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

2011 Crab SAFE

Compiled by

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of the Bering Sea and Aleutian Islands

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Fisheries of the Bering Sea and Aleutian Islands Regions

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Introduction

The annual stock assessment and fishery evaluation (SAFE) report is a requirement of the North Pacific Fishery Management Council's *Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (FMP)*, and a federal requirement [50 CFR Section 602.12(e)]. The SAFE report summarizes the current biological and economic status of fisheries, total allowable catch (TAC) or Guideline Harvest Level (GHL), and analytical information used for management decisions. Additional information on Bering Sea/Aleutian Islands (BSAI) king and Tanner crab is available on the 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 four 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 19-22, 2011 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 2011 Crab SAFE report contains all recommendations for all 10 stocks including those whose OFL and ABC were determined in June 2011. 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), Ginny Eckert (Vice-Chair), Wayne Donaldson, Bill Bechtol, Karla Bush, Heather Fitch, Brian Garber-Yonts, Gretchen Harrington, Steve Martell, Doug Pengilly André Punt, Lou Rugolo, Shareef Siddeek, Diana Stram and Jack Turnock.

Stock Status Definitions

The FMP (incorporating all changes made following adoption of Amendments 24 and 38) 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 amendments 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.

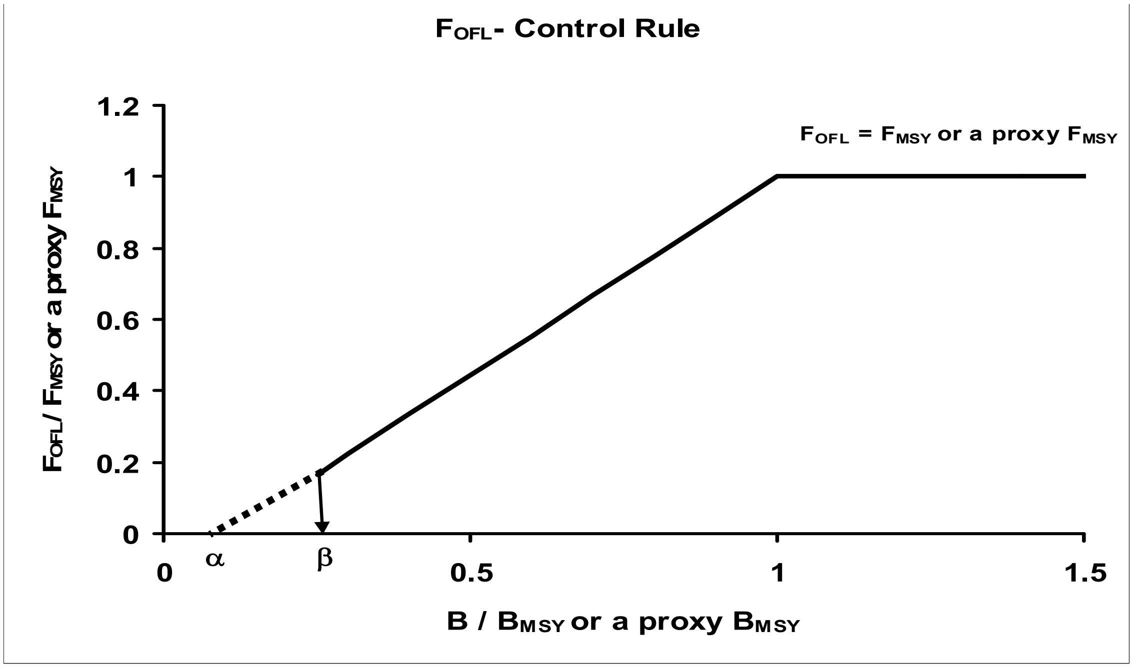

Table 1 Five-Tier System for setting overfishing limits (OFLs) and Acceptable Biological Catches (ABCs) for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.

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:
  - F_{MSY} — the instantaneous F that will produce MSY at the MSY-producing biomass
    - A proxy of F_{MSY} may be used; e.g., $F_{x\%}$, the instantaneous F that results in x% of the equilibrium spawning per recruit relative to the unfished value
  - B — a measure of the productive capacity of the stock, such as spawning biomass or fertilized egg production.
    - A proxy of B may be used; e.g., mature male biomass
  - B_{MSY} — the value of B at the MSY-producing level
    - A proxy of B_{MSY} may be used; e.g., mature male biomass at the MSY-producing level
  - β — a parameter with restriction that $0 \le \beta < 1$.
  - α — a parameter with restriction that $0 \le \alpha \le \beta$.
- The maximum value of F_{OFL} is F_{MSY}. $F_{OFL} = F_{MSY}$ when $B > B_{MSY}$.
- F_{OFL} decreases linearly from F_{MSY} to $F_{MSY}\cdot(\beta-\alpha)/(1-\alpha)$ as B decreases from B_{MSY} to $\beta\cdot B_{MSY}$
- When $B \le \beta\cdot B_{MSY}$, F = 0 for the directed fishery and $F_{OFL} \le F_{MSY}$ for the non-directed fisheries, which will be determined in the development of the rebuilding plan.
- The parameter, β, determines the threshold level of B at or below which directed fishing is prohibited.
- The parameter, α, determines the value of F_{OFL} when B decreases to $\beta\cdot B_{MSY}$ and the rate at which F_{OFL} decreases with decreasing values of B when $\beta\cdot B_{MSY} < B \le B_{MSY}$.
  - Larger values of α result in a smaller value of F_{OFL} when B decreases to $\beta\cdot B_{MSY}$.
  - Larger values of α result in F_{OFL} decreasing at a higher rate with decreasing values of B when $\beta\cdot B_{MSY} < B \le B_{MSY}$.
- The parameter, b_y, is the value for the annual buffer calculated from a P* of 0.49 and a probability distribution for the OFL that accounts for scientific uncertainty in the estimate of OFL.
- 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 2011/2012 on Tier assignments, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs and ABCs. The team recommends two stocks be placed in Tier 3 (EBS snow crab and Bristol Bay red king crab), five stocks in Tier 4 (EBS Tanner crab, 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 2011/12. Stock status in relation to status determination criteria are shown in Table 5.

The team has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2012 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 2011 CPT Report).

General recommendations for all assessments

1. In relation to whether mature male biomasses should be reduced by the actual catches or the projected catches using an F_{MSY} strategy when computing the B_{MSY} proxy for Tier 4 stocks, the team recommended that the analysts provide a more complete and general analysis supporting the possible application of "bias" corrections for the May 2012 meeting.
2. The team had a further discussion of the relative merits of male-catch-only versus total-catch OFLs. While the team has striven to calculate total-catch OFLs in recent years, there are good reasons why a male-catch-only OFL may better satisfy the aims of OFL setting, including: (a) the formulae used to calculate OFLs are generally based on data for males, with females as an 'add on', and (b) if the OFL is calculated including females, the entire OFL could be males without the conclusion that overfishing occurred. The team requests that the SSC reconsider whether the team can recommend male-only OFLs when the situation suggests that this is warranted, even when it is possible to calculate a total-catch OFL (e.g. EBS Tanner crab). A white paper is being developed to discuss this issue further at the May 2012 CPT meeting and will be provided to the SSC for their consideration in June 2012.
3. The team recommends that analysts provide a list of the parameters (e.g. natural mortality, Q, the appropriateness of F_{MSY} and B_{MSY} proxies), an indication of whether the estimates / assumption used to compute the OFL is likely wrong in systematic way (leading to under- or over-estimation of the OFL) and a range for the extent of error. The analysts should then calculate how the OFL would change for the extremes of the ranges. The team will discuss this approach to quantifying error further at the January modeling workshop.
4. 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.
5. 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 β from the standard errors from the analysis on which the estimates for these parameters were based.
6. 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).

By convention the CPT used the following conversions to include tables in both pounds (lb) and metric tons (t) in the status summary sections:

- lb to 1000 t [/2.204624]
- 1000 t to lbs [x 0.453592]

Ecosystem SAFE overview

The ecosystem chapter is composed of three main sections 1) ecosystem assessment, 2) current status of ecosystem indicators, and 3) ecosystem-based management indicators. The objectives of this chapter are to assess the BSAI ecosystem trends, identify and provide annual updates of ecosystem status indicators and research priorities for BSAI crab stocks, and to update management status indicators.

A summary of the most recent ecosystem trends affecting BSAI crab is summarized below with additional information detailed in the ecosystem consideration indicators chapter. Crab Plan Team comments and recommendations on the ecosystem chapter are contained in the September 2011 CPT report.

Recent trends in the 2011 ecosystem indicators (physical & biological trends)

- Extensive sea ice coverage in 2010 persisted into late spring, resulting in one of the largest summer cold pools in 2010.
- Analysis of sea ice extent suggests that the northern Bering Sea will remain relatively cold in the future; affecting distribution of species (crab and predators).
- Pacific cod and pollock on 2010 EBS survey distributed outside the cold pool.
- Winter 2011 was a moderately cold compared to previous five years, although winter ice cover advanced in late spring (April 2011).
- Moderate La Niña for winter 2011 may result in a transitional year in summer 2011.

2010/2011 Status of Predators

- Pacific cod biomass of 0.84 t doubled from 2009.
- Pollock biomass of 3.75 t highest since 2007.
- YFS, NRS, SRS, ATF and HAB all increasing.
- Overall predator abundance is increasing including a significant increase in age 2-3 Pacific cod.

