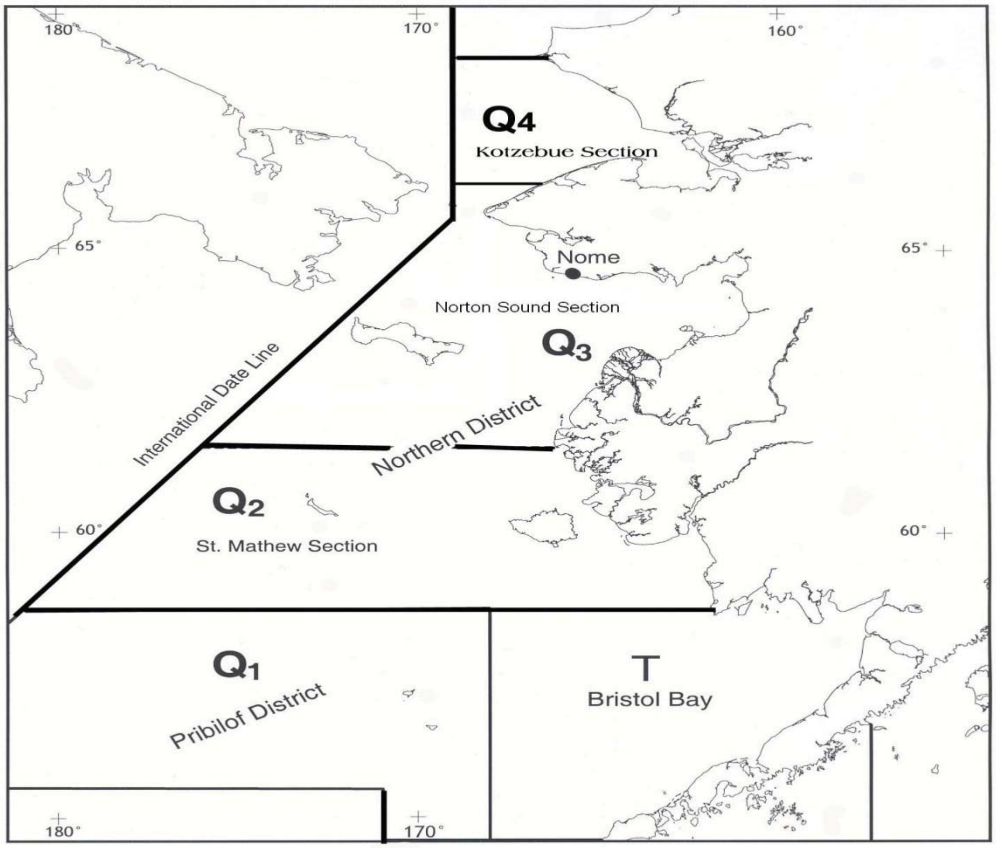


Figure 1. King crab fishing districts and sections of Statistical Area Q.

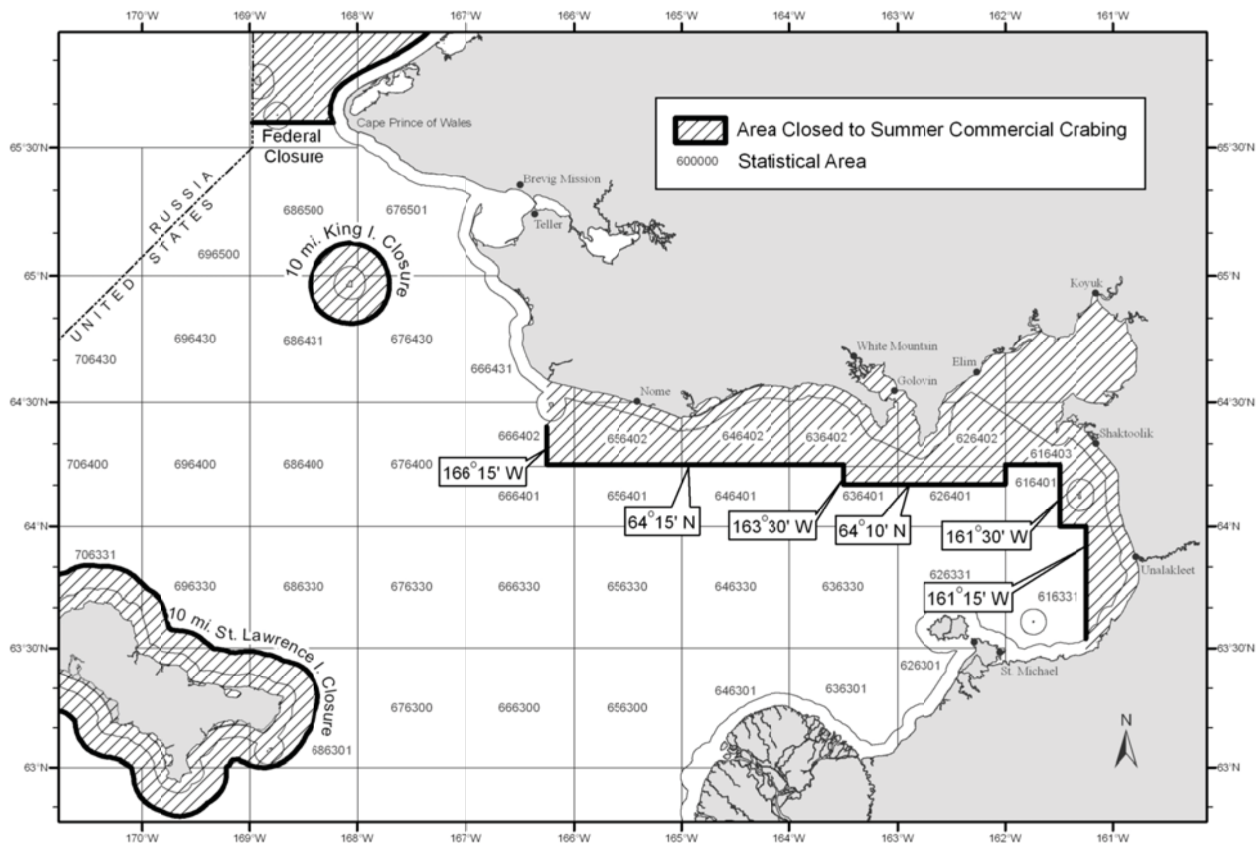
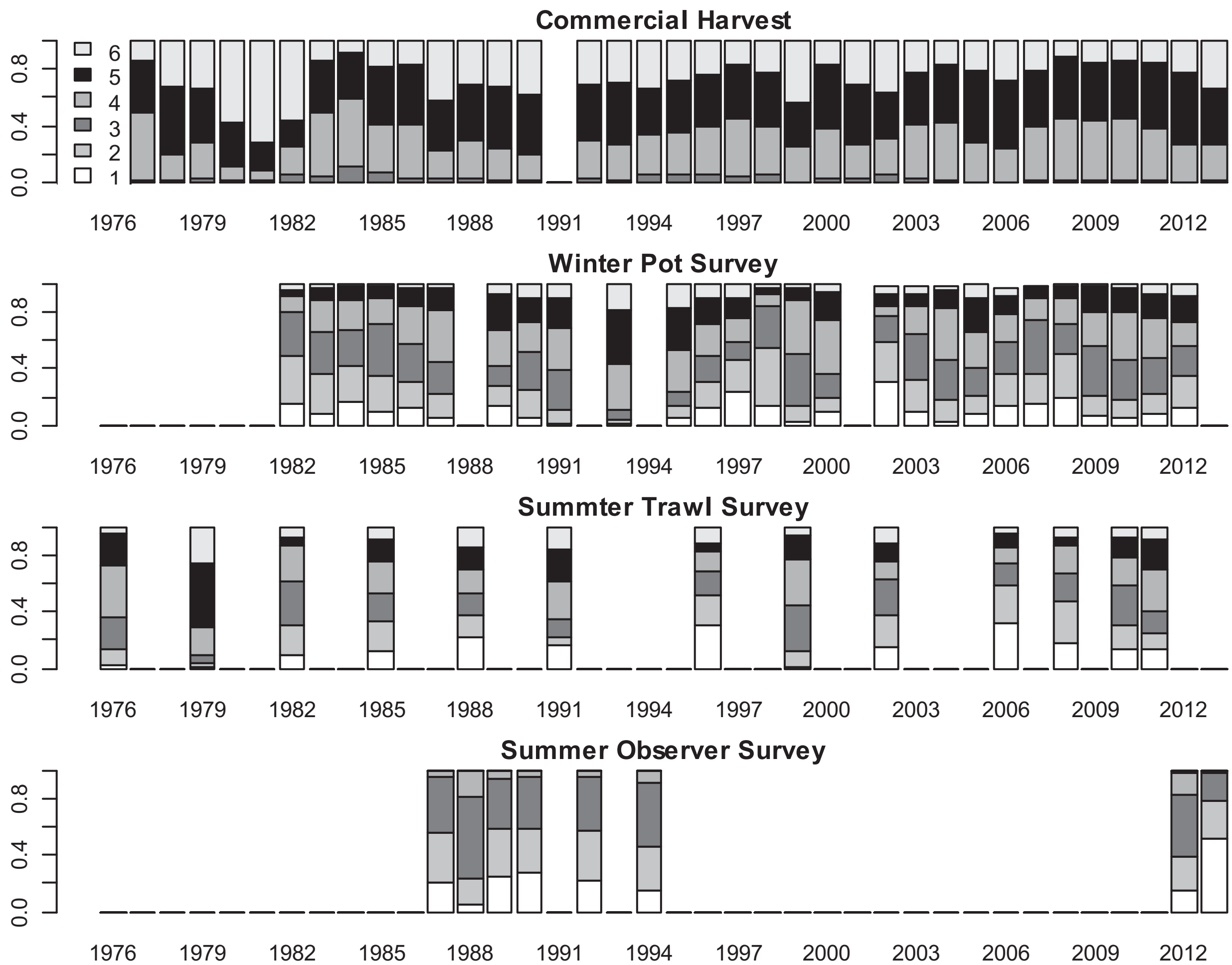


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 3. Observed length compositions 1976-2013.

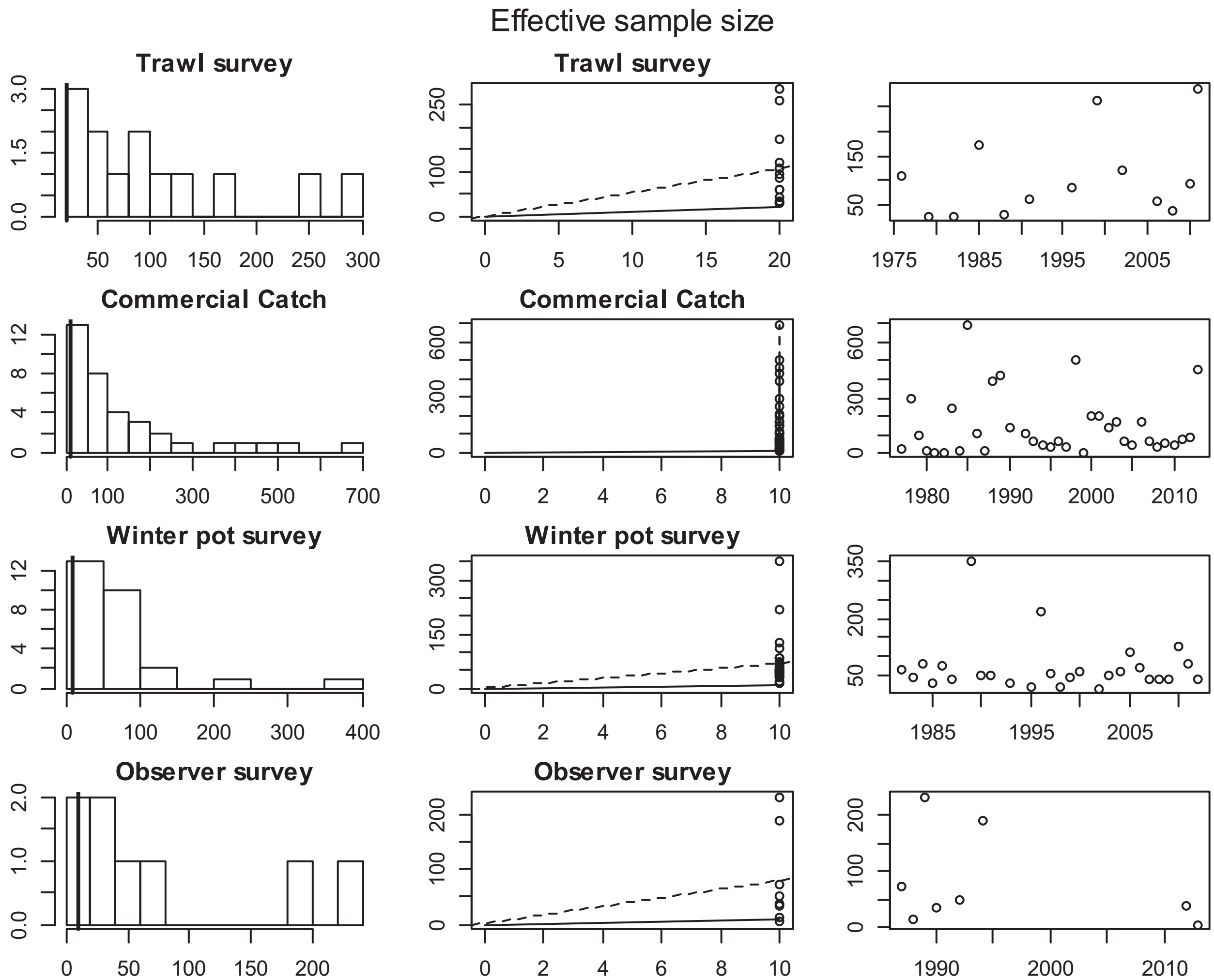


Figure 4a: Effective sample size vs. implied sample size (Full data)

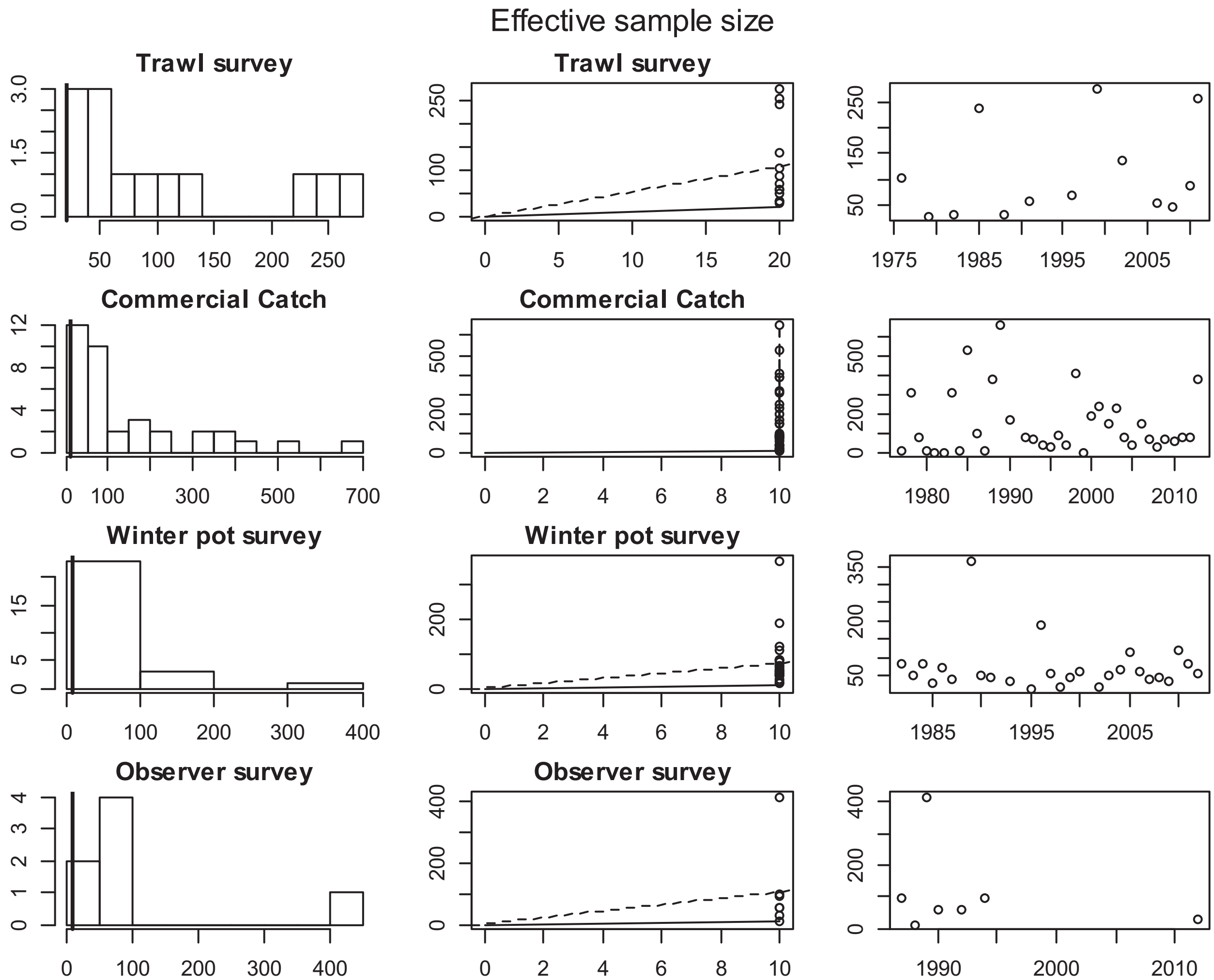


Figure 4b: Effective sample size vs. implied sample size (without 2013 Observer data)

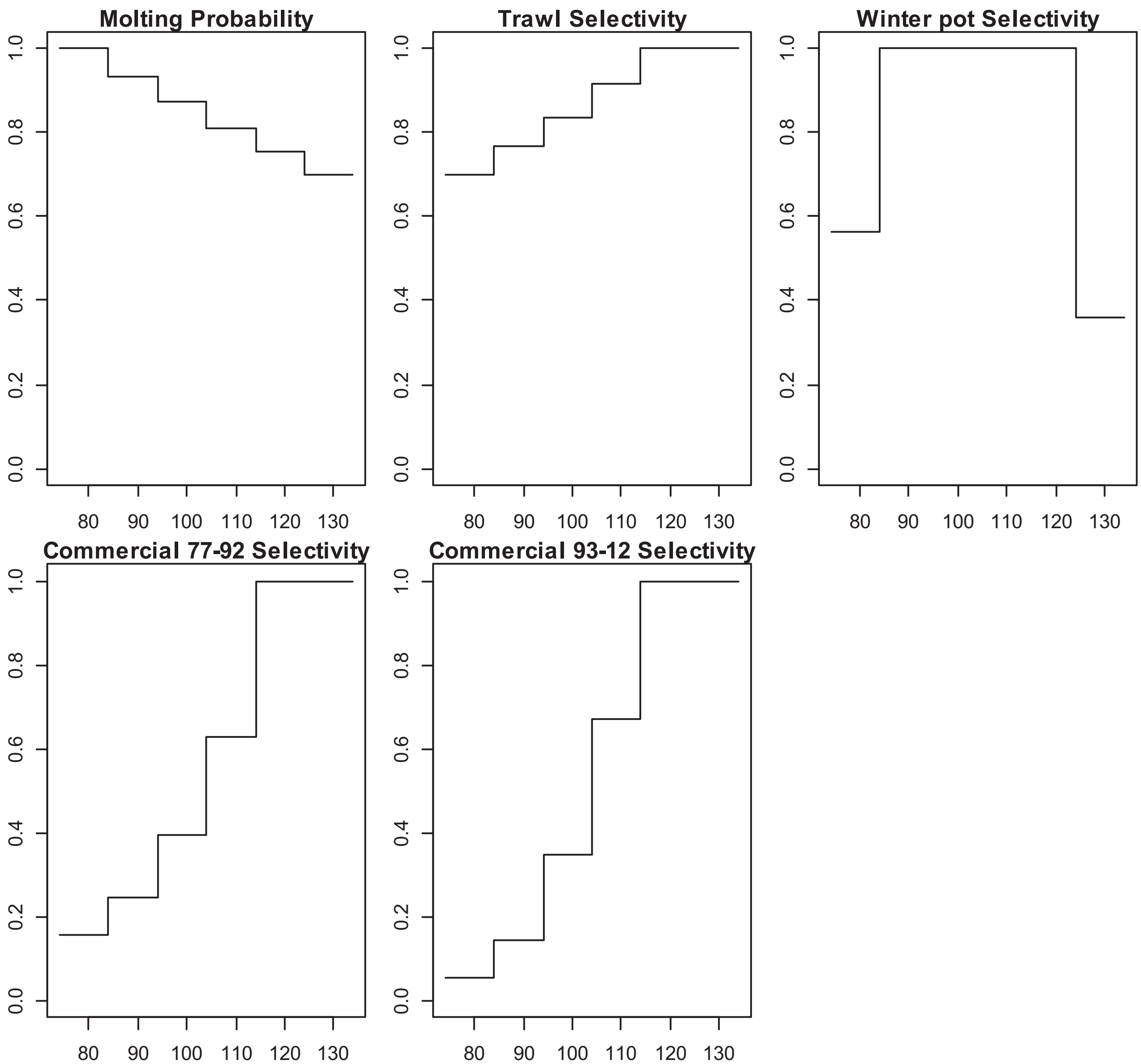


Figure 5a. Molting probability and trawl/pot selectivity (Full data).

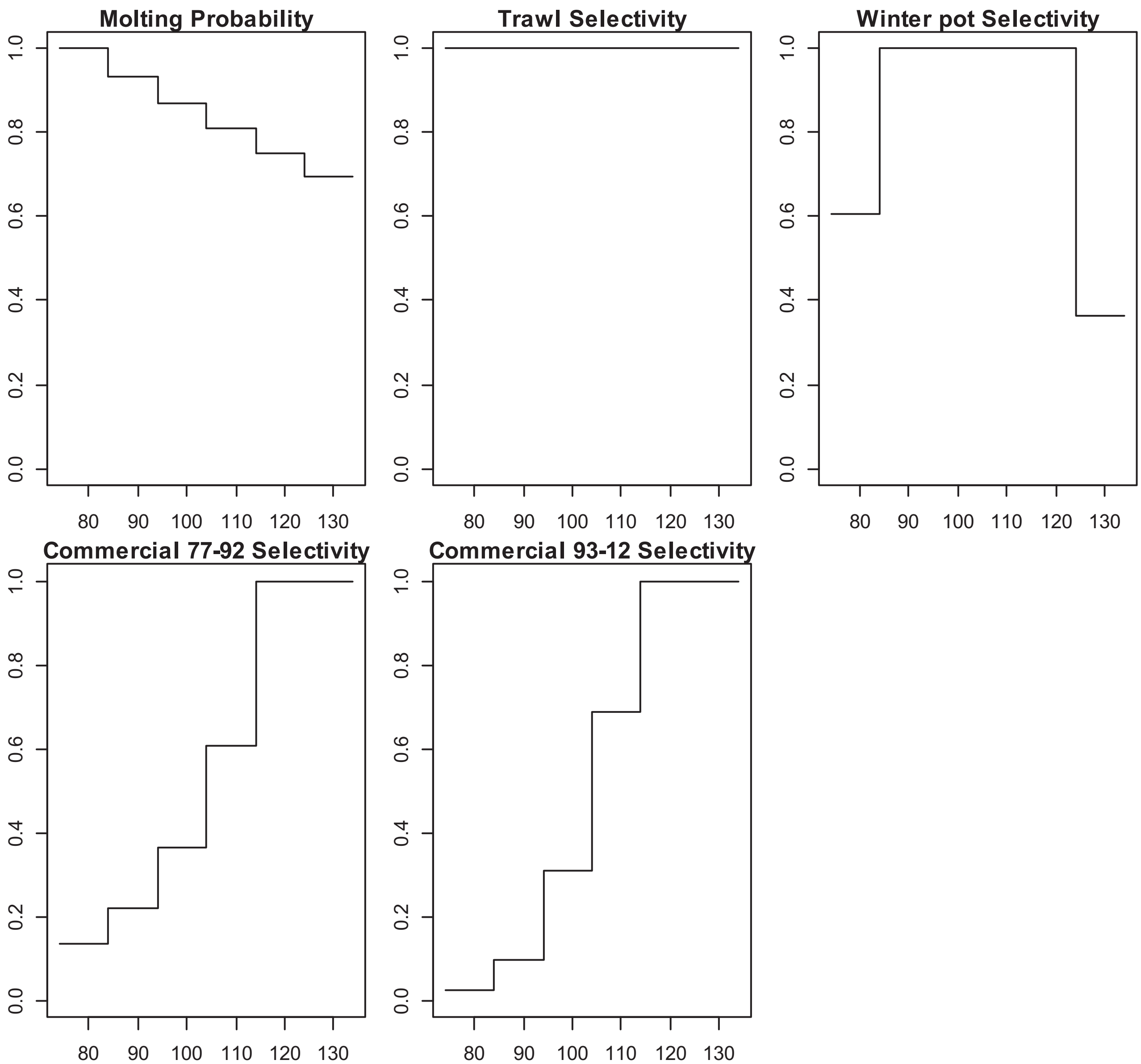


Figure 5b. Molting probability and trawl/pot selectivity (without 2013 Observer data).

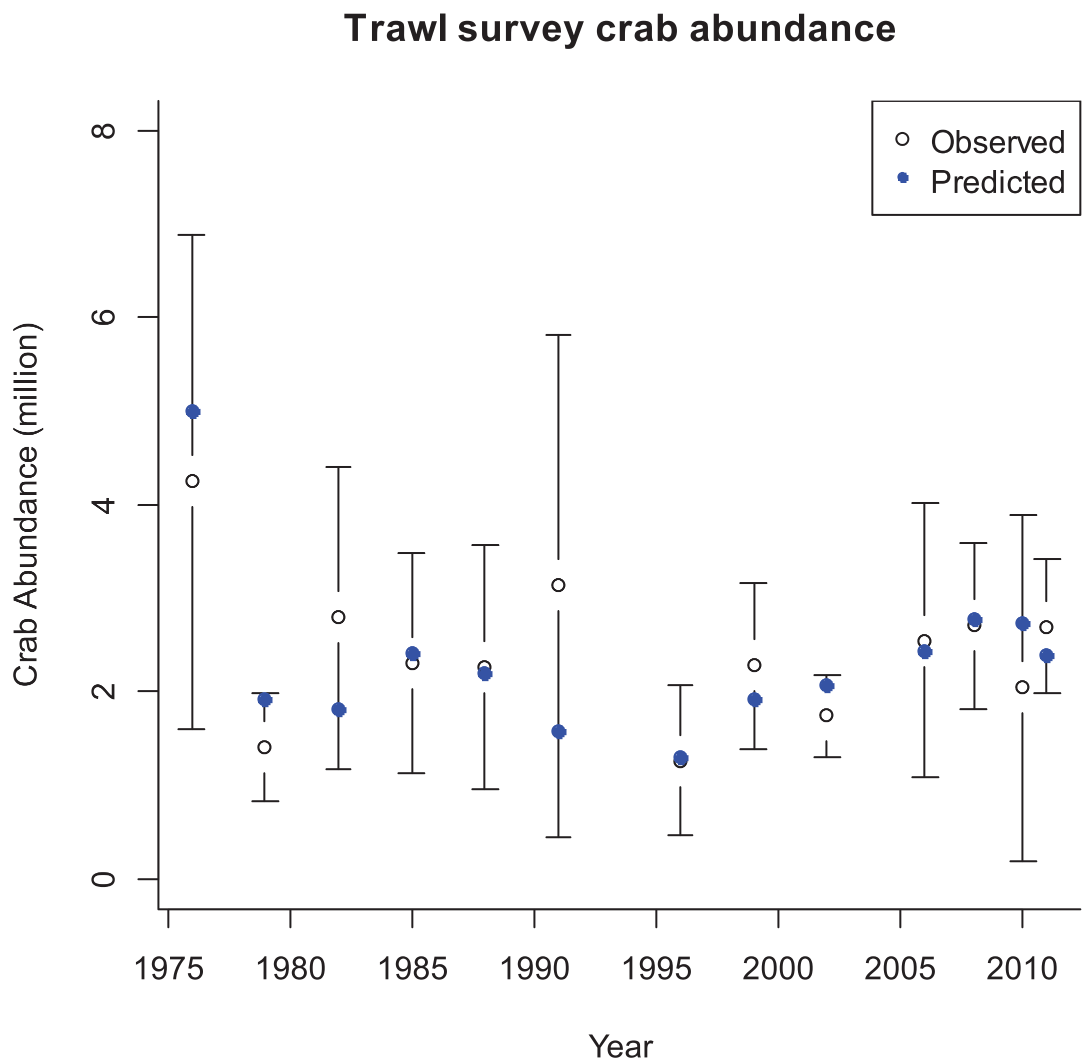


Figure 6a. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male. (Full data)

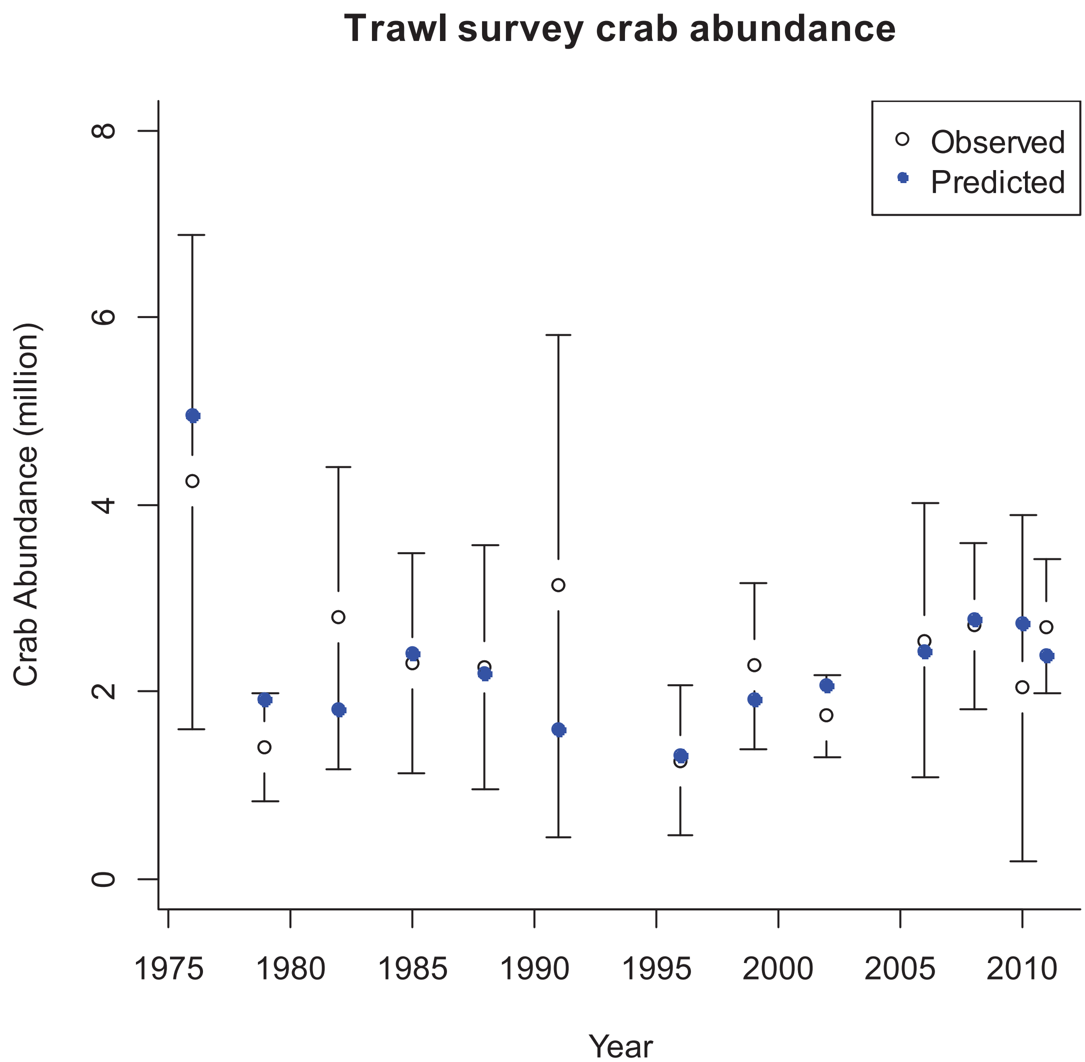


Figure 6b. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male (Without 2013 Observer data)

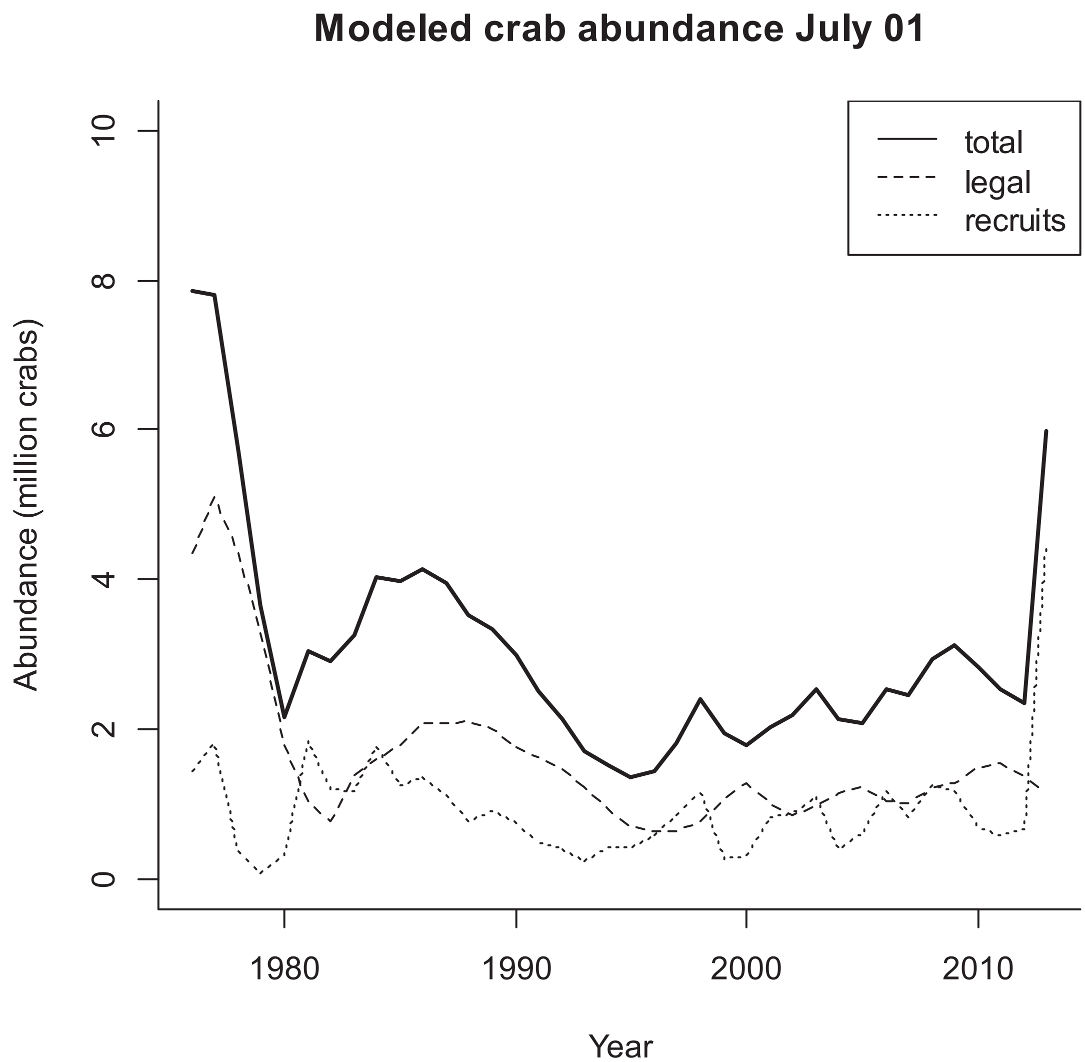


Figure 7a. Estimated abundance of legal male from 1976-2013 (Full data)