Stock Status Summaries

1 Eastern Bering Sea Snow Crab

Fishery information relative to OFL setting

The total catch in the 2010/11 fishery was estimated at 26,720 t (including model estimated bycatch). This is below the 2010/11 OFL of 44,400 t. Since 1992 when observers were placed on the boats, estimated discard mortality from the directed pot fishery has averaged 15.5% with an assumed discard mortality rate of 50%. Retained catch in the 2010/11 fishery was 24,670 t, which is a slight increase over the 2009/10 fishery of 21,785 t. Snow crab is taken as bycatch in the trawl fishery and estimates of trawl bycatch in recent years are less than 1% of the total snow crab catch. Current estimates of stock status have been above B_{MSY}(418,150 t) for the past three years. Recent trends in mature biomass have continued to increase since 2008. Since 1999, estimates of exploitation rates on mature male biomass have been well below estimates of exploitation rates corresponding to fishing at $F_{35\%}$.

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 an exponential growth function with the transition probability based on a gamma distribution where the variance term for the growth increment is fixed. The model is fitted to abundance data from the NMFS trawl survey, total catch data from the directed fishery and the bycatch data from the trawl fishery, size frequency data by maturity status for the male crab pot fishery, female bycatch in the crab pot fishery, trawl fishery bycatch. The model is also fitted to the 2009 and 2010 BSFRF study area biomass estimates and length frequency data. Changes to the model for 2011 include: i) immature M for male and females, ii) mature male M that is either fixed or estimated depending on the model scenario, iii) reformulation of the survey selectivity in the BSFRF study areas in 2009 and 2010, iv) a nonparametric availability curve for the BSFRF study area in 2009 and 2010,, v) model scenarios with a fixed growth curve based on data from a 2011 growth study.

A total of 13 alternative model scenarios were evaluated. The base model chosen by the author was scenario 7 where natural mortality rates for all stages were fixed at 0.23 yr^{-1} and a logistic curve was used for the availability BSFRF survey data. The Crab Plan Team recommends scenario 6, where a nonparametric availability model was used and natural mortality rates were estimated in conjunction with an informative prior for adult M (see CPT minutes for discussions regarding model selection and natural mortality rates).

Stock biomass and recruitment trends

All model scenarios investigated indicated that the stock is above the B_{MSY} proxy. This indicates that under any model scenario the stock is rebuilt. Estimated trends (model 7) in mature male biomass (MMB) at mating have increased since 2002/03 to 2010/11, and 2011/12 estimates (179,000 t) are slightly less than 2010/11 (184,900 t). Observed survey mature male biomass increased from 157,310 t in summer 2010 to 167,400 t in summer 2011. Trends in recruits per mature male biomass have increased between 2001/02 and 2005/06, and the estimates of recruitment (25-50 mm size class) in the last 5 years are dominated by an above average cohort in 2009/10.

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

The CPT recommends that the EBS snow crab is a tier 3 stock so the OFL will be determined by $F_{35\%}$ control rule. The team recommends that the proxy for B_{MSY} ($B_{35\%}$) be the mature male biomass at mating is 147,500 t, based on average recruitment over 1979 to present, and the minimum stock size threshold is 73,700 t. The CPT recommends that the ABC be less than maxABC

The Team had difficulty in determining the buffer between the OFL and the ABC that appropriately addresses uncertainty. The Team considered many options for an ABC <maxABC permissible including the following options:

1. a default 10% buffer;
2. use of the OFL from model 7 as an ABC;
3. using the recommended total uncertainty (i.e., σw and σb from the EA for amendment 38) to estimate a buffer using a P* of 0.49; and
4. using the ratios of OFL from model scenarios (e.g., use ratios between different model scenarios) to define a range of values to be used as a multiplier (buffer) for the ABC.

Despite extensive discussion of these items, the CPT was unable to recommend a specific ABC but wishes to identify the following information on uncertainty that should be captured in an ABC: a) using M fixed at prior value would have led to a lower OFL value; and b) use of the new growth data (which has not yet been reviewed in much detail) would have resulted in a lower value. However, the Team recognized that given the uncertainty noted, risk tolerance is required to choose an appropriate buffer based on the model results presented.

In October 2011, the SSC recommended an ABC less than the maximum permissible. The SSC recommended a 10% buffer for an ABC of 66.15 1000 t.

Historical status and catch specifications for snow crab (kt).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	72.1	98.9	28.6	28.6	35.0		
2008/09	74.1	109.3	26.6	26.5	31.5	35.1	
2009/10	66.6	127.7	21.8	21.8	23.9	33.1	
2010/11	73.7	196.6	24.6	24.7	26.7	44.4	
2011/12		133.8*				73.5	66.15

*Model forecast based on the 2011 assessment under the assumption that the 2011/12 catch equals to the OFL. This value will be updated during the September 2012 assessment when the 2012 survey data and the 2011/12 catch data become available.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	159.0	218.0	63.1	63.1	77.2	NA	
2008/09	163.4	241.0	58.6	58.4	69.4	77.4	
2009/10	146.8	281.5	48.1	48.1	52.7	73.0	
2010/11	162.5	433.4	54.2	54.5	58.9	97.9	
2011/12		295.0*				162.0	145.8

*Model forecast based on the 2011 assessment under the assumption that the 2011/12 catch equals to the OFL. This value will be updated during the September 2012 assessment when the 2012 survey data and the 2011/12 catch data become available.

Additional Plan Team recommendations

See the CPT Report (September 2011) for additional recommendations on the Snow Crab assessment for 2012 specification cycle.

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 lbs (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 (≥ 165.1mm (6.5-in) carapace width), sex (male only), and season (no fishing during mating/molting periods). Prior to 1990, the harvest rate was based on estimated population size and prerecruit and postrecruit abundances at survey time, and varied from 20% to 60% of legal males. In 1990, the harvest strategy became 20% of the mature male (≥120-mm CL) abundance, with a maximum of 60% on legal males, and a threshold abundance of 8.4 million mature females. The current stepped 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), and a minimum GHL of 4.0 million lb (8.8 thousand t) 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. Catch of legal males per pot lift was relatively high in the 1970s and low in the 1980s to mid-1990s. Following implementation of the crab rationalization program in 2005, CPUE increased to31 crab/pot in 2006, but fell to 18 crab/pot by 2010/11. 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 17.0 million lb (7.7 thousand t) in 2010/11 to 23.4 million lb (10.6 thousand t) in 2008/09.

Data and assessment methodology

The stock assessment model is based on a length-structured population dynamics model incorporating data from the NMFS eastern Bering Sea trawl survey, commercial catch, and at-sea observer data program. Annual stock abundance is estimated for male and female crabs ≥ 65-mm carapace length during 1968/69−2010/11 to the time of the 2011 survey and mature male biomass is projected for 15 February 2012. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date from the fishery which targets males ≥ 165mm (6.5 in. carapace width) 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 2010/11 crab fishery year. The 2011 assessment was based on model scenario 7ac. Model scenario 7ac assumes three levels of molting probabilities, a constant natural mortality 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), incorporates the BSFRF data, estimates effective sample sizes, estimates proportions in initial years, and (with respect to the "Bristol Bay retow data") uses only the standard survey data for males and uses the retow data for females.

Stock biomass and recruitment trends

Model estimates of total survey biomass increased from 162.5 million lb (73.7 thousand t) in 1968 to 631.1 million lb (286.3 thousand t) in 1978, fell to 77.0 million lb (34.9 thousand t) in 1985, generally increased to 201.2 million lb (91.3 thousand t) in 2007, and declined to 166.9 million lb (75.7 thousand t) in 2011. Model estimates of mature male biomass at mating (15 February) generally increased from 48.3 million lb (21.9 thousand t) in 1993/94 to 73.8 million lb (33.5 thousand t) in 2009/10 and to 72.0 million lb (32.6 thousand t) in 2010/11; the projected value for mature male biomass on 15 February 2012 is 65.6 million lb (29.8 thousand t) if the 2011/12 catch equals the OFL. Estimated recruitment was high during the 1970s and early 1980s and has been generally low since 1985. Estimated recruitment to the modeled size classes (i.e., ≥65 mm CL) from the 2007−2011 surveys has been below the average for 1984−2011. The 2011 survey produced a high catch of juvenile males and females <65 mm CL, but that catch occurred in only one survey tow and hence has high uncertainty as a predictor of future recruitment.

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

This assessment showed improvement in exploring the use of the data that are available, particularly with regard to exploring physical and biological oceanographic trends to support the choice of 1984−2011 as recruitment period to use in estimating $B_{35\%}$. The CPT supports the use of model scenario 7ac for the 2011 assessment for stock status determination.

The Plan Team recommends Bristol Bay red king crab as a Tier 3 stock. The team recommends that the proxy for B_{MSY} ($B_{35\%}$) be the mature male biomass at mating, computed as the average recruitment from 1984 to the last year of the assessment (2011) multiplied by the mature male biomass-per-recruit corresponding to $F_{35\%}$ less the mature male catch under an $F_{35\%}$ harvest strategy. Estimated $B_{35\%}$ for 2010/11 is 27.3 t (60.0 million lb). Total catch includes retained male catch and all other bycatch sources.

The team recommends that the OFL for 2011/12 be set according to the model scenario 7ac results at 19.39 million pounds (8.80 thousand t). The team recommends that the ABC for 2011/12 be set below the maximum ABC (19.35 million pounds, or 8.78 thousand t). The team identified uncertainty in the OFL estimation due to the unknown effects on the recruitment time series of the assumption of periods of additional mortality in the model. A downward bias trend in the male abundance estimates that was revealed in a retrospective analysis of model scenario 7ac was also identified as a source of uncertainty in OFL estimation. The team recommends that the ABC be set at 15.84 million lb (7.19 thousand t) to account for the uncertainty arising from that downward bias trend based on an analysis of the retrospective pattern contained in the assessment (see CPT Report for additional details on this adjustment).

In October 2011, the SSC recommended an ABC below the maximum permissible. The SSC recommended a 10% buffer for an ABC of 7.92 thousand (t) or 17.46 million lb.

Status and catch specifications (kt) of Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	20.32	37.69	9.24	9.30	10.54		
2008/09	17.06	39.83	9.24	9.22	10.48	10.98	
2009/10	15.56	40.37	7.26	7.27	8.31	10.23	
2010/11	13.63	32.64	6.73	6.76	7.71	10.66	
2011/12		29.76[D]				8.80	7.92

*Model forecast based on the 2011 assessment under the assumption that the 2011/12 catch equals to the OFL. This value will be updated during the September 2012 assessment when the 2012 survey data and the 2011/12 catch data become available.

Status and catch specifications (million lb.) of Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	44.8	85.9	20.38	20.51	23.23		
2008/09	37.6	87.8	20.37	20.32	23.10	24.20	
2009/10	34.3	89.0	16.0	16.0	18.31	22.56	
2010/11	30.0	72.0	14.84	14.91	17.00	23.52	
2011/12		65.6*				19.39	17.46

*Model forecast based on the 2011 assessment under the assumption that the 2011/12 catch equals to the OFL. This value will be updated during the September 2012 assessment when the 2012 survey data and the 2011/12 catch data become available.
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The 2010/2011 MMB estimate exceeds the MSST for 2010/11, so the stock is not currently overfished (the 2010/11 MMB is 109% of the B_{MSY} proxy of $B_{35\%}$). The total catch for 2010/11 (17.00 million lb, or 7.71 thousand t) was less than the 2010/11 OFL (23.52 million lb, or 10.66 thousand t), so overfishing did not occur during 2010/11.

Additional Plan Team comments

See the September 2011 Crab Plan Team report for additional comments and recommendations on the assessment.

3 Eastern Bering Sea Tanner crab

Fishery information relative to OFL setting.

Eastern Bering Sea (EBS) Tanner crabs are caught 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). Two directed fisheries, one east and one west of 166˚ W. longitude, harvest EBS Tanner crab. Under the Crab Rationalization Program, ADF&G sets separate TACs and NMFS issues separate individual fishing quota (IFQ) for these two fisheries. However, one OFL is set for the EBS Tanner crab because there is no evidence that the EBS Tanner crab is not one stock. Both fisheries were closed from 1997 to 2005 due to low abundance and the fisheries were closed again for the 2010/11 crab fishery year. NMFS declared this stock overfished in 1999 and the Council developed a rebuilding plan. In 2005, abundance increased to a level to support a fishery in the area west of 166^0 W. 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 B_{MSY} for two consecutive years. The mature male biomass was, however, estimated to be below the Minimum Stock Size Threshold ($0.5B_{\mathrm{MSY}}$) in February 2010 (the assumed time of mating), and NMFS declared the stock overfished in September 2010 and a rebuilding plan will be developed for implementation in 2012/13. New minimum size limits adopted by the Alaska Board of Fisheries will be implemented in the 2011/12 fishing season.

Data and assessment methodology

This stock is surveyed annually by the NMFS EBS trawl survey. Although a stock assessment model has been developed for the eastern portion of the stock, and a model is currently under development for the entire stock, no currently approved model exists for the stock. Area-swept estimates of biomass from the EBS trawl survey are therefore used to estimate the biomass of stock components: mature male biomass (MMB), legal male biomass (LMB), and females. The current assessment used NMFS trawl survey data with measured net width (as opposed to the fixed-width assumed in previous assessments). Fish ticket data were used for computing retained catch, and observer data from the crab and groundfish fisheries were used to estimate non-retained catch; assumed handling mortality rates for fishery components were used to estimate the discard mortality.

Stock biomass and recruitment trends

MMB and LMB showed peaks in the mid-1970s and early 1990s. MMB at the survey revealed an all-time high of 257.0 thousand t in 1975, and a second peak of 108.3 thousand t in 1991. From late-1990s through 2007, MMB has risen at a moderate rate from a low of 10.4 thousand t in 1997. Post-1997, MMB at the time of survey increased to 73.6 thousand t in 2007, but subsequently declined to MMB at the time of survey of 32.1 thousand t in 2010. The survey estimate of MMB from the 2011 survey was 41.8 thousand t, an increase of 30.2% from 2010, but this estimate is not used in the Tier 4 assessment given the way this assessment is applied. The MMB projected for February 2012 (26.06 thousand t) is less than the MMB in February 2011 (26.73 thousand t) if the total catch for 2011/12 equals the OFL. The 2011 survey estimated a high abundance of small (25-35 mm CW) animals.

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

The team recommends the OFL for this stock be based on the Tier 4 control rule because no stock assessment model has been adopted. Based on the estimated biomass at 15 February 2011, the stock is at stock status level b. The team recommends that $B_{\mathrm{MSY\ proxy}}$ be based on the average MMB for the years 1974-80, discounted by fishery removals (retained and non-retained mortalities) and natural mortality between the time of survey and the time of mating. This time period is thought to represent the reproductive potential of the stock. The range of years on which B_{MSY} is based differs from that used for the 2010 assessment because the range of years was shortened from 1969-80 to 1974-80 following the February 2011 assessment workshop recommendation that survey estimates for 1969-73 not be used for assessments owing to data quality issues. The $B_{MSY\ proxy}$ for the 2011 assessment is 83.33 thousand t MMB at mating. The 2010/11 estimate of MMB at mating is 26.73 thousand t, or 32% of $B_{MSY\ proxy}$. Hence, the stock is estimated to have been in overfished condition. The team recommends that γ=1.0 and M = 0.23yr^{-1}. Under the OFL Control Rule, the 2010/11 F_{OFL}=0.05, equating to a total male and female catch of 1.57 thousand t.

Given a P* of 0.49 and a within-model standard error of 0.13 on terminal biomass, the maximum permissible ABC would be 1,570 t. The author recommended a total catch ABC of 1,290t, i.e., 82% of the OFL based on an assumed additional uncertainty of 0.3. This level of uncertainty reflects several aspects not accounted for in the measure of uncertainty captured in the assessment: (a) pre-specified population dynamic parameters and life-history rates such as natural mortality, size-weight, and maturity; (b) the assumption F_{MSY}=M; and (c) the assumption that B_{MSY} is the average biomass over 1974-80. However, the assessment is based on a Q of 1.0 for all sizes, whereas the stock assessment model includes a prior of Q <1.0 and that selectivity is a logistic function of size. The team recommended that the ABC be set equal to the maximum permissible ABC in the absence of a defensible way to specify a larger buffer, and the fact that a Q lower than 1.0 provides some buffer.

In October 2011, the SSC recommended an ABC less than the maximum permissible. The OFL reviewed by the CPT as listed above mistakenly used the 2010 survey value instead of the 2011 survey value in the calculation and was thus later revised (note the 2011 Tanner crab assessment chapter now includes the revised survey values). Thus the SSC recommended the revised OFL value of 2,750 t and a 10% buffer to calculate the ABC resulting in an ABC recommendation of 2,480 t.

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

Year	MSST	Biomass (MMB)	TAC (east + west)	Retained Catch	Total Catch	OFL	ABC
2007/08 [b/]		68.76	2.55	0.96	3.63		
2008/09 [b/]	43.04 [e/]	53.63	1.95	0.88	2.25	7.04	
2009/10	41.90 [e/]	28.44	0.61 [a/]	0.60	1.69	2.27	
2010/11	41.67	26.73	0.00	0.00	0.87	1.61	
2011/12		26.06 [c/]				2.75	2.48

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

Year	MSST	Biomass (MMB)	TAC (east + west)	Retained Catch	Total Catch	OFL	ABC
2007/08 [b/]		151.59	5.62	2.12	8.00		
2008/09 [b/]	94.89	118.23	4.30	1.94	4.96	15.52	
2009/10	92.37	62.70	1.34 [a/]	1.32	3.73	5.00	
2010/11	91.87	58.93	0.00	0.00	1.92	3.55	
2011/12		57.45 [c/]				6.06	5.47

a/ Only the area east of 166 deg. W opened in 2009/10; TAC was 1.85 million lb.
b/ Biomass and threshold definitions based on survey estimates derived using 50ft net width area-swept calculations
c/ Projected 2011/12 MMB at time of mating after extraction of the estimated total catch OFL.

EBS Tanner crab MMB was below MSST at the time of mating in mid-February 2011 and is still in an overfished state. Overfishing did not occur during the 2010/11 fishing year because total catch losses (0.87 thousand t) did not exceed the total catch OFL (1.61 thousand t). The stock is projected to remain below MSST in February 2012, under a catch equal to the OFL.

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

The ADF&G has not published harvest regulations for the Pribilof Islands red king crab fishery. The fishery began 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 2010/1 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 2010/11.