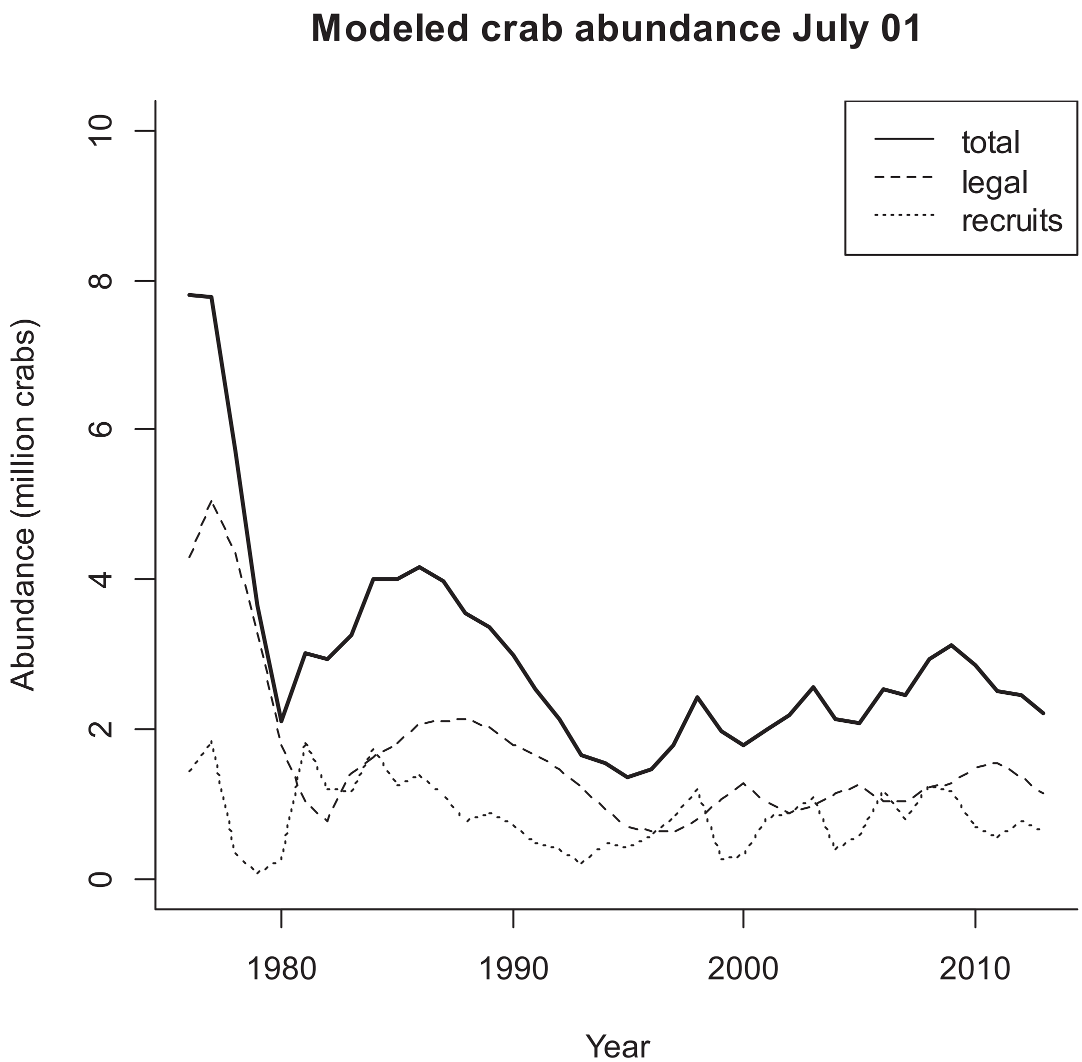


Figure 7b. Estimated abundance of legal male from 1976-2013 (without 2013 Observer data)

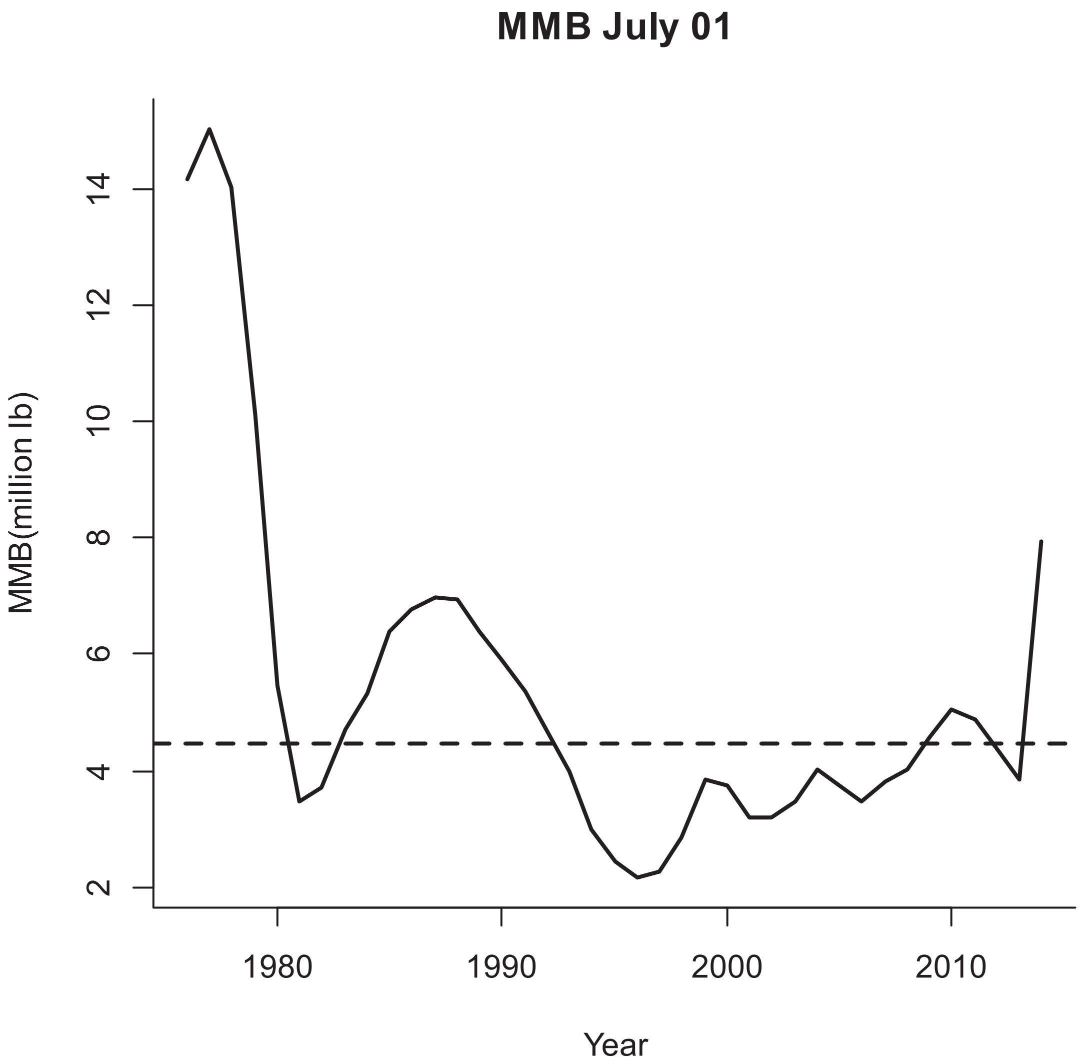


Figure 8a. Estimated abundance of leg recruits from 1976-2014 (Full data). Dash line shows Bmsy (Average MMB of 1980-2014)

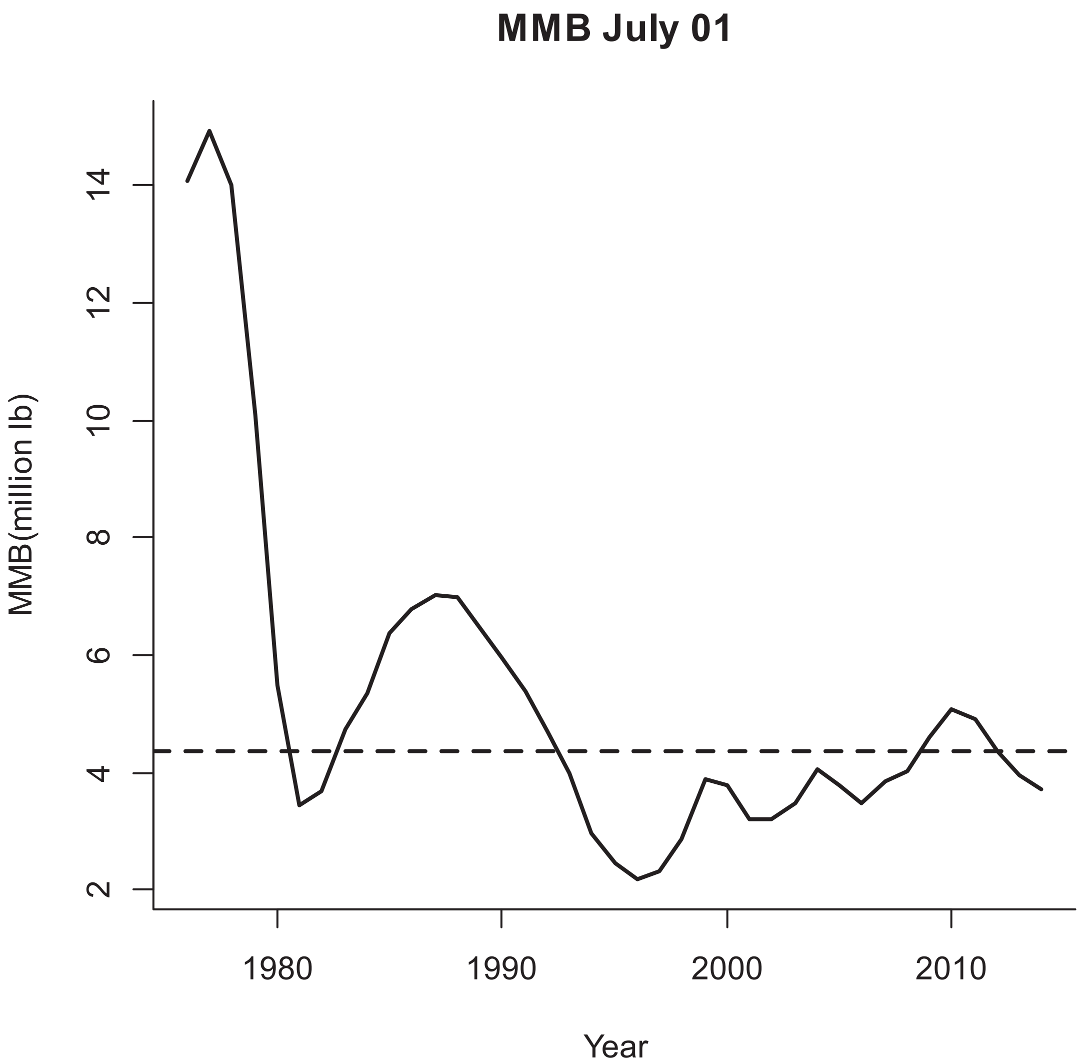


Figure 8b. Estimated abundance of leg recruits from 1976-2014 (without 2013 Observer data). Dash line shows Bmsy (Average MMB of 1980-2014)

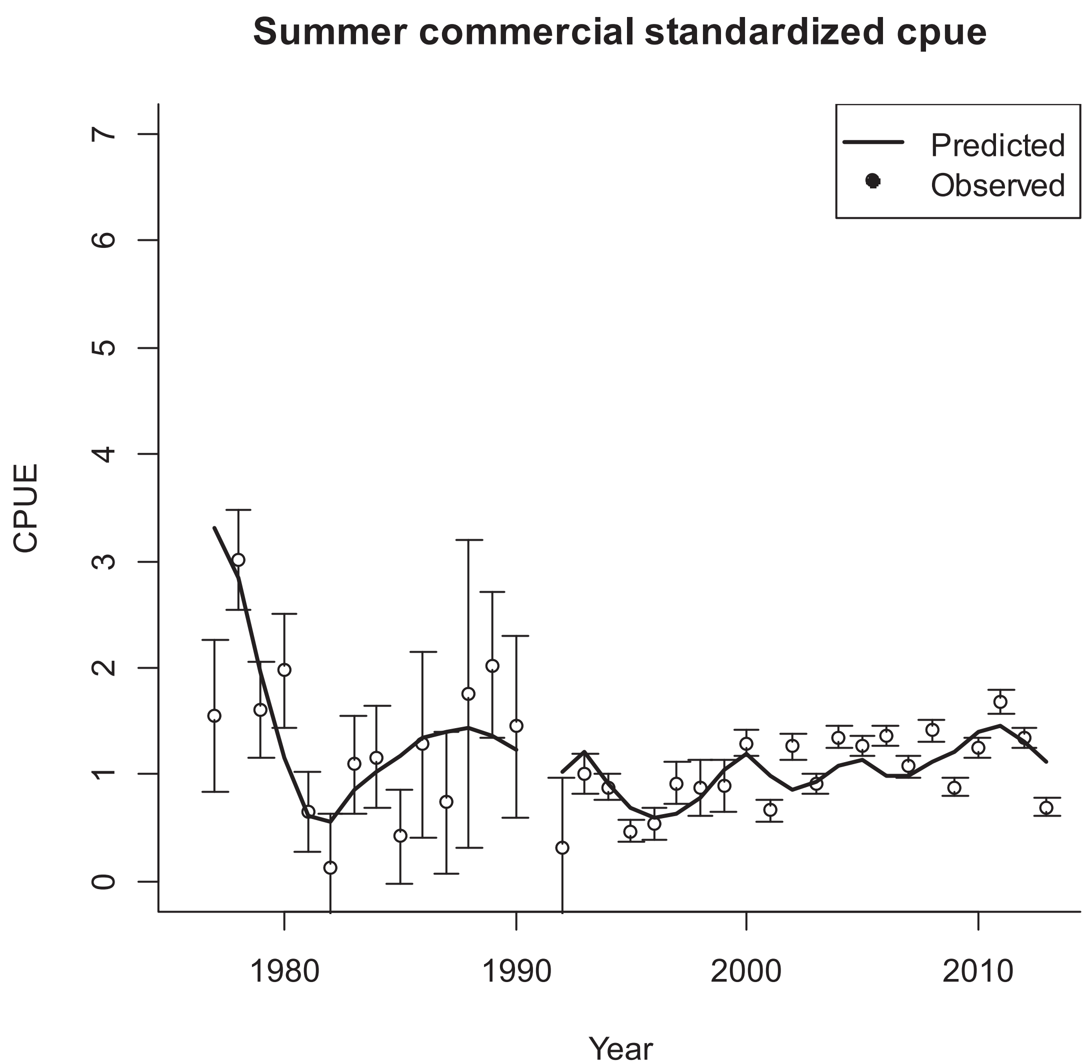


Figure 9a. Summer commercial standardized cpue (1977-2013) (Full data)

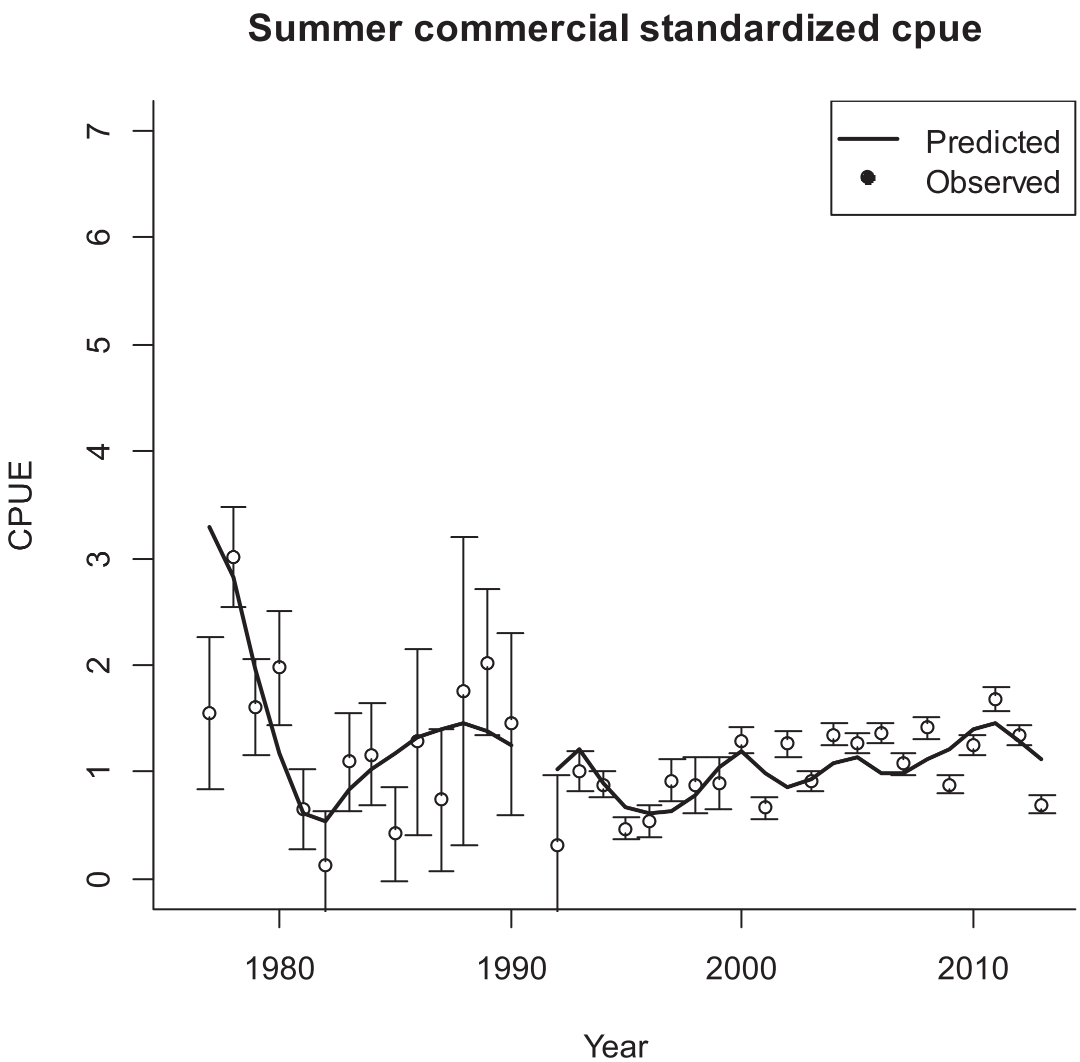


Figure 9b. Summer commercial standardized cpue (1977-2013) (without 2013 Observer data)

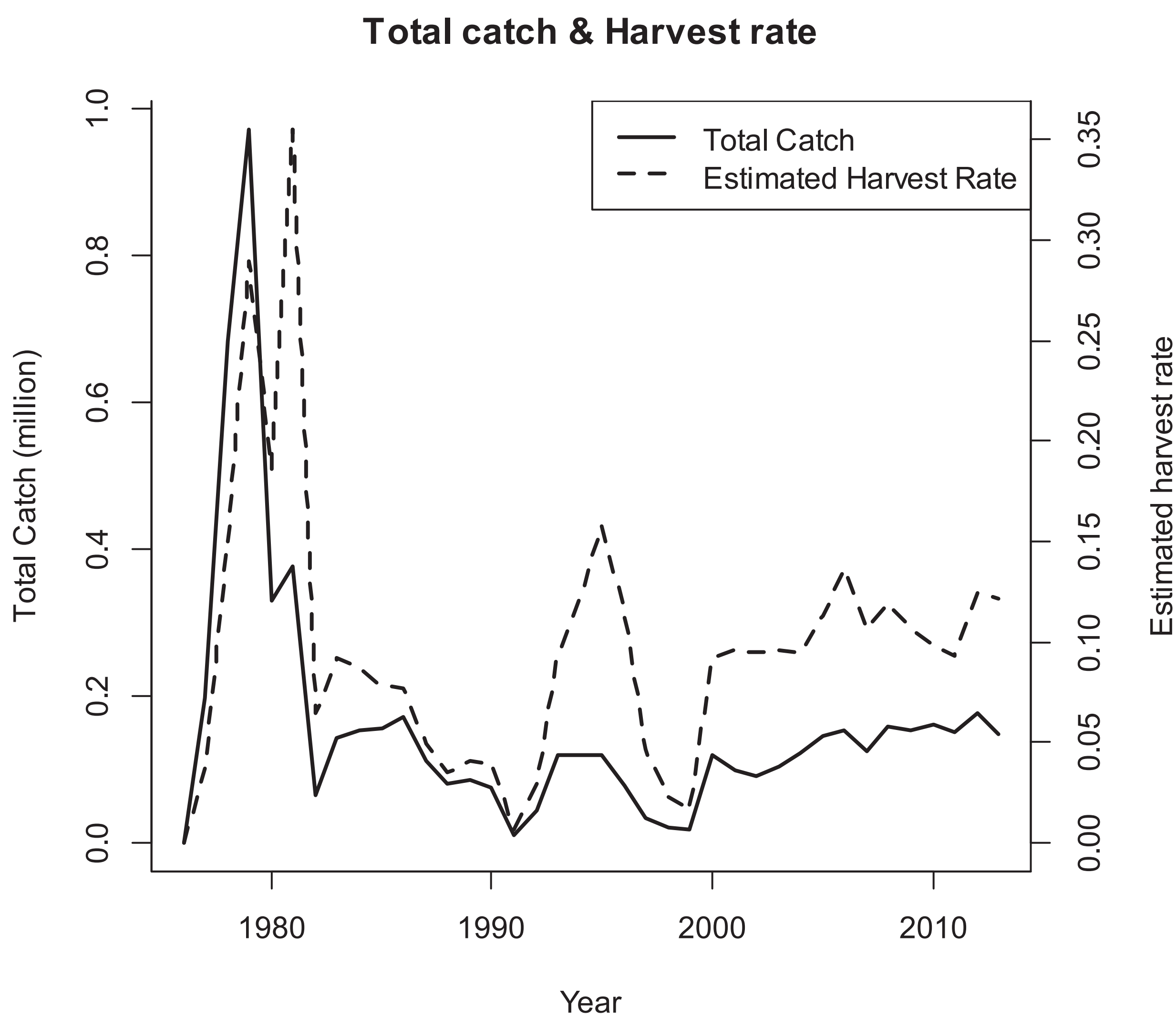


Figure 10a: Total catch and estimated harvest rate 1976-2013 (Full data)

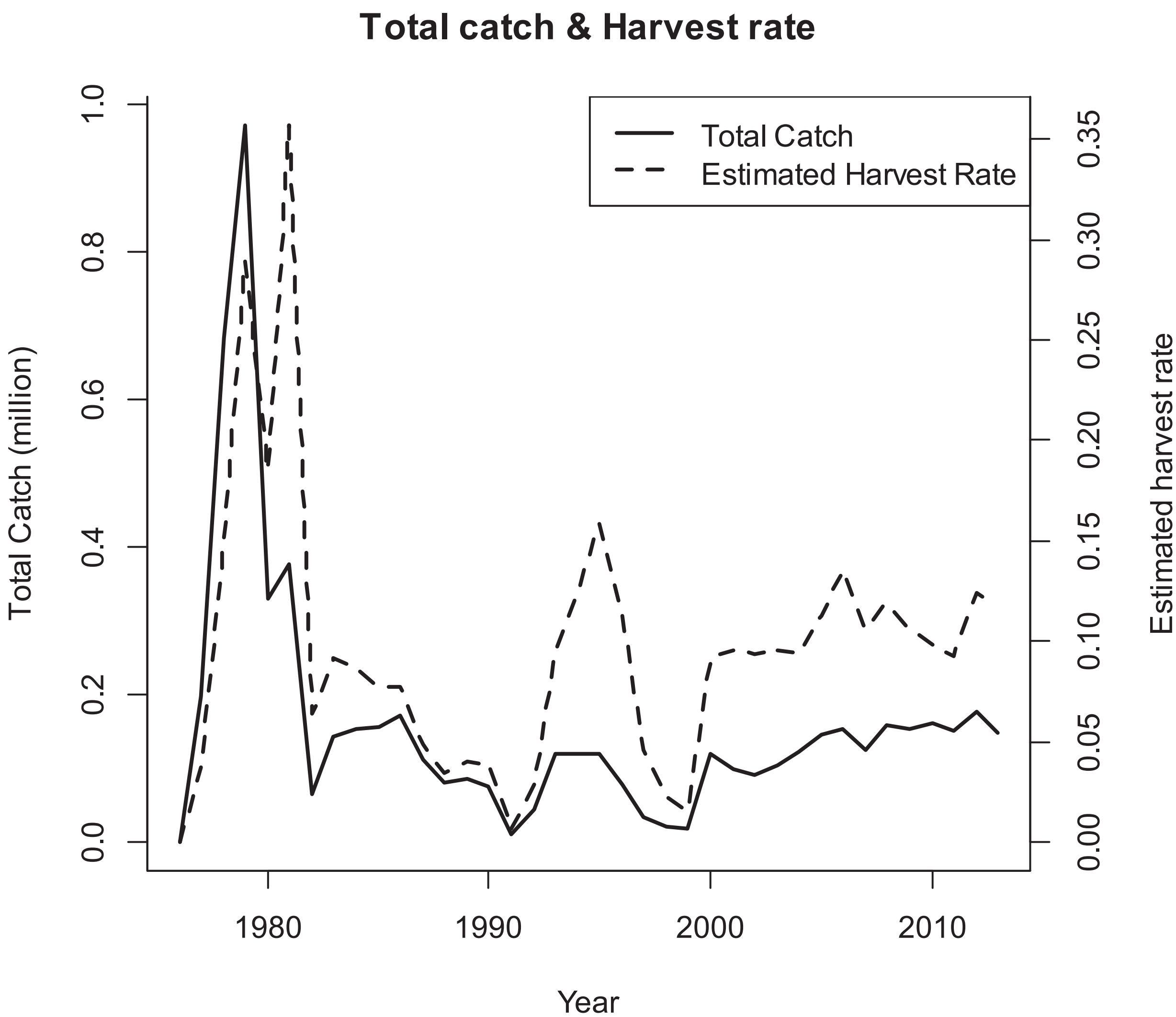


Figure 10b: Total catch and estimated harvest rate 1976-2013 (without 2013 Observer data)

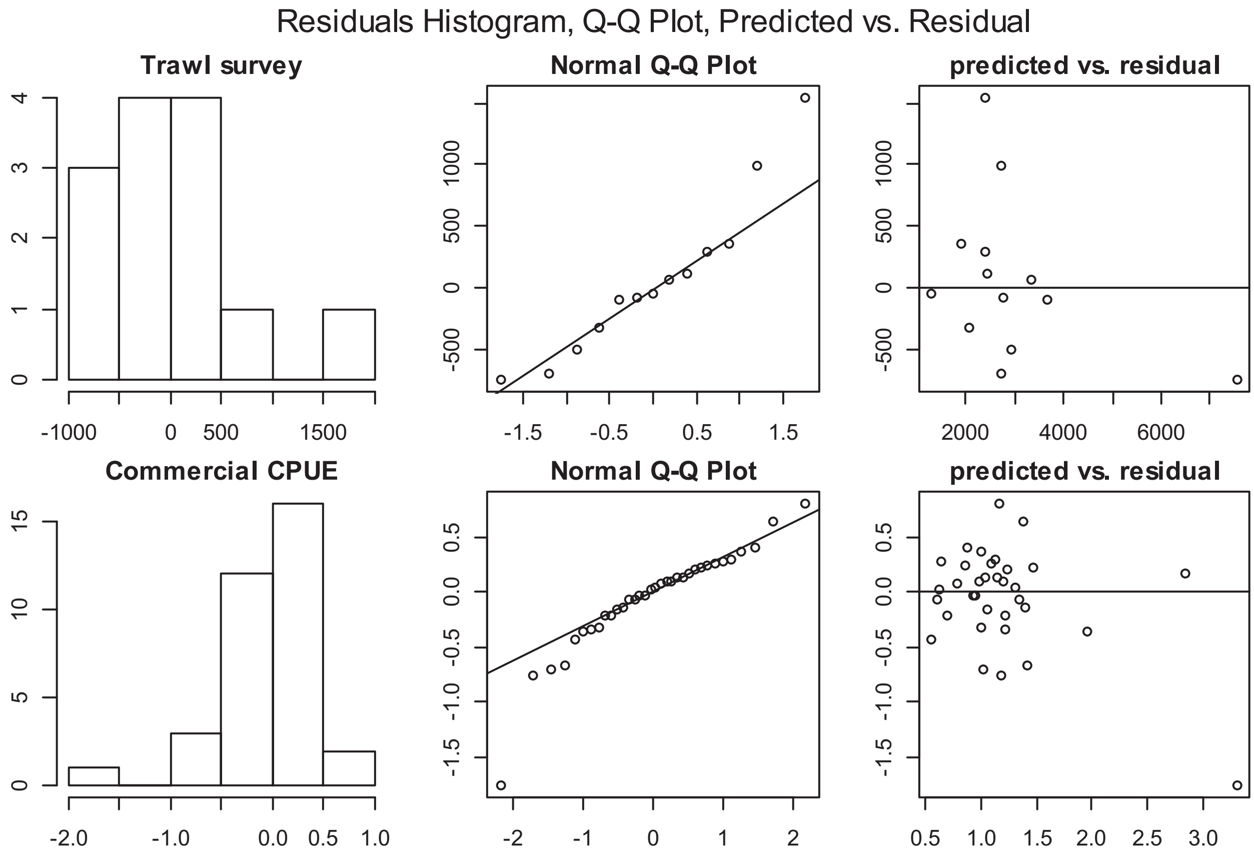


Figure 11a: Residual and QQ plot (Full data)

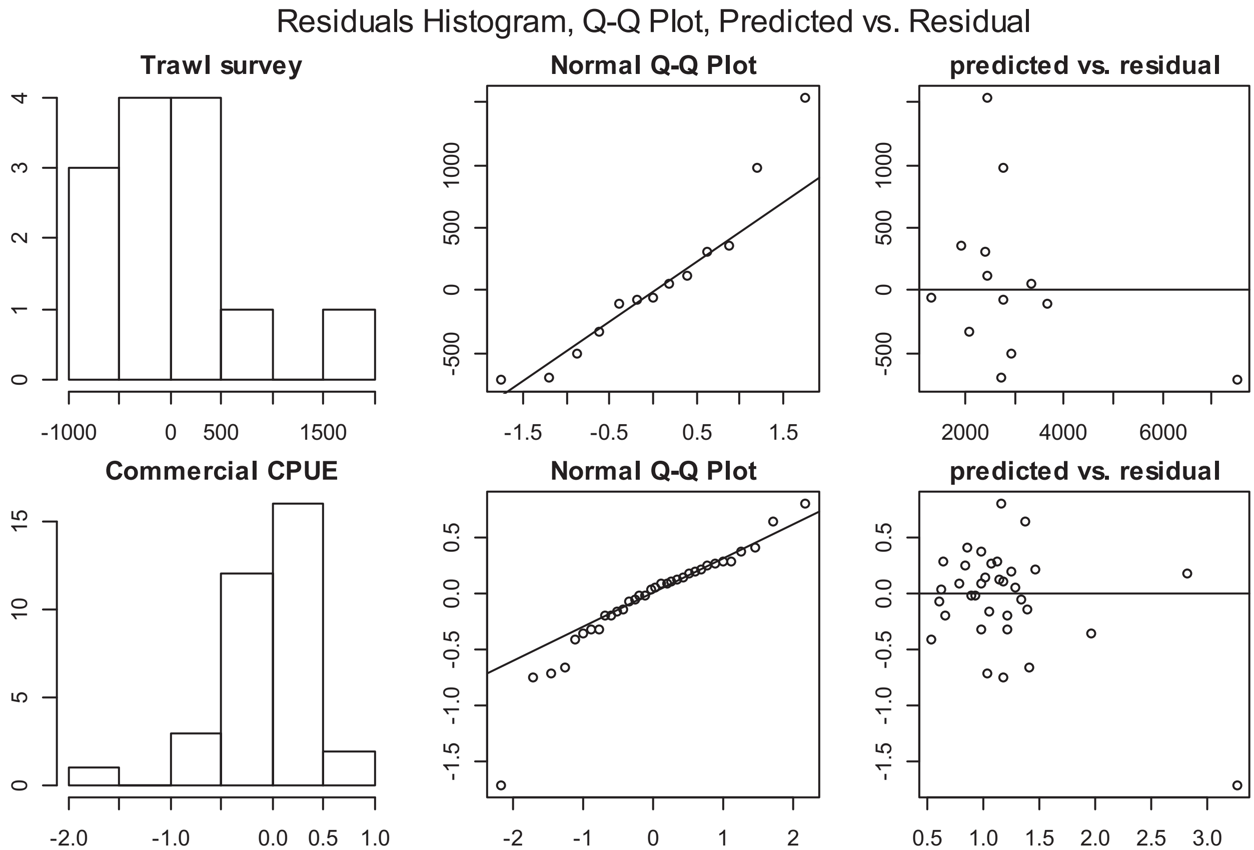
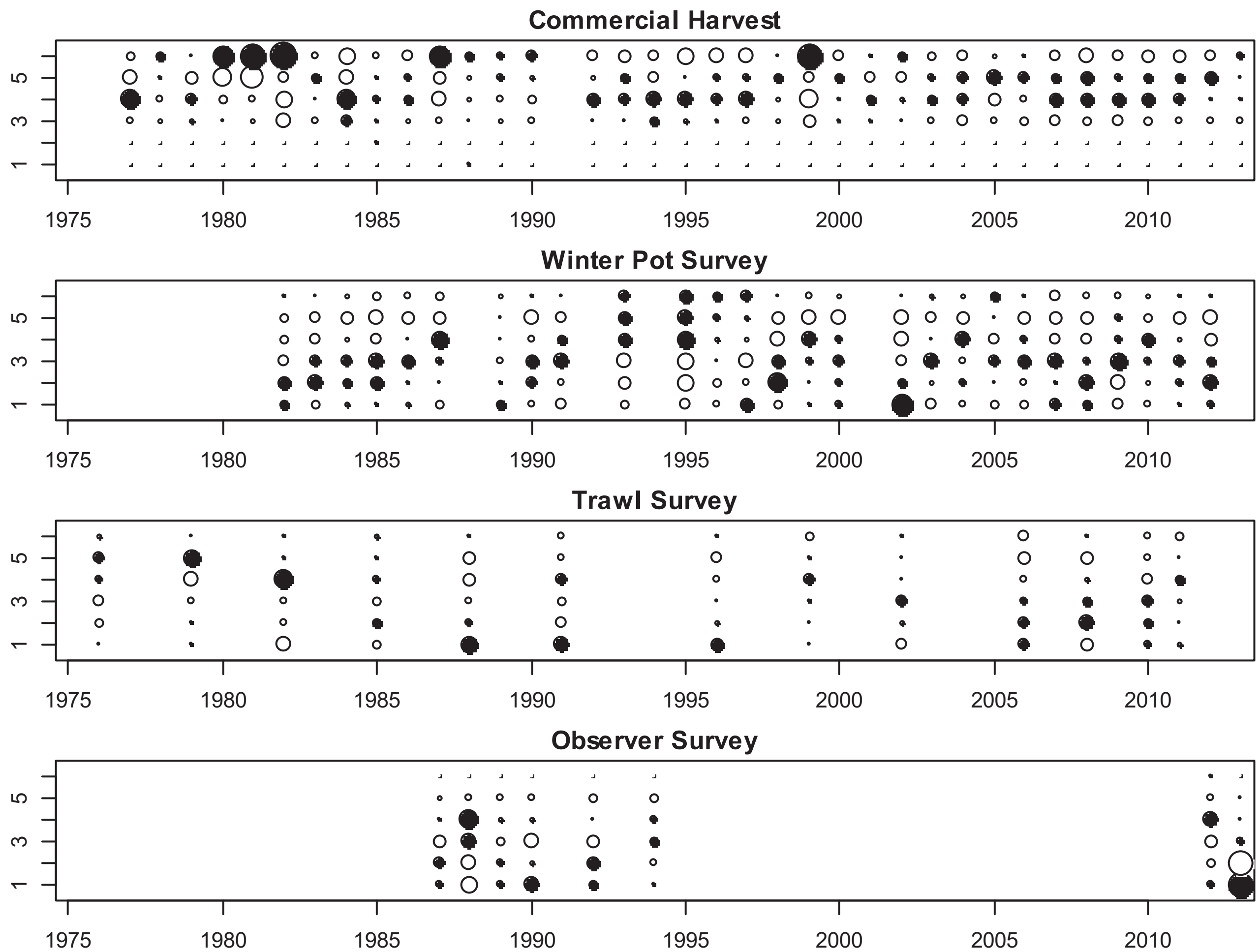
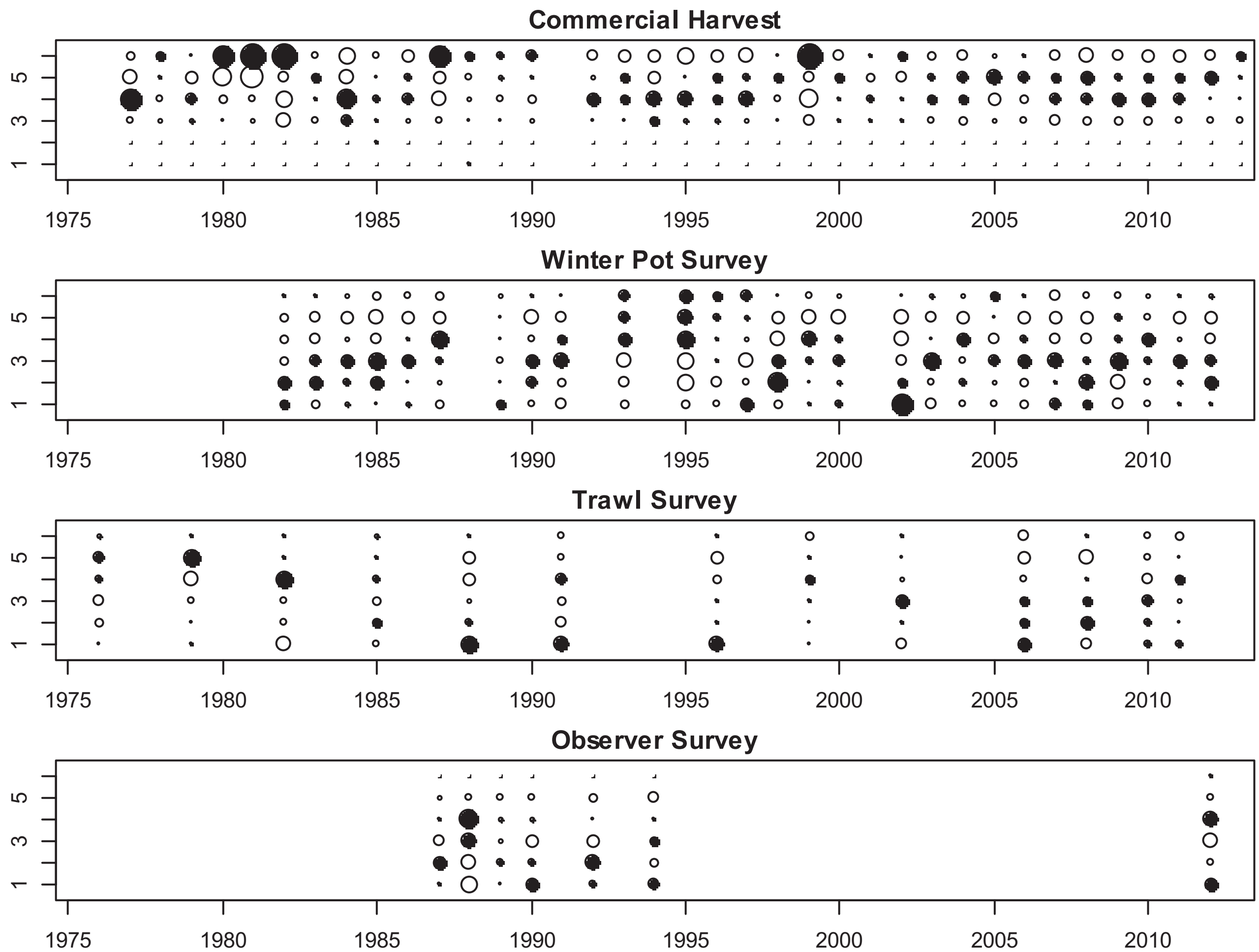


Figure 11b: Residual and QQ plot (without 2013 Observer data)



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 12a: Bubble plot of predicted and observed length proportion (Full data).



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 12b: Bubble plot of predicted and observed length proportion (without 2013 Observer data).

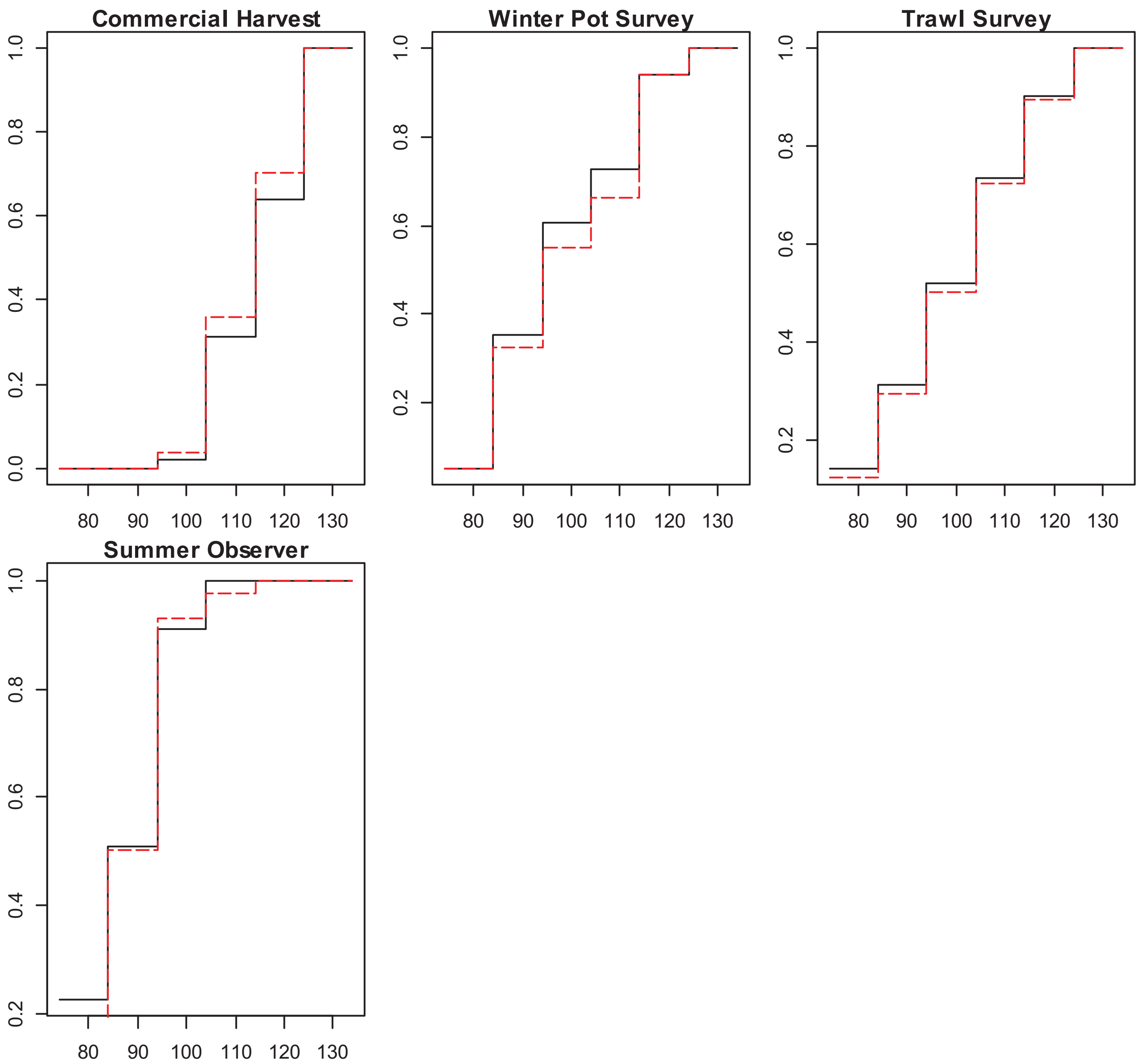


Figure 13a:. Cumulative frequency of length classes between observed and modeled (Full data)

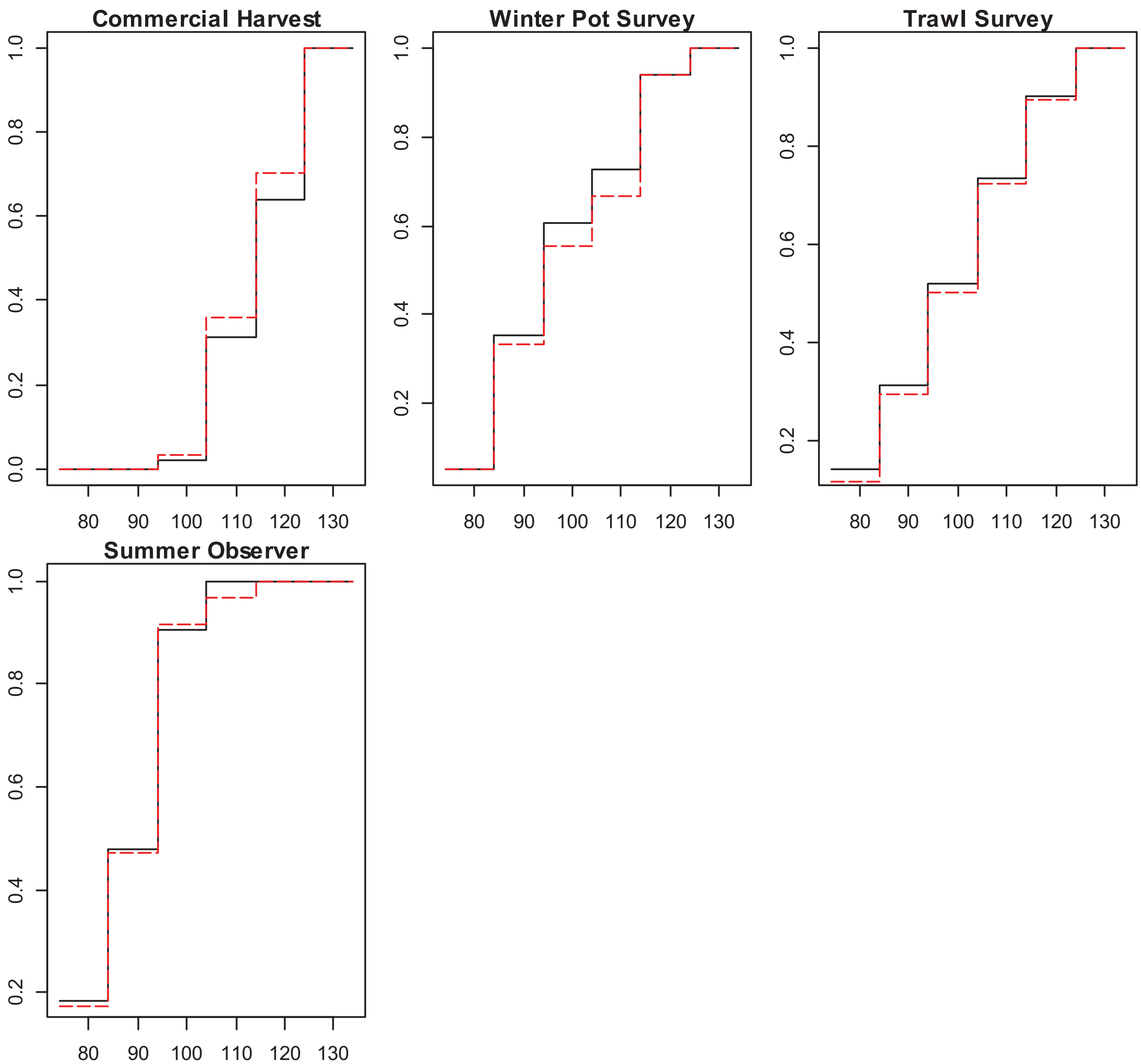


Figure 13b: Cumulative frequency of length classes between observed and modeled (without 2013 Observer data)

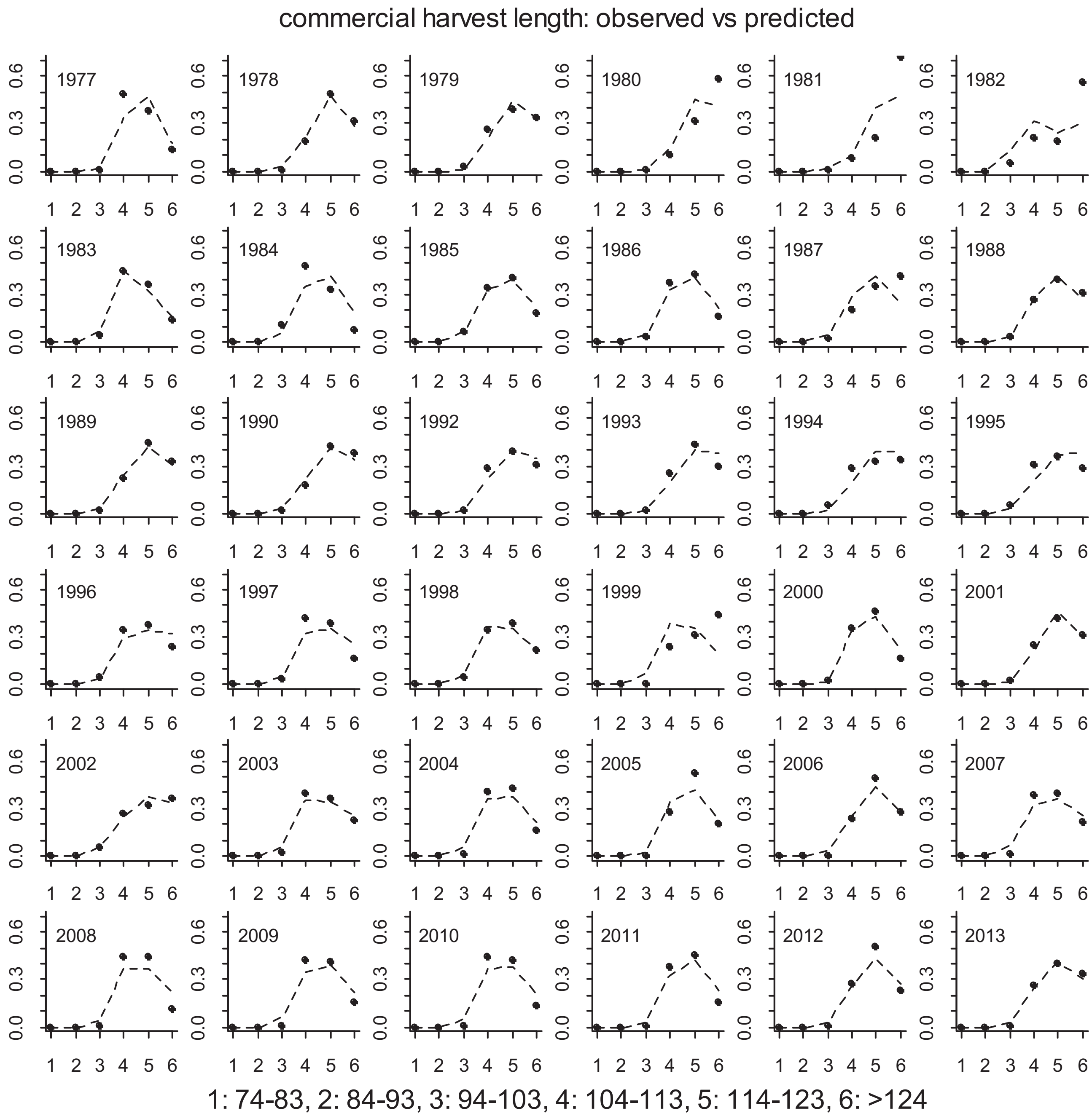


Figure 14a: Predicted vs. observed length class proportion for commercial catch (Full data)

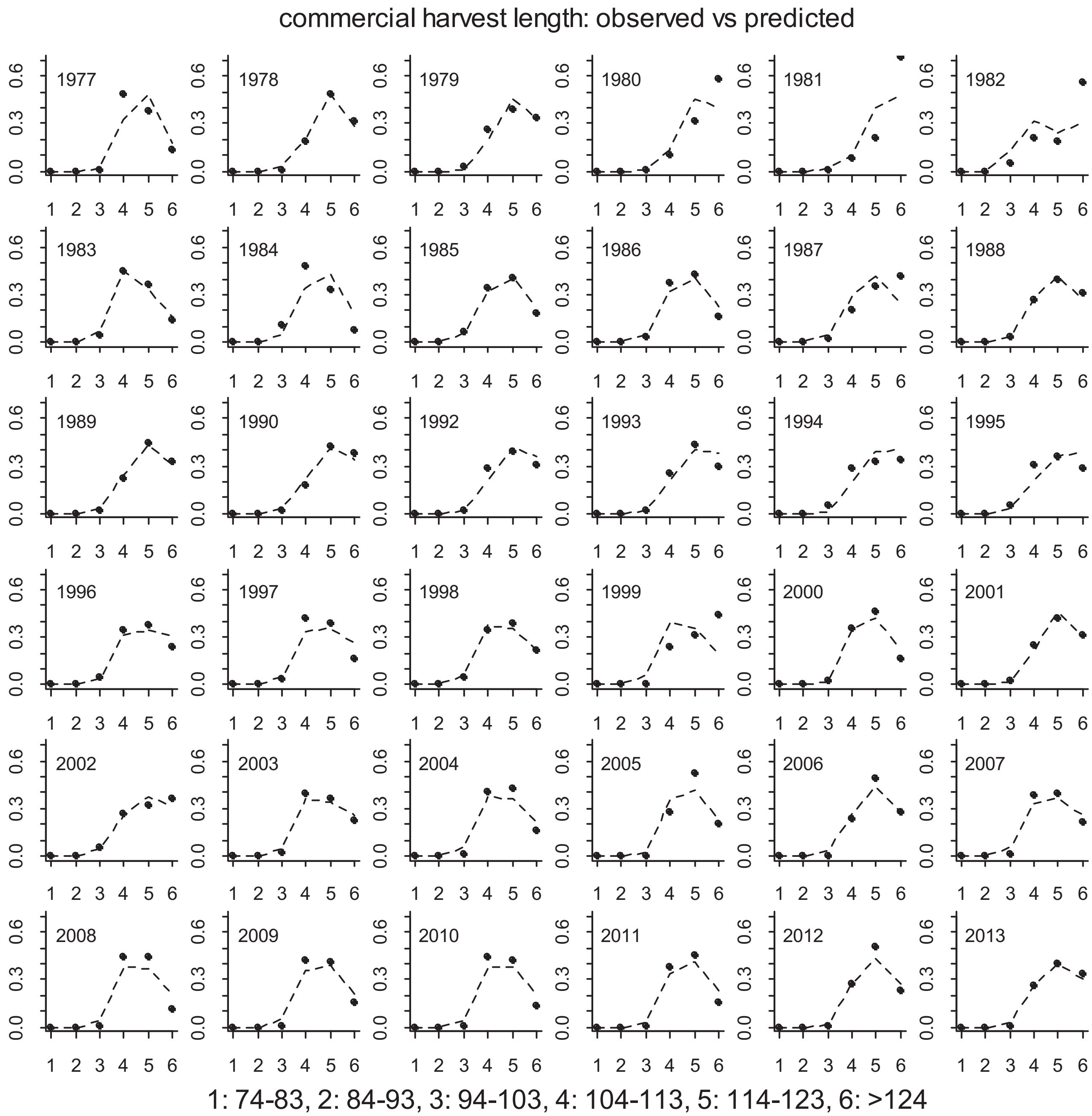


Figure 14b: Predicted vs. observed length class proportion for commercial catch (without 2013 Observer data)

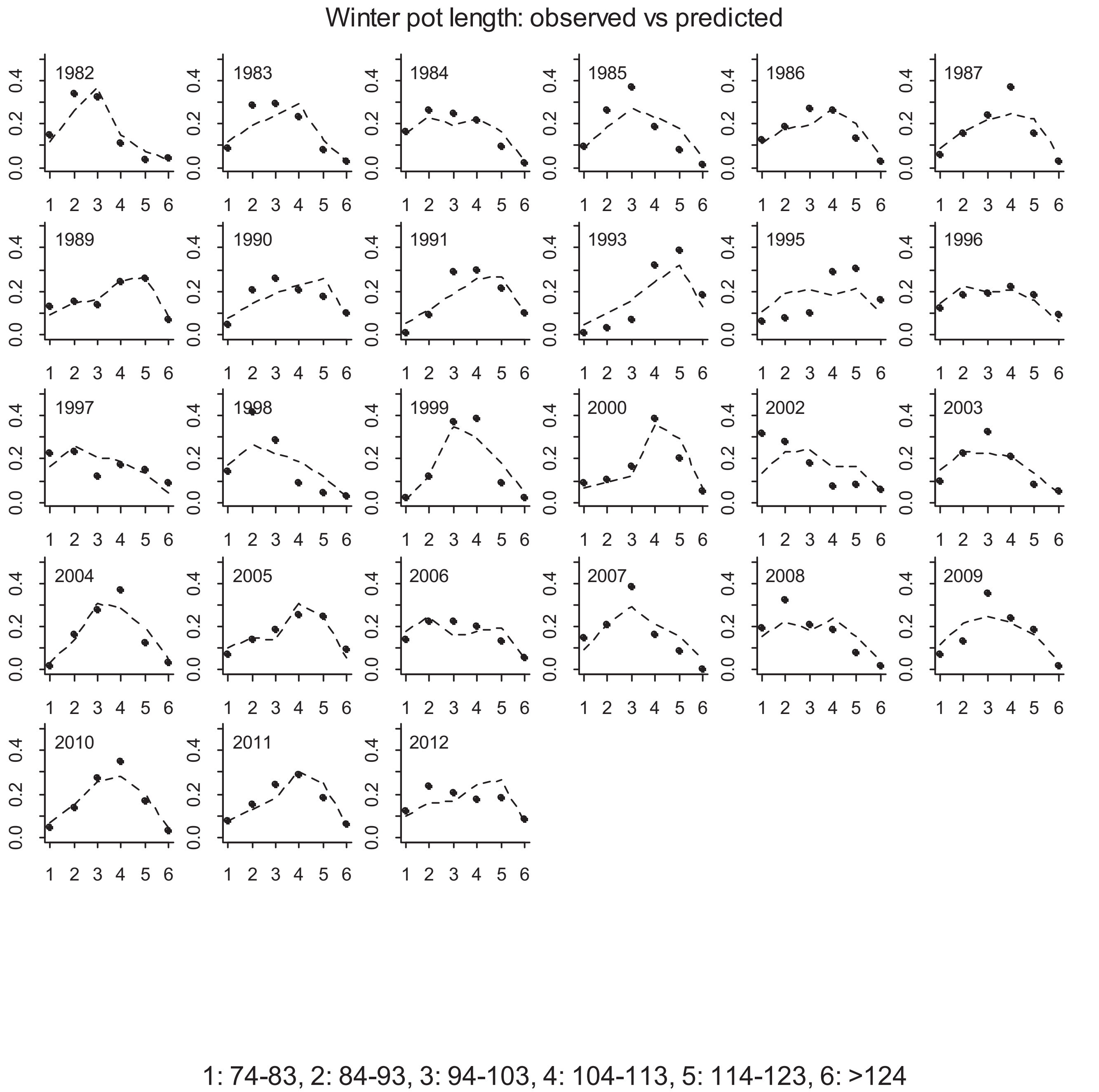


Figure 15a: Predicted vs. observed length class proportion for winter pot survey (Full data)

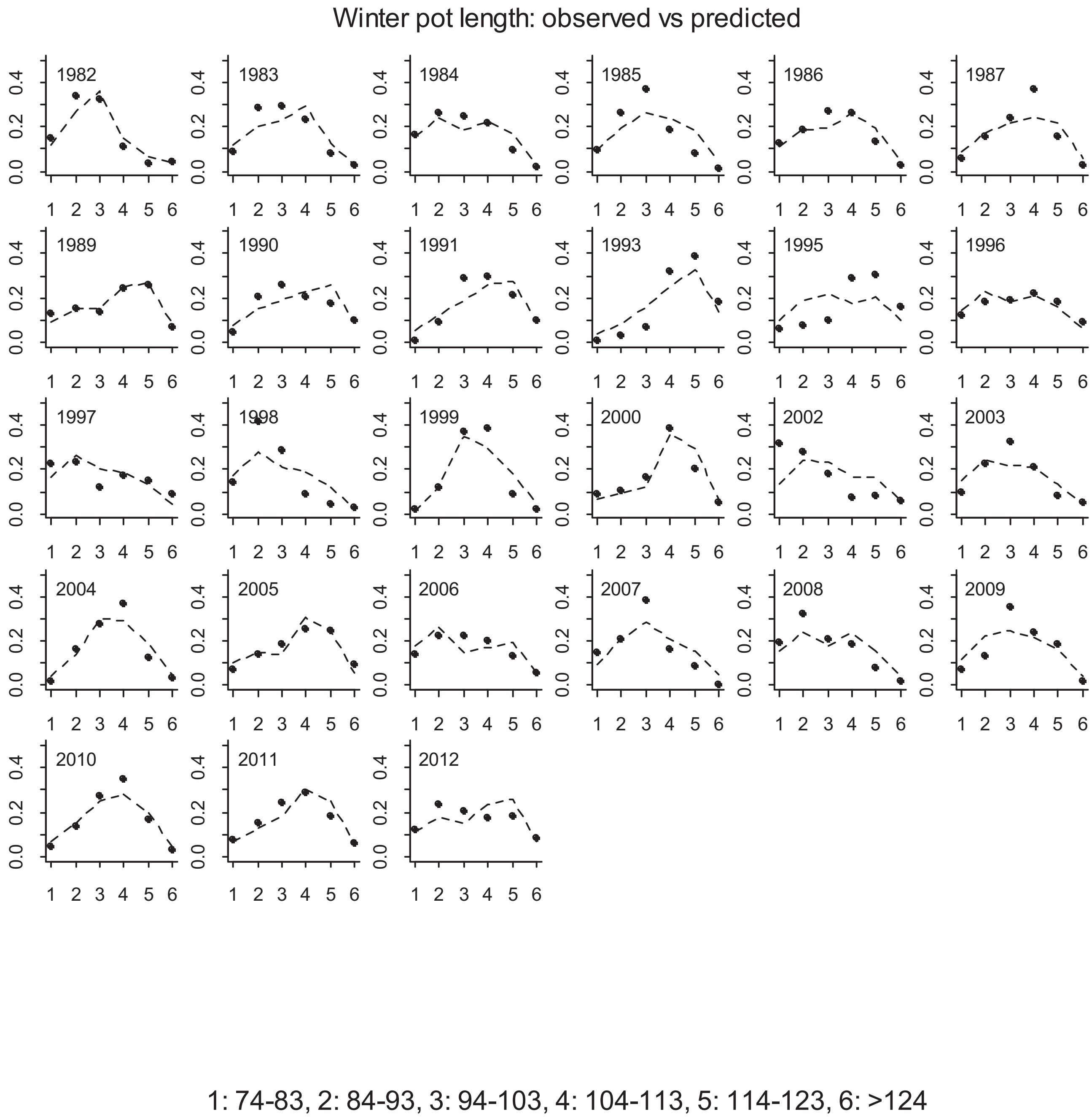


Figure 15b: Predicted vs. observed length class proportion for winter pot survey (without 2013 Observer data)

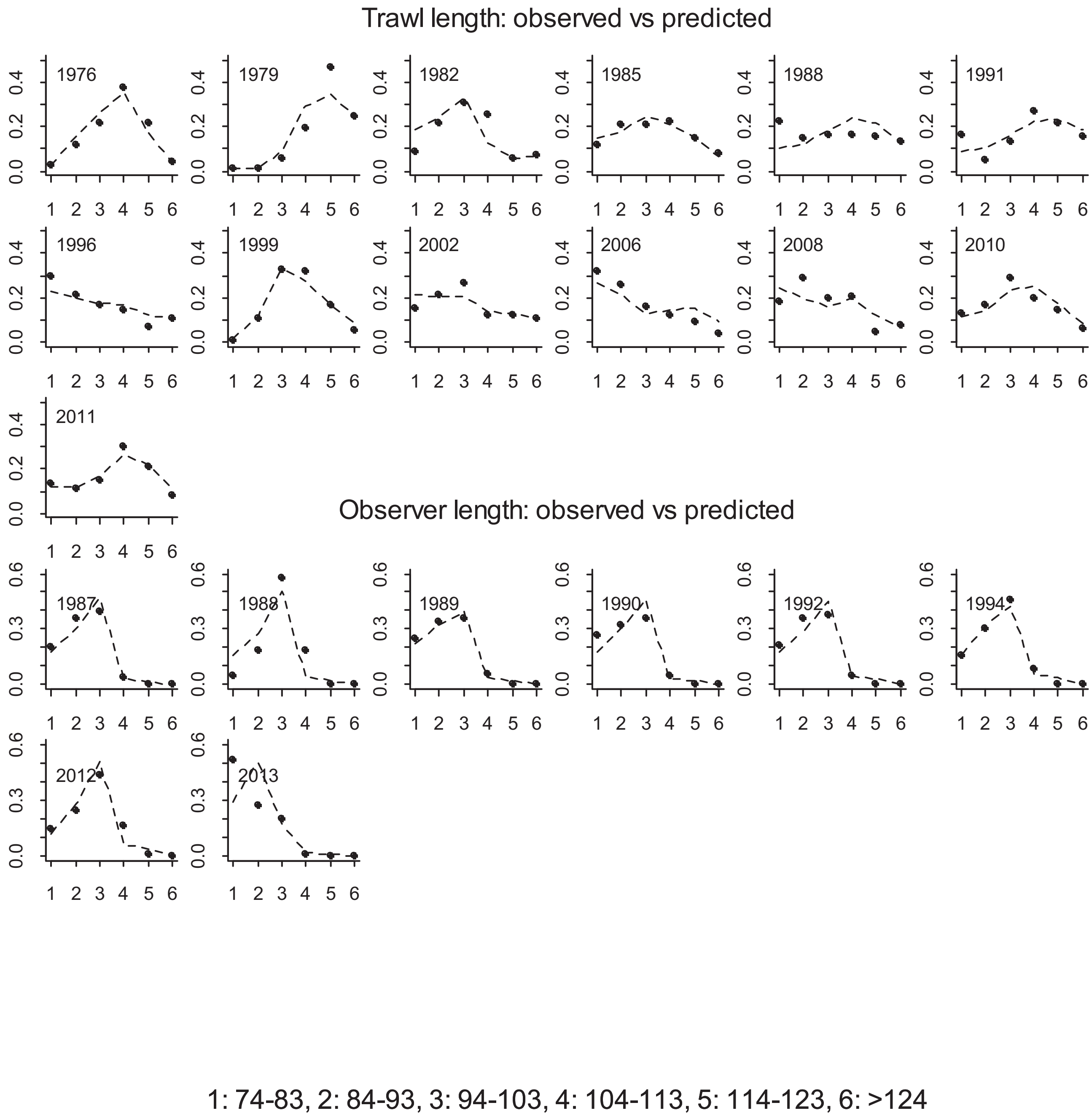
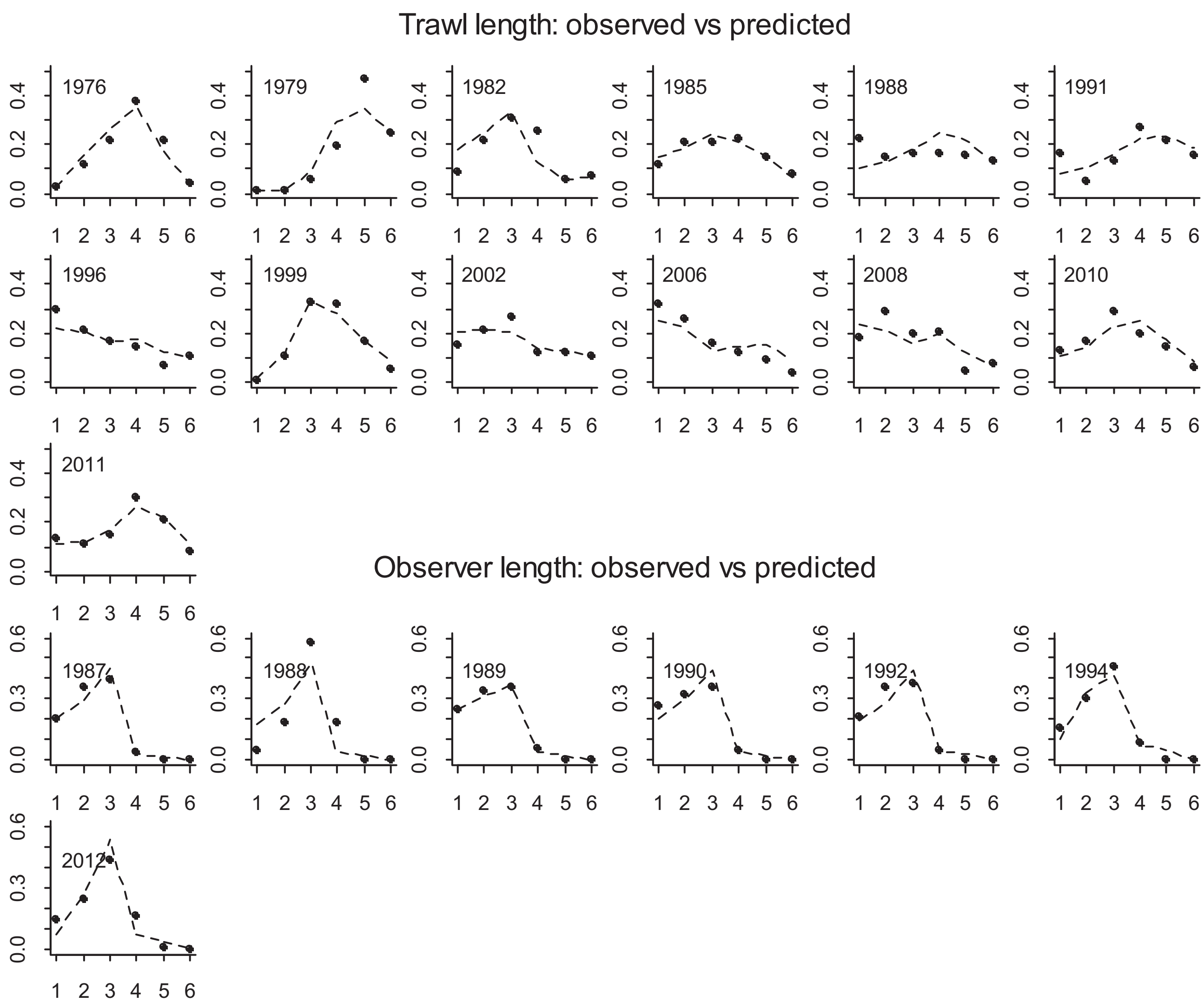


Figure 16a: Predicted vs. observed length class proportion for trawl survey and commercial observer (Full data).



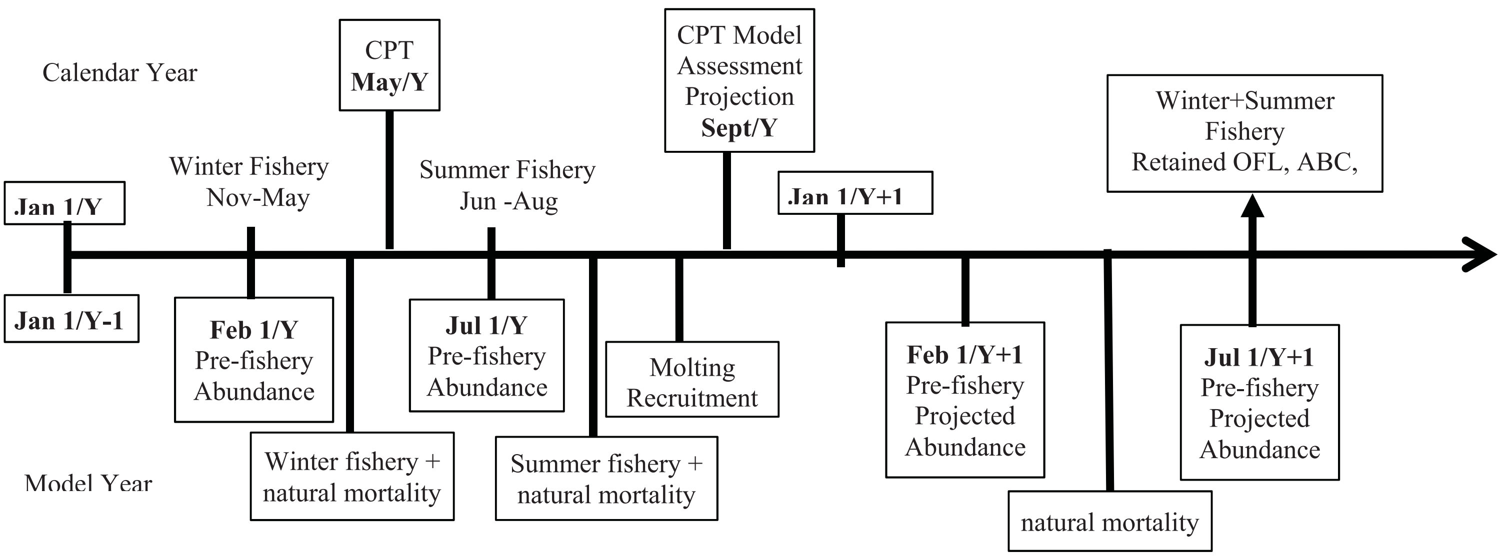
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 16b: Predicted vs. observed length class proportion for trawl survey and commercial observer. (without 2013 Observer data)

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 length classes with model parameters estimated by the maximum likelihood method. The model estimates abundances of crabs with CL ≥74 mm and with 10-mm length intervals because few crabs with CL <74 mm were caught during surveys or fisheries and there were relatively small sample sizes for trawl and winter pot surveys. The model was made for newshell and oldshell male crabs separately, but assumed they have the same molting probability and natural mortality.



Timeline of calendar events and crab modeling events.

In this assessment model, model year starts February1st to January 31st of the following year. Model year starts in February 1st 1976.