Data and assessment methodology

Although a catch survey analysis which incorporated data from the trawl survey, commercial catch, pot survey and at-sea observer data has been used for assessing the stock in the past, the 2011/12 assessment is based on trends in male mature biomass (MMB) at the time of mating inferred from NMFS bottom trawl survey from 1975-2011 and commercial catch and observer data from 1973/74 to 2010/11. The revised time-series of historical NMFS trawl survey abundance estimates were used in this assessment. The 2010/11 assessments of non-retained catch from all non-directed pot and groundfish fisheries were included in the SAFE report. Groundfish catches of red king crab are reported for all crab combined by federal reporting areas. Catches from observed fisheries were used to estimate total annual catch. An F_{OFL} for 2011/12 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 (May 2011) and SSC (June 2011), the annual index of MMB for this stock was derived as the 3-yr running average of the current year MMB and estimates of MMB in the previous two years. The $B_{MSY\ proxy}$ was estimated as the mean MMB over the period 1991-2011 in which each yearly MMB index is the 3-yr running average as described. The resultant F_{OFL} from the control rule was applied to the projected legal male biomass at the time of the fishery to determine the total male catch OFL. Exploitation rates on legal male biomass and on mature male biomass are estimated as the sum of total retained plus non-retained stock losses as a fraction of legal male biomass and on mature male biomass, respectively, at the time of the fishery.

Stock biomass and recruitment trends

The stock exhibited widely varying mature male and female abundances during 1975-2011. The average MMB estimatedfor 2011 was 3,834 t (8.45 million lb). Recruitment is not well understood for Pribilof red king crab. 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 and 2011/12. 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 declined slightly from 2009/10 to 2010/11, while losses resulting from discards in the groundfish trawl fleet increased from 2,450 t (5.40 million lb) to 3,870 t (8.53 million lb) between 2009/10 to 2010/11. In 2011, estimates of survey mature female biomass, legal male biomass and mature male biomass all increased substantially relative to 2010. The 2011 length frequency distributions reveal an increase in the proportion of old shell and very old shell males in the stock relative that seen in the 2009 and 2010 survey, and most notably in the legal component of the stock in 2011.

Pribilof Islands red king crabs have been historically harvested with blue king crabs and are currently the dominant of the two species in this area. Total catch losses of male and female red king crab in 2010/11 from all fisheries was 4,200 t (9.19 million lb) which increased from 2,800 t (6.13 million lb) in 2009/10. The 2011/12 stock is not overfished and overfishing did not occur in the 2010/11.

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

This stock is in Tier 4b and γ is set to 1.0. The time period for estimating the proxy for B_{MSY} was selected to be representative of the stock being fished at an average rate approximating F_{MSY} resulting in biomass fluctuating around B_{MSY}. In this assessment, the $B_{MSY\ Proxy}$ was estimated as the mean MMB at mating from 1991 to 2011, resulting in $B_{MSY\ Proxy}$=5,143 t (11.34 million lb) and MSST=2,572 t (5.67 million lb). The estimated 2010/11 MMB at mating was estimated at 2,577 t (5.68 million lb) which represents 0.501$B_{MSY\ Proxy}$. For the 2011/12 fisheries, the F_{OFL} estimated from the control rule (0.08) was applied to the projected legal male biomass at the time of the fishery to determine the total male catch OFL.

The author recommended an ABC less than the maximum permissible as calculated by the maxABC control rule. The estimated 2011/12 maxABC was 390 t (0.75 million lb). The CPT concurred with the author's recommendation to set the ABC below the maximum permissible. Sources of additional uncertainty outside the assessment resulted from the generally insufficient or imprecise data on this stock: the high survey coefficients of variation on survey estimates of mature biomass, the pre-specification of survey catchability (Q) and natural mortality rate (M); that F_{MSY} is assumed equal to the product of γM in which are both unknown; and that B_{MSY} is represented as the running 3-yr average survey MMB.

The CPT recommended an ABC which incorporates additional uncertainty (σ_b) in addition to the within assessment uncertainty (σ_w). In this calculation, σ_w=0.645, σ_b=0.40 and σ_{total}=0.759. This resulted in a multiplier of 0.78, and a recommended ABC for the 2011/12 fisheries of 307 t (0.68 million lb).

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	1.96	6.66	0	0	0.007		
2008/09	1.99	5.02^{A}	0	0	0.010	1.51	NA
2009/10	1.91	2.02^{B}	0	0	0.003	0.23	NA
2010/11	2.57	2.75^{C}	0	0	0.004	0.35	NA
2011/12		2.58^{D}				0.39	0.31

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	4.33	14.69	0	0	0.015		
2008/09	4.39	11.06^{A}	0	0	0.021	3.32	NA
2009/10	4.22	4.46^{B}	0	0	0.006	0.50	NA
2010/11	5.67	5.44^{C}	0	0	0.009	0.77	NA
2011/12		5.62^{D}				0.87	0.68

A – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
B – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
C – Based on survey data available to the Crab Plan Team in September 2010
D – Based on 3-yr average of 2009, 2010 and 2011 MMB estimates

Overfishing did not occur during 2010/11. The 2010/11 MMB was 2,577 t (5.68 million lb) which was above MSST (2,572 t; 5.67 million lb) but below $B_{\text{MSY Proxy}}$ (5,143 t; 11.34 million lb). Therefore, the stock was assigned to Tier 4b for the 2011/12 OFL calculation.

$B_{\text{MSY Proxy}}$=5,143 t (11.34 million lb) and MSST=2,572 t (5.67 million lb). The estimated 2010/11 MMB at mating was estimated at 2,577 t (5.68 million lb) which represents 0.501$B_{\text{MSY Proxy}}$.

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 until 1995. The fishery reopened from 1995 to 1998. Fishery harvests during this period ranged from 1.3 to 2.5 million lb. The fishery closed again in 1999 due to declining stock abundance and has remained closed through the 2010/11 season. The stock was declared overfished in 2002.

Data and assessment methodology

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

Stock biomass and recruitment trends

The survey biomass time series was recalculated in 2011 to include actual measured net widths. Based on 2011 NMFS bottom-trawl survey, the estimated total mature-male biomass increased to 461 t from 322 t in 2010. The 2011/12 MMB at mating is projected to be 365 t (average of the last three years)(0.80 million lb) which is about 4% of B_{MSYproxy}. The Pribilof blue king crab stock biomass continues to be low. From recent surveys there is no indication of recruitment. Station by station survey data for red king crab and blue king crab show they occupy similar areas, indicating red king are not displacing blue king crab.

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 period 1975/76 - 1984/85 plus 1990/1991-1997/1998, i.e. excluding the period 1985/1986-1989/1990. 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 8,839 t (19.49 million pounds).

The retained catch OFL is 0 because the 2010/11 estimate of MMB is less than 25% B_{MSY}. Due to the Tier level and stock status an F_{OFL} must be determined for the non-directed catch. Ideally this should be based on the rebuilding strategy. However the current rebuilding plan needs to be revised due to inadequate progress towards rebuilding.

The OFL for 2011/12 was estimated at 1.16 t (0.003 million lb), reduced from 2010/11 OFL of 1.81 t (0.004 million lb). The OFL is estimated from the average groundfish bycatch between 1999/00 and 2005/06, which was recalculated in 2011, resulting in the drop in the average catch.

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. The ABC was estimated at

1.04 t (0.002 million lb.).

In October 2011, the SSC recommended that the time period for estimating B_{MSY} be consistent with the 2010 assessment (1980/81- 1984/85 and 1990/91 to 1997/98) for a B_{MSY} of 4,490 t. The SSC concurred with the CPT on recommending an ABC less than the maximum permissible employing a 10% buffer on the average catch calculation for the OFL.

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
2007/08		300	closed	0	2.3		
2008/09	2,105	110	closed	0	0.5	1.81	
2009/10	2,105	510	closed	0	0.5	1.81	
2010/11	4,420	286	closed	0	0.18	1.81	
2011/12		365*				1.16	1.04

*- 3- year average survey biomass

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
2007/08		0.66	closed	0	0.005		
2008/09	4.64	0.25	closed	0	0.001	0.004	
2009/10	4.64	1.13	closed	0	0.001	0.004	
2010/11	9.74	0.63	closed	0	0.0004	0.004	
2011/12		0.80*				0.003	0.002

*- 3- year average survey biomass

The total catch for 2010/11 (0.18 t, 0.0004 million lb) was less than the 2010/11 OFL (1.81 t, 0.004 million lb) so overfishing did not occur during 2010/11. The 2011/12 projected MMB estimate of 365 t (0.80 million lb) is below the proxy for MSST (MMB/Bmsy = 0.08) so the stock continues to be in an overfished condition.

Additional Plan Team comments

A revised rebuilding plan is under development. Final action on this analysis will occur at the October 2011 Council meeting.

6 Saint Matthew blue king crab

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. The fishery developed when 10 U.S. vessels harvested 1.202 million pounds during 1977/78. Harvests peaked in 1983/84 when 9.454-million pounds were landed. The fishery was fairly stable from 1986/87 to 1990/91, with a mean annual harvest of 1.252-million pounds. The mean catch increased to 3.297-million pounds during the period from

1991/92 to 1998/99.

This 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 and an area closure to control bycatch as well as gear modifications. In 2008/09 and 2009/10, the MMB was above B_{MSY} for two years and was declared rebuilt in 2009.

The fishery re-opened in 2009/10 with a TAC of 1.167 million pounds and 0.461 million pounds of retained catch were harvested. The 2010/11 TAC was 1.6 million pounds and the fishery reported a retained catch of 1.264 million pounds Commercial crab fisheries near St. Matthew Island were scheduled in the fall and early winter to reduce the potential for bycatch from handling mortalities due to molting and mating crabs. Some bycatch has been observed of non-retained St. Matthew blue king crab in the St. Matthew blue king crab fishery, the eastern Bering Sea snow crab fishery, and groundfish fisheries. Based on limited observer data, bycatch of sublegal male and female crabs from 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. The 2009/10 fishery had lower observed bycatch in the directed fishery than historical estimates. Observed bycatch in 2010/11 more than doubled from 2009/10, but was still below historical estimates.