Initial pre-fishery summer crab abundance on February 1st 1976

Abundance of the initial pre-fishery population was defined as

$$B_1 = e^{\log\_N_{76}} \quad (1)$$

The length proportion of the first year was calculated as

$$p_i = \frac{\exp(a_i)}{1+\sum_{i=1}^{n-1}\exp(a_i)} \text{ for } i = 1,..,n\text{-}1$$
$$p_n = 1 - \frac{\sum_{i=1}^{n-1}\exp(a_i)}{1+\sum_{i=1}^{n-1}\exp(a_i)} \qquad (2)$$

Abundance of crab length class was is a multiplication of the first year abundance. In this it was assumed no oldshell crab exist for the first year.

$$N_{w,l,1} = p_i \cdot B_1 \qquad (3)$$

Where

$N_{s,l,1}$, $O_{s,l,1}$: summer abundances of newshell and oldshell crabs in length class l in the first year.

p_n : proportion of the neswshell crab

$p_{n,l}$: conditional proportion of l-th length neswshell crab, $p_{n,0}$ =0

$p_{o,l}$: conditional proportion of l-th length oldwshell crab, $p_{o,0} = p_{o,1}$ =0

Crab abundance on July 1st

Summer crab abundance of new and oldshells is survivors of winter commercial and subsistence crab fishery and natural mortality

$$\begin{aligned} N_{s,l,t} &= (N_{wl,t} - C_{w,t}\hat{P}_{w,n,l,t} - C_{p,t}\hat{P}_{p,n,l,t} - D_{w,n,l,t} - D_{p,n,l,t})e^{-0.42M_l} \\ O_{s,l,t} &= (O_{w,l,t} - C_{w,t}\hat{P}_{w,o,l,t} - C_{p,t}\hat{P}_{p,o,l,t} - D_{w,o,l,t} - D_{p,o,l,t})e^{-0.42M_l} \end{aligned} \qquad (4)$$

where

$N_{s,l,t}$, $O_{s,l,t}$: summer abundances of newshell and oldshell crabs in length class l in year t
$N_{w,l,t}$, $O_{w,l,t}$:winter abundances of newshell and oldshell crabs in length class l in year t
$C_{w,t}$, $C_{p,t}$: total winter commercial and subsistence catches in year t,
$P_{w,n,l,t}$, $P_{p,n,l,t}$: Length proportion of winter commercial and subsistence catches for newshell crabs for length class l in year t
$P_{w,o,l,t}$, $P_{p,o,l,t}$: length compositions of winter commercial and subsistence catches for oldshell crabs in length class l in year t

$D_{w,n,l,t}$, $D_{p,n,l,t}$: Discards of winter commercial and subsistence catches for newshell crabs in length class l in year t
$D_{w,o,l,t}$, $D_{p,o,l,t}$: Discards of winter commercial and subsistence catches for oldshell crabs in length class l in year t
M_l : instantaneous natural mortality in length class l, constant for all sizes and shell conditions
0.42 : proportion of the year from Feb 1 to July 1 is 5 months, or 0.42 year

Crab abundance on Feb 1st

Abundance of newshell crab of the t-th year and l-th length class ($N_{w,l,t}$), is a newshell and oldshell population of previous (t-1th) year that survived from summer commercial fishery and molted plus recruitment.

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} G_{l',l}[(N_{s,l',t-1} + O_{s,l',t-1})e^{-y_c M_l} - C_{s,t}(\hat{P}_{s,n,l',t-1} + \hat{P}_{s,o,l',t-1}) - D_{l',t-1}]\, m_{l'}\, e^{-(0.58-y_c)M_l} + R_{l,t-1} \qquad (5)$$

Abundance of oldshell crabs $O_{w,l,t}$ is the non-molting portion of survivors of crabs from summer fishery:

$$O_{w,l,t} = [(N_{s,l,t-1} + O_{s,l,t-1})e^{-y_c M_l} - C_{s,t}(\hat{P}_{s,n,l,t-1} + \hat{P}_{s,o,l,t-1}) - D_{l,t-1}]\,(1 - m_l)\, e^{-(0.58-y_c)M_l} \qquad (6)$$

where

$G_{l',l}$: a growth matrix representing the expected proportion of crabs molting from length class l' to length class l (independently estimated outside of the assessment model frame),
$C_{s,t}$: total summer catch in year t (assumed to be accurate without error),
$P_{s,n,l,t}$, $P_{s,o,l,t}$: Compositions of summer catch for newshell and oldshell crabs in length class l in year t,
$D_{l,t}$: discards of length class l in year t,
m_l : molting probability in 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

In summer and winter 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.

Discards of length class l in year t from the commercial pot fishery were estimated as:

$$D_{l,t} = (N_{s,l,t} + O_{s,l,t})\, S_{s,l}\, (1 - L_l)\, hm_s\, [C_{s,t} / \sum_l (N_{s,l,t} + O_{s,l,t})\, S_{s,l}\, L_l] \quad (7)$$

$$D_{w,n,l,t} = (N_{w,l,t})\, S_{w,l}\, (1 - L_l)\, hm_w\, [C_{w,t} / \sum_l (N_{w,l,t} + O_{w,l,t})\, S_{w,l}\, L_l] \quad (8)$$

$$D_{w,o,l,t} = (O_{w,l,t})\, S_{w,l}\, (1 - L_l)\, hm_w\, [C_{w,t} / \sum_l (N_{w,l,t} + O_{w,l,t})\, S_{w,l}\, L_l] \quad (9)$$

$$D_{p,n,l,t} = C_{d,t} P_{d,n,l,t} hm_w \quad (10)$$

$$D_{p,o,l,t} = C_{d,t} P_{d,o,l,t} hm_w \quad (11)$$

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
L_l : the proportion of legal males in length class *l*.
Reflecting the change of commercial acceptable crab size since 2005, proportion of legal males in the length class 4, was calculated as $p_4 L_4$. Where p_4 is the proportion of commercially acceptable crab among legal crab of the length class 4. p_4 was estimated from the model. (This was removed because the estimate of p_4 was 1.0).
$S_{s,l}$: Selectivity of the summer commercial fishery.
$P_{d,n,l,t}$, $P_{d,o,l,t}$: Compositions of discards for newshell and oldshell crabs in length class *l* in year *t*,

Molting Probability

Molting probability for length class *l*, m_l, was calculated using a reverse logistic function fitted as a function of length and time (Balsiger's 1974)

$$m_l = 1 - \frac{1}{1 + e^{-\alpha(i-\beta)}} \quad (12)$$

where
α and β are parameters, and *i* is the mid-length of length class *l*.
m_l was re-scaled such that $m_1 = 1$.

Trawl net and pot selectivity

Selectivity of length class *l* for summer commercial fishery ($S_{s,l}$), summer trawl survey ($S_{st,l}$), summer pot survey ($S_{p,l}$), winter pot survey ($S_{w,l}$), and summer trawl survey were assumed to be an asymptotic logistic function with parameters ϕ and ω, where *i* is the mid-length of the length class *l*.

$$S_l = \frac{1}{1 + e^{-\phi(i-\omega)}} \quad (13)$$

Selectivity of $S_{1\text{-}4}$ were re-scaled such that $S_5 = S_6 = 1$.

For summer commercial fisheries, two sets of parameters (ϕ_1, ω_1), (ϕ_2, ω_2) were estimated: 1) before 1993, and 2) 1933 to present reflecting changes in fisheries, and crab pot configurations.

For winter pot survey and winter harvest, selectivity ($S_{w,l}$) was assumed to be dome shaped, with $S_{w,5}$ =1, and $S_{w,6}$ was directly estimated from the model.

Estimation of Recruitment

We modeled recruitment of year t, R_t, as a stochastic process around the mean, R_0:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2) \qquad (14)$$

R_t was assumed to come from only length classes 1 ($R_{1,t}$) and 2 ($R_{2,t}$) , and was calculated as

$$\begin{aligned} R_{1,t} &= r\,R_t \\ R_{2,t} &= (1-r)\,R_t \end{aligned} \qquad (15)$$

where r is a parameter with a value less than or equal to 1. $R_{l,t} = 0$ when $l \geq 3$.

Observation model

Estimates of survey abundances

Summer trawl survey abundance

Abundance of t-th year trawl survey was estimated by subtracting population of July 1st abundance minus summer commercial fisheries harvested by before trawl survey, multiplied by selectivity of trawl.

$$\begin{aligned} \hat{B}_{st,t} &= \sum_l [(N_{s,l,t} + O_{s,l,t})\, e^{-y_c M_l} - C_{s,t}(\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t}) P_{c,t}]\, e^{-(y_{st}-y_c)M_l} S_{st,l} \\ \hat{B}_{st,1} &= \sum_l (N_{s,l,1} + O_{s,l,1}) e^{-(y_{st})M_l}\, S_{st,l} \end{aligned} \qquad (16)$$

Where

y_{st} : the time in year from July 1 to the mid-point of the summer trawl survey.

(y_{st} > y_c: Trawl survey starts after opening of commercial fisheries)

$P_{c,t}$: proportion of summer commercial crab harvested before the survey.

Summer pot survey abundance (Removed from likelihood components)

Abundance of t-th year pot survey was estimated as

$$\hat{B}_{p,t} = \sum_{l} [(N_{s,l,t} + O_{s,l,t}) e^{-y_p M_l}] S_{p,l} \tag{17}$$

Where
y_p : the time in year from July 1 to the mid-point of the summer trawl survey.

Estimation of 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, C_t.

$$\hat{f}_t = q_i (A_t - 0.5 C_t) \tag{18}$$

Because fishing fleet and pot limit configuration changed in 1993 and 2008, q_1 is for fishing efforts before 1993, q_2 is from 1994 to present.

Estimates of length composition

Winter commercial catch

Length compositions of winter commercial catch ($P_{w,n,l,t}$, $P_{w,o,l,t}$) for length l in year t were estimated from the winter population, winter pot selectivity, and proportion of legal crabs for each length class as:

$$\begin{aligned} \hat{P}_{w,n,l,t} &= N_{w,l,t} S_{w,l} L_l / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l] \\ \hat{P}_{w,o,l,t} &= O_{w,l,t} S_{w,l} L_l / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l] \end{aligned} \tag{19}$$

Winter subsistence catch

Subsistence fishery does not have a size limit; however, crabs of size smaller than length class 3 are generally not retained. Hence, we assumed proportion of length composition $l = 1$ and 2 as 0, and estimated length compositions ($l \geq 3$) as follows

$$\begin{aligned} \hat{P}_{p,n,l,t} &= N_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \\ \hat{P}_{p,o,l,t} &= O_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \end{aligned} \tag{20}$$

Winter subsistence discards

Subsistence fishery discards proportion was assumed to be length composition l = 1 and 2 only, and was estimated as follows

$$\hat{P}_{pd,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l=1}^{2}[(N_{w,l,t} + O_{w,l,t})S_{w,l}]$$
$$\hat{P}_{pd,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l=1}^{2}[(N_{w,l,t} + O_{w,l,t})S_{w,l}] \quad (21)$$

Winter pot survey

The above equations were also used to calculate length compositions of winter pot survey for newshell and oldshell crabs, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$).

$$\hat{P}_{sw,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l}[(N_{w,l,t} + O_{w,l,t})S_{w,l}]$$
$$\hat{P}_{sw,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l}[(N_{w,l,t} + O_{w,l,t})S_{w,l}] \quad (22)$$

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 calculated based on summer population, selectivity, and legal abundance;

$$\hat{P}_{s,n,l,t} = N_{s,l,t} S_{s,l} L_l / A_t$$
$$\hat{P}_{s,o,l,t} = O_{s,l,t} S_{s,l} L_l / A_t \quad (23)$$

Where A_t is exploitable legal abundance in year t, estimated as

$$A_t = \sum_{l}[(N_{s,l,t} + O_{s,l,t})S_{s,l} L_l] \quad (24)$$

Observer discards

Length/shell compositions of Observer discards in 87-90, 92, 94, and 2012 were estimated as

$$\hat{P}_{b,n,l,t} = N_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)]$$
$$\hat{P}_{b,o,l,t} = O_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)] \tag{25}$$

Summer trawl survey

Some trawl surveys occurred during the molting period, and thus we combined the length compositions of newshell and oldshell crabs as one single shell condition, $P_{st,l,t}$, and were estimated as

$$\hat{P}_{st,,l,t} = \frac{[(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} (\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t}) P_{c,t}] e^{-(y_{st} - y_c) M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} (\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t}) P_{c,t}] e^{-(y_{st} - y_c) M_l} S_{st,l}} \tag{26}$$

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 crabs as:

$$\hat{P}_{sf,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]$$
$$\hat{P}_{sf,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \tag{27}$$

This was not incorporated into likelihood calculation because of one year data.

Summer pot survey (1980-82, 85) (Removed from likelihood due to failure to locate original data)

The length/shell condition compositions of summer pot survey were estimated as

$$\hat{P}_{sp,n,l,t} = N_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}]$$
$$\hat{P}_{sp,o,l,t} = O_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}] \tag{28}$$

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

c. Likelihood components.

Under assumptions that measurement errors of annual total survey abundances and summer commercial fishing efforts follow lognormal distributions and each type of length composition has a multinomial error structure (Fournier and Archibald 1982; Methot 1989), the log-likelihood function is:

$$
\begin{aligned}
&\sum_{i=1}^{i=5}\sum_{t=1}^{t=n_i} K_{i,t}\left[\sum_{l=1}^{l=5} P_{i,l,t}\ln(\hat{P}_{i,l,t}+\kappa)) - \sum_{l=1}^{l=5} P_{i,l,t}\ln(P_{i,l,t}+\kappa)\right] \\
&-\sum_{t=1}^{t=n_i}\frac{[\ln(q\cdot\hat{B}_{i,t}+\kappa)-\ln(B_{i,t}+\kappa)]^2}{2\cdot ln(CV_{i,t}^2+1)} \\
&-\sum_{t=1}^{t=n_i}\left[\frac{\ln\left[\ln(CV_t^2+1)+w_t\right]}{2}-\frac{[\ln(\hat{f}_t+\kappa)-\ln(f_t+\kappa)]^2}{2\cdot\left[\ln(CV_t^2+1)+w_t\right]}\right] \\
&-W_R\sum_{t=1}\tau_t^2
\end{aligned}
\qquad (29)
$$

where
i: length/shell compositions of :

1 triennial summer trawl survey
2 summer pot survey (1980-82, 85): Removed
3 annual winter pot survey
4 summer commercial fishery
5 observer bycatch 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
W_R : the weighting factor of recruitment = 0.01

It is generally believed that total annual commercial crab catches in Alaska are fairly accurately reported. Thus, no measurement error was imposed on total annual catch.

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, and the growth matrix.

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 (NPFMC 2007) 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 8).

Mean growth increment per molt, standard deviation for each pre-molt length class, and the growth matrix (Table 8), were estimated from tagging surveys conducted in summer 1981-1985, and winter 1981-present. In summer 1981-1985 study legal and sublegal males captured by the survey pots were tagged, and in the1981-present winter survey, sublegal males were tagged. All tagged crabs were recaptured by summer and winter commercial/subsistence fisheries.

ii. Parameters Estimated Conditionally

Estimated parameters are listed in Table 5. Selectivity and molting probabilities based on these estimated parameters are summarized in Table 4.

A likelihood approach was used to estimate parameters, which include fishing catchability, parameters for selectivity of survey and fishing gears and for molting probabilities, recruits each year (except the first and the last years), and total abundance in the first year (Table 5).

f. Definition of model outputs.

i. Mature Male Biomass (MMB) on July 1st was defined as size classes 3 to 6

$$MMB = \sum_{l=3} (N_{s,l,} + O_{s,l,}) wm_l$$

For the projected year's MMB we used projected Feb 1st crab abundance, reduced by

$$MMB = \sum_{l=3} (N_{w,l,} + O_{w,l,}) e^{-0.42 M_l} wm_l$$

ii. Projected Legal Male Biomass for winter+summer fishery OFL calculation was calculated as the projected number of crab on Feb 1st of size class greater than 94mm (N_{wl}+O_{wl}) multiplied by 1) mortality from Feb 1st to July 1st, 2) commercial pot selectivity(S_{sl}), 3) proportion of legal crab (L_l), and 4) mean weight lb (w_{ml})

$$Legal\_B = \sum_{l} (N_{w,l,} + O_{w,l,}) e^{-0.42 M_l} S_{s,l} L_l wm_l$$

iii. Recruitment: the number of males of the length classes 1 and 2.

Aleutian Islands Golden King Crab – 2013 Tier 5 Assessment

2013 Crab SAFE Report Chapter (Sept 2013)

Douglas Pengilly, ADF&G, Kodiak

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). Management towards a formally established guideline harvest level (GHL) was introduced for the first time in the 1996/97 season. A GHL of 5.900-million lb (2,676 t) was established for the 1996/97 season, which was 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 season. 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 5.884-million lb (2,669 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 to conduct test fisheries. 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 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 (representing 199% of the retained catch during that season), to 9.100-million lb (4,128 t) in 1996/97 (representing 156% of the retained catch for that season), and to 4.321-million lb (1,960 t) in the 2004/05 season (representing 78% of the retained catch for that season). Over the eight seasons (2005/06–2012/13) prosecuted as rationalized fisheries, estimated weight of discarded bycatch during crab fisheries has ranged from 2.524-million lb (1,145 t) for the 2005/06 season (representing 46% of the retained catch for that season) to 3.035-million lb (1,377 t) for the 2007/08 season (representing 55% 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 1995/96–2012/13; estimated total fishery mortality for 2012/13 was 6.868-million lb (3,115 t).

3. Stock biomass:

Estimates of stock biomass are not available for this Tier 5 assessment.

4. Recruitment:

Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

5. Management performance:

No overfished determination (i.e., MSST) is possible for this Tier 5 stock. Overfishing did not occur during 2012/13; the estimated total catch did not exceed the OFL of 12.54-million lb (5.69 kt). The total catch did not exceed the ABC established for 2012/13 (11.28-million lb, or 5.12 kt). Values given in the tables below for the 2013/14 OFL and ABC are those recommended by the SSC in June 2013.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a, c]	ABC[a, c]
2009/10	N/A	N/A	5.99	5.91	6.51	9.18, R	N/A
2010/11	N/A	N/A	5.99	5.97	6.56	11.06, T	N/A
2011/12	N/A	N/A	5.99	5.96	6.51	11.40, T	10.26, T
2012/13	N/A	N/A	6.29	6.27	6.87	12.54, T	11.28, T
2013/14	N/A	N/A	6.29			12.54, T	11.28, T

a. Millions of lb.

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

c. Noted as “R” for retained-catch only and as “T” for total-catch.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a, c]	ABC[a, c]
2009/10	N/A	N/A	2.72	2.68	2.59	4.16, R	N/A
2010/11	N/A	N/A	2.72	2.71	2.98	5.02, T	N/A
2011/12	N/A	N/A	2.72	2.71	2.95	5.17, T	4.66, T
2012/13	N/A	N/A	2.85	2.84	3.12	5.69, T	5.12, T
2013/14	N/A	N/A	2.85			5.69, T	5.12, T

a. kt.

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

c. Noted as “R” for retained-catch only and as “T” for total-catch.

Basis for the OFL and ABC: See table below; 2013/14 values are the recommended (status quo) values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality[a]	Buffer
2009/10	5	1985/86–1995/96[b]	0.18	N/A
2010/11	5	1985/86–1995/96[c]	0.18	N/A
2011/12	5	1985/86–1995/96[c]	0.18	10%
2012/13	5	1985/86–1995/96[c]	0.18	10%
2013/14	5	1985/86–1995/96[c]	0.18	10%

a. Assumed value for FMP king crab in NPFMC (2007b); does not enter into OFL estimation for Tier 5 stock.
b. OFL was for retained catch only and was determined by the average of the retained catch for these years.
c. OFL was for total catch and 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. The standard deviation of the estimated sampling distribution of the recommended OFL is 1.18-million lb (CV = 0.09). See section G.1.

7. **Basis for the ABC recommendation:** A 10% buffer on the OFL; i.e., ABC = (1.0-0.1)·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:** None.

2. **Changes to the input data:**
   - Fishery data has been updated with the results for 2011/12: retained catch for the directed fishery and bycatch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries.

3. **Changes to the assessment methodology:** None. 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 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 recommended OFL and ABC for 2013/14 are a total-catch OFL of 12.54-million lb (569 t) and an ABC set at the maximum (i.e., with a 10% buffer below the OFL) of 11.28 million lb (512 t); those are the status quo values from 2012/13 and no alternative OFL/ABC is offered.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment)</u>:**
    - <u>CPT, May 2012</u>: *None.*
    - <u>SSC, June 2012</u>: *None.*
    - <u>CPT, September 2012 (via Sept 2012 SAFE)</u>:
        - *"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."*
            - <u>Response</u>: Not applicable for Tier 5 assessment.
        - *"The CPT recommends the listing of sigmas instead of absolute weights as being more informative for factors such as L_{50} and β. Also, the team recommends specifying weights for the penalties on L_{50} and from the standard errors from the analysis on which the estimates for these parameters were based."*
            - <u>Response</u>: Not applicable for Tier 5 assessment.
        - *"The team requests all authors to consult 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."*
            - <u>Response</u>: Guidelines for SAFE preparation as supplied in 26 July 2012 email from the CPT chair were consulted and followed.
        - *"The team requests that to the extent possible assessments include a listing of the tables and figures in the assessment (i.e., Table of Tables, Table of Figures)."*
            - <u>Response</u>: A list of tables and a list of figures are included.
    - <u>SSC, October 2012</u>: *None.*

2. **<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:**

- CPT, May 2012 (May 2012 CPT minutes): *None.*
- SSC, June 2012 (June 2012 SSC minutes): *"... The SSC agrees with the CPT recommendation that this stock continue to be managed using Tier 5 allowing a total catch OFL of 5.69 kt and ABC of 5.12 kt for 2012/2013. The ABC is based on the ABC control rule which specifies a 10% buffer between the OFL and ABC."*
    - Response: The author's recommended OFL and ABC for 2013/14 follow the SSC's recommendations for 2012/13.
- CPT, September 2012 (via Sept 2012 SAFE): *None*.
- SSC, October 2011: *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, golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (page 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 (page 3-43).

The Aleutian Islands king crab stock boundary is defined by the boundaries of the Aleutian Islands king crab Registration Area O (Figure 1). Baechler (2012, 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 2012). At its March 1996 meeting, 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, as is shown by the longitudinal pattern in fishery production prior to the 1996/97 season (Figure 3). The longitudinal pattern in fishery production during recent fisheries since that change in management is shown in 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 2011/12 season the pots sampled by at-sea observers were fished at an average depth of 189 fathoms (346 m; N=361) in the area east of 174° W longitude and 170 fathoms (311 m; N=837) for the area west of 174° W longitude (Gaeuman 2013).

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 is largely limited to the geographic location of commercial fishery catch and effort. Effort and catch by statistical area since 1982 and locations of over 70,000 fished pots that were sampled by observers since 1996 seasons indicate that habitat for legal-sized males may be continuous throughout the waters adjacent to the Aleutian Islands. However, regions in which available habitat is attenuated, or in which golden king crab are present at only low densities, are suggested by regions of low fishery catch. In particular, Figures 3 and 4 show that catch has been low in the fishery in the area between 174° W longitude and 176° W longitude (i.e., the Atka Island area) in comparison to adjacent areas. Catches of golden king crab during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys (von Szalay et al. 2011) also showed an area of low CPUE for golden king crab in between 174° W longitude and 176° W longitude (i.e., the Atka Island area) in comparison to adjacent areas (Figure 5). Additionally, there is a gap of catch and effort in statistical areas between Petrel Bank/Petrel Spur and Bowers Bank, both of which areas 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 (L. J. Watson, 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).

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. **Brief summary of management history:**

A complete summary of the management history through the 2010/11 season is provided in Baechler (2012, pages 12–18). 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 the 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 that specified if conservation concerns arise. Over the period 1996/97–2012/13 the total of the annual retained catch has averaged 2% below the total of the annual GHL/TACs. By season, over the period 1996/97–2012/13 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 2012/13 season was <1% below the 6.290-million lb (2,853 t) TAC.

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 to be 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 legal 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) ≥135 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." 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 August 15 through May 15.

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.

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 2012/13 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 2012/13 have been added.
- Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 2012/13 have been added.

2. <u>Data presented as time series</u>:

a. <u>Total catch</u> and b. <u>Information on bycatch and discards</u>:

- Fish ticket data on retained catch numbers, retained catch weight, pot lifts, CPUE, and average weight of retained catch for the 1981/82–2012/13 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 1995/96–2012/13 (Table 2). Some observer data exists for the 1988/89–1989/90 seasons, but that data is 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 1993/94–2012/13 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 1995/96–2012/13 directed and non-directed crab fisheries and 1993/94–2011/12 groundfish fisheries are presented in Table 4. Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 1995/96–2012/13 are presented (Table 4). Following Siddeek et al. (2012), 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. <u>Catch-at-length</u>: Not used in a Tier 5 assessment; none are presented.

d. <u>Survey biomass estimates</u>: 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 has 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. **History of modeling approaches for this stock:** This is a Tier 5 stock. There is an assessment model in development for this stock (Siddeek et al. 2012).

2. **Model Description:** *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. Such a model is in development (Siddeek et al. 2012), but has not been accepted. In 2012 the SSC recommended that this stock be managed under Tier 5 for 2012/13 (June 2012 SSC minutes).

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 2013/14.

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 6 seasons (1990/91–1995/96), for computing average annual retained catch to estimated 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 first five 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 was 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).

3. **Model Selection and Evaluation:**

a. ***Description of alternative model configurations***

During the 2008–2012 reviews of a Tier 5 OFL stock (see section 2, above), the SSC has recommended the "time period be frozen to stabilize the control rule" and that computation of the Tier 5 OFL 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 was not available and presented in 2012, 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 that was established in 2012):

$$OFL_{2013/14} = (1+R_{90/91\text{-}95/96})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

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 6; the column means in Table 6 are the calculated values of $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09.}$ Using those calculated values of $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09}$, $OFL_{2013/14}$ is computed as,

$$OFL_{2013/14} = (1+0.363)\bullet(9{,}178{,}438) + 23{,}359 = 12{,}537{,}757 \text{ lb (12.54-million lb; 5.69 kt)}$$

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 section A.4.

c. ***<u>Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models</u>:*** See the section A.4.

d. ***<u>Convergence status and convergence criteria for the base-case model (or proposed base-case model)</u>:*** Not applicable.

e. ***<u>Table (or plot) of the sample sizes assumed for the compositional data</u>:*** Not applicable.

f. ***<u>Do parameter estimates for all models make sense, are they credible?</u>:***
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 1985/86–2012/13 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 1985/86–2012/13. Retained catch data come from fish tickets and annual retained catch is assumed to be known. Estimates of bycatch from crab fisheries data are generally considered credible (e.g., Byrne and Pengilly 1998; Gaeuman 2013). Estimates of bycatch mortality were derived as estimates of bycatch times an assumed bycatch mortality rate. The assumed bycatch mortality rates have not been estimated from data.

g. ***<u>Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty</u>:*** 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 mintues) 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, although we can note here that 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 Table 2; see also Figure 8 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 estimates of bycatch biomass due to groundfish fisheries is small relative to the biomass of retained catch (≥4.819-million lb [2,186 t] annually during 1985/86–2010/11), 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. 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: double the assumed bycatch mortality rate from 0.2 to 0.4, and the OFL estimate increases by a factor of 1.4/1.2 = 1.17; half the assumed bycatch mortality rate from 0.2 to 0.1, and the OFL estimate decreases by a factor of 1.1/1.2 = 0.92.

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 2013/14 are those recommended by the SSC in June 2013.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a, c]	ABC[a, c]
2009/10	N/A	N/A	5.99	5.91	6.51	9.18, R	N/A
2010/11	N/A	N/A	5.99	5.97	6.56	11.06, T	N/A
2011/12	N/A	N/A	5.99	5.96	6.51	11.40, T	10.26, T
2012/13	N/A	N/A	6.29	6.27	6.87	12.54, T	11.28, T
2013/14	N/A	N/A	6.29			12.54, T	11.28, T

a. Millions of lb.

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

c. Noted as "R" for retained-catch only and as "T" for total-catch.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a, c]	ABC[a, c]
2009/10	N/A	N/A	2.72	2.68	2.59	4.16, R	N/A
2010/11	N/A	N/A	2.72	2.71	2.98	5.02, T	N/A
2011/12	N/A	N/A	2.72	2.71	2.95	5.17, T	4.66, T
2012/13	N/A	N/A	2.85	2.84	3.12	5.69, T	5.12, T
2013/14	N/A	N/A	2.85			5.69, T	5.12, T

a. kt.
b. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
c. Noted as "R" for retained-catch only and as "T" for total-catch.

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 $R_{90/91-95/96}$, $RET_{85/86-95/96}$, $BM_{GF,93/94-08/09}$ and $OFL_{Alt-2,2010/11}$). Table 6 provides statistics on the generated distributions.

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 addititional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

5. Author recommended ABC.

(1.0-0.1)·12,537,757 lb = 11,283,981 lb (11.28-million lb; 5,118 t)

H. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Currently, there are no biomass estimates for this stock. The process of development and annual use of an assessment model (e.g., Siddeek et al 2012) to estimate spawning biomass or a proxy will identify data gaps and research priorities. Triennial pot surveys for a portion of stock were not performed in 2009 or 2012 and will likely not be performed in the future. Bycatch mortality rate in directed fishery is unknown.

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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 that has been used since the 1996/97 to manage Aleutian Island golden king crab as separate stocks east and west of 174° W longitude (from Figure 4-2 *in* Morrison et al. 1998).

Figure 4: page 33. 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 2012/13 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 2012 SAFE, updated with data for 2012/13 received in 24 June 2013 email from H. Fitch, ADF&G).

Figure 5: page 34. Average golden king crab CPUE (kg/nm^2) for tows, number of tows, and average depth of tows by one-degree longitude intervals for the tows performed during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands; preliminary summary of data obtained on 1 April 2013 from
http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

Figure 6: page 35. 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 Aleutian Islands golden king crab during groundfish fisheries
(from http://www.fakr.noaa.gov/rr/figures/fig1.pdf).

Figure 7: page 36. Retained catch during the Aleutian Islands golden king crab fishery and estimated bycatch mortality (when available) during all crab fisheries and estimated bycatch mortality (when available) during all groundfish fisheries of Aleutian Islands golden king crab, 1985/86–2012/13 (from Table 4; thousands of lb on left axis and t on right axis).

Figure 8: page 37. 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, 1990/91–2012/13 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

Figure 9: page 38. 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, 1990/91–2012/13 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

Figure 10: page 39. Bootstrapped estimates of the sampling distribution of the recommended 2013/2014 Tier 5 OFL (lb of total-catch) for the Aleutian Islands golden king crab stock; histograms in left column, quantile plots in right column.

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 2012/13 season (includes the CDA and ACA fisheries for the 2005/06–2012/13 seasons; from 2012 SAFE, updated with data for 2012/13 received in 24 June 2013 email from H. Fitch, ADF&G).

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]

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.

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,1990/91–2012/13; from 2012 SAFE, updated for 2012/13 with data received in 24 June 2013 email from H. Fitch, ADF&G, and bycatch estimates provided by W.B. Gaeuman on 9 August 2013.

	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

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) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1991/92–2012/13 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries; from 2012 SAFE, updated with values for 2012/13 provided by R. Foy, NMFS-AFSC, 15 Aug 2013 email).

	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	595	19,674	20,270

Table 4. Estimated annual weight (thousands of lb) of total fishery mortality to Aleutian Islands golden king crab, 1990/91–2012/13, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries; from 2012 SAFE, updated for 2012/13 with values in Table 2 (assumes bycatch mortality rate of 0.2 for crab fisheries) and Table 3.

		Bycatch Mortality by Fishery Type		
Season	Retained Catch	Crab	Groundfish	Total Estimated 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

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 2013/14 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
Mean	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 2013/14 OFL calculation, with the computed OFL for comparison.

	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

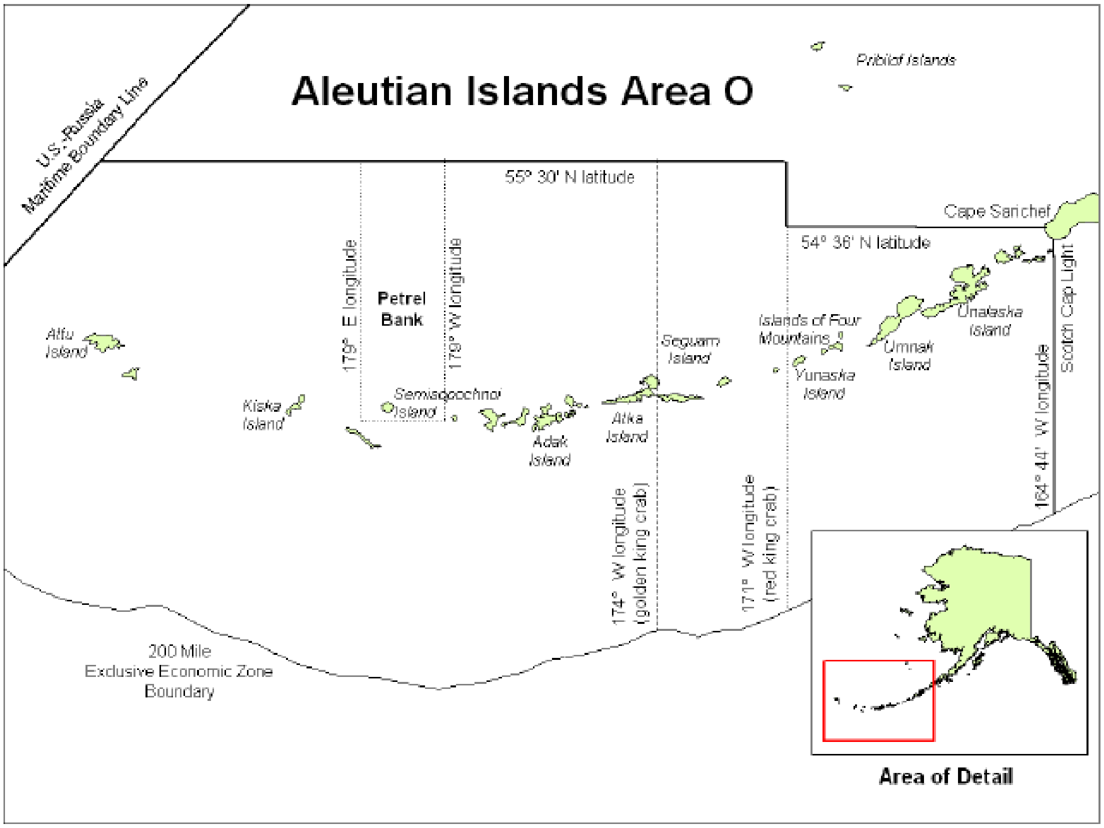

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler 2012).

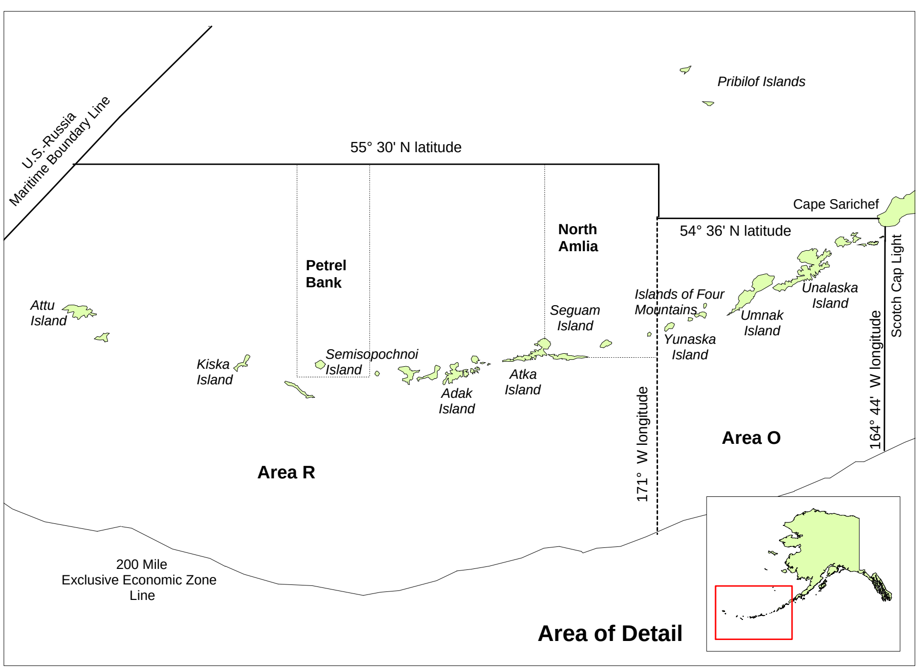

Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85–1995/96 seasons (from Baechler 2012).

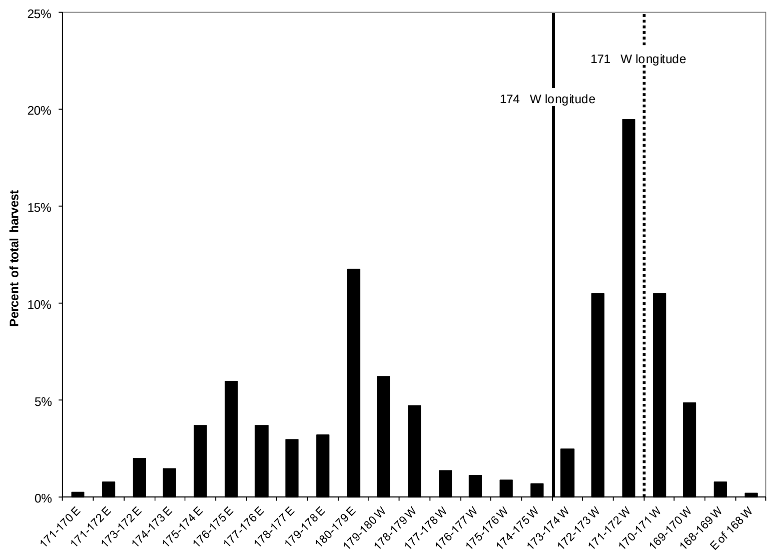

Figure 3. Percent of total 1981/82–1995/96 golden king crab harvest from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W 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 to manage crab east and west of 174° W longitude (adapted from Figure 4-2 *in* Morrison et al. 1998).