Data and assessment methodology

A three-stage catch-survey analysis (CSA) is used to assess the male component of the stock. The CSA incorporates the following data: (1) commercial catch data from 1978 to 2010/11; (2) annual trawl survey data from 1978 to 2011; (3) triennial pot survey data from 1995 to 2010; (4) bycatch data in the groundfish trawl fishery from 1989 to 2006 and in the groundfish fixed-gear fishery from 1996 to 2008; and (5) ADF&G crab-observer data for the years 1990/91-1998/99, 2009/10, and 2010/11. Fishery effort and catch data are the vessel numbers, potlifts, catch number and weight, and CPUE for the directed pot fishery; total annual retained catches (including deadloss) were used in the catch-survey analysis. 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 four size and shell-condition categories that were used in the assessment: 105–119 mm carapace length (CL); 90–104 mm CL; new-shell 120–133 mm CL; and old-shell ≥120 mm CL and new-shell ≥134 mm CL) males.

Pot survey data are from the July–August 1995, 1998, 2001, 2004, 2007, and 2010 ADF&G triennial pot surveys for Saint Matthew Island blue king crab. The pot survey samples areas of important habitat for 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 surveys. The CPUE (catch per pot lift) indices from those 96 stations for the male sex and shell-condition categories listed above were used in the assessment.

NMFS observer data were used to estimate groundfish trawl and fixed-gear bycatch. 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 stock is estimated to have been above B_{MSY} during 2008/09 through 2010/11 and is projected to be above B_{MSY} in 2011/12. MMB has fluctuated substantially over three periods. MMB increased during the first period (1978 to 1981) from 7.6 to over 17.6 million lb, followed by a steady decrease to 2.9 million lb. in 1985. The second period had a steady increase from the low in 1985 to 13.3 million lb. in 1997 followed by a rapid decrease to 2.8 million lb. in 1999. The third period had a steady increase in all size classes from the low in 1999 to the present high of over 15.8 million lb. in 2011/2012.

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

The CPT and SSC recommends that the stock be in Tier 4, with gamma (γ)=1 used for calculating F_{OFL}, and stock status level a. The CPT concurs with the use of the author recommended survey-based assessment while the model is undergoing revisions. The B_{MSYproxy} varies as a function of years used to calculate average MMB. The time period for estimating B_{MSYproxy} is 1989/90 to 2009/10 because the stock was harvested at extremely high rates before 1986 and this time period incorporates stock abundance during rebuilding. The B_{MSYproxy} during this time period is 6.865 million lb. The OFL is a total male OFL, as recommended by the team. The maxABC is based on cv = 0.5 and P*=0.49, which is 3.6 million pounds. However, to do the nature of the scientific uncertainty in the OFL, the team recommended a 10% buffer for an ABC of 3.4 million lb (1,530 t). Unaccounted for scientific uncertainty for this stock relates to the estimate of natural mortality, and that the survey does not cover the stock distribution (catchability) or the location of fishery. The trawl survey is a poor indication of abundance and may underestimate abundance. However, how the abundance index in the survey relates to the crab caught in the fishery or the total population is uncertain. The team discussed how to use this uncertainty to calculate an ABC because there is no expectation for information or analyses to resolve these uncertainties in the near future.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08		4.39	closed	closed	0.16		
2008/09	1.81	4.87	closed	closed	0.09	0.74 [retained]	
2009/10	1.52	5.79	0.53	0.20	0.25	0.78	
2010/2011	1.52	6.7	0.73	0.57	0.64	1.04	
2011/2012		7.17*				1.7	1.5

* Forecast based on survey data available in the 2011 assessment under the assumption that the 2010/11 catch is equal to the OFL. This value will be updated during the September 2012 assessment when the 2012 survey data and the 2011/12 catch data become available.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08		9.7	closed	closed	0.35		
2008/09	4.0	10.74	closed	closed	0.20	1.63 [retained]	
2009/10	3.4	12.76	1.17	0.46	0.53	1.72	
2010/2011	3.4	14.77	1.6	1.26	1.4	2.29	
2011/2012		15.8*				3.74	3.4

The total catch for 2010/11 (1.4 million lb) was less than the 2010/11 OFL (2.29 million lb) so overfishing did not occur during 2010/11. Likewise, the 2010/2011 MMB (14.77 million pounds) is above the MSST (3.4 million lb.) so the stock is not overfished.

Additional Plan Team recommendations

The team made additional recommendations for the stock assessment model for the 2012 assessment cycle. These recommendations are contained in the September 2012 Crab Plan Team report.

7 Norton Sound red king crab

Fishery information relative to OFL setting

This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence. The summer commercial fishery, which accounts for the majority of the catch, reached a peak in the late 1970s at a little over 2.9 million pounds retained catch. Retained catches since 1982 have been below 0.5 million pounds, averaging 275,000 pounds, including several low years in the 1990s. Retained catches in the past three years have been about 400,000 pounds.

Data and assessment methodology

Four types of surveys have been conducted periodically during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot, but none of these surveys were conducted every year. To improve abundance estimates, a length-based stock synthesis model of male crab abundance was previously developed that combines multiple sources of survey, catch, and mark-recovery data from 1976 to 1996. A maximum likelihood approach was used to estimate abundance, recruitment, and catchabilities of the commercial pot gear. The model has been updated with data from 2010/11 and estimated population abundance in 2011. The current model assumes $M=0.18yr^{-1}$ for all length classes, except $M=0.288\ yr^{-1}$ for the largest (> 123 mm CL) length group.

Stock biomass and recruitment trends

Mature male biomass was estimated to be on an upward trend following a recent low in 1997 and an historic low in 1982 following a crash from the peak biomass in 1977. 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. Uncertainty in biomass is driven in part by temporal (every 3 to 5 years) and spatial variability in trawl survey coverage.

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

The team recommended Tier 4 stock status for Norton Sound red king crab. The model was the same as that recommended by the Team for the 2010 assessment. This model estimates bycatch mortality in the directed fishery, assumes M to 0.288 yr^{-1} for the largest length bin and 0.18 yr^{-1} for other length bins, and assumes flat selectivity for the summer fishery. The estimated abundance and biomass in 2011 are:

Legal males: 1.471 million crabs with a standard deviation of 0.199 million crabs.
Mature male biomass: 4.699 million lb with a standard deviation of 0.644 million lb.

Average of mature male biomasses during 1983-2011 was used as the B_{MSY} proxy and the CPT chose gamma =1.0 to derive the F_{MSY} proxy.
Estimated B_{MSY} proxy, F_{MSY} proxy and retained catch limit in 2010 are:

- B_{MSY} proxy = 2.490 million lb,
- F_{MSY} proxy = 0.18

The maximum permissible ABC would be 0.65 million lb. A retrospective analysis in the assessment showed that each time new data are added, estimates of historic abundance become lower, i.e. the assessment tends to over-estimate abundance, particularly in the most recent year. Regressing the predicting legal abundance one year beyond the end of the assessment against the corresponding estimates from 2011 indicates that hindcast legal abundance is 59.2% of the estimate. Applying a 59.2% adjustment as a bias correction to the OFL results in a recommended ABC of 0.388 million lb.

In June 2011, the SSC recommended an ABC of 0.59 mill lb. The rationale for the SSC recommendation is provided in their minutes (SSC minutes June 2011).

Status and catch specifications (kt)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2007/08		2.00	0.15	0.14	0.18		
2008/09	0.81[A]	2.38[A]	0.19	0.18	0.21	0.31[A]	
2009/10	0.70[B]	2.64[B]	0.17	0.18	0.22	0.32[B]	
2010/11	0.71[C]	2.47[C]	0.18	0.19	0.22	0.33[C]	
2011/12	0.56[D]	2.13 [D]	0.16	0.18		0.30 [D]	0.27

A-Calculated from the assessment reviewed by the Crab Plan Team in May 2008
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2009
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2010
D- Calculated from the assessment reviewed by the Crab Plan Team in May 2011

Status and catch specifications (millions lb.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2007/08		4.40	0.32	0.31	0.36		
2008/09	1.78[A]	5.24[A]	0.41	0.39	0.43	0.68 [A]	
2009/10	1.54[B]	5.83[B]	0.38	0.40	0.43	0.71 [B]	
2010/11	1.56[C]	5.44[C]	0.40	0.42	0.46	0.73 [C]	
2011/12	1.25[D]	4.70[D]	0.36	0.40		0.66 [D]	0.59

A – Calculated from the assessment reviewed by the Crab Plan Team in May 2008
B – Calculated from the assessment reviewed by the Crab Plan Team in May 2009
C – Calculated from the assessment reviewed by the Crab Plan Team in May 2010
D - Calculated from the assessment reviewed by the Crab Plan Team in May 2011

Total catch in 2010/11 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 agrees with the authors that systematic declines in the retrospective estimates of abundance points to a model mis-specification that needs to be resolved.

The retrospective analysis shows a strong influence of the periodic trawl survey data. The CPT recommends conducting a retrospective analysis in which profiles are provided for other parameters. The 2011 assessment included only a likelihood profile for M based on the full time series.
Other requested changes and modification for the next assessment include:

- Provide greater consideration of selectivity as applied to the fisheries and surveys.
- Model notations used for equations need to be clarified.

This stock would be a good candidate for the subject of a modeling workshop.

8 Aleutian Island golden king crab

Fishery information relative to OFL setting

The directed fishery has been prosecuted annually since the 1981/82 season. Retained catch peaked during the 1986/87 season at 14.7 million lb , but average harvests dropped sharply from the 1989/90 to 1990/91 season to an average harvest 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, based on the previous five-year average catch, was subsequently reduced to 5.7- million lb beginning with the 1998/99 season. The GHL (or TAC, since the 2005/06 season) remained at 5.7 million lb through the 2007/08 season. Average retained catch for the period 1996/97–2007/08 was 5.6 million lb. In March 2008, the Alaska Board of Fisheries increased the TAC for this stock in regulation, to 5.985 million lb. Average retained catch for the period 2008/09–2009/10 was 5.8 million lb. This fishery is rationalized under the Crab Rationalization Program.

Data and assessment methodology

An assessment model is currently being developed for this stock. 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 2009/10 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. A triennial survey was scheduled for 2009, but was cancelled.

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.

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 2011/12. 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. For other time periods under consideration 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.

Thus, the CPT concurred with the author's recommended approach for establishing the OFL. This method is as follows:

$\mathrm{OFLTOT} = (1+\mathrm{RATE}90/91\text{-}08/09)\bullet\mathrm{OFLRET}(85/86\text{-}95/96) + \mathrm{BM}_{\mathrm{GF}}\ 93/94\text{-}08/09 = 11.40$ million lb

where:

RATE90/91-08/09 = mean annual rate = (bycatch mortality in crab fisheries)/(retained catch) over the period 1990/91-2008/09.

OFLRET85/86-95/96 = mean annual retained catch over the period 1985/86-1995/96, and

$\mathrm{BM}_{\mathrm{GF}}$93/94-08/09 = mean of annual bycatch mortality in groundfish fisheries over the period 1993/94-2008/09.

The recommended OFL is set following the June 2010 recommendation of the SSC, but uses additional historical data on bycatch that was not available for review in 2010.

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 10.26 million 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
2007/08	NA	NA	5.70	5.51	6.25		
2008/09	NA	NA	5.99	5.68	6.31	9.18 [A]	
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			11.40	10.26

A – retained catch

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	NA	NA	2.59	2.50	2.83		
2008/09	NA	NA	2.72	2.58	2.86	4.16 [A]	
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			5.17	4.66

A – retained catch

No overfished determination is possible for this stock given the lack of biomass information. Total catch in 2010/11 was below the retained catch OFL thus overfishing did not occur.

Additional Plan Team recommendations

In May 2011, the plan team reviewed a developing stock assessment model for Aleutian Islands golden king crab. Use of an assessment model could allow for this stock to be moved out of Tier 5 and would provide focus for establishing research and data collection priorities. The team recommended incorporation of plan team comments into the model for the September 2011 plan team meeting but did not recommend adopting the model for OFL determination in this year. The team subsequently reviewed the modeified stock assessment model at the September 2011 CPT meeting. Specific model recommendations are contained in the September 2011 Crab Plan Team report. This stock was identified for inclusion in the 2012 Crab Modeling workshop to assist the author in further development of this model.

9 Pribilof Island 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-thousandlb. Non-retained bycatch occurs in the directed fishery as well as Bering Sea snow crab, Bering Sea grooved Tanner crab, and Bering Sea groundfish fisheries. Estimated total fishing mortality in crab fisheries averages 78-thousand lb (2001-2010). Crab mortality in groundfish fisheries (July 1–June 30, 1991/92–2009/10) averages 6-thousand lb. There was no participation in the directed fishery from 2006-2009; one vessel participated in 2010. 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 NMFS upper-continental-slope trawl surveys in 2002, 2004, and 2008. 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 is confidential due to low number of participants.

Stock biomass and recruitment trends

Estimates of stock biomass (all sizes, both sexes) were provided for Pribilof Canyon. The 2008 Pribilof Canyon area-swept estimate of golden king crab biomass from the triennial slope survey was 2.026 million lb (CV=38%). This estimate is not being used for estimating stock biomass because it does not represent the whole distribution of the stock.

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

The Team recommends this stock be managed under Tier 5 in 2012.

The assessment author presented three alternatives for establishing the OFL. The Team concurs with the author's recommendation for an OFL based on Alternative 1 for 2012 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:

$OFL_{TOT,2012} = (1+R_{2001\text{-}2010}) * RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93\text{-}98/99}$

- R2001–2010 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.
- RET1993-1998 is the average annual retained catch in the directed crab fishery during 1993–1998 (period of unconstrained catch).
- BMNC,1994-1998 is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998.
- BMGF,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 (t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2008	N/A	N/A	68	0	0.0		
2009	N/A	N/A	68	0	0.5	77.1[A]	
2010	N/A	N/A	68	Conf.	Conf.	77.1[A]	
2011	N/A	N/A	68			81.6	
2012	N/A	N/A				90.7	81.6

A= Retained-catch OFL
Conf. = confidential

Status and catch specifications (millions lb)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2008	N/A	N/A	0.15	0	0.000		
2009	N/A	N/A	0.15	0	0.001	0.17[A]	
2010	N/A	N/A	0.15	Conf.	Conf.	0.17[A]	
2011	N/A	N/A	0.15			0.18	
2012	N/A	N/A				0.20	0.18

A= Retained-catch OFL
Conf. = confidential

No overfished determination is possible for this stock given the lack of mature biomass information. Although catch information is confidential under Alaska statute (AS 16.05.815) the assessment author indicated that the retained catch did not exceed the retained catch OFL of 0.17 million lb therefore overfishing did not occur. The 2011 fishery is ongoing until the GHL is achieved or until December 31.

10 Adak red king crab

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 21.193 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 0.943 million lb, but the retained catch during the 1995/96 season was low, only 0.039 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 0.5 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 0.506 million lb (2002/03) and 0.479 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 1995/96-2009/10 seasons averaged 0.003 million lb in crab fisheries and 0.022 million lb in groundfish fisheries. Estimated annual total fishing mortality (in terms of total crab removal) during 1995/96-2009/10 averaged 0.109 million lb. The average retained catch during that period was 0.084 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 1995/96-2009/10 and from groundfish fisheries during 1993/94-2009/10 are available. There is no assessment model in use 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 Petrol Bank area in 2006 provided no evidence of strong recruitment. A 2009 survey conducted by ADF&G in the Petrol 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 2011/12 season. The CPT concurs with the assessment author's recommendation of an OFL based on the 1995/96–2007/08 average total catch. The CPT recommends a total catch OFL for 2010/11 of 0.12 million lb, following the recommendation of the SSC in June 2010 to freeze the time period for computing the total-catch OFL at 1995/96–2007/08.

The team recommends that the directed fishery remain closed given concerns of stock status. The team struggled to establish an ABC which would account solely for bycatch in other fisheries. Groundfish bycatch in recent years has accounted for the majority of the catch of this stock. The maximum permissible ABC is 0.111 million lb based on the Tier 5 control rule of a 10% buffer on the OFL.

However, the CPT recommends an ABC of 0.074 million lb based on the maximum annual groundfish and crab fishery bycatch during the period 1995/96–2009/10.. Based on the limited information available on this stock, the team struggled to adequately quantify the uncertainty in order to develop an ABC below the maximum permissible. The team recognizes that the stock is distributed over a wide area, making an appropriate recommendation for an ABC difficult.

The SSC recommended an ABC of 0.03 in June 2011, their rationale for this choice is reflected in their minutes from that meeting (SSC minutes June 2011).

Status and catch specifications (t) of Adak RKC.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	NA	NA	Closed	0	4.99		
2008/09	NA	NA	Closed	0	6.35	208.7[A]	
2009/10	NA	NA	Closed	0	5.44	226.8[A]	
2010/11	NA	NA	Closed	0		54.43[B]	
2011/12	NA	NA				54.43[B]	12

A-Retained catch OFL based on 1984/85-2007/08 mean retained catch
B-Total catch OFL of 54.43 t based on the average for 1995/96-2007/08.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2007/08	NA	NA	Closed	0	0.011		
2008/09	NA	NA	Closed	0	0.014	0.46[A]	
2009/10	NA	NA	Closed	0	0.012	0.50[A]	
2010/11	NA	NA	Closed	0	0.004	0.12[B]	
2011/12	NA	NA				0.12[B]	0.03

A-Retained catch OFL based on 1984/85-2007/08 mean retained catch
B-Total catch OFL of 0.12 million lb based on the average for 1995/96-2007/08.

No overfished determination is possible for this stock given the lack of biomass information. Total catch was below the OFL in 2010/11 therefore overfishing did not occur.

Table 3 Crab Plan Team recommendations for September 2011 (stocks 1-6) and SSC final recommendations (in **bold**) from October 2011. Note that recommendations for stocks 7-10 represent those final values recommended by the SSC in June 2011. Note diagonal fill indicates parameters are not applicable for that tier level. Values in 1000 (t)

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2011/12[2] [3] MMB	2011 MMB / MMB_{MSY}	γ	Mortality (M)	2011/12 OFL	2011/12 ABC
1	EBS snow crab	3	b	1.42	147.48	1979-current [recruitment]	133.8	0.91		0.23(females) 0.319 (imm) 0.299 (mat males)	73.50	**66.15**
2	BB red king crab	3	a	0.32	27.3	1984-2011	29.76	1.05		0.18default Estimated[4]	8.80	**7.92**
3	EBS Tanner crab	4	b	0.08	83.33	1974-1980	33.20	0.40	1.0	0.23	2.75	**2.48**
4	Pribilof Islands red king crab	4	b	0.08	5.14	1991/92-2010/11	2.58	0.50	1.0	0.18	0.393	0.307
5	Pribilof Islands blue king crab	4	c	0	**4.49**	**1980/81-** 1984/85 1990/91/-1997/98	0.37	0.08	1.0	0.18	0.00116	.00104
6	St. Matthew Island blue king crab	4	a	0.18	3.11	1989/90-2009/10	7.17	2.31	1.0	0.18	1.7	1.5 [total male catch]
7	Norton Sound red king crab	4	a	0.18	1.13	1983-current [model estimate]	2.13	1.9	1.0	0.18	0.30	**0.27**
8	AI golden king crab	5				See intro chapter					5.17	4.66
9	Pribilof Island golden king crab	5				See intro chapter					0.09	0.08
10	Adak red king crab	5				1995/96–2007/08					.054	**0.014**

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 2/15/2012 at time of mating.
3 Model mature biomass on 7/1/2011
4 Additional mortality males: two periods-1980-1985; 1968-1979 and 1986-2008. Females three periods: 1980-1984; 1976-1979; 1985 to 1993 and 1968-1975; 1994-2008. See assessment for mortality rates associated with these time periods.