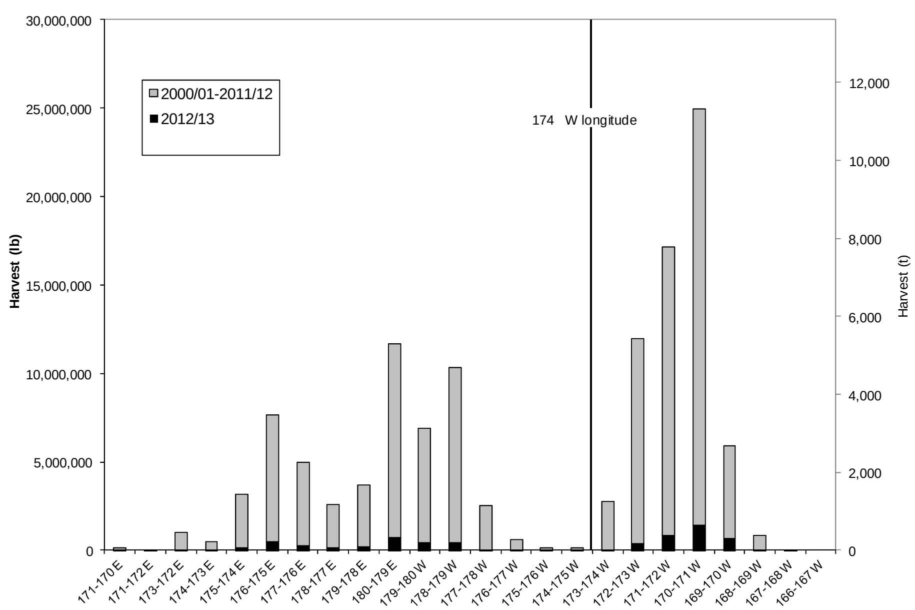

Figure 4. Harvest (lb on left axis and t on right axis) of golden king crab from one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2012/13 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crab as separate stocks east and west of 174° W longitude (from 2012 SAFE, updated with data for 2012/13 received in 24 June 2013 email from H. Fitch, ADF&G).

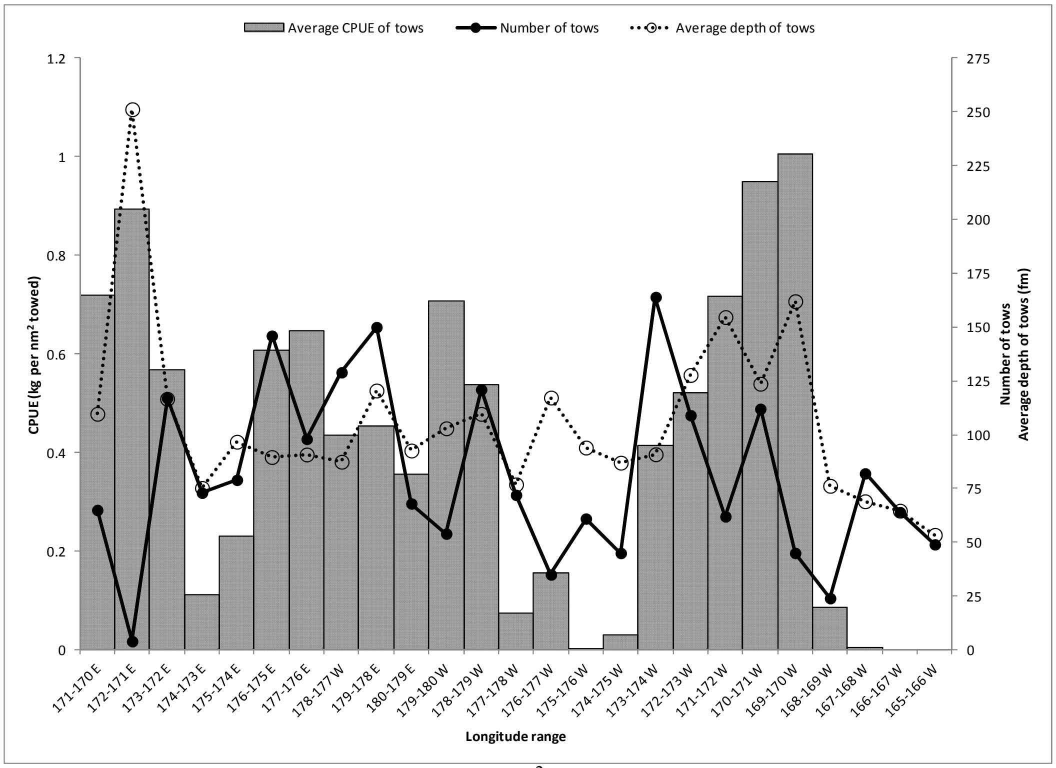

Figure 5. Average golden king crab CPUE (kg/nm^2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

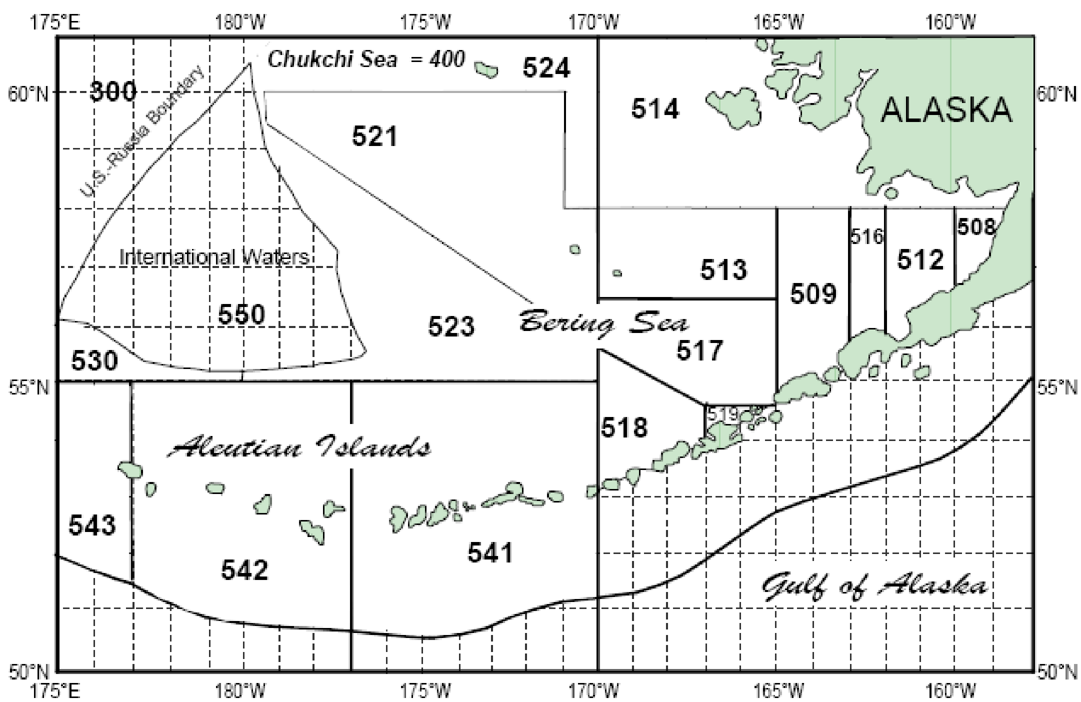

Figure 6. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to summarize groundfish fisheries bycatch data for Aleutian Islands golden king crab (from http://www.fakr.noaa.gov/rr/figures/fig1.pdf).

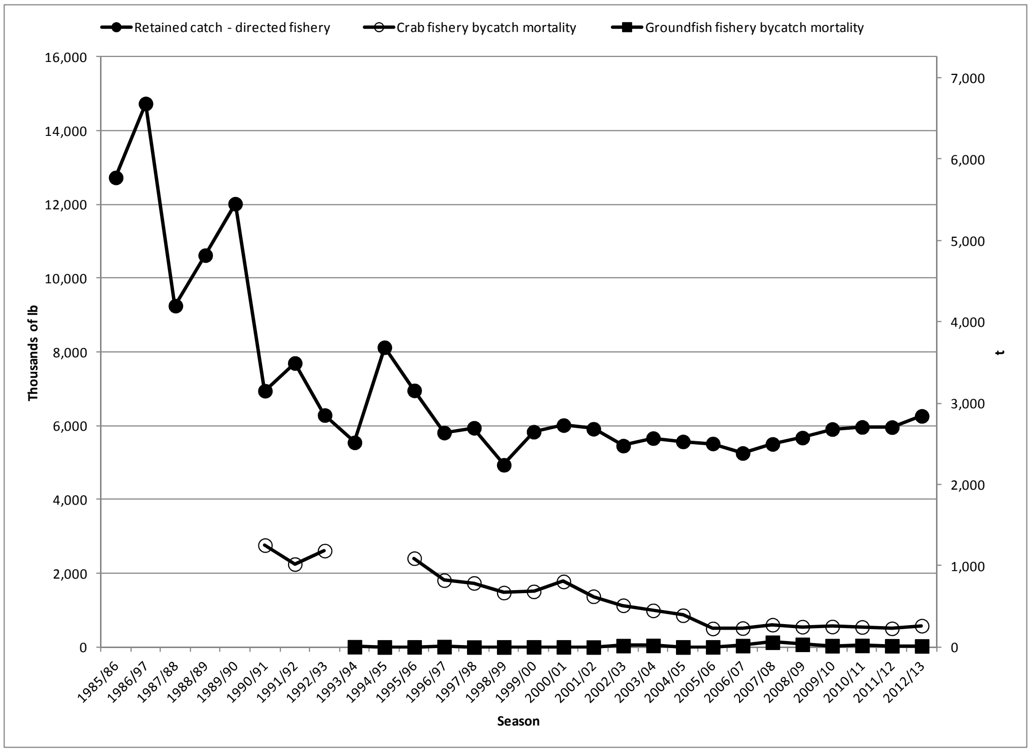

Figure 7. Retained catch during the Aleutian Islands golden king crab fishery and estimated bycatch mortality (when available) during all crab fisheries and estimated bycatch mortality (when available) during all groundfish fisheries of Aleutian Islands golden king crab, 1985/86–2012/13 (from Table 4; thousands of lb on left axis and t on right axis).

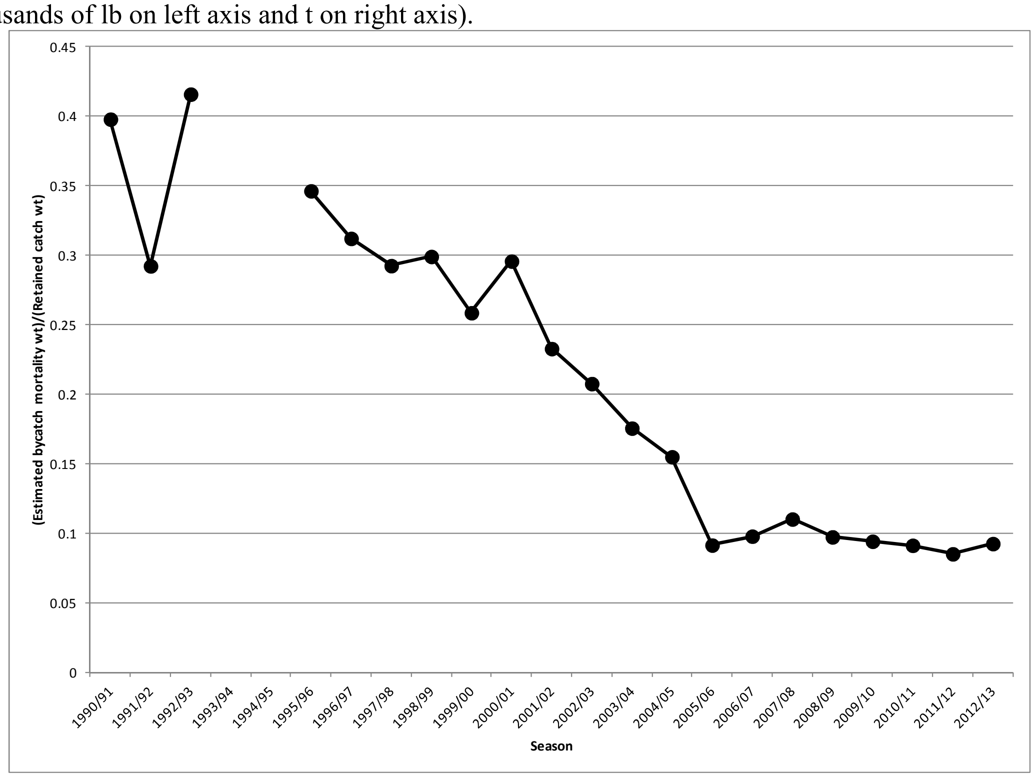

Figure 8. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Islands golden king crab, 1990/91–2012/13 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

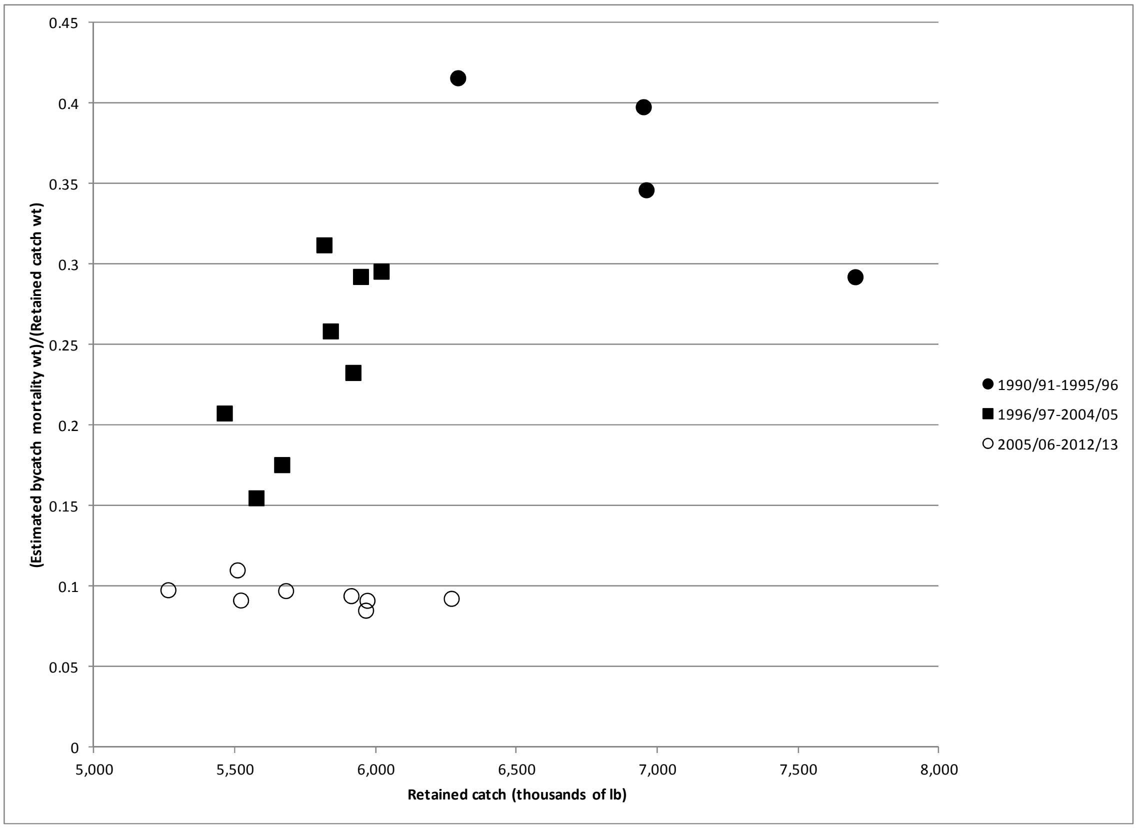

Figure 9. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Islands golden king crab plotted against weight of retained catch, 1990/91–2012/13 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

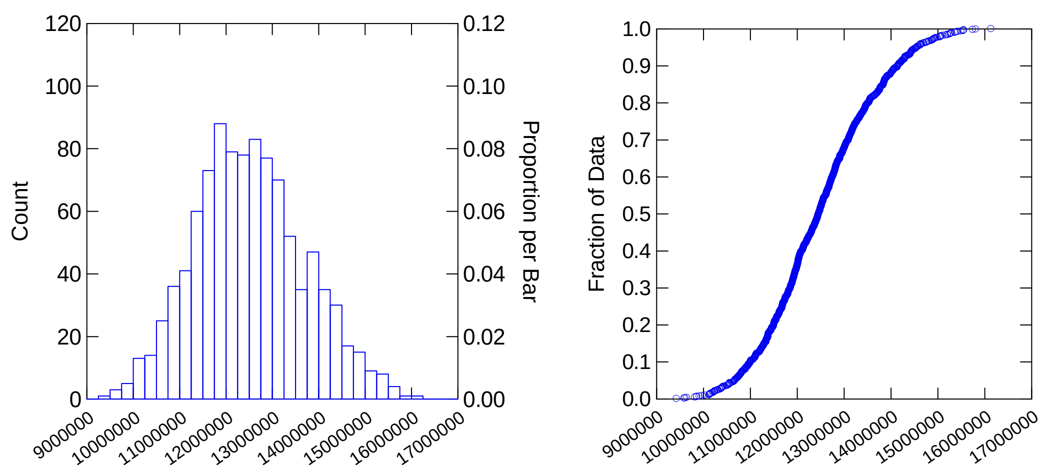

Figure 10. Bootstrapped estimates of the sampling distribution of the recommended 2013/2014 Tier 5 OFL (lb of total-catch) for the Aleutian Islands golden king crab stock; histograms in left column; quantile plots in right column.

Pribilof Islands Golden King Crab – 2013 Tier 5 Assessment

2013 Crab SAFE Report Chapter (Sept 2013)

Douglas Pengilly, ADF&G, Kodiak

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 fishing season for this stock has been defined as a calendar year (as opposed to a "crab fishery year") following the close of the 1983/84 season. 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. 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 towards 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 2012; directed fishery catch cannot be reported for those three years 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, 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 2001–2012 ranges from 0 lb to 0.049-million lb (22 t). Estimates of annual total fishery mortality during calendar years 2001–2012 due to crab fisheries range from 0 to 0.160-million lb (73 t), with an average of 0.076-million lb (34 t). 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 1991/92–2011/12 crab fishery years. Estimates of annual fishery mortality during 1991/92–2011/12 due to groundfish fisheries range from <0.001-million lb (<1 t) to 0.019-million lb (9 t), with an average of 0.006-million lb (3 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 during eastern Bering Sea upper continental slope trawl surveys performed by NMFS-AFSC in 2002 (Hoff and Britt 2003), 2004 (Hoff and Britt 2005), 2008 (Hoff and Britt 2009), and 2010 (Hoff and Britt 2011). Data is available from the 2012 upper continental slope survey (C. Armistead, NMFS-AFSC, Kodiak). Complete data on size-sex composition of survey catch is available only from the 2008, 2010, and 2012 surveys (C. Armistead, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, and 2012 surveys are presented in a separate May 2013 report to the Crab Plan Team (Gaeuman 2013a).

4. Recruitment:

From data collected during the 2002, 2004, 2008, and 2010 NMFS-AFSC eastern Bering Sea upper continental slope surveys biomass of golden king crab (all sizes and both sexes) are estimated to have increased in the surveyed area of eastern Bering Sea. Biomass in the Pribilof Canyon area was estimated to have increased from 1.504-million lb (682 t) in 2002 to 3.560-million lb (1,615 t) in 2010; biomass for the entire slope survey area was estimated to have increased from 2.227-million lb (1,010 t) in 2002 to 5.071-million lb (2,300 t) in 2010. Using data from the 2012 NMFS-AFSC eastern Bering Sea upper continental slope survey, Gaeuman (2013a) estimated total biomass for 2012 in the Pribilof Canyon area to be 1.567-million lb (711 t) and 4.244-million lb (1,925 t) for the entire survey area.

5. Management performance:

No overfished determination (i.e., MSST) has been made for this stock, but see Gaeuman (2013a) for estimates of mature male biomass for this stock from the 2008, 2010, and 2012 eastern Bering Sea upper continental slope trawl survey data. Overfishing did not occur during 2012 (the golden king crab season in the Pribilof District is based on a calendar year); the estimated total catch did not exceed the OFL of 0.20-million lb (91 t). Total catch did not exceed the total-catch ABC of 0.18-million lb (82 t) that was established for the 2012 season. Retained catch and total-catch mortality in 2012 are confidential under the requirements of Sec. 16.05.815 (SOA statute). The 2013 season is currently ongoing; 2014 season hasn't started yet. The 2014 OFL and ABC are those recommended by the SSC in June 2013.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c,e]	ABC[c,e]
2010	N/A	N/A	0.150	Conf.[f]	Conf.[f]	0.17 R	N/A
2011	N/A	N/A	0.150	Conf.[f]	Conf.[f]	0.18 T	N/A
2012	N/A	N/A	0.150	Conf.[f]	Conf.[f]	0.20 T	0.18 T
2013	N/A	N/A	0.150			0.20 T	0.18 T
2014	N/A	N/A				0.20 T	0.18 T

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 is 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. Noted as "R" for retained-catch-only OFL and "T" for total-catch OFL and ABC.
f. 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,e]	ABC[c,e]
2010	N/A	N/A	68	Conf. [f]	Conf. [f]	77 R	N/A
2011	N/A	N/A	68	Conf. [f]	Conf. [f]	82 T	N/A
2012	N/A	N/A	68	Conf. [f]	Conf. [f]	91 T	82 T
2013	N/A	N/A	68			91 T	82 T
2014	N/A	N/A				91 T	82 T

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 is 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. Noted as "R" for retained-catch-only OFL and "T" for total-catch OFL and ABC.
f. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

6. **Basis for the OFL and ABC:** The values for 2014 are those recommended by the SSC in June 2013.

Year[a]	Tier	Years to define Average catch (OFL)	Natural Mortality[e]	Buffer
2010	5	1993–1998[b]	0.18 yr^{-1}	N/A
2011	5	1993–1998[c]	0.18 yr^{-1}	N/A
2012	5	1993–1998[d]	0.18 yr^{-1}	10%
2013	5	1993–1998[d]	0.18 yr^{-1}	10%
2014	5	1993–1998[d]	0.18 yr^{-1}	10%

a. Season is based on a calendar year.
b. OFL was for retained catch and was determined by the average of the retained catch for these years.
c. OFL was for total catch and was determined by the average of the annual retained catch for these years times a factor of 1.05 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.
d. 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.
e. 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 (Alternative 1) Tier 5 OFL for 2014 was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 0.51-million lb (CV = 0.25). See section G.1.

8. **Basis for the ABC recommendation:** A 10% buffer on the OFL, the default; i.e., ABC = (1-0.1)·OFL.

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 continues 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 28 March 2013, one vessel had registered for the 2013 season, but had not yet begun fishing (W. Donaldson, ADF&G, 28 March 2013 *pers. comm*).

2. **Changes to the input data:**
   - Retained catch and bycatch data has been updated with the results for the 2012 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).
   - Bycatch estimates from other non-directed crab fisheries have been updated with data from 2012.
   - Bycatch estimates have been updated using the data collected from groundfish fisheries during 2011/12.

3. **Changes to the assessment methodology:** None. 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 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 and 2013 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 lb 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.,

$$OFL_{TOT(1),2013} = (1+R_{2001\text{–}2010}) * RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,1992/93\text{–}1998/99},$$

     where,

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

- The recommended Tier 5 OFL for 2014 is a total-catch OFL of 0.20-million lb, estimated by the calculations given for the 2013 OFL.

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 2012: None.
   - SSC, June 2012: None.
   - CPT, September 2012 (via Sept 2012 SAFE):
     - *"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."*
       - Response: Not applicable for Tier 5 assessment.
     - *"The CPT recommends the listing of sigmas instead of absolute weights as being more informative for factors such as L_{50} and β. Also, the team recommends specifying weights for the penalties on L_{50} and from the standard errors from the analysis on which the estimates for these parameters were based."*
       - Response: Not applicable for Tier 5 assessment.
     - *"The team requests all authors to consult 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."*
       - Response: Guidelines for SAFE preparation as supplied in 26 July 2012 email from the CPT chair were consulted and followed.
     - *"The team requests that to the extent possible assessments include a listing of the tables and figures in the assessment (i.e., Table of Tables, Table of Figures)."*
       - Response: Listing of tables and figures is included.
   - SSC, October 2012: *None*.

2. **Responses to the most recent two sets of SSC and CPT comments specific to the assessment:**
   - CPT, May 2012: *None.*
   - SSC, June 2012:
     - *"Following the advice of the assessment author and CPT, the SSC recommends a total catch OFL of 0.09 kt (91 t) and ABC (using the 10% buffer for tier-5 stocks) of 0.08 kt (82 t) for 2012/13, based on Alternative 1 in the assessment, which uses bycatch data for the directed fishery through 2010 only."*

        - Response: The SSC meant "2013" and not "2012/13." This assessment presents the same Alternative 1 OFL with a 10% buffer for determination of the ABC for consideration of a Tier 5 OFL and ABC for 2014.
    - *"For the next assessment cycle, the SSC requests that the slope survey data be used to bring forward Tier 4 calculations because estimates from the slope survey appear reasonable, cover the known depth range of golden king crab, and size composition data are available to calculate biomass of legal-sized males."*
        - Response: A report on the issues for consideration of a Tier 4 assessment using the slope survey data was prepared by Gaeuman (2013a) for consideration at the May 2013 CPT meeting.
    - *"The SSC also notes that the assessment uses calendar year for all calculations except for PSC in the groundfish fisheries, which are estimated based on "crab fishing years." For consistency, the SSC suggests that calendar year be used throughout."*
        - Response: The author has noted this situation in the past assessments, but has not directly asked NMFS-AFSC for the bycatch data to be summarized by calendar year. The author suggests that the CPT explore the feasibility of NMFS-AFSC providing the data on bycatch of this stock for the most recent calendar year by 1 April. If that is feasible, the CPT should request that, beginning in 2014, NMFS-AFSC provide the data from all previous calendar years to the assessment author by 1 April. If the author receives the bycatch data summary for the previous calendar year by 1 April, all fishery data will be summarized by calendar year in the 2014 and subsequent assessment reports.
- CPT, September 2012 (via Sept 2012 SAFE): *"The team concurs with the author's recommendation for an OFL based on Alternative 1 for 2013 of 0.2 million lb and the maximum permissible ABC of 0.18 million lb. The ABC was derived by applying the Tier 5 control rule a 10% buffer of the OFL, ABC = 0.9*OFL."*
    - Response: This assessment presents the same Alternative 1 OFL with a 10% buffer for determination of the ABC for consideration of a Tier 5 OFL and ABC for 2014.
- SSC, October 2012: *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, 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. (2012, page 85) 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.

Results of the 2002, 2004, 2008, 2010, and 2012 NMFS-AFSC eastern Bering Sea continental slope trawl surveys presented by Haaga et al. (2009), Hoff and Britt (2003, 2005, 2009, 2011), and Gaeuman (2013a) 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. Highest densities, biomass, and abundance of golden king crab in the Bering Sea occur in the Pribilof Canyon, as does most of the commercial catch of golden king crab (Fitch et al. 2012; Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006).

> Results of the 2002, 2004, 2008, and 2010 NMFS-AFSC eastern Bering Sea continental slope trawl surveys presented by Haaga et al. (2009) and Hoff and Britt (2003, 2005, 2009, and 2011) show that majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges. Commercial fishing for golden king crab in the Bering Sea typically occurs at depths of 100–300 fathoms (183–549 m; Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Gaeuman 2011, 2013b); average depth of pots fished in the Pribilof golden king crab fishery during the 2002 fishery (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 m).

3. **Evidence of stock structure:** Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff and Britt 2003, 2005, 2009, 2011, Gaeuman 2013a). 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 reported by (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).

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. (2012, pages 89–91).

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, whereas the GHL for 2000–2013 has been 0.150-million lb.

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 2012 directed fishery (both of which are confidential), estimated bycatch in non-directed crab fisheries during 2012, and estimated bycatch in groundfish fisheries during the 2010/11 crab fishery year have been added. Results for golden king crab from the 2012 eastern Bering Sea upper continental slope survey were presented in Gaeuman (2013a).

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, 1984–2012 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 1993–2012 time series of weight of retained catch, estimated bycatch and estimated weight of fishery mortality of Pribilof golden king crab during commercial crab fisheries are given in Table 2. 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 2010−2012. Following Siddeek et al. (2011), 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 (2012a, 2012b), 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 data were grouped into crab fishery years, rather than into calendar years. The 1991/92–2011/12 time series of estimated annual weight of bycatch and total fishery mortality of golden king crab in reporting areas 513, 517, and 521 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 (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: Survey biomass estimates are not used in a Tier 5 assessment. However, see Gaeuman (2013a) for biomass estimates of golden king crab using data from 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 (2013a) for size data composition by sex of golden king crab during Bering Sea upper continental slope trawl surveys.

f. ***Other data time series:*** None.

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>

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. ***<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 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. ***<u>Natural mortality rate</u>:*** 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. <u>Information on any data sources that were available, but were excluded from the assessment:</u>

- Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea (EBS) 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). Data from the EBS upper continental slope surveys are not presented in this tier 5 assessment but were presented for consideration by Gaeuman (2013a).
- 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>: 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>: *Subsections a–i are not applicable to a Tier 5 stock.*
Accordingly, it has been recommended by NPFMC (2007) and by the CPT and SSC in 2008−2012 that the Pribilof Islands golden king crab stock be managed as a Tier 5 stock. 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 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 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 OFL for this stock. This assessment recommends – and only considers – use of a total-catch Tier 5 OFL for 2014. See Gaeuman (2013a) for consideration of the utility of data from the biennial NMFS EBS continental slope survey for stock assessment.

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 2012. 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.

Only the status quo Alternative 1 approach is offered as the recommendation for computing the 2014 Tier 5 OFL.

3. **Model Selection and Evaluation:**

a. ***Description of alternative model configurations***

Alternative 1 (status quo and author's recommendation). 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 lb 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.,

$$OFL_{1,\ 2014} = (1+R_{2001–2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93–98/99},$$

where,

- $R_{2001–2010}$ is the average of the estimated annual ratio of 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
- $BM_{GF,92/93–98/99}$ 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 is no data on bycatch for the directed fishery during 1993–1998, there is 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 is 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 $BM_{GF,93/94\text{-}98/99}$, $OFL_{1,\,2014}$ is,

$$OFL_{1,2014} = (1+0.052)*173{,}722 + 13{,}418 + 8{,}353 = 204{,}611 \text{ lbs } (0.20\text{-million lbs}).$$

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** See the table, below.

Model	Retained- vs. Total-catch	Time Period	Resulting OFL (millions of lb)
Alt. 1 – recommended/status quo	Total-catch	1993–1998	0.20

Alternative 1 is recommended and is the status quo; it 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 to calculation of the OFL at that established for the 2012 OFL.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** See Section E, above.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:*** The time period used for determining the OFL was established by the SSC in June 2010, but choice of time period is made difficult due to sporadic, low-effort nature of the fishery. 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, 2013b), 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 4.

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 during the period used to compute the OFL is available. 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 is 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 time period used to establish OFL for the 2010–2013 seasons. The time period 1993–1998 provides the longest continuous time period through 2012 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 in the recommended Alternative 1.

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. Although the retained and total catch for 2012 cannot be presented here due to the confidentiality of data, the author can report that total catch in 2012 did not exceed the 2012 OFL. Values for the 2014 OFL and ABC are those recommended by the SSC in June 2013.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c,e]	ABC[c,e]
2010	N/A	N/A	0.150	Conf.[f]	Conf.[f]	0.17 R	N/A
2011	N/A	N/A	0.150	Conf.[f]	Conf.[f]	0.18 T	N/A
2012	N/A	N/A	0.150	Conf.[f]	Conf.[f]	0.20 T	0.18 T
2013	N/A	N/A	0.150			0.20 T	0.18 T
2014	N/A	N/A				0.20 T	0.18 T

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 is 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. Noted as "R" for retained-catch-only OFL and "T" for total-catch OFL and ABC.
f. 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,e]	ABC[c,e]
2010	N/A	N/A	68	Conf. [f]	Conf. [f]	77 R	N/A
2011	N/A	N/A	68	Conf. [f]	Conf. [f]	82 T	N/A
2012	N/A	N/A	68	Conf. [f]	Conf. [f]	91 T	82 T
2013	N/A	N/A	68			91 T	82 T
2014	N/A	N/A				91 T	82 T

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 is 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. Noted as "R" for retained-catch-only OFL and "T" for total-catch OFL and ABC.
f. 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).

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 $OFL_{1,2014}$). 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."

3. List of addititional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

4. Author recommended ABC. 10% buffer on OFL; i.e., ABC = (1-0.1)·(204,612 lb) = 0.18-million lb (82 t).

H. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Data from the 2002, 2004, 2008, 2010, and 2012 NMFS-AFSC eastern Bering Sea upper continental shelf trawl surveys were examined for their utility in determining overfishing levels and stock status by Gaeuman (2013a).

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Table of Tables.

data).

<u>Table of Figures</u>.

Table 1. Harvest history for the Pribilof District golden king crab fishery from the 1981/82 season through 2012 (from 2012 SAFE, updated with 2012 data provided by J. Shaisnikoff, ADF&G, Kodiak via 28 March 2013 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

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 (lb) of retained catch and estimated non-retained bycatch of Pribilof golden king crab during crab fisheries, 1993–2012, 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 2012 Crab SAFE, with update for 2012 catch and bycatch data).

		Bycatch			
Year	Retained Catch	Pribilof Islands golden king crab	Bering Sea snow crab	Bering Sea grooved Tanner crab	Total Fishery Mortality
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

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 2013b). 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).

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) in reporting areas 513, 517, and 521, 1991/92–2010/12, 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 2012 SAFE with 2011/12 data provided by R. Foy AFSC, Kodiak Laboratory via 15 August 2012 email).

Season	Fixed	Trawl	Total Bycatch	Total Bycatch Mortality
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	7,228	13,464	13,574	10,826
2010/11	1,966	1,213	3,179	1,953
2011/12	3,489	5,664	9,153	6,276
Average	4,337	4,834	8,832	5,866

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 Alternative 1 Pribilof Islands golden king crab Tier 5 2014 total-catch OFL (lb); 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 2012 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 2014 OFL (lb) for Pribilof Islands golden king crab stock calculated according to Alternatives 1 with the computed OFL for comparison.

	Alternative 1 OFL
Computed OFL (lb)	204,611
Mean of 1,000 bootstrapped OFLs (lb)	203,870
Std. dev. of 1,000 bootstrapped OFLs	51,030
CV = (std. dev.)/(Mean)	0.25

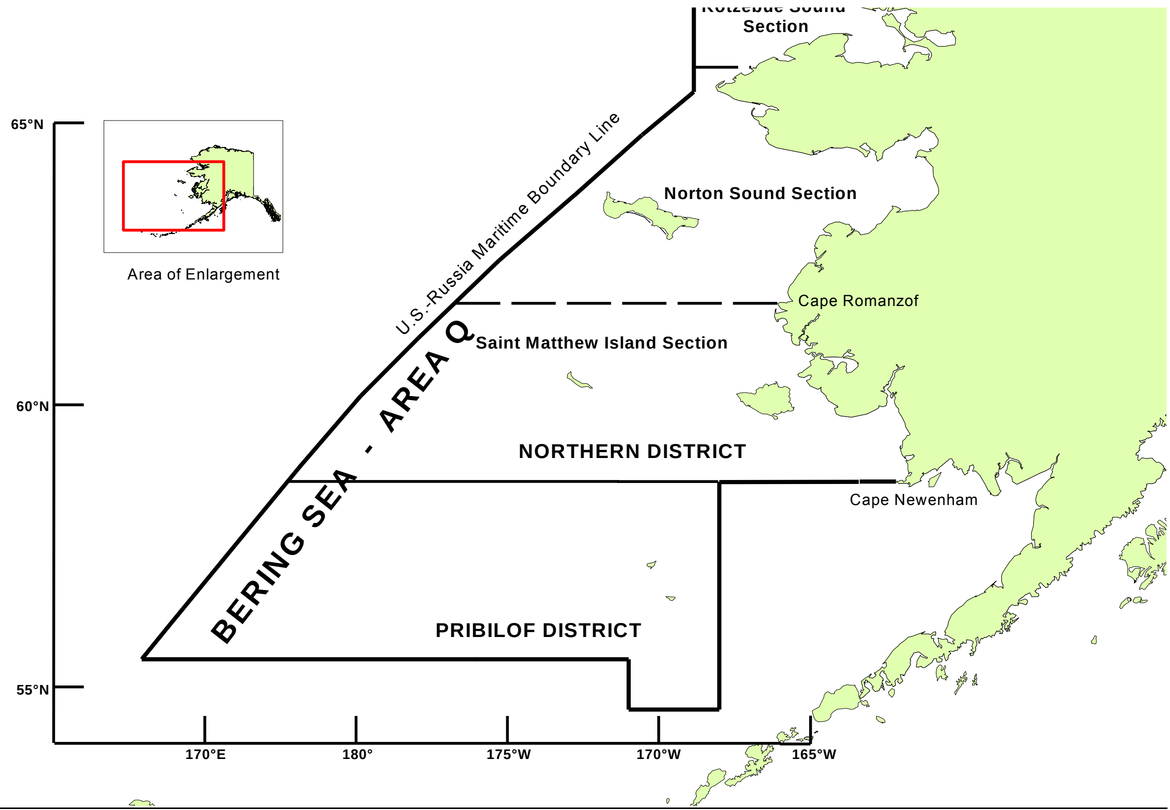

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Fitch et al. 2012).