Table 4 Maximum permissible ABCs for 2011/12 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 in **bold** represent those final values recommended by the SSC in June/October 2011.

Stock	Tier	2011/12 *Max*ABC	2011/12 ABC
EBS snow crab	3a	73.4	**66.15**
Bristol Bay red king crab	3a	8.78	**7.92**
EBS Tanner crab	4b	2.75	**2.48**
Pribilof Islands red king crab	4b	0.390	0.307
Pribilof Islands blue king crab	4c	NA	0.00104
Saint Matthew blue king crab	4a	1.63	1.50
Norton Sound red king crab	4a	0.29	**0.27**
Adak red king crab	5	0.05	**0.014**

Table 5. Stock status in relation to status determination criteria 2010/11
(Note diagonal fill indicates parameters not applicable for that tier level)

Chapter	Stock	Tier	MSST	B_{MSY} or $B_{MSYproxy}$	2010/11[4] MMB	2010/11 MMB / MMB_{MSY}	2010/11 OFL 1000 t	2010/11 Total catch
1	EBS snow crab	3	73.7	147.5	196.6	1.33	44.4	26.7
2	BB red king crab	3	13.63	27.26	32.64	1.19	10.67	7.71
3	EBS Tanner crab	4	41.67	83.34	26.73	0.32	1.61	0.87
4	Pribilof Islands red king crab	4	2.57	5.14	2.75	0.54	0.35	0.004
5	Pribilof Islands blue king crab	4	2.25	4.49	0.29	0.06	0.0018	0.0002
6	St. Matthew Island blue king crab	4	1.52	3.04	6.70	2.20	1.04 [total male catch]	0.64 [total male catch]
7	Norton Sound red king crab	4	0.71	1.42	2.47	1.74	0.33	0.22
8	AI golden king crab	5					5.02	2.98
9	Pribilof Island golden king crab	5					0.08	Conf.
10	Adak red king crab	5					0.05	0.02

4 MMB as estimated during this assessment for 2009/10 as of 2/15/2010.

Stock Assessment of eastern Bering Sea snow crab

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National Marine Fisheries Service
September 9, 2011

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 762,100 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. Using the current definitions for estimating B_{MSY}, and Model results for any scenario presented here (models 1 through 10), the snow crab stock was above B_{MSY} for the last three years (2008/09, 2009/10 and 2010/11). The total mature observed survey biomass in 2011 was 447,400 t which is 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 female mature biomass in 2011.

Observed survey mature male biomass increased from 157,310 t in 2010 to 167,400 t in 2011. Observed survey mature female biomass also increased from 145,099 t in 2010 to 280,000 t in 2011 (a 93% increase). The 2011 estimate of males greater than 101 mm was 150.7 million, an increase from 135.0 million in 2010. Observed survey numbers of small crab, and the large increase in mature female biomass in 2011 indicate an above average recruitment moving through the stock.

Model estimates (Model 7) of mature male biomass at mating decreased from 184,900 t in 2009/10 to 179,000 t in 2010/11 (110% of B35% (162,190 t)).

Catch has followed survey abundance estimates of large males, since the survey estimates have been the basis for calculating the GHL (Guideline Harvest Level for retained catch). 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 since the 2000/01 fishery. Retained catch in the2010/11 fishery was 24,670 t, compared to the 2009/10 fishery catch of 21,785 t. The total catch in the 2010/11 fishery was estimated at 26,720t, below the OFL of 44,400 t.

Estimated discard mortality (mostly undersized males and old shell males) in the directed pot fishery has averaged about 15.5% (with assumed discard mortality of 50%) 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 2010 assessment was the model recommended by the CPT in May 2010 and the SSC in June 2010 ("Model 5" of the May 2010 assessment, Model 0 of this assessment). The September 2010 assessment model estimated natural mortality for mature male crab in the model (M= 0.29) and included the 2009 study area data to inform estimates of survey Q. This assessment presents 10 model scenarios, and an additional 3 model scenarios in progression from the September 2010 model and the 10 model scenarios. The formulation of survey selectivity for NMFS in the 2009 and 2010 study areas was modified from the September 2010 assessment for all model scenarios 1-10 (see text). The 2010 study area data from BSFRF and NMFS was added to the assessment model scenarios 1-10 as an additional survey for estimation of survey selectivity. Model scenarios 8-10 include the new growth per molt curve estimated from the 2011 growth study (Somerton, pers. Comm.).

The OFL for 2011/12 ranged from 47,200 t to 79,400 t, depending on the model scenario (Table 10). The 2010/11 OFL was 44,400 t

The MMB at mating projected for 2011/12 when fishing at the F35% control rule (OFL) ranged from 88% to 92% of B35%. The MMB projected for 2011/12 when fishing at 75% F35% control rule, ranged from 93% to 99% of B35%. Projected total catch fishing at 75% F35% control rule ranged from 39,200 t to 69,200 t.

Year	Bmsy [a] proxy (1000t)	MSST (1000t)	Biomass (MMB) (1000t)	TAC (1000t)	Retained Catch (1000t)	Total Catch[b] (1000t)	OFL (1000t)
2005/06				16.7	16.8	19.5	NA[c]
2006/07				16.4	16.5	20.4	NA
2007/08	144.1	72.1	98.9	28.6	28.6	35.0	NA
2008/09	148.2	74.1	109.3	26.6	26.5	31.5	35.1
2009/10	133.2	66.6	127.7	21.8	21.8	23.9	33.1
2010/11				24.6	24.7	26.7	44.4
2011/12							

[a] Bmsy proxy for 2009/10 based Sept 2010 assessment.
[b] 50% mortality applied to pot discard mortality, 80% mortality applied to groundfish bycatch.
[c] The first year of implementation of the OFL was 2008/09.

Changes to the Model

Changes to the model for September 2011 from the September 2010 assessment are: 1) Immature M for male and females and mature male M fixed and/or estimated in the model depending on scenario (Tables 7, 8 and 18), 2) formulation of survey selectivity in the 2009 and 2010 study areas for NMFS tows revised (February Crab Modeling Workshop recommendation, see text), 3) Model scenarios 4,5 and 6 estimated the availability curve for BSFRF in the 2009 and 2010 study areas as a smooth function 4) code for calculation of the growth transition matrix revised to work with the most recent versions of ADMB (same as with the Tanner crab model assessment) and 5) postmolt distributions in the growth transition matrix were truncated (set to zero) at 40mm above the premolt bin, 6) Model scenarios 8, 9 and 10 have growth fixed at the growth curve estimated from the 2011 growth study data.

Changes to the Data

The 2010 survey length frequency and biomass data from the BSFRF and NMFS special study area of the Bering Sea were added to the model for estimation of survey selectivity.
2011 Bering Sea survey biomass and length frequency data added to the model. 2010/11 directed fishery retained and discard catch and length frequencies. Groundfish dicard length frequency from 2008-2010 added and 2010 groundfish discard catch.

April 2011 SSC comments

The main issue for the current snow crab assessment concerns incorporation of information into the model from a cooperative field study of gear selectivity between BSFRF and AFSC in 2009 and 2010 (see SSC report, February 2011). Workshop participants examined the study results in depth and provided suggestions on alternative analyses, including averaging 2009 and 2010 results and fitting a mixed effects linear model. Snow crab assessment scientist Jack Turnock (AFSC) presented preliminary results of an analysis which incorporated the experimental results directly into the stock assessment model. Workshop participants were not satisfied with the preliminary results, because, counterintuitively, the 2010 selectivity curve increased dramatically at larger crab sizes, which were poorly represented in the data (also noted by the SSC in their report). Suggestions were made for alternate selectivity curves and inclusion of an availability parameter.

Since the workshop, the stock assessment analyst has continued to develop the model and presented new results at this SSC meeting. He examined 3- and 6-parameter logistic curves and a 23-parameter smooth-penalty function, and included an additional parameter for availability. The resulting selectivity curves were promising, except there was still a hump in male selectivity at small crab sizes using the smoothing approach. Because natural mortality and selectivity are often confounded, assessment author explored the use of higher natural mortality on immature crabs. The likelihood was maximized for values of immature male natural mortality between 0.35 and 0.40, compared to the standard male mortality of 0.23. This also smoothed out the hump and made the curve look more like a logistic curve. The SSC is pleased with the progress that has been made but suggests that immature mortality should be estimated internally in the model. The SSC also notes that the assessment author has followed the spirit of SSC recommendations from

February. ***For the May-June crab meetings, the SSC is supportive of the approach of incorporating the experimental data directly into the assessment model, instead of outside the model as the SSC suggested in February.***

The SSC notes that there are other suggestions contained in our June 2010 and October 2010 reports that still might be useful. These suggestions include estimation of natural mortality for females and mature males, bivariate distributions of catchability and natural mortality, and sensitivity studies of population parameters and reference points to various model components.