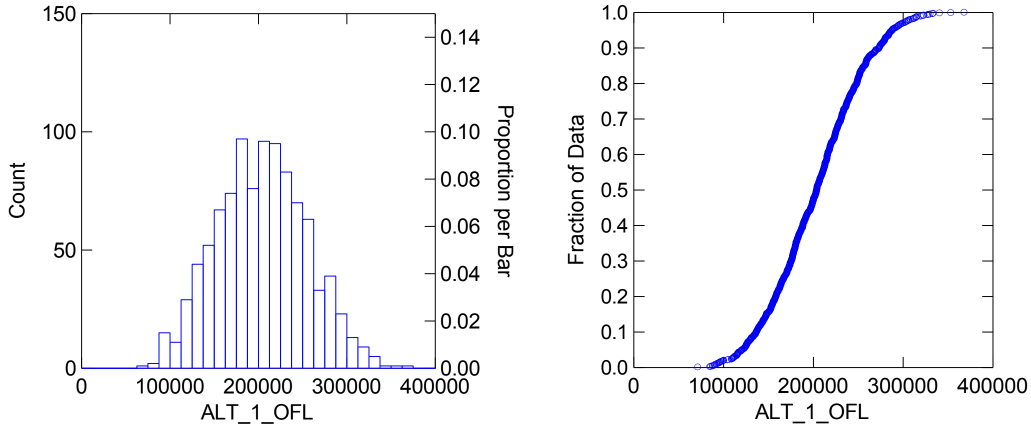

Figure 2. Bootstrapped estimates of the sampling distribution of the Alternative 1 2014 Tier 5 OFLs (total catch, lb) for the Pribilof Islands golden king crab stock; histograms in left column, quantile plots in right column.

ALTERNATIVE PRIBILOF ISLANDS GOLDEN KING CRAB STOCK ASSESSMENT STRATEGY

William Gaeuman, ADF&G Kodiak
Sept 2013

Introduction

As mandated by State of Alaska regulation **5 AAC 34.910 (b) (3)**, the Alaska Department of Fish and Game (ADF&G) currently manages the Pribilof Islands (Pribilof District; Figure 1) golden king crab (PIGKC) fishery as a calendar-year fishery under the terms of an ADF&G commissioner's permit, and the stock is currently assessed in accordance with the Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs as a Tier-5 crab stock (2012 Crab SAFE). However, both the NPFMC Crab Plan Team (CPT) and Scientific and Statistical Committee (SSC) have encouraged development of an alternative assessment strategy incorporating results from the biennial NMFS eastern Bering Sea upper continental slope trawl survey. Specifically, in June 2013 the SSC requested for Fall 2013 elaboration of a "modified Tier 5" approach that "would use the average of [slope-survey estimates of] mature male biomass for 2008, 2010, and 2012 as an estimate of current biomass, with F=M applied to estimate an OFL and a suitable buffer applied to set ABC."[1] Though this approach falls outside the crab stock assessment Tier system, it closely corresponds to the North Pacific groundfish stock assessment Tier-5 methodology specified in the Bering Sea/Aleutian Islands Groundfish FMP, a notable difference being the use of mature male biomass (MMB) as the measure of (crab) stock biomass. This document "runs the numbers" and presents OFL and ABC calculations for the calendar-year 2014 PIGKC fishery using the requested alternative approach. Catch accounting for determination of overfishing in 2014 would then occur, hypothetically, sometime in 2015 after completion of the directed fishery. Note that this exercise is not intended as a revision of the 2014 OFL already proposed in the May draft 2013 PIGKC SAFE chapter, which provides further details on the PIGKC stock and fishery, but rather as a concrete illustration of the requested alternative assessment strategy.

The EBS upper continental slope survey

Details about eastern Bering Sea upper continental slope-survey methods are provided in Hoff and Britt (2011). Standardized surveys were conducted in 2002, 2004, 2008, 2010, and 2012; although intended to be biennial, no survey was performed in 2006. The survey occurs during June and July and the surveyed region consists of a swath of trawlable[2] ocean bottom at depths of 200 to 1,200 m extending northwest from near Dutch Harbor some 600 mi along the EBS continental shelf slope (Figure 2). The survey area is divided into 6 geographic subareas running south to north in the survey area: the Bering Canyon area, the Pribilof Canyon area, the inter-canyon area between Pribilof Canyon and Zhemchug Canyon, the Zhemchug Canyon area, the inter-canyon area between Zhemchug and Pervenets Canyon, and the Pervenets and Navarin Canyons area. Each subarea is partitioned into five 200-m depth zones between 200 and 1,200 m.

[1] Report of the Scientific and Statistical Committee to the North Pacific Fishery Management Council, June 3-5, 2013, p. 10.

[2] A site was considered trawlable "when the depth changed less than 50 m over the 2-nmi transect and there were no detectable obstacles in the trawl path." (Hoff and Britt 2011, p.4)

The survey samples approximately 200 locations by stratified simple random sampling from the 30 area-by-depth-zone strata. In 2010 sampling densities within strata ranged from one haul per 112.39 km^2 to one haul per 368.96 km^2 (survey tow sampling is denser at depths less than 800 m), and the mean sampling density over the total surveyed area of 32,723 km^2 was one haul per 204.48 km^2. That sampling density compares to one haul per 400 nmi^2 (1,372 km^2) for the standard stations in the annual NMFS eastern Bering Sea shelf survey. The slope survey uses a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweep roller gear constructed of 203 mm solid rubber disks strung over 16 mm high-tensile chain. The standard tow is 30 minutes at 2.5 knots.

<u>Slope-survey golden king crab catchability</u>

So far as the author is aware, the fishing characteristics of the slope-survey mud-sweep roller gear with respect to golden king crab (GKC) and how they compare to those of the shelf-survey gear are largely unknown. There is some conjecture that GKC catchability of the slope-survey gear is less than that of the shelf-survey gear and that the slope-survey systematically misses much of the GKC habitat in the survey area because the gear is unsuited to the rocky terrain the crab prefer.[3] If so, golden king crab slope-survey catchability may effectively be significantly less than 1 over the nominal design-specified survey region, with standard probability-survey based estimators of abundance and biomass biased low.

<u>2014 PIGKC Stock MMB</u>

The assessment methodology described here depends on an estimate of stock MMB based on results from the NMFS eastern Bering Sea upper continental slope survey, with PIGKC measuring at least 107 mm carapace length classified as mature (Otto and Commiskey 1985). Because length measurements on individual crab were not recorded during the 2002 survey[4] and incompletely so in 2004 (250 of 321 captured GKC in successful tows; Hoff and Britt 2005) and no survey was conducted in 2006, only results from the years 2008, 2010, and 2012 are suitable for this purpose. For each of these years, estimates of PIGKC MMB and its standard error were calculated by the present author in accordance with the survey's stratified simple-random-sample design from data supplied by C. Armistead of the NMFS-AFSC Kodiak lab (Table 1). Necessary size-to-weight conversions were computed using the equation $w = \alpha l^{\beta}$ relating male carapace length (CL) l in millimeters to weight w in grams, with $\alpha = 0.0002988$ and $\beta = 3.13$ (NPFMC 2007). Note that error associated with the allometric modeling of crab weight was not taken into account.

To specify a meaningful estimate of PIGKC stock biomass from slope-survey results it is first necessary to choose the appropriate survey-design strata for use in the computation. Uncertainty about PIGKC stock distribution and spatial misalignment between survey strata and the boundaries of the PIGKC fishery complicate this choice. The PIGKC fishery area is determined by the boundaries of the Pribilof District of Registration Area Q (Figure 1) and, within that area, the fishery has occurred mostly in the Pribilof Canyon area to the south of the Pribilof Islands (Fitch et al. 2012). By contrast, the surveyed area extends north into the Northern District of

[3] D. Sommerton, 2 May 2013 email exchange with C. Rose, M. Dorn, and J. Hoff as summarized in May 2013 CPT report.
[4] C. Armistead, NMFS-AFSC Kodiak Laboratory, 18 Mar 2013 email.

Registration Area Q (north of 58° 39' N) and south and east into the Aleutian Islands Registration Area O (south of 54° 36' N and east of 168° W). Though a large proportion of the GKC encountered in the slope survey are caught in the Pribilof Canyon area, some GKC crab are captured sporadically throughout the surveyed region (Hoff and Britt 2003, 2005, 2009, 2011), and a Northern District GKC fishery has been successfully prosecuted historically, mostly to the west of St. Matthew Island in the area of the northern-most extent of the slope survey, with a peak harvest of 414,000 lb in 1987 (Fitch et al. 2012).

Three alternative areas for biomass estimation were discussed at the May 2013 CPT meeting: 1) the Pribilof Canyon slope-survey area; 2) the Pribilof District as established in state regulations; and 3) the total slope-survey area. For purposes of this assessment methodology the author has chosen as the most reasonable and straightforward approach to use the full set of 20 strata comprising subareas 2-5 of the survey region because those subareas are entirely or mostly contained within the Pribilof District (Figures 3-5). Subareas 2 and 3 lie completely within the Pribilof District, whereas subareas 4 and 5 straddle its boundary in the north. By contrast, subarea 6 lies outside the Pribilof District to the north, and only a small portion of subarea 1 intersects the Pribilof District in the southeast. Moreover, survey catches of mature male GKC in subarea 1 have occurred almost exclusively outside the Pribilof District. Proposed alternatives (1) and (3) exclude or include, respectively, relevant mature male GKC survey catches; proposed alternative (2) would introduce extra practical and theoretical complexities relating to, for example, random sample sizes, variance calculation, and determination of proper expansion factors that in the author’s view are unjustified given the close alignment of subareas 2-5 and the Pribilof District and of mature male GKC survey catches within the two regions. Although the author recommends the use of subareas 2-5 for PIGKC biomass estimation, results are provided for each subarea individually to facilitate estimation based on any combination of subareas (Table 1).

2014 PIGKC OFL Computation

Slope-survey estimates for the three years 2008, 2010, and 2012 based on the 20 strata within subareas 2-5 were averaged to obtain a single estimate of PIGKC MMB equal to 1.227×10^6 lb with **estimated** CV 0.16 (Table 1). In accordance with May 2013 CPT and June 2013 SSC recommendations, the 2014 PIGKC OFL was then computed by multiplying the estimate of stock MMB by the default postulated value of instantaneous natural mortality M, which is taken to be 0.18 yr^{-1} for BSAI king crab (NPFMC 2007). This approach, which parallels that used for Tier-5 North Pacific groundfish stocks, here yields an annual mature male OFL of

$$OFL_{MM} = M \times \widehat{MMB} = 0.18\ \times 1{,}227{,}180\ lb = 220{,}892\ lb. \qquad [1]$$

All subsequent calculations here used to obtain estimates of discard mortality biomass required in deriving various components of the OFL rely on NMFS groundfish observer data, ADF&G crab observer length-frequency data, NMFS crab size-to-weight models, and conventional NPFMC assumptions about Bering Sea king crab handling mortality in the different fisheries.

Given the mature male OFL, the first step in determining the retained-catch portion of the OFL is to subtract suitable estimates of mature male discard mortality biomass attributable to the relevant non-directed fisheries. Based on historical fishing in the region, these consist of the

Bering Sea groundfish, snow crab *Chionoecetes opilio*, and grooved Tanner crab *C. tanneri* fisheries (2012 Crab SAFE , Fitch et al. 2012, ADF&G Crab Observer Database). In the Bering Sea groundfish fisheries, Pengilly (draft May 2013 PIGKC SAFE chapt.) estimated a 10-year maximum annual PIGKC total discard mortality of 10,826 lb over the period 2002/03 through 2011/12, with the maximum value coming from 2009/10. (Relevant NMFS groundfish observer data for 2012/13 were not yet available at the time this document was prepared.) Pengilly used data from NMFS reporting areas 512, 513, and 521 and assumed standard GKC handling mortalities of 0.8 and 0.5, respectively, for trawl and fixed gear types. Extending Pengilly's work, this author estimated a maximum PIGKC total discard mortality of 1,061 lb in the Bering Sea snow crab fishery over the 10-year period 2003/04 through 2012/13 under assumption of a 50% handling mortality. The maximum annual estimate is from the 2008/09 fishery when observers encountered 1 sublegal and 4 legal-sized GKC in pot lift sampling. Because virtually all of the few GKC captured in the snow crab fishery have been unmeasured males, the most recently reported PIGKC fishery average retained weight was used in biomass estimation and the estimated discard mortality biomass was fully ascribed to the mature male component of the stock. Groundfish discard mortality of PIGKC was likewise here assumed to affect only mature males since the underlying NMFS groundfish observer data provide limited information about size or sex of crab bycatch.

The third non-directed fishery with historical impact on the PIGKC stock, the Bering Sea grooved Tanner crab fishery, recorded a peak harvest of close to 985,000 lb in 1995 (Fitch et al. 2012). In 1999 ADF&G established a GHL range of 50,000 to 200,000 lb for this calendar-year fishery (Fitch et al. 2012). The fishery performed erratically in subsequent years and has not been prosecuted since 2005. Estimates of the ratio of mature-male-GKC-bycatch weight to retained-grooved-Tanner-crab weight based on ADF&G observer length-frequency data from the last three years in which the fishery occurred (2003, 2004, 2005) average about 6.6%. Applying a 0.5 handling morality for king crab in non-directed fixed-gear fisheries, a plausible upper bound on expected PIGKC mature male discard morality in a potential Bering Sea grooved Tanner crab fishery is thus *200,000 lb × 0.066 × 0.5 = 6,600 lb*. This leads to

$$OFL_{MM,DF} = 220{,}892\ lb - (10{,}826 + 1{,}061 + 6{,}600)\ lb = 202{,}405\ lb \qquad [2]$$

as the mature male OFL in the directed PIGKC fishery after accounting for mature male discard mortality biomass in the three relevant non-directed fisheries: Bering Sea groundfish, snow crab, and grooved Tanner crab fisheries.

The retained catch OFL in the PIGKC directed fishery is then calculated as

$$OFL_{RET} = \frac{202{,}405\ lb}{1+(0.2)(0.129)} = 197{,}314\ lb, \qquad [3]$$

where 0.129 is the average estimated ratio of mature-male-discard weight to retained-catch weight in the last three prosecuted PIGKC fisheries (2010, 2011, 2012), and 0.2 is the assumed mortality rate of discarded PGKC in the directed fishery. Note that this value is about 31% more than the 150,000-lb guideline harvest level (GHL) in place under ADF&G management of the PIGKC fishery since 2001 (Fitch et al. 2012).

The PIGKC total catch OFL may now be obtained by adjoining to the retained catch OFL appropriate estimates of expected total discard mortality. In the directed fishery estimates of the ratio of total-discard weight to retained-catch weight average 0.212 over the last three years (2010, 2011, 2012), again based on ADF&G observer length-frequency data. Assuming 20% handling mortality, an estimate of OFL total discard mortality in the directed fishery is then *0.212 × 197,314 lb × 0.2 = 8,366 lb*. In the grooved Tanner crab fishery, average estimated total-GKC-discard weight to retained-grooved-Tanner-catch weight is 0.079 for the last three years of the fishery (2003, 2004, 2005), so an estimate of expected total PIGKC discard mortality in a fully prosecuted fishery is *0.079 × 200,000 lb × 0.5 = 7,900 lb*, assuming 50% handling mortality of PIGKC. As all PIGKC discard mortality in the Bering Sea groundfish and snow crab fisheries was assumed comprised of mature males, the PIGKC total catch OFL is thus

$$OFL_{TC} = 197{,}314\ lb + 8{,}366\ lb + 10{,}826\ lb + 1{,}061\ lb + 7{,}900\ lb = 225{,}467\ lb. \qquad [4]$$

Table 2 lists the primary estimates and parameters used in obtaining this result; Table 3 lists the components in the total catch OFL and summarizes the key steps [1] – [4] in its derivation.

2014 PIGKC ABC Calculation

Consistent with Tier-5 crab and Tier-5 groundfish assessment methodology, the author recommends use of a 10% buffer to specify the (hypothetical) PIGKC 2014 ABC according to

$$ABC = (1 - 0.1)OFL. \qquad [5]$$

When applied to the total-catch OFL this yields an author-recommended ABC of *202,921 lb* (Table 3).

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Table 1: Author computed EBS slope-survey estimates (10^3 lb) of golden king crab mature male biomass by survey subarea. The author recommended estimate of PIGKC MMB is 1.227×10^6 lb based on survey subareas 2 through 5. Survey data supplied by C. Armistead, NMFS-AFSC Kodiak lab.

	Subarea (south to north)						
Year	1	2	3	4	5	6	2-5
2008	103	1,080	140	186	049	066	1,456
2010	370	970	173	101	022	056	1,266
2012	723	565	322	058	014	108	960
Avg Percent	23%	51%	12%	7%	2%	4%	96%
3-year Avg	399	872	212	115	028	77	1,227
CV(Avg)	0.28	0.19	0.47	0.33	0.63	0.27	0.16

Table 2: Key quantities used in 2014 PIGKC OFL computation.

Estimate/Parameter	Value	Basis
PIGKC MM CL	107 mm	Otto and Commiskey 1985
PIGKC stock MMB	1,227,180 lb	average estimate from 2008, 2010, 2012 NMFS EBS slope-survey results for subareas 2-5
Bering Sea king crab natural mortality	0.18 yr^{-1}	NPFMC 2007
directed fishery king crab handling mortality	0.2	draft May 2013 PIGKC SAFE chapt.
king crab handling mortality in other fixed-gear fisheries	0.5	draft May 2013 PIGKC SAFE chapt.
king crab handling mortality in trawl fisheries	0.8	draft May 2013 PIGKC SAFE chapt.
male GKC size-to-weight power model	CL millimeters -> grams α=0.000298, β=3.135	NPFMC 2007
female GKC size-to-weight power model	CL millimeters -> grams α=0.001424, β=2.781	NPFMC 2007
male grooved Tanner crab size-to-weight power model	CW millimeters -> grams α=0.0001186, β=3.1892	NPFMC 2007
PIGKC MM and total discard mortality in Bering Sea groundfish fisheries	10,826 lb	10-year maximum estimate from draft 2013 PIGKC SAFE chapter
PIGKC MM and total discard mortality in Bering Sea snow crab fishery	1,061 lb	10-year maximum estimate from draft 2013 PIGKC SAFE chapter, and author estimate for 2012/13 fishery
PIGK-MM-discard/retained-catch in Bering Sea grooved Tanner fishery	0.066	2003-2005 ADF&G observer length-frequency data; NMFS size-to-weight models
PIGKC-MM-discard/retained-catch in PIGKC directed fishery	0.129	2010-2012 ADF&G observer length-frequency data; NMFS size-to-weight models
PIGKC-total-discard/retained-catch in PIGKC directed fishery	0.212	2010-2012 ADF&G observer length-frequency data; NMFS size-to-weight equations
PIGKC-total-discard/retained-catch in Bering Sea grooved Tanner fishery	0.079	2003-2005 ADF&G observer length-frequency data; NMFS size-to-weight models

Table 3: Steps in 2014 PIGKC OFL/ABC computation.

BRP	Description	Computation	Value[a]
mature male OFL	natural mortality x estimated MMB	(0.18)(1,227,180)	221
mature male OFL in directed fishery	MM OFL less MM bycatch discard mortality in GF, snow crab, and GT crab fisheries	220,892 – 10,826 – 1,061 – 6,600	202
retained catch OFL in directed fishery	retained proportion of MM fishing mortality in directed fishery	202,405 / [1+(0.2)(0.129)]	197[b]
total catch OFL	retained catch OFL plus **total** discard mortality in directed, GF, snow crab, and GT crab fisheries	197,314 + 8,366 + 10,826 + 1,061 + 7,900	225[c]
ABC (total catch)	total catch OFL with 10% buffer	(1 – 0.1)(225,467)	203[d]

[a] 10^3 lb to three significant digits.
[b] 126 if only subarea 2 (Pribilof Canyon) is used for stock biomass estimation.
[c] 154 if only subarea 2 (Pribilof Canyon) is used for stock biomass estimation.
[d] 138 if only subarea 2 (Pribilof Canyon) is used for stock biomass estimation.

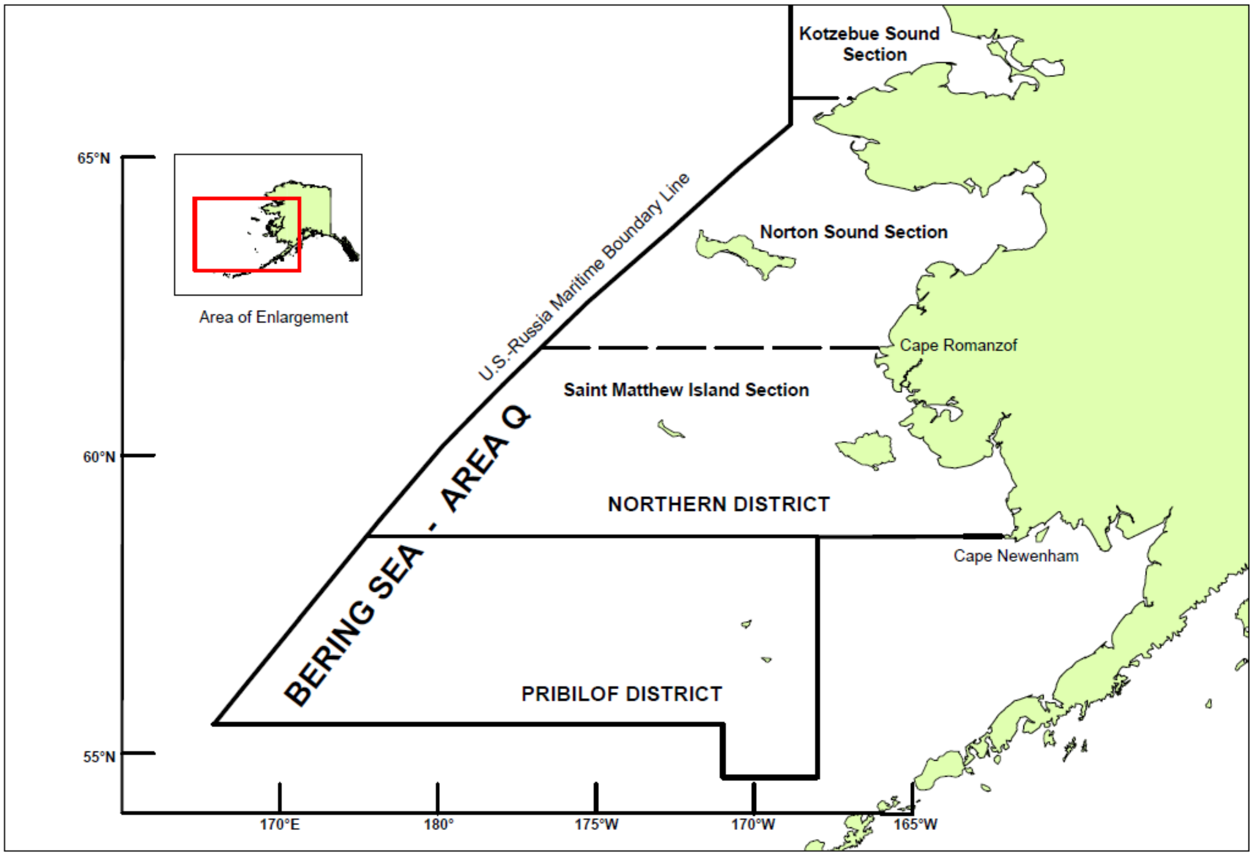

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Fitch et al. 2012).

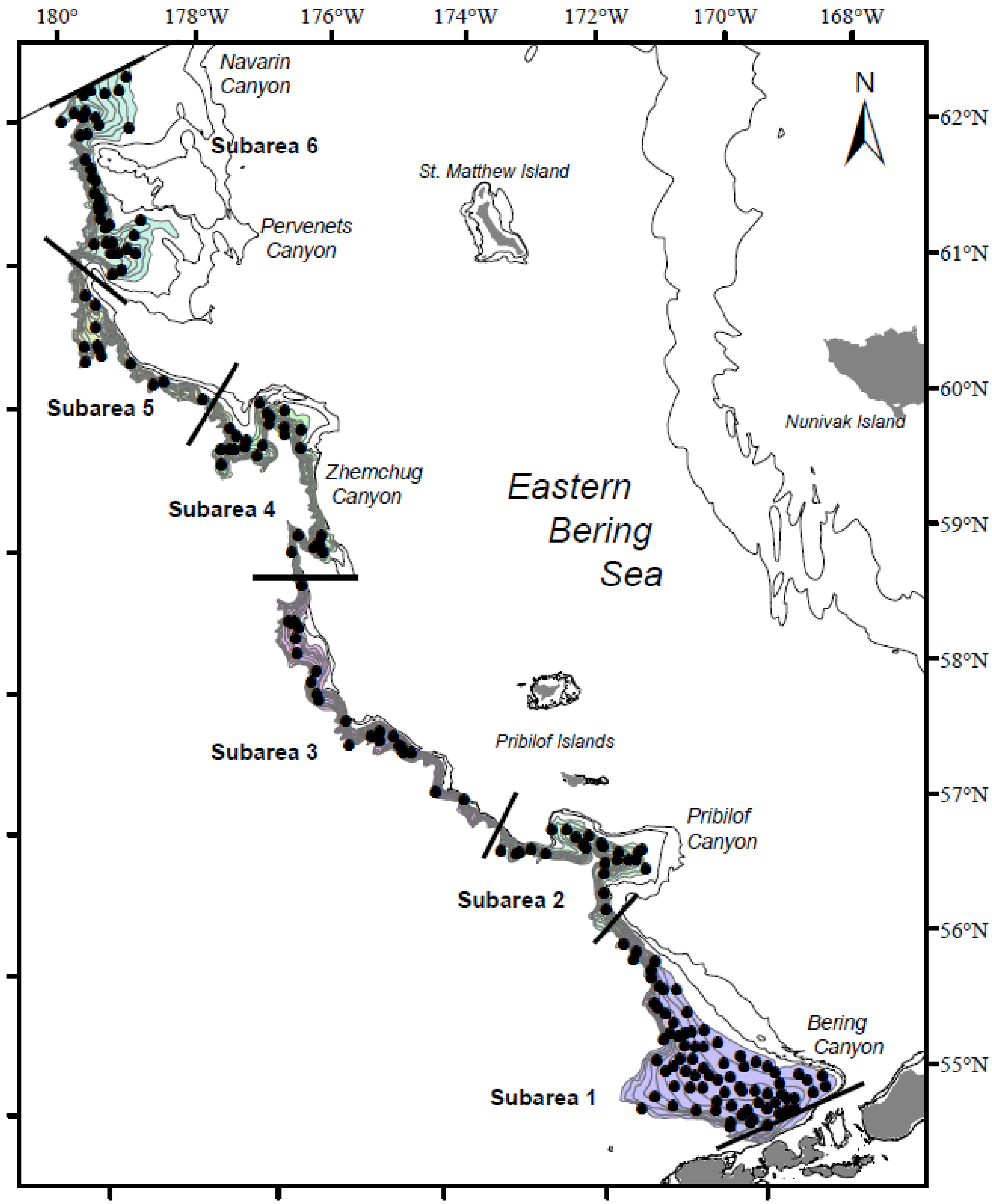

Figure 2. Map of standard survey area for NMFS eastern Bering Sea upper continental slope trawl survey with survey subareas identified; black dots show locations of successful tows during the 2010 survey (from Figure 1 *in* Hoff and Britt 2011).

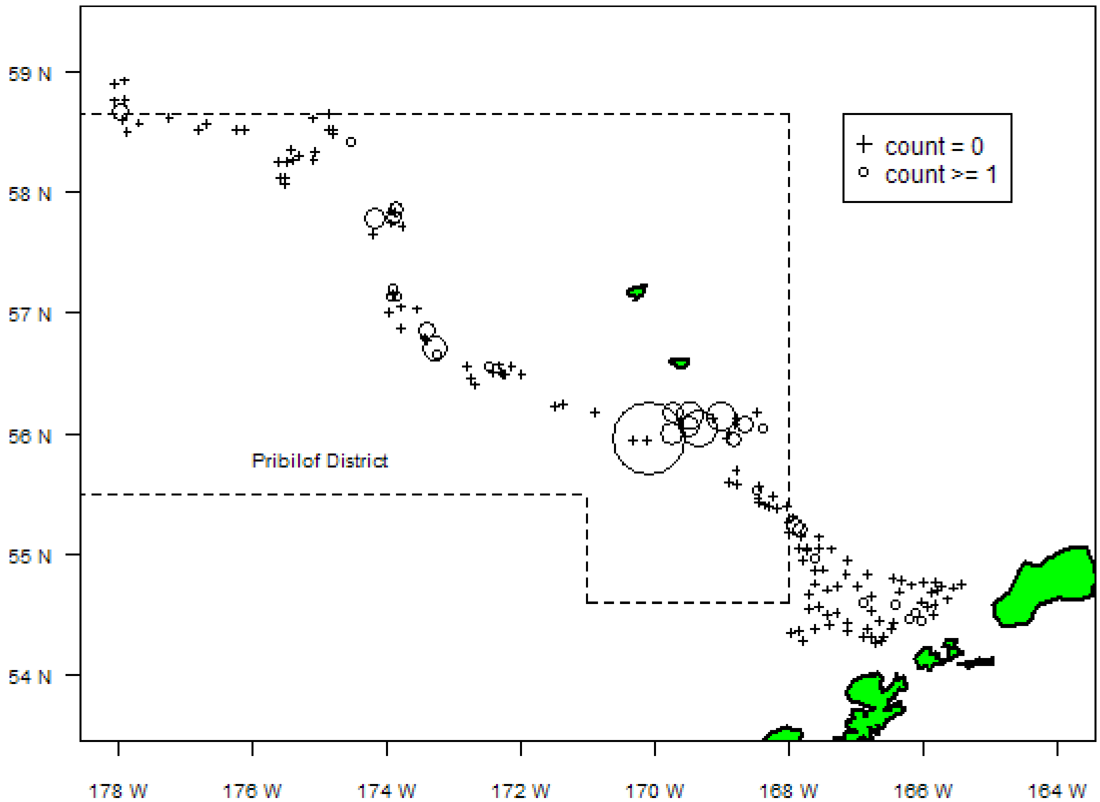

Figure 3. GKC mature male catch distribution in subareas 1-5 of the 2008 EBS continental slope survey. Nonzero catches are proportional to symbol areas. The maximum catch was 48 GKC.

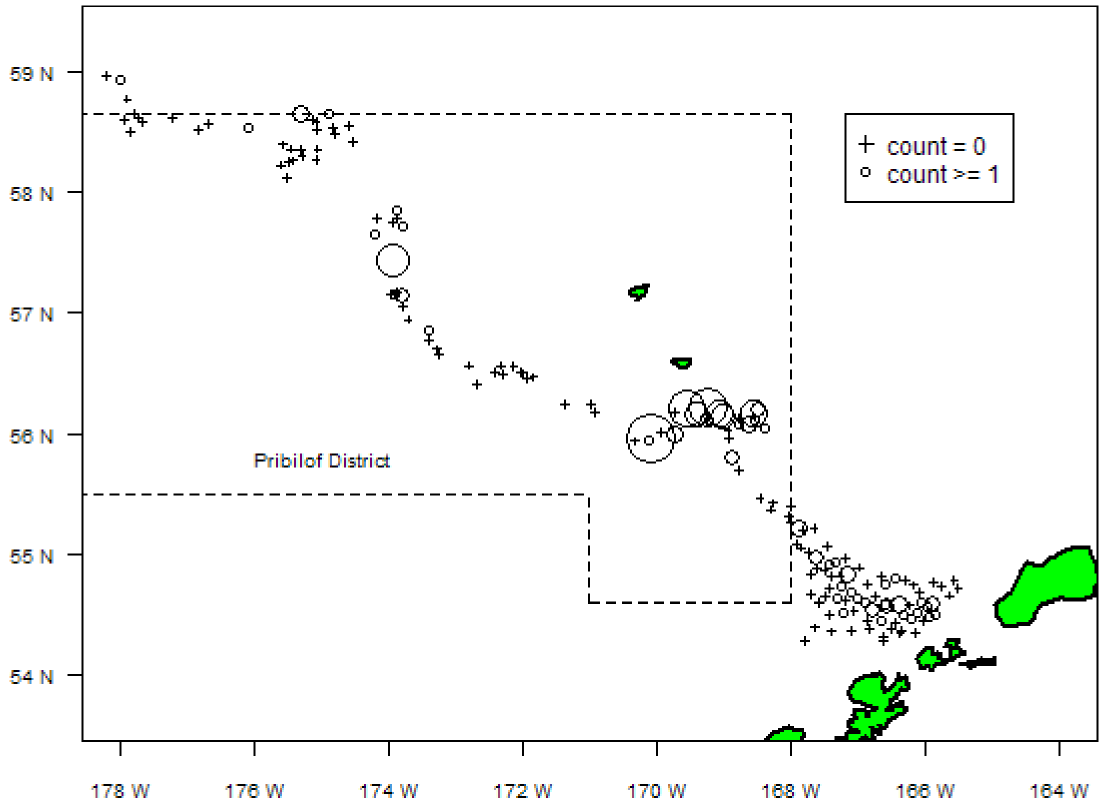

Figure 4. GKC mature male catch distribution in subareas 1-5 of the 2010 EBS continental slope survey. Nonzero catches are proportional to symbol areas. The maximum catch was 21 GKC.

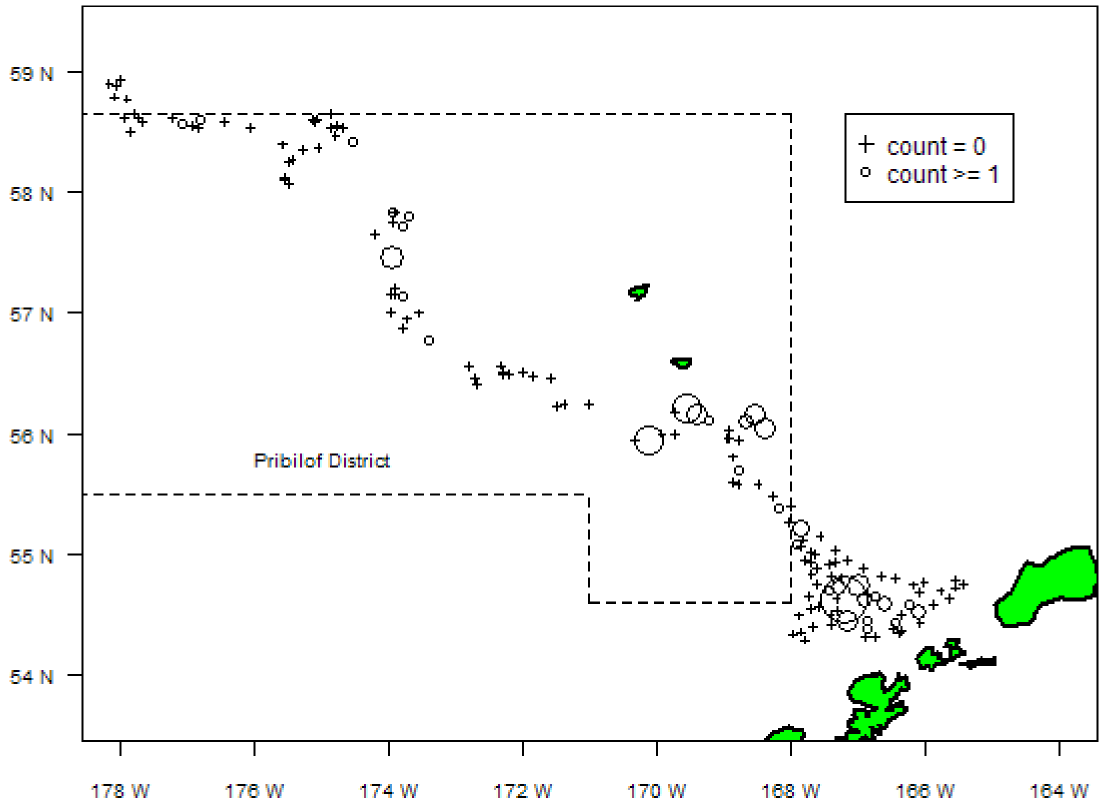

Figure 5. GKC mature male catch distribution in subareas 1-5 of the 2012 EBS continental slope survey. Nonzero catches are proportional to symbol areas. The maximum catch was 20 GKC.

Adak Red King Crab – 2013 Tier 5 Assessment

2013 Crab SAFE Report Chapter (Sept 2013)

Douglas Pengilly, ADF&G, Kodiak

Executive Summary

1. **Stock:**

Adak/Western Aleutian Islands (the Aleutian Islands, west of 171° W longitude) red king crab *Paralithodes camtschaticus*

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). During the 1995/96 through 2011/12 seasons, the fishery was opened only occasionally. 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-milliion lb (217 t) in 2003/04. The fishery has been closed season since the end of the 2003/04 season through the 2012/13 season. 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 1995/96–2012/13 seasons averaged 0.002-million lb (1 t) in crab fisheries and 0.019-million lb (9 t) in groundfish fisheries. Estimated weight of annual total fishery mortality during 1995/96–2012/13 averaged 0.091-million lb (41 t); the average annual retained catch during that period was 0.070-million lb (32 t). Estimated total fishery mortality for 2012/13 was <0.001-million lb (<1 t).

3. **Stock biomass:**

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. **Recruitment:**

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 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 2012/13; the estimated total catch did not exceed the OFL of 0.12-million lb (56 t). The total catch did not exceed the ABC established for 2012/13 (0.7-million lb, or 34 t). Values given in the tables below for the 2012/13 OFL and ABC are those recommended by the SSC in June 2012 (note that the text in the June 2013 Draft SSC Report gives that value as "54 t" rather than as "56 t"; the author guesses that the difference is due to the SSC making their lb-to-t conversion on rounded value).

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a,c]	ABC[a,c]
2009/10	N/A	N/A	Closed	0	0.012	0.50 R	N/A
2010/11	N/A	N/A	Closed	0	0.004	0.12 T	N/A
2011/12	N/A	N/A	Closed	0	0.002	0.12 T	0.03 T
2012/13	N/A	N/A	Closed	0	<0.001	0.12 T	0.07 T
2013/14	N/A	N/A				0.12 T	0.07 T

a. Millions of lb.
b. Includes bycatch mortality of discarded bycatch.
c. Noted as "R" for retained-catch OFL and "T" for total-catch OFL.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a,c]	ABC[a,c]
2009/10	N/A	N/A	Closed	0	5	227 R	N/A
2010/11	N/A	N/A	Closed	0	2	56 T	N/A
2011/12	N/A	N/A	Closed	0	1	56 T	12 T
2012/13	N/A	N/A	Closed	0	<1	56 T	34 T
2013/14	N/A	N/A				56 T	34 T

a. t.
b. Includes bycatch mortality of discarded bycatch.
c. Noted as "R" for retained-catch OFL and "T" for total-catch OFL.

6. **<u>Basis for the OFL and ABC</u>:** See table, below; values for 2013/14 are the recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality	Buffer
2009/10	5	1985/86-2007/08[a]	0.18[b]	N/A
2010/11	5	1995/96-2007/08[c]	0.18[b]	N/A
2011/12	5	1995/96-2007/08[c]	0.18[b]	75%
2012/13	5	1995/96-2007/08[c]	0.18[b]	40%
2013/14	5	1995/96-2007/08[c]	0.18[b]	40%

a. OFL was for retained catch and was determined by the average of the retained catch for these years.
b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.
c. OFL was for total catch and was determined by the average of the total catch for these years

7. **<u>PDF of the OFL:</u>** 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.

8. **<u>Basis for the ABC recommendation:</u>** The recommended ABC is the status quo; i.e., the ABC as was recommended by the CPT and SSC for 2012/13. The 2012/13 ABC was an increase from the ABC established for 2011/12 (0.027 million lb, 12 t) and was made to accommodate an Industry request for a small test fishery during 2012/13 (Industry chose not to conduct a test fishery in 2012/13); 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).
.

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.

2. **Changes to the input data:**
   - Data on non-retained bycatch and estimates of bycatch mortality in crab and groundfish fisheries during 2012/13 have been added to judge if overfishing occurred in 2012/13, but are not put into the calculation of the recommended 2013/14 total-catch OFL.

3. **Changes to the assessment methodology:** None.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:** None.

B. Responses to SSC and CPT Comments

1. **Responses to the most recent two sets of SSC and CPT comments on assessments in general:**
   - CPT, May 2012: *None*.
   - SSC, June 2012: *None*.
   - CPT, September 2012 (via Sept 2012 SAFE):
     - *"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."*
       - Response: Not applicable for Tier 5 assessment.
     - *"The CPT recommends the listing of sigmas instead of absolute weights as being more informative for factors such as L_{50} and β. Also, the team recommends specifying weights for the penalties on L_{50} and from the standard errors from the analysis on which the estimates for these parameters were based."*
       - Response: Not applicable for Tier 5 assessment.
     - *"The team requests all authors to consult 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."*
       - Response: Guidelines for SAFE preparation as supplied in 26 July 2012 email from the CPT chair were consulted and followed.
     - *"The team requests that to the extent possible assessments include a listing of the tables and figures in the assessment (i.e., Table of Tables, Table of Figures)."*
       - Response: A table of tables and a table of figures are included.
   - SSC, October 2012: *None*.

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

- CPT, May 2012: *None*.
- SSC, June 2012: *None*.
- CPT, September 2012 (via Sept 2012 SAFE): *None*.
- SSC, October 2012: *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 Adak 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 2012) 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 "Adak Area". The Aleutian Islands king crab Registration Area O is described by Baechler (2012, 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 Adak 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.

3. <u>Evidence of stock structure</u>:

Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crab originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51° 51' N latitude, 176° 39' W longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)."

We know of no analyses of genetic relationships among red king crab from different locations within the Adak Area. However, given the expansiveness of the Adak Area 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 Adak red king crab stock would be expected. 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. <u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crab fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987, McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen

1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crab:

> "Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season."

McMullen and Yoshihara (1971) reported that from 804 female red king crab (79–109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crab in the western Aleutians appeared to begin mating at 83 millimeters carapace length and virtually all females appeared to be mature at 102 millimeters length." Blau (1990) estimated size at maturity for Adak Area 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 Adak Area male red king crab. However, because the estimated SM50 for Adak Area 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 Adak stock as a proxy.

Few data are available on the molting and mating period for red king crab specifically in the Adak Area. 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 Adak 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 age (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 smaller, younger mature females and the primiparous females tend to ovulate, and that males that do molt early in the mating period participate in the later mating period, when the larger, older females tend to be mated.

5. Brief summary of management history:

A complete summary of the management history through 2010/11 is provided in Baechler (2012, pages 7–12). The domestic fishery for red king crab in the Adak Area began with the 1960/61 season. Retained catch of red king crab in the Aleutians west of 172º 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 2). 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 Adak 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 3). The Adak 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 2004/05–2012/13 seasons. Management history since the 1996/97 closure is summarized in the table below. 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 regulations and management actions pertaining to the Adak red king crab fishery since the 1996/97 season is provided below.

Season	Change in management measure
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 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 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 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 o 30 vessels o 479,113 lb o 10 legals/pot lift
2004/05–2012/13	• Fishery closed o 2006 and 2009 ADF&G pot surveys in Petrel Bank area

Only males of a minimum legal size may be retained by the commercial red king crab fishery in the Adak Area. 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 Adak Area 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)**).

By State of Alaska regulation (**5 AAC 34.610 (a)**) the Adak red king crab commercial fishing season is from October 15 to February 15, unless closed by emergency order.

The Adak Area 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 6805). The Adak Area red king crab fishery in the area east of 179° W longitude was not included in the Crab Rationalization program (Baechler 2012). In March 2013, the Alaska Board of Fisheries reduced the vessel size limit in state waters from 171° W longitude to 179° W longitude from a maximum of 90 feet to no more than 60 feet in overall length and established a 10 pot limit for vessels fishing red king crab in state waters from 171° W longitude to 179° W longitude; there are no vessel size limits or pot limits in the federal waters from 171° W longitude to 179° W longitude. There is a pot limit of 250 pots per vessel for vessels fishing for red king crab in the Petrel Bank area (**5 AAC 34.625 (d)**).

The Adak 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 Adak Area since the 1998/99 season:

- The 1998/99 season for red king crab in the Adak Area 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 2012). The Adak Area 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 2012) 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 Adak 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 Adak Area 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 2012). The remaining area in the Adak Area was closed to commercial red king crab fishing during the 2003/04 season.

6. <u>Brief description of the annual ADF&G harvest strategy</u>:

There is no harvest strategy in state regulation for Adak 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 2012). 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.

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 2012/13 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 2012/13 Aleutian Islands golden king crab fishery and the 2012/13 groundfish fisheries in reporting areas 541, 542, and 543 (Figure 4).

2. **Data presented as time series:**

a. Total catch and b. Information on bycatch and discards:

   - The 1960/61–2012/13 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 1960/61–20012/13 time series of retained catch (lb of landed crab) is presented graphically in Figure 2.
   - The 1995/96–2012/13 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 Adak Area during commercial crab fisheries is given in Table 2. 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 Adak 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 a vessel is fishing in the red king crab fishery west of 179° W longitude. All 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 2004/05–2012/13 seasons were counted and recorded for capture location and biological data.
   - The 1993/94–2012/13 time series of estimated weight of bycatch and estimated bycatch mortality of red king crab in the Adak Area (reporting areas 541, 542, and 543; i.e., Aleutian Islands west of 170° W longitude; Figure 4) during federal groundfish fisheries by gear type (fixed or trawl) is provided in Table 3. 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 1993/94–2012/13 groundfish fisheries by reporting area (541, 542, or 543) is provided in Table 4. Bycatch estimates for 1992/93 are available, but appear to be suspect because they are extremely low.

- The 1995/96–2012/13 time series of estimated weight of total fishery mortality of red king crab in the Adak Area, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries, is provided in Table 5. 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 5 by applying that assumed bycatch mortality rate to the estimates of non-retained catch given in Tables 2. The estimates of bycatch mortality in groundfish fisheries given in Table 5 are from Table 3.

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented here.

d. Survey biomass estimates: Not available; there is no program for regular performance of standardized surveys sampling from the entirety of the stock range.

e. Survey catch at length: Not used in a Tier 5 assessment; none are presented here.

f. Other data time series:

Data on CPUE (number of retained crab per pot lift) during the red king crab in the Adak Area are available for the 1972/73–2012/13 seasons (see Table 1).

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 was estimated for Adak Area 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 Adak Area red king tagged and released in new-shell condition would molt within 8–14 months after release (see Tables 6 and 7 in Pengilly 2009).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.000361 and B = 3.16 for males and A = 0.022863 and B = 2.23382 for females; note that although the estimated parameters, A and B, are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to lb by dividing by 453.6.

c. ***Natural mortality rate:*** Natural mortality rate has not been estimated specifically for red king crab in the Adak Area. NPFMC (2007) assumed a natural mortality rate of M =0.18 for king crab species.

4. **Information on any data sources that were available, but were excluded from the assessment:**
   - Distribution of effort and catch during the 2006 ADF&G Petrel Bank red king crab pot survey (Gish 2007) and the 2009 ADF&G Petrel Bank red king crab pot survey (Gish 2010).
   - Sex-size distribution of catch and distribution of effort and catch during the January/February 2001 and November 2001 ADF&G-Industry red king crab survey of the Petrel Bank area (Bowers et al. 2002) and ADF&G-Industry red king crab pot survey conducted as a commissioner's permit fishery in November 2002 in the Adak Island and Atka-Amlia Islands areas (Granath 2003).
   - Observer data on size distribution and geographic distribution of bycatch of red king crab in the Adak red king crab fishery and the Adak/Aleutian Islands golden king crab fishery, 1988/89–2009/10 (ADF&G observer database).
   - Summary of data collected by ADF&G Adak 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 Adak Area 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. **History of modeling approaches for this stock:** This is a Tier 5 stock; there is no assessment model and no history of assessment modelling approaches for this stock.

2. **Model Description:** There is no regular survey of this stock. No assessment model for the Adak Area red king crab stock exists and none is in development. The SSC in June 2010 recommended that: the Adak Area 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 2013/14 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 2013/14 is

$$OFL_{2013/14} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

   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

- $BM_{GF, 95/96-07/08}$ 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 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 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. **<u>Specification of the Tier level and stock status level for computing the OFL:</u>**
   - Recommended as Tier 5: total-catch OFL specified as the estimated average annual total-catch during the period 1995/96–2007/08; i.e.,

$$OFL_{2013/14} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

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 5. Using the calculated values of $RET_{95/96\text{-}07/08}$, $BM_{CF,\ 95/96\text{-}07/08}$, and $BM_{GF,95/96\text{-}07/08}$, $OFL_{2013/14}$ is,

$$OFL_{2013/14} = 96{,}932 + 3{,}000 + 23{,}935 = 123{,}867 \text{ lb (0.12-million lb; 56 t).}$$

[Note: The text in the June 2013 Draft SSC Report gives that value as "54 t" rather than as "56 t"; the author guesses that the difference is due to the SSC making their lb-to-t conversion on rounded value.]

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 2013/14 are those recommended by the SSC in June 2013.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a,c]	ABC[a,c]
2009/10	N/A	N/A	Closed	0	0.012	0.50 R	N/A
2010/11	N/A	N/A	Closed	0	0.004	0.12 T	N/A
2011/12	N/A	N/A	Closed	0	0.002	0.12 T	0.03 T
2012/13	N/A	N/A	Closed	0	<0.001	0.12 T	0.07 T
2013/14	N/A	N/A				0.12 T	0.07 T

a. Millions of lb.
b. Includes bycatch mortality of discarded bycatch.
c. Noted as “R” for retained-catch OFL and “T” for total-catch OFL.

4. **Specification of the recommended retained-catch portion of the total-catch OFL:**
   a. Equation for recommended retained portion of the total-catch OFL,
   Retained-catch portion = average retained catch during 1995/96–2007/08
   = 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 5 (the sample means of 1,000 samples drawn with replacement from the 1995/96–2007/08 estimates of total fishery mortality in Table 5). 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 5.

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 based on the ABC for 2012/13 that was recommended by the SSC in June 2012 as a value that would “be sufficient to allow for bycatch and PSC in non-directed fisheries and the proposed test fishery catch” (June 2012 SSC 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 and June 2011 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 Adak Area: 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 2012). 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 Adak Area. 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 Adak Area during periods of limited stock distribution and overall low density, as apparently currently exists.

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from 2012 SAFE, updated for 2012/13 with data in the ADF&G observer database as of 14 August 2013).

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Table 1. Aleutian Islands, Area O, red king crab commercial fishery data, 1960/61–2012/13, 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 2012 Crab SAFE, updated for the 2012/13 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**				

		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]
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**	

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Table 1. page 2 of 3.

Season	Locale	Number of Vessels[a]	Number of Landings	Number of Crabs[b]	Number of Pots Lifted	Harvest[b,c]	Average Weight[c]	Average CPUE[d]	Average 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**		

Season	Location	Number of Vessels	Number of Landings	Number of Crab[a]	Number of Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Average Weight[c]	Average CPUE[d]	Average 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

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Season	Locale	Number of Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Average 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								

Season	Location	Number of Vessels	Landings	Crab[a]	Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Average 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
2011/12–2012/13		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. Retained catch (lb) of western Aleutian Islands ("Adak") 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, 1995/96–2012/13; from 2012 SAFE, updated for 2012/13 with data in the ADF&G observer database as of 14 August 2013).

	Adak 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
Average	70,007	145	2,390	3,633	3,673	845	558	11,480

[a.] Data on non-retained bycatch of red king crab during the red king crab fishery not available (see Moore et al. 2000).

Table 3. 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), 1993/94–2012/13 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries; from 2012 SAFE, updated with values for 2012/13 provided by R. Foy, NMFS-AFSC, 15 Aug 2013 email).

	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
Average	6,477	23,080	3,239	18,437	21,675

Table 4. Estimated lb of bycatch (not discounted by an assumed bycatch mortality) during federal groundfish fisheries (all gear types combined) by NMFS Reporting Area, 1993/94–2011/12; from 2012 SAFE, updated with values for 2012/13 provided by R. Foy, NMFS-AFSC, 15 Aug 2013 email.

	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
Average	12,508	11,426	5,622	29,557

Table 5. Estimated annual weight (thousands of lb) of total fishery mortality to Western Aleutian Islands ("Adak") red king crab, 1995/96–2012/13, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries; from 2012 SAFE, updated for 2012/13 with values in Table 2 (assumes bycatch mortality rate of 0.2 for crab fisheries) and Table 3.

		Bycatch Mortality by Fishery Type		
Season	Retained Catch	Crab	Groundfish	Total Estimated 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
Mean, 1995/96–2007/08	96,932	3,000	23,935	123,867
CV of mean	52%	37%	23%	43%
Mean, 1995/96–2012/13	70,007	2,254	19,023	91,283
CV of mean	53%	37%	23%	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.

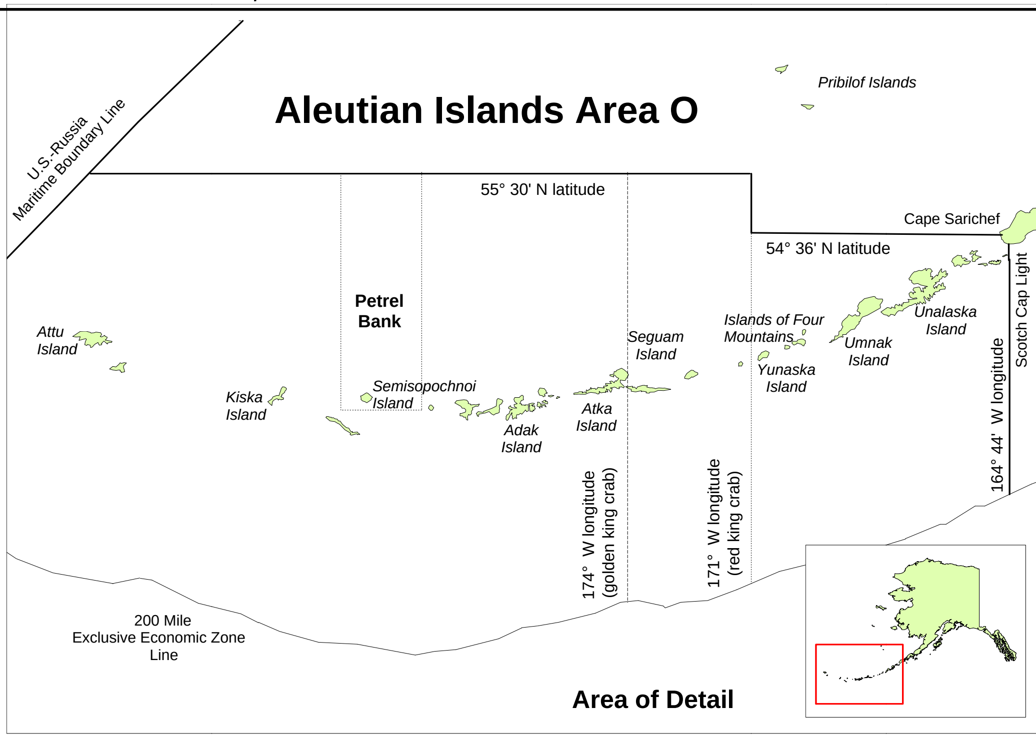


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler 2012).

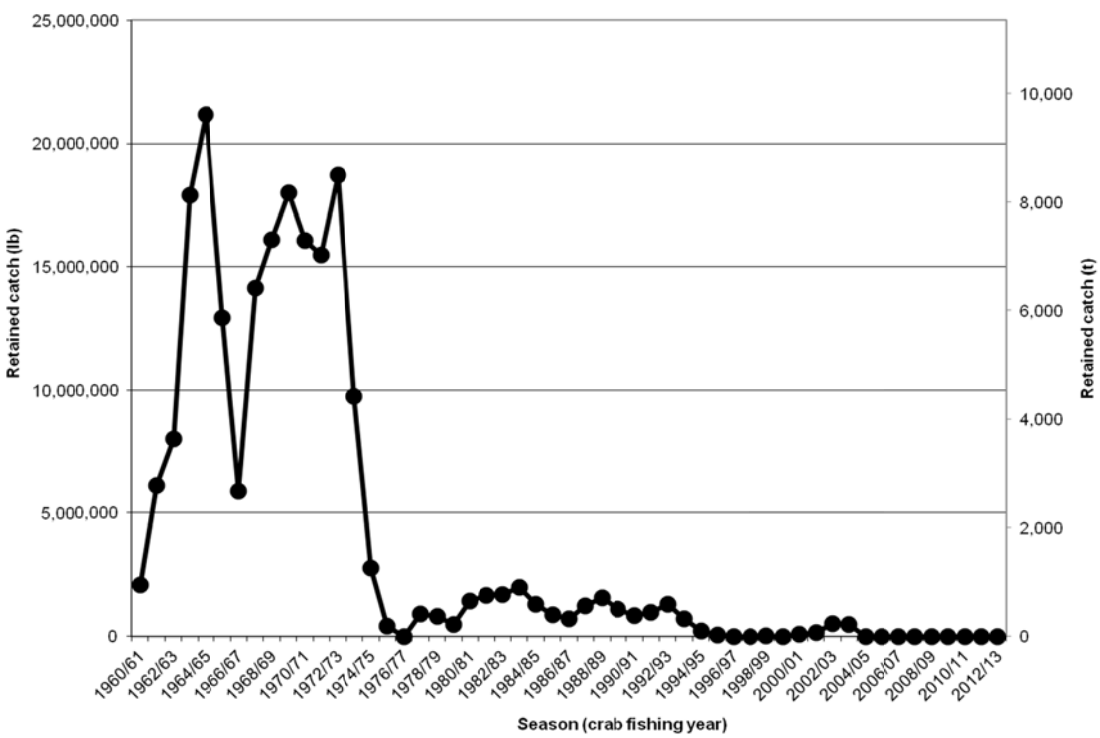


Figure 2. Retained catch (lb on left axis, t on right axis) in the Adak red king crab fishery, 1960/61–2012/12 (catch is for the area west of 172º W longitude during 1960/61–1983/84 and for the area west of 171º W longitude during 1984/85–2012/13; see Table 1).

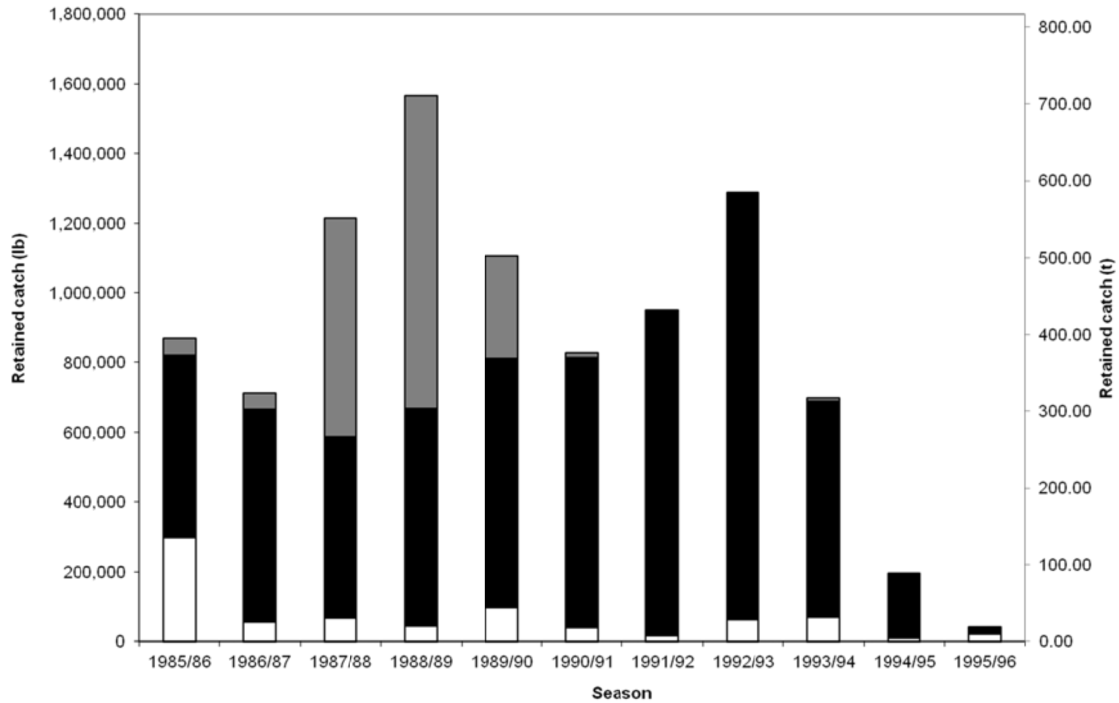


Figure 3. Retained catch (lb on left axis, t on right axis) in the Adak red king crab fishery for the 1985/86–1995/96 seasons, partitioned into three longitudinal zones: 171º W longitude to 179º W longitude (white bars); 179º W longitude to 179º E longitude (black bars); and 179º E longitude to 171º E longitude (gray bars; data from ADF&G fish ticket summary provided by F. Bowers, ADF&G, March 2008).

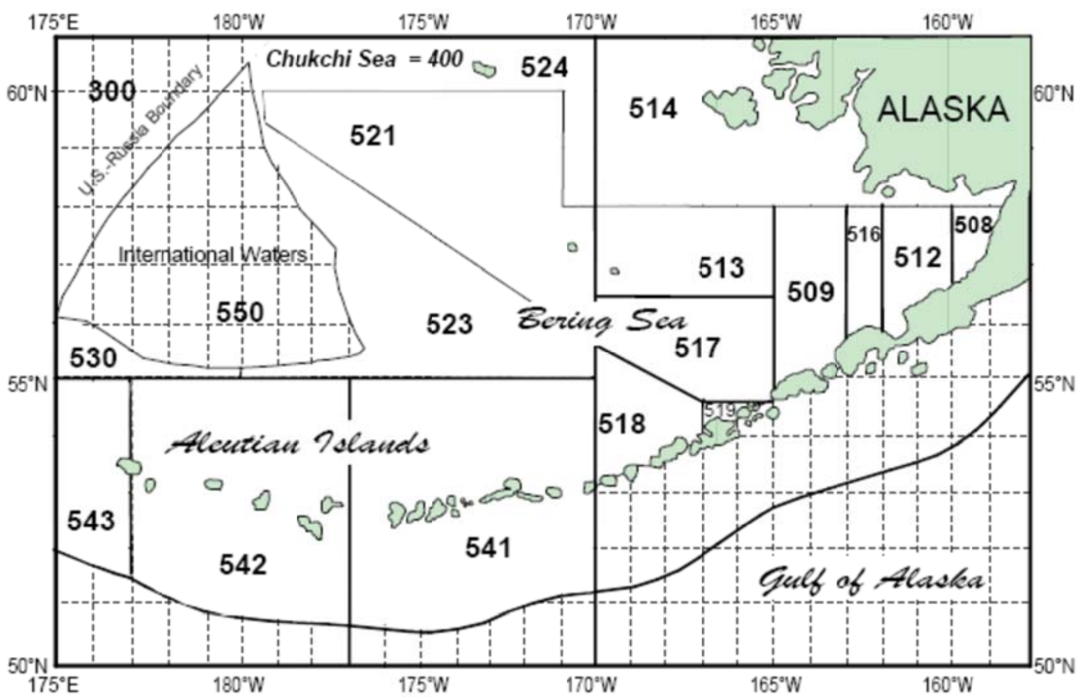


Figure 4. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to obtain data on bycatch of Adak red king crab during groundfish fisheries (from http://www.fakr.noaa.gov/rr/figures/fig1.pdf).

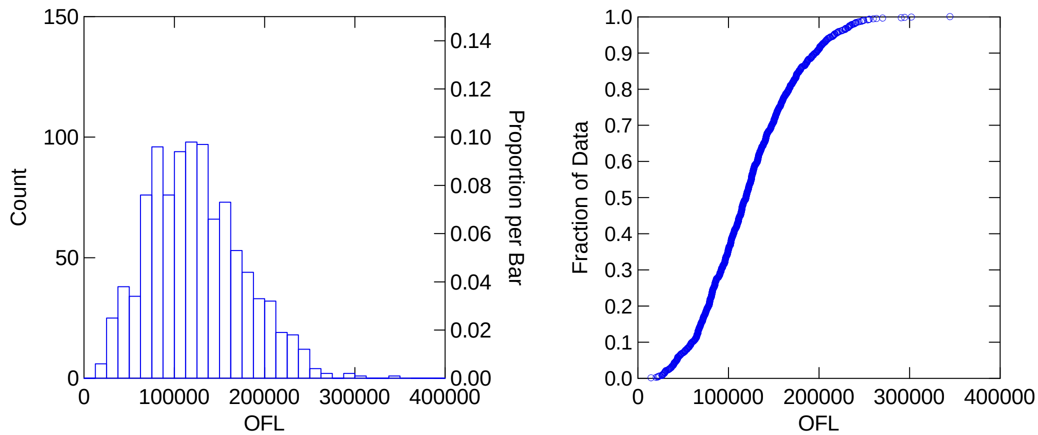


Figure 5. Bootstrapped estimate of the sampling distribution of the recommended 2012/2013 Tier 5 OFL (total catch, lb) for the Adak red king crab stock; histogram in left column, quantile plot in right column (from 2012 SAFE).

Economic Status Report Summary: BSAI Crab Fisheries, 2013

The BSAI crab fisheries managed under the North Pacific Fishery Management Council's Fishery Management Plan (FMP) for Bering Sea/ Aleutian Islands crab are currently prosecuted by an active fleet of 110 catcher vessels and three catcher processors, and landed and processed at 21 processing facilities throughout the region. Of the 10 crab stocks managed under the FMP, seven[1] are currently open to targeted fishing. Pribilof Islands red- and blue king, and Western Aleutian red king crab stocks are currently designated overfished, as detailed in the assessments for these stocks, and the Eastern Bering Sea Tanner (EBT) crab fishery remained closed to targeted fishing for the 2012/13 season under the State of Alaska's management strategy. This report provides a brief summary of key indicators of economic status and performance of BSAI crab fisheries for 2013.[2]

Fishery production and economic value – 2008-2012

Harvest- and processing sector production statistics by crab fishery, including ex-vessel and 1st wholesale output, estimated revenue, and average prices are shown in Table 1 for calendar years 2008-2012 and summarized in Figure 1. Across all fisheries managed under the BSAI Crab FMP, the total volume of ex-vessel landings during 2012 was 104 million pounds, a 48 percent increase from the previous year. Processing sector finished production volume during 2012 was 67 million pounds aggregated over all FMP crab species and product forms, a 39 percent increase over the previous year. After reaching the highest levels observed since 2004, average prices reported in both sectors declined toward 2010 levels for most BSAI crab produced in 2012, with the result of total gross revenues over all fisheries remaining nearly constant from 2011 levels despite substantial increases in physical output: $253[3] million ex-vessel for the year, decreased from $258 million for 2011 (-2%), and $392 million first wholesale revenues (+8% from the previous year).

As of 2012, allowable catch quantities in all BSAI crab fisheries currently open to targeted fishing are fully exploited (> 98% of total allocation landed), and recent inter-annual variation in commercial landings largely reflects stock assessment results and catch limits rather than changes in fishing capacity or exploitation rate. Notably,

[1] Individual statistics where indicated in Tables 1 and 2 are suppressed in this report due to confidentiality restrictions and the small number of reporting entities; this includes most values for the Pribilof Island golden king (PIG) crab fishery and processing sector results for the Norton Sound red king (NSR) crab fishery; values that are indicated as suppressed in Tables 1 and 2 are also excluded from values reported in aggregate over multiple crab fisheries. Except where noted, the suppressed values are sufficiently small that they have minimal effect on the accuracy of aggregate information at the level of precision reported here.

[2] The Economic Status Report for BSAI Crab provides a comprehensive presentation of statistical information and analysis regarding economic dimensions of the fishery evaluation; update of the report for 2013 is in preparation and will include information on operating and quota lease costs for 2012 provided by revised EDR data collection.

[3] All prices are inflation-adjusted to 2012 dollars.

however, 2012 represented the first season that landings in the Saint Matthew blue king (SMB) crab fishery approached 100% of the combined target allocation, from less than 50% in 2009 when the fishery re-opened. The increase in aggregate production during 2012 was driven largely by the 88.9 million pounds of Bering Sea snow crab (BSS) landed, a 63 percent increase in volume over the previous year. Norton Sound red king crab (NSR) landings increased to 500 thousand pounds landed (+28%), and landings of 5.8 million pounds in Aleutian Islands golden king (AIG) and 7.8 million pounds in Bristol Bay red king (BBR) crab fisheries changed only slightly from the previous year, with the latter remaining at approximately half the level of the previous 5-year average.

Similar to ex-vessel production, the proportional increase in processing sector output aggregated over all active crab fisheries was driven by the 56.9 million pounds of BSS fishery production, increased by 50 percent in volume over the previous year. Finished volume in the BBR fishery of 5.2 million pounds (2.4 mt) was unchanged from 2011, where both years were near historical lows for the period since 1998. AIG and SMB fisheries produced 3.8 million and 1.13 million pounds of finished volume, respectively, the latter decreasing by 15 percent from 2011 output.

Ex-vessel and wholesale Alaska crab prices in 2012 reversed the upward trend of 2009-2011 in four of the five fisheries. BBR fishery average ex-vessel price dropped by 30 percent for 2012, to $7.27 per pound, reversing the 34 percent price increase from 2010-2011; the average 2012 BBR wholesale price reported by processors declined by 20 percent, to $15.09 per pound for 2012. AIG prices in both sectors similarly offset 2011 increases, falling to $3.51 ex-vessel (-24%) and $8.37 first wholesale (-13%) per-pound averages. The SMB average first wholesale price of $12.45 fell by 12%, and the $3.77 average ex-vessel price fell 28% from 2011. The exception to the general result of falling prices for 2012, NSR crab sales continued a gradual four-year trend of increasing average ex-vessel price, reaching $5.48 per pound, 5.6% over the 2011 average[4].

The estimated gross revenue value of production in the 2012 BSS fishery increased from 2011 levels to $167 million ex-vessel (+21% over 2011), and $268 million first wholesale (+28%), compared to much larger proportional increases in physical output of 68 percent and 50 percent, respectively. With physical output of both sectors in BBR and AIG fisheries largely held constant, estimated gross revenues for BBR fell to $56.8 million ex-vessel (-30%) and $78.7 million first wholesale (-36%), and AIG estimated revenues fell to $20.5 million ex-vessel (-26%) and $31.6 million wholesale (-10%). Declines in both physical output and prices in the SMB fishery combined to reduce ex-vessel gross revenue to an estimated $5.97 million (-39%), and estimated first wholesale revenue fell to $14.1 million (-25%). The NSR fishery exhibited the opposite, with increases in both price and output combining to increase gross ex-vessel revenue an to an estimated $2.72 million (+30%).   The 20-35% proportional inter-annual variation in gross revenue from 2011-2012 for these fisheries is approximately consistent with the average degree of variation over the last 15 years; longer time series for these and other

[4] Processing sector results for the Norton Sound red king crab fishery are not available.

measures of crab fishery performance are available in the full BSAI Crab Economic Status Report, currently being updated for release in November, 2013.

Price and revenue forecasts for 2013

As noted above, calendar year 2012 data is the most current information available from primary economic data sources for Alaska fisheries. To provide more current information for this report, preliminary estimates of 2013 production and price variables are produced using forecasts of wholesale price for AIG, BBR, and BSS fisheries, extending the econometric model framework developed previously for the Council's analysis for Amendment 38 (NMFS, 2011). The forecast analysis uses vector autoregression (VAR) time-series methods to model historical data series (1991-2012) of wholesale prices for Alaska red- and golden king crab and snow crab from Commercial Operators Annual Report (COAR), and U.S. import- and export- volume and price series for king and snow crab from the U.S. Merchandise Trade Statistics to estimate median and 90% confidence intervals for Alaska crab wholesale market prices. To improve the precision of near-term forecasts, i.e., estimation of Alaska crab wholesale prices established during early 2013 for which COAR data are not yet available, the analysis leverages import/export trade data published up to a year in advance of Alaska-specific data sources.

A detailed description of the analytical methodology and model development is provided in Dalton (2008), and documentation of model selection and estimation results for price forecasts used in this report are provided in Appendix A. Price forecast intervals for 2013 AIG, BBR, and BSS fisheries are shown in Table 2, with estimates of ex-vessel and finished wholesale volume and revenue to-date for 2012/13 season AIG and BSS landings after January 1 of this year. Ex-vessel price estimates were derived using the wholesale price forecasts and conversion factors based on the average ratio of ex-vessel price to first-wholesale price observed over the 2007-2011 period. In-season commercial landings data for AIG and BSS fisheries to-date, combined with price forecasts and average product recovery rates observed over 2007-2011 were used to estimate production volume and revenue to-date in the ex-vessel and processing sectors for these fisheries. All data used in these estimations reflect final ex-vessel settlement prices, such that the price and revenue estimates shown in Table 2 represent final settlement values.

Wholesale price for golden king crab produced and sold in the AIG fishery during 2013 is estimated at $10.24, with a 90% confidence forecast interval of $9.17-$11.34, substantially higher than the average price of $8.37 observed for 2012. Wholesale price for snow crab produced and sold in the BSS fishery during 2013 is estimated at $5.48, with a 90% confidence interval of $5.18-$5.78. The Bristol Bay red king crab price for 2013 is forecast with a median of $18.38 ($15.90-$20.96 confidence interval). Forecasts for both red- and golden king crab indicate an increase of approximately 22% above 2012 averages, and snow crab price is forecast to increase 16% over the 2011 average. All three forecast medians approximate the 2011 average wholesale prices for the respective fisheries, which established high points for the post-rationalization period.

With 1.36 million pounds of golden king crab landed in the western and eastern AIG fishery during January-May, 2013 year-to-date finished production is estimated at 0.86 million pounds, and gross wholesale revenue is estimated at $8.86 million; this does not represent the full calendar year total for 2013 as these figures will increase when updated to include 2013/14 season catch landed during August-December of 2013. No additional landings in the BSS fishery are expected, and estimated values shown in Table 2 for this fishery represent preliminary totals for the full 2013 calendar year. With 65 million pounds landed and sold during 2013 (>98% of the 2012/13 66.35 million pound catch limit), final ex-vessel revenue for the fishery is estimated at $154 million (± $8 million), based on an estimated ex-vessel price of $2.36 (± 0.13) per pound. At an estimated 42.7 million pounds finished volume, forecasted BSS wholesale revenue for 2013 is $234.22 (±$12.82) million. For the BBR fishery, Table 2 displays price information only; no landings have occurred to date as the fishery does not open until October.

Employment and Income

A summary of selected indicators from the most recent employment data available for Crab Rationalization (CR) program fisheries is provided in Table 3. Crab EDR data for calendar year 2012 are reported where available[5], but results are preliminary pending completion of data validation and additional analyses. Due to a change in EDR crew and processing labor employment and pay reporting for catcher-processors, 2012 EDR data for AIG, BBR, and BSS fisheries are suppressed pending determination of appropriate aggregation protocols to maintain confidentiality for these data; full 2012 results are presented for the SMB fishery only.

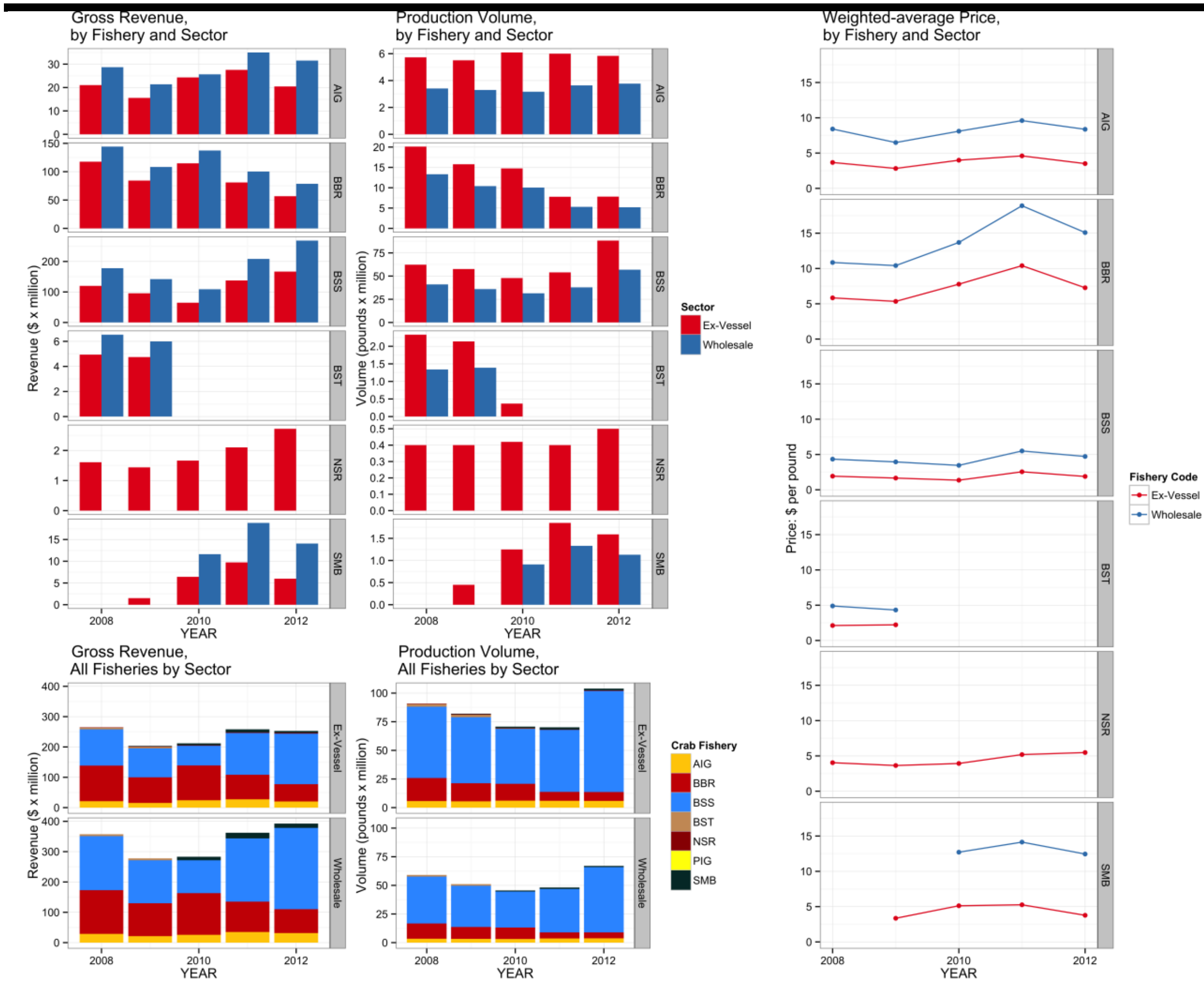
The number of vessels operating in CR fisheries in 2012 increased from 77 to 83, and from 102 to 113 across all BSAI crab fisheries. Based on the average (mean) number of crew onboard (as reported in eLandings catch accounting records for crab vessels), there were an estimated 1037 crew positions across all 83 vessels in CR fisheries in 2012. Over the last 5 years, both the aggregate number of vessels and total crew positions have varied contemporaneously with the total size of crab catch allocations, declining in 2010 and 2011 and increasing in 2012 as BSS allocations were substantially increased. However, neither the number of vessels operating in individual fisheries or the number of crew positions has varied proportionally with catch, with vessel and crew participation rates varying to a lesser degree than catch. For example, changes in crew positions have varied from year-to-year by -14% to +19% in the BSS fishery, compared to much larger annual variations in catch.

Crew compensation and processing sector employment and pay for 2008-2011 are shown in Table 3; these results will be updated for 2012 upon completion of validation and analysis of crab EDR data submitted by crab industry participants in July of this year, and will be released with the full Economic Status Report for BSAI Crab for 2013. Revenue-share payments to crab vessel crew members as a group totaled approximately $34.7

million in 2011, with $16.1 million of that total going to vessel captains. For both groups, incomes rose in 2011, reflecting the overall increase in ex-vessel revenue described above. However, crew and captain revenue-share earnings increased by 31 and 27 percent over 2010 levels, somewhat greater proportionally than the corresponding increase in aggregate ex-vessel revenue. 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 some limited consolidation that occurred 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).

Crab processing labor input associated with the IFQ and CDQ fisheries is estimated at nearly 681 thousand hours of processing labor expended on crab production in 2011, generating slightly greater than $8 million in labor income. Most processing facilities that receive crab landings do not exclusively process crab, however, and it may be difficult to attribute crab processing labor to specific employment effects. The high degree of variance in the measure of crab processing labor hours likely reflects variation in processors' ability to track labor input by species for reporting compliance. The trend in processing labor input as reported in the BSAI Crab Economic Data Report (EDR) indicates general consistency with catch and production volume fluctuations. However, total processing labor hours declined across all CR fisheries, and by approximately 14% from 2010 overall, despite aggregate production volume remaining approximately constant from 2010 to 2011.

Figure 1: BSAI Crab Ex-vessel and First Wholesale Production, 2008-2012



(a)Revenue, (b)Volume, and (c) Weighted Average Price, 2008-2012; 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. See Table 1 footnotes for details.

Table 1: BSAI crab harvest and processing sector output - production volume, gross revenue, and average price, 2008-2012

Fishery: Year	Vessels	CFEC permits	Harvest Sector: Ex-Vessel Statistics [a] Landed volume 1000 *mt*	Landed volume million lbs	Gross revenue $million	Average price $/lb	Plants	Buyers	Processing Sector: First Wholesale Statistics [b] Finished volume 1000 *mt*	Finished volume million lbs	Gross revenue $million	Average price $/lb
Total - All BSAI crab fisheries [d]												
2008	116	261	41.2	90.82	$264.93		21	23	26.8	59.07	$357.65	
2009	112	242	37.18	81.96	$203.35		22	26	23.16	51.06	$277.69	
2010	102	232	32.08	70.72	$211.95		19	24	20.65	45.53	$283.30	
2011	102	235	31.79	70.09	$258.04		18	27	21.85	48.17	$362.50	
2012	113	284	47.15	103.95	$252.76		20	26	30.39	67.01	$392.61	
Aleutian Islands golden king - Eastern and Western (AIG)												
2008	5	12	2.6	5.73	$21.03	$3.67	7	7	1.55	3.41	$28.71	$8.41
2009	5	13	2.5	5.51	$15.56	$2.82	6	9	1.5	3.3	$21.39	$6.49
2010	5	13	2.76	6.09	$24.32	$3.99	5	9	1.44	3.17	$25.67	$8.10
2011	5	13	2.72	6	$27.58	$4.60	7	14	1.65	3.64	$35.00	$9.60
2012	6	14	2.65	5.84	$20.49	$3.51	8	14	1.71	3.77	$31.56	$8.37
Bristol Bay red king (BBR)												
2008	79	97	9.13	20.13	$117.54	$5.84	15	17	6.04	13.31	$144.35	$10.85
2009	70	86	7.16	15.78	$84.22	$5.34	13	16	4.72	10.4	$108.27	$10.41
2010	65	79	6.68	14.73	$114.68	$7.78	14	17	4.55	10.03	$137.29	$13.69
2011	62	71	3.53	7.79	$80.95	$10.40	14	18	2.41	5.3	$100.18	$18.89
2012	64	74	3.54	7.8	$56.77	$7.27	12	17	2.36	5.21	$78.65	$15.09
Eastern Bering Sea snow (BSS)												
2008	78	108	28.23	62.23	$119.81	$1.93	16	17	18.61	41.02	$178.06	$4.34
2009	77	103	26.17	57.69	$95.87	$1.66	15	17	16.31	35.97	$142.04	$3.95
2010	68	87	21.7	47.84	$64.88	$1.36	11	13	14.25	31.41	$108.71	$3.46
2011	68	88	24.52	54.05	$137.68	$2.55	14	16	17.18	37.89	$208.48	$5.50
2012	72	109	40.02	88.23	$166.81	$1.89	13	16	25.81	56.9	$268.32	$4.72

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 2012-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 (2008-2011 for CR program fisheries) and secondarily from CFEC gross earnings estimates (2012 for CR fisheries; all years for non-CR fisheries).

Table 1 (continued)

Fishery: Year	Vessels	CFEC permits	Harvest Sector: Ex-Vessel Statistics [a] Landed volume 1000 *mt*	Landed volume million lbs	Gross revenue $million	Average price $/lb	Processing Sector: First Wholesale Statistics [b] Plants	Buyers[c]	Finished volume 1000 *mt*	Finished volume million lbs	Gross revenue $million	Average price $/lb
Eastern Bering Sea Tanner (BST)[d]												
2008	30	38	1.06	2.33	$4.94	$2.12	11	11	0.61	1.34	$6.53	$4.89
2009	18	24	0.97	2.14	$4.75	$2.22	10	11	0.63	1.39	$5.99	$4.32
2010	4	5	0.17	0.37	--	--	7	7	--	--	--	--
2011-2012						CLOSED						
Norton Sound red king (NSR) [e]												
2008	22	34	0.18	0.4	$1.61	$4.04	2	2	--	--	--	--
2009	23	29	0.18	0.4	$1.44	$3.64	3	3	--	--	--	--
2010	23	37	0.19	0.42	$1.66	$3.93	2	3	--	--	--	--
2011	25	38	0.18	0.4	$2.10	$5.19	2	2	--	--	--	--
2012	30	64	0.23	0.5	$2.72	$5.48	3	3	--	--	--	--
Pribilof Island golden king (PIG)												
2008- 2009						CLOSED						
2010	1	1	--	--	--	--	2	2	--	--	--	--
2011	2	2	--	--	--	--	1	1	--	--	--	--
2012	1	1	--	--	--	--	1	1	--	--	--	--
Saint Matthew blue king (SMB)												
2008						CLOSED						
2009	7	7	0.2	0.45	$1.51	$3.35	2	6	--	--	--	--
2010	11	14	0.57	1.25	$6.41	$5.12	5	9	0.41	0.91	$11.63	$12.71
2011	18	23	0.84	1.85	$9.73	$5.26	6	11	0.6	1.33	$18.83	$14.14
2012	17	22	0.72	1.59	$5.97	$3.77	6	11	0.51	1.13	$14.08	$12.45

[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 (2008-2011), or eLandings ex-vessel sales volume adjusted by average product recovery rate (PRR) by fishery (2012). Wholesale price results are sourced from crab processor EDR gross earnings reports where available (2008-2011) and secondarily from COAR gross earnings estimates (2012); 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: 2013 Wholesale price forecasts and estimated year-to-date production - AIG, BBR, and BSS fisheries

						Estimated Production Values, 2013 To-Date				
						Ex-vessel		Wholesale		
Fishery	WS Price Forecast ±90%CI[a]	Price Ratio[b]	PRR[c]	Landed volume[e] 2013 YTD[d]		Price ±90%CI	Gross Revenue ±90%CI	Finished volume		Gross Revenue ±90%CI
	$/lb			1000 *mt*	million lbs	$/lb	$million	1000 *mt*	million lbs	$million
AIG	$10.24 ±1.07	0.46	0.63	0.62	1.36	$4.72 ±0.49	$6.43 ±0.67	0.39	0.86	$8.86 ±0.93
BSS	$5.48 ±0.3	0.43	0.66	29.60	65.25	$2.36 ±0.13	$153.98 ±8.48	19.39	42.74	$234.22 ±12.82
BBR	$18.38 ±2.48	0.54	0.68			$9.97 ±1.35				

Source: ADF&G Commercial Operator's Annual Report, eLandings, NMFS AFSC BSAI Crab Economic Data Report (EDR) database.

[a] See Appendix A for forecast methods and model estimation results.

[b] Calculated as arithmetic mean of $(p_e/p_w)_{t=2007\text{-}2011}$, where p_e is average ex-vessel price and p_w is average wholesale price calculated from 2007-2011 crab EDR data.

[c] Calculated as arithmetic mean of $(v_e/v_w)_{t=2007\text{-}2011}$, where v_e is total volume of commercial ex-vessel landings and v_w total finished crab product volume calculated from 2007-2011 crab EDR data.

[d] Landings to-date for AIG and BSS represent catch of 2012-2013 season allocations for these fisheries landed between 1/1/13 and 5/31/13; does not include catch of 2013/14 season allocations; BSS landings represent the total expected volume for 2013.

[e] Confidence intervals for derived price and revenue estimates are propagated solely on the basis of wholesale price forecast model standard errors and do not reflect distributional information for other variables used in the calculation of estimated values.

Table 3: CR program fisheries crew and processing sector employment and earnings, 2008-2012

	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]	Obs	Total	Vessel mean	Total $million	Vessel median $1000	Total $million	Vessel median $1000	Obs	Total 1000 hrs[d]	Plant median 1000 hrs	Total $1million	Plant median $1000	Median $/hour[e]
All CR Program Fisheries[e,g]													
2008	96	1045		*$32.4*		*$15.1*		*18*	*1022*		*$13.5*		
2009	89	1072		$26.9		$12.6		17	917		$11.1		
2010	79	918		$26.5		$12.7		15	*796*		*$8.3*		
2011	77	967		$34.7		$16.1		16	751		$8.4		
2012	83	1037	--	--	--	--	--		--		--		
Aleutian Islands golden king - Eastern and Western (AIG)[f,g]													
2008	4	--	--	--	--	--	--	6	38	2.8	$0.6	$101	$12.38
2009	5	31	6.2	$2.0	$409	$1.2	$221	5	48	3.7	$0.9	$147	--
2010	5	31	6.2	$3.2	$642	$1.8	$277	4	--	--	--	--	--
2011	5	33	6.6	$3.9	$652	$2.1	$347	7	52	3.3	$1.1	$74	$9.89
2012	6	46	7.67	--	--	--	--		--	--	--	--	--
Bristol Bay red king (BBR)[g]													
2008	76	452	5.95	$14.9	$170	$6.7	$82	11	245	12.6	$3.0	$301	$11.89
2009	70	424	6.06	$10.2	$130	$4.8	$68	12	205	9.7	$2.4	$139	$11.46
2010	65	401	6.16	$13.1	$194	$6.2	$100	13	222	15.5	$2.4	$194	$10.10
2011	62	385	6.21	$10.3	$150	$4.8	$82	14	107	4.7	$1.2	$73	$10.14
2012	64	413	6.45	--	--	--	--		--	--	--	--	--
Eastern Bering Sea snow (BSS)[g]													
2008	74	447	6.03	$16.9	$210	$8.1	$107	12	712	30.5	$9.4	$540	$11.56
2009	77	491	6.38	$13.9	$159	$6.2	$78	14	633	24.7	$7.4	$339	$11.38
2010	67	418	6.24	$9.2	$124	$4.1	$58	11	548	39.6	$5.6	$373	$10.19
2011	68	437	6.43	$19.3	$272	$8.6	$126	14	575	31.2	$6.0	$345	$10.25
2012	72	473	6.56	--	--	--	--		--	--	--	--	--

Table 3: 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]
Eastern Bering Sea Tanner (BST)													
2008	26	146	5.62	$0.6	$15	$0.3	$8	8	27	2.9	$0.5	$49	$11.62
2009	14	87	6.21	$0.6	$30	$0.4	$17	8	31	3.3	$0.3	$36	$10.88
2010	4	--	--	--	--	--	--	5	6	0.7	$0.1	$7	$10.16
Saint Matthew blue king (SMB)													
2009	7	39	5.57	$0.2	$19	$0.1	$8	2	--	--	--	--	--
2010	12	68	5.67	$1.0	$78	$0.6	$45	5	19	0.4	$0.2	$4	$9.90
2011	18	112	6.56	$1.2	$57	$0.6	$31	6	17	0.8	$0.2	$8	$9.11
2012	17	106	6.24	$0.8	$43	$0.4	$22	6	21.12	0.76	$0.2	$7	$9.59

Source: NMFS AFSC BSAI Crab Economic Data. Crew positions from eLandings. Data shown for all BSAI crab fisheries by calendar year. All dollar values are adjusted for inflation to 2012-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 BSAI 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.

[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] Aggregate 2008 statistics for AIG, BBR, BSS, and BST are not directly comparable to results for later years; 2008 results exclude catcher processor data to preserve confidentiality, while sector-level results for 2009 and later reflect combined catcher processor data and catcher vessel/shoreside processor data. Due to change in CP EDR labor reporting, 2012 EDR data for AIG, BBR, BSS fisheries are suppressed pending determination of aggregation protocol for these data.

References

Dalton, M. 2008. "A Time-Series Analysis of U.S. Import Prices and Alaska Processors' Wholesale Prices for King Crab (Draft)," Seattle, WA: NOAA Fisheries, Alaska Fisheries Science Center, 26p.

National Marine Fisheries Service (NMFS). 2011. "Environmental Assessment for Proposed Amendment 38 (Annual Catch Limits) and Amendment 39 (Snow Crab Rebuilding Plan) to the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs," Juneau, Alaska: National Marine Fisheries Service, Alaska Regional Office. 401p, additional appendices.

Appendix to Economic Status Report Summary: BSAI Crab Fisheries, 2013

PROBABILITY FORECASTS FOR ALASKA KING CRAB AND SNOW CRAB WHOLESALE PRICES: VAR(3) ANALYSIS

INTRODUCTION

This document briefly summarizes model development and data updates and extensions to documentation of price forecast methods and results developed to support analysis of Proposed Amendments 38 and 39 of the BSAI Crab FMP (NMFS, 2011; pp 417-439). That report described a time series model that was used to estimate probabilistic forecast trajectories of crab wholesale prices for use in economic analysis of long-term simulations of crab population scenarios under management alternatives for implementation of Annual Catch Limits (ACLs). This appendix updates the VAR(3) model documentation from July, 2011. Specifically, it employs models for gold king crab and red king crab based on time series for king crab import and export prices, and COAR price indices for gold king crab and red king crab, respectively, and replaces the model for snow crab with one based on time series for snow crab COAR price, snow crab import price, and snow crab export price. The selected models are used to estimate short-term price forecasts of COAR price indices to estimate current-year (2013) Alaska crab wholesale prices based on 1991-2012 time series, updated with import/export price series current to July 2013.

DATA

Time series data for the period 1991-2012 were derived from COAR reports and U.S. Census Bureau Merchandise Trade Statistics, the latter were accessed via the U.S. Trade Policy Information System (TPIS). The COAR time series represent the i) physical quantity of production in each year and ii) an index of real first-wholesale prices (i.e., economic value per physical unit) for (all) types of frozen crab products. Separate series were derived from COAR for gold king crab, red king crab, and snow crab. Similarly, quantities and price indices for exports and imports were retrieved from the TPIS. However, the trade data do not distinguish among the three king crab species, and thus, are most comparable to the aggregate COAR series. In forming the real price indices, all nominal economic values were converted into 2012-equivalent real economic values using a price deflator based on a producer price index (PPI)available from the U.S. Bureau of Labor Statistics (BLS), WPU0223= Processed and unprocessed fish, a general category that includes frozen shellfish commodities.

MODEL

Vector autoregression (VAR) models with (alternatively) lags of 1-2-3 years were considered. Model specification tests based on the Akaike Information Criterion (AIC) and the Bayesian-Schwarz Information Criterion (BIC) were conducted using the 1991-2008 dataset. These, and a battery of bivariate, trivariate, quadravariate Granger causality tests, had the strongest support for the VAR(3) model specification. The number of parameters to estimate grows with each lag and the VAR(4) model exhausted the time series. Likewise, the number of parameters grows for each series that is added to the system, and the statistical software (S+Finmetrics) had severe problems with bad results,

for example, with a VAR(3) and 4 series. In terms of the backtesting results, the VAR(2) model with 4 series was outperformed by the best VAR(3) with 3 series. Therefore, model selection here is limited to the VAR(3) specification, each with three time series for prices. The software that was used is S+8 with the module Finmetrics 3. All tests, estimation, and forecasting procedures are described in Chapter 11 ("Vector autoregressive models for multivariate time series") of Zivot and Wang (2003).
The final set of models that were used to forecast prices are each represented by three time series (x1, x2, x3):

1. Gold king crab: COAR gold king crab price index (x1), TPIS king crab export price index (x2), TPIS king crab import price index (x3);

2. Red king crab: COAR red king crab price index (x1), TPIS king crab export price index (x2), TPIS king crab import price index (x3);

3. Snow crab: COAR snow crab price index (x1); TPIS snow crab export price index (x2), TPIS snow crab import price index (x3).

DATA and SOURCES:
Alaska 1st Wholesale price:
ADFG Commercial Operators Annual Report (COAR)
Series for golden king crab, red king crab, snow crab, all product forms, processors with 4 or 5 active years in 2008-2012: COAR_GKC, COAR_RKC, COAR_SNOW

Trade data source: US Census Bureau Merchandise Trade Statistics
Retrieved September 2013: US International Trade Administration Trade Policy Information System (TPIS),
Group: Processed foods and feeds
Item: Unprocessed and packaged fish

HS Series for Exports and Imports, All US customs districts and trade partners:
0306144010--KING CRABS, FROZEN, EXCEPT CRABMEAT
0306144020--SNOW CRABS, FROZEN, EXCEPT CRABMEAT
EX_KING, EX_SNOW, IM_KING, IM_SNOW

Data for all years adjusted to real 2012 dollars using BLS PPI for commodities WPU0223

Table A1: COAR and Import/Export Price Data, 1991 – 2012 ($/lb)

YEAR	COAR_GKC	COAR_RKC	COAR_SNOW	EX_KING	EX_SNOW	IM_KING	IM_SNOW
1991	12.98223	14.36648	3.41510	12.14609	4.15738	11.16507	6.29570
1992	10.74099	14.84132	3.42922	13.46351	4.07182	8.46008	4.42860
1993	8.37371	13.97920	4.10292	12.07161	4.88861	9.60061	5.34092
1994	12.79516	21.15540	6.37853	10.62373	6.63825	10.60611	6.06463
1995	10.01360	15.87560	9.03913	9.38057	7.70603	8.58858	6.26093
1996	8.89815	14.97745	5.83919	9.96496	5.77208	8.04923	5.13870
1997	7.41687	9.99136	3.38848	7.37067	3.86481	8.26375	3.82689
1998	6.65579	8.70834	3.16661	5.23578	3.18347	7.32151	3.62520
1999	10.27565	16.81486	4.38953	6.39187	4.04600	8.10128	4.60276
2000	10.59610	13.33107	6.13693	9.80251	5.72646	9.50330	5.49610
2001	10.58051	14.40638	5.56687	12.33516	5.52188	10.15675	4.72700
2002	11.16835	17.92830	5.47993	9.98210	5.34943	12.13933	4.79191
2003	11.36093	14.41550	6.48630	8.49169	6.42167	10.82452	5.62810
2004	9.38381	12.84945	6.67197	7.54108	6.09675	8.94444	5.40048
2005	7.70076	10.99487	5.03481	8.04401	5.10287	7.91203	4.11737
2006	5.47028	9.02126	3.46218	7.29848	4.62483	6.51205	3.58240
2007	6.71228	10.01576	4.62054	7.89444	3.82110	6.42673	4.49657
2008	7.44145	10.77325	4.52042	8.12229	4.07862	8.44604	4.46656
2009	6.19374	9.87337	3.91481	10.19693	4.25341	7.99778	3.82768
2010	7.92843	14.06370	3.44703	10.72556	3.99238	8.47409	4.10541
2011	10.45640	17.45717	5.35147	10.80889	4.84520	9.11247	5.54826
2012	9.13707	15.04263	4.75031	11.56523	4.58220	7.91697	4.71944

Table 1: Regression results produced by the S+finmetrics software for three models. The regression runs through 2012 and 1991-1993 data are used as lags, so the time series actually used for estimation starts in 1994.

```
2013 GKC COAR price index

CONDITIONAL FORECAST (NOWCAST):
median(90%CI): 10.24 (9.17,11.31)
Conditional on (Jan-July 2013):
EXKING=13.03, IMKING=7.92

UNCONDITIONAL FORECAST
(90%CI):8.7850 (5.957179,11.61287)

GKC VAR2012 SUMMARY:
x1 = COAR_GKC
x2 = EX_KING
x3 = IM_KING

Coefficients:
               x1      x2      x3
(Intrcpt)  2.6872  4.0469  4.3186
(std.err)  5.5846  2.2793  3.0302
 (t.stat)  0.4812  1.7755  1.4252

  x1.lag1  0.2336 -0.0921  0.0646
(std.err)  0.6256  0.2553  0.3395
 (t.stat)  0.3733 -0.3609  0.1902

  x2.lag1  0.1541  0.9805  0.2573
(std.err)  0.5306  0.2165  0.2879
 (t.stat)  0.2904  4.5281  0.8939

  x3.lag1  0.5674  0.5351  0.6389
(std.err)  1.0943  0.4466  0.5938
 (t.stat)  0.5185  1.1982  1.0761

  x1.lag2 -0.0422  0.1430  0.0591
(std.err)  0.4892  0.1997  0.2655
 (t.stat) -0.0862  0.7159  0.2227

  x2.lag2  0.0756 -0.5940 -0.1270
(std.err)  0.7975  0.3255  0.4328
 (t.stat)  0.0948 -1.8249 -0.2934

  x3.lag2 -0.2878 -0.5363 -0.2456
(std.err)  0.7996  0.3263  0.4338
 (t.stat) -0.3600 -1.6434 -0.5660

  x1.lag3  0.0499 -0.7899  0.1985
(std.err)  0.4571  0.1865  0.2480
 (t.stat)  0.1091 -4.2347  0.8003

  x2.lag3 -0.0138  0.3212 -0.1669
(std.err)  0.6008  0.2452  0.3260
 (t.stat) -0.0229  1.3097 -0.5119

  x3.lag3 -0.0368  0.6063 -0.1831
(std.err)  0.7218  0.2946  0.3916
 (t.stat) -0.0510  2.0582 -0.4676

Regression Diagnostics:
                  x1      x2     x3
     R-squared 0.4036  0.8832  0.6574
Adj. R-squared -0.1928  0.7664 0.3147
  Resid. Scale  2.2066  0.9006 1.1973

Information Criteria:
  logL      AIC      BIC       HQ
-56.5810 173.1620 201.4952  177.9571

                    total residual
Degree of freedom:    19        9
Time period: from 1994 to 2012
```

```
RKC 2013 COAR price index

CONDITIONAL FORECAST (NOWCAST):
median(90%CI): 18.38 (15.90,20.86)
Conditional on (Jan-July 2013):
EXKING=13.03, IMKING=7.92

UNCONDITIONAL FORECAST:
(90%CI)15.24136 (10.63752,19.84521)

RKC VAR2012 SUMMARY:
x1 = COAR_RKC
x2 = EX_KING
x3 = IM_KING

Coefficients:
               x1      x2      x3
(Intrcpt)  2.8777  7.1668  2.8479
(std.err)  8.0677  2.0837  2.6823
 (t.stat)  0.3567  3.4395  1.0617

  x1.lag1 -0.0344  0.1188 -0.0241
(std.err)  0.4480  0.1157  0.1489
 (t.stat) -0.0769  1.0264 -0.1621

  x2.lag1  1.0114  0.8181  0.3532
(std.err)  0.8717  0.2251  0.2898
 (t.stat)  1.1603  3.6341  1.2187

  x3.lag1  0.2194 -0.1264  0.8494
(std.err)  1.3560  0.3502  0.4508
 (t.stat)  0.1618 -0.3610  1.8841

  x1.lag2 -0.3434  0.0433 -0.0697
(std.err)  0.3854  0.0995  0.1281
 (t.stat) -0.8910  0.4348 -0.5438

  x2.lag2  0.0424 -0.3982 -0.2080
(std.err)  1.1141  0.2877  0.3704
 (t.stat)  0.0381 -1.3840 -0.5615

  x3.lag2  0.4720  0.0153 -0.2163
(std.err)  1.2532  0.3237  0.4167
 (t.stat)  0.3767  0.0473 -0.5191

  x1.lag3 -0.2003 -0.3700  0.0823
(std.err)  0.3702  0.0956  0.1231
 (t.stat) -0.5410 -3.8697  0.6685

  x2.lag3  0.4413  0.0632 -0.0868
(std.err)  0.9359  0.2417  0.3112
 (t.stat)  0.4715  0.2616 -0.2790

  x3.lag3 -0.1458  0.1441 -0.0050
(std.err)  0.8574  0.2214  0.2851
 (t.stat) -0.1700  0.6507 -0.0175

Regression Diagnostics:
                   x1     x2     x3
     R-squared 0.4515 0.8760 0.6591
Adj. R-squared -0.0970 0.7520 0.3181
  Resid. Scale 3.5924  0.9278  1.1944

Information Criteria:
    logL      AIC      BIC        HQ
 -73.2738  206.5475 234.8807 211.3426

                    total residual
Degree of freedom:    19        9
Time period: from 1994 to 2012
```

```
SNOW 2013 COAR price index

CONDITIONAL FORECAST (NOWCAST):
median(90%CI): 5.475 (5.170,5.779)
Conditional on (Jan-July 2013):
EXSNOW=4.94, IMSNOW=4.85

UNCONDITIONAL FORECAST:
(90%CI) 4.2457 (2.968881,5.522541)

SNOW VAR2012 SUMMARY:
x1: COAR_SNOW
x2: EX_SNOW
x3: IM_SNOW

Coefficients:
               x1      x2      x3
(Intrcpt)  2.0451  1.6435  4.0006
(std.err)  2.9193  2.4178  1.5729
 (t.stat)  0.7005  0.6798  2.5434

  x1.lag1 -0.9469 -0.3563 -0.3548
(std.err)  0.6477  0.5365  0.3490
 (t.stat) -1.4618 -0.6641 -1.0166

  x2.lag1  1.8653  1.0658  0.7214
(std.err)  0.7723  0.6397  0.4161
 (t.stat)  2.4151  1.6661  1.7336

  x3.lag1  0.4335  0.3368  0.3416
(std.err)  0.8290  0.6866  0.4466
 (t.stat)  0.5230  0.4905  0.7648

  x1.lag2 -0.8483 -0.2684 -0.2675
(std.err)  0.6074  0.5031  0.3273
 (t.stat) -1.3965 -0.5336 -0.8174

  x2.lag2  0.4817 -0.2089  0.2425
(std.err)  0.8809  0.7296  0.4746
 (t.stat)  0.5469 -0.2864  0.5109

  x3.lag2 -0.2012 -0.0369 -0.6572
(std.err)  0.9031  0.7480  0.4866
 (t.stat) -0.2228 -0.0493 -1.3506

  x1.lag3 -0.1883 -0.1800 -0.0689
(std.err)  0.5736  0.4751  0.3091
 (t.stat) -0.3283 -0.3789 -0.2231

  x2.lag3  0.2273  0.0159 -0.1924
(std.err)  0.6991  0.5790  0.3767
 (t.stat)  0.3251  0.0275 -0.5107

  x3.lag3 -0.2024  0.3296  0.3785
(std.err)  0.5524  0.4575  0.2976
 (t.stat) -0.3664  0.7205  1.2718

Regression Diagnostics:
                   x1     x2     x3
     R-squared 0.7664 0.7487 0.7814
Adj. R-squared 0.5328 0.4974 0.5628
  Resid. Scale 0.9963 0.8252 0.5368

Information Criteria:
   logL      AIC      BIC        HQ
 -7.7503  75.5005 103.8337   80.2956

                    total residual
Degree of freedom:    19        9
Time period: from 1994 to 2012
```

BACKTESTING and CURRENT-YEAR FORECAST (NOWCAST) RESULTS

Fig. 1a: Gold king crab VAR(3) model and data 1991-2012 with three price series based on COAR wholesale values for gold king crab (plot), TPIS king crab import price index, and TPIS king crab export price index. The regression runs through 2013 with 90% 1-step forecasts for 2011 and 2012, where the latter is conditioned on Jan-July 2013 average values for TPIS series. The expected values of each forecast are represented by squares in the forecast intervals for each year. All values are in 2012 dollars per pound.

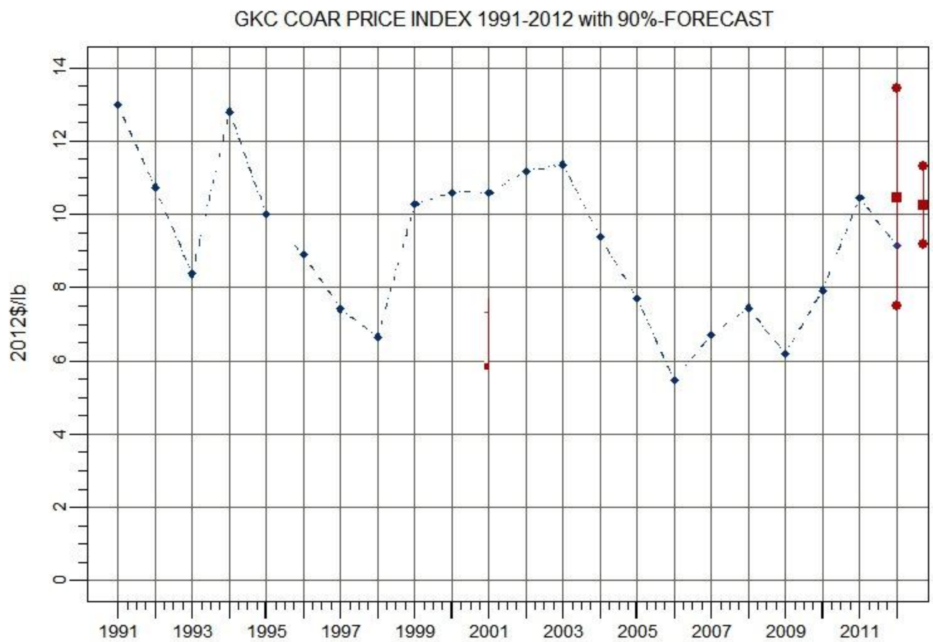


Fig. 1b: Red king crab VAR(3) model and data 1991-2012 with three price series based on COAR wholesale values for red king crab (plot), TPIS king crab import price index, and TPIS king crab export price index. The regression runs through 2013 with 90% 1-step forecasts for 2011 and 2012 where the latter is conditioned on Jan-July 2013 average values for TPIS series. The expected values of each forecast are represented by squares in the forecast intervals for each year. All values are in 2012 dollars per pound.

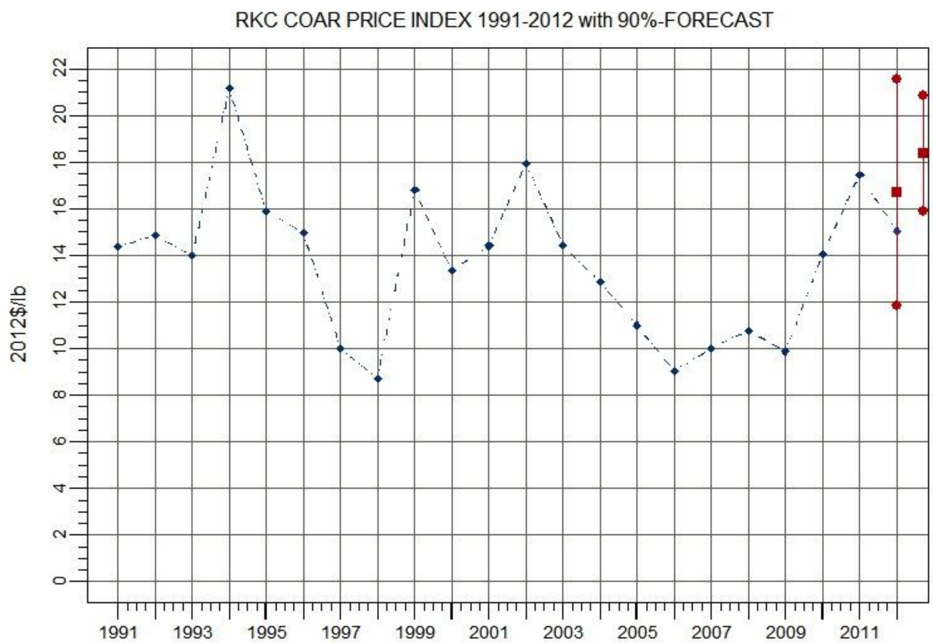


Fig. 1c: Snow crab VAR(3) model and data 1991-2008 with three price series based on COAR wholesale values for snow crab (plot) TPIS snow crab import price index, and TPIS snow crab export price index. The regression runs through 2013 with 90% 1-step forecasts for 2011 and 2012 where the latter is conditioned on Jan-July 2013 average values for TPIS series. The expected values of each forecast are represented by squares in the forecast intervals for each year. All values are in 2012 dollars per pound.