In the long term, the SSC recommends that crab researchers pursue further analysis of the experimental data. *This leads to two recommendations that are concisely stated in the workshop report as short-term recommendation 2 (developing a logical scheme to combine the 2009 and 2010 data) and long-term recommendation 1 (developing a negative binomial mixed effects model). This work could help validate the selectivity estimates from the stock assessment model and provide further understanding of the factors affecting selectivity.*

Authors Response to April 2011 SSC Comments

The Base Model presented in this assessment (May 2011) includes the recommendaions of the February Modeling Workshop and the March 2011 SSC, where natural mortality for immature crab is estimated in the model and the 2009 and 2010 experimental data are fit in the model.

May 2011 CPT comments

The team recommends that September 2011 assessment be based on the following six scenarios:

1. *Assume logistic availability, estimate immature M, fixed mature M to 0.23yr^{-1}.*
2. *Assume logistic availability, fix immature M to 0.23 yr^{-1}, estimate mature M with a prior centered at 0.23yr^{-1}.*
3. *Assume logistic availability, estimate immature M, estimate mature M with a prior centered at 0.23yr^{-1}.*
4. *Estimate availability using length-specific parameters subject to a smoothing penalty, estimate immature M, fixed mature M to 0.23yr^{-1}.*
5. *Estimate availability using length-specific parameters subject to a smoothing penalty, fix immature M to 0.23 yr^{-1}, estimate mature M with a prior centered at 0.23yr^{-1}.*
6. *Estimate availability using length-specific parameters subject to a smoothing penalty, estimate immature M, fixed mature M to 0.23yr^{-1}.*

The team agreed that the selectivity pattern for the NMFS survey obtained when separate selectivity parameters were estimated for each length-class was unexpected (dome-shaped), and, while some possible reasons for this were identified (e.g. larger crab burrowing in the substrate, larger crab out of the survey area), the team did not wish to see this option pursued for the September 2011 assessment.

The results presented to the team differ substantially from those of the 2010 assessment. The team therefore recommended that the assessment author provide a sequence of scenarios which start from the model on which the September 2010 was based (model '0') and show the consequences of each change to the model in terms of time-trajectories of MMB and other key *model outputs. This will allow the team the ability to evaluate the major reasons for the changes to the assessment outcomes.*

The team identified that the following changes need to be made to the assessment report:

- *Update the document so that it includes all of the material in the powerpoint presentation (before the June SSC review of the report); the document presented to the CPT did not include some key material included in the powerpoint presentation.*
- *Add the fit of the model with separate selectivity parameters for each length-class for the NMFS survey in the Bering Sea to Figures 98 and 99.*
- *Add measures of uncertainty to the circles in Figures 92 and 93.*
- *Fully specify the model (add the equations used to calculate the length-composition of the catches by the BSFRF survey; add the equations which specify the smoothness penalty; specify how the length-frequencies for the NMFS and BSFRF surveys in the BSFRF survey area were computed; clarify that availability and Q_{BSFRF} are year-specific; specify how the 'offsets' are calculated).*
- *Include the CVs for the survey estimates in the table of observed biomass.*
- *Include likelihood profiles over Q and M for immature crab.*
- *Include a list of sources of uncertainty not considered in the within-assessment uncertainty estimated.*
- *Include a retrospective analysis (and comment on the causes for any major changes to the assessment outcomes; e.g. due to exclusion of the 2010 BSFRF-NMFS side-by-side data).*
- *Add a table comparing the likelihood values and discuss it in the text*

The team noted that the results of the likelihood profile for Q as well as models based on alternative assumptions could be used as the basis for ABC recommendations. Only models which are 'plausible' (i.e. at least the fit the data) should be considered when developing ABC recommendations below the maximum ABC.

Authors Response to May 2011 CPT Comments

Model scenarios are presented for 1-6 above as well as an additional scenarios 7-10. Model scenarios 0, 0.1 and 0.2 progression from September 2010 model also run. Likelihood profiles on Q and M included.

June 2011 SSC comments

The SSC received an update on the current status of the snow crab model, which has undergone substantial changes since September 2010. Four models were explored including the September 2010 model that estimates mature male mortality, models estimating immature M with either a logistic or smooth selectivity function, and a model keeping all mortality rates (immature, mature males, mature females) constant at M=0.23 and fixed growth parameters. All other models estimated growth within the model as in September 2010, which greatly improved residual patterns. The SSC agrees that model formulations, which estimate growth within the model is most appropriate. All models also incorporate the BSFRF data and estimate survey selectivity within the model as endorsed by the SSC in April 2011. While the SSC noted some concern that there is still considerable discrepancy between the selectivity curve estimated by

Somerton, as presented to the SSC in December 2010, and the model-based estimates of selectivity, the model takes into account both the 2009 and 2010 survey and the estimated selectivity may reflect a trade-off between somewhat conflicting trends in the 2009 and 2010 data.

The CPT requested six models for the September 2011 assessment that focus on exploring two selectivity options (logistic and smooth selectivities) and three mortality scenarios in a factorial design. ***The SSC concurs with these recommendations and encourages the authors to clearly lay out the consequences of incremental changes to the base model in the September 2011 assessment.***
The SSC re-iterates requests from previous minutes for the authors and the plan team, and other survey specialists to consider for future assessments:

- *Development of a spatial model for snow crab*
- *Evaluation of the weights that are used for different likelihood components and the effective sample size for the multinomial likelihood to increase consistency with how likelihood components are weighted in other assessments (both crab and groundfish) and to provide a better rationale for the values used.*
- *Development of a logical scheme to combine data from the 2009 and 2010 trawl experiments to better understand the factors affecting selectivity.*

Authors Response to June 2011 SSC Comments

Model scenarios are presented for 1-6 above as well as an additional scenarios 7-10. Model scenarios 0, 0.1 and 0.2 progression from September 2010 model also run. Likelihood profiles on Q and M included.

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 retained catch for the 2007/08 fishery increased to 28,600 t and was 26,560 t in 2008/09 due to increasing biomass. The retained catch for the 2009/10 fishery was 21,820 t. The total catch for the 2009/10 fishery was estimated at 23,780 t, which was below the 75% F35% control rule value determined in the September 2009 assessment at 27,180 t (retained catch 22,910 t) and below the 2009/10 OFL of 33,100 t total catch.

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 1992 trawl discard mortality was about 1,950 t, increased to about 3,550 t in 1995, then declined to about 0900 t to 1,500t until 1999. Trawl bycatch in 2008/09 and 2009/10 was 300 t and 680 t respectively. Discard in groundfish fisheries from highest to lowest snow crab bycatch 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 may be 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. The maximum full selection fishing mortality rate is close to 1.0 at the maximum harvest rate of 0.225 of mature male biomass.

DATA

Data Sources

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from 1978 to the 2010/11 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 2009/10. Total discarded catch was estimated from observer data from 1992 to 2010/11 (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 2010/11. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The mortality of discarded crab was assumed to be 50%. This estimate differs from the current rebuilding harvest strategy used since

2001, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discard mortality assumptions will be discussed in a later section. 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	1978/79-2010/11
Discarded male and female crab pot fishery size frequency	1992/3-2010/11
Trawl fishery bycatch size frequencies by sex	1991-2010
Survey size frequencies by sex and shell condition ("new" survey data)	1978-2011
Retained catch estimates	1978/79-2010/11
Discard catch estimates from snow crab pot fishery	1992/93-2010/11 from observer data
Trawl bycatch estimates	1973-2010/11
Total survey biomass estimates and coefficients of variation ("new" survey data)	1978-2011
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 89% 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 2 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 302,400 t in 2010 and increased again to 447,400 t in 2011.

Survey mature male biomass increased from 141,300 t in 2009 to 157,300 t in 2010 and 167,400 t in 2011.
The observed survey estimate of males greater than 101 mm increased from 125.9 million in 2009 to 137.6 million in 2010 and 150.7 million in 2011 (Table 2).

Survey mature female biomass increased from 103,800t in 2009 to 145,100t in 2010 and 280,000 t in 2011 (a 93% increase).

The term mature for male snow crab will be used here to mean 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 show high abundance in the 40 to 50 mm range. The recruitment has progressed into the mature female abundance in 2011. 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° 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° N. (Figure 9). In 2003 and 2004 the ice edge was farther north than past years, allowing some fishing to occur as far north as 60-61° N. Catch in the 2006/07 fishery was similar to recent years (Figure 10) with most catch south of 58 ° N. and west of the Pribilof Islands between about 171° W and 173° 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 ° longitude and 55.5 to 56.6 ° latitude which has not occurred in recent years (Figure 11). About 93% of the retained catch came from south of 58.5° N.

Survey data from 2010 estimated a larger abundance of small crab than in 2009 (male and female) mostly in the northern part of the survey area (Figures 12 through 18). Large males (>101mm) were distributed similar to 2009, however, farther south than in previous years (Figure 14). Mature females with less than or equal to half clutch of eggs were mostly in the northern part of the survey area above 58 ° N (Figure 17).

Distribution of snow crab by haul for 2011 are shown in Figures 19 through 25).
Survey data from 2011 show more widespread distributions of male crab greater than 77mm and >101mm (Figures 19 and 21). Immature female snow crab distribution extends farther south than in 2010 (Figures 15 and 22).

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° 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 ° N, in the 1990's the centroids were about 59.5 ° N. The centroids of old shell male distribution was south of 58 ° 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 ° N in the early 1980's, then was farther north (58.5 to 59 ° 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 3). The NMFS abundance of females >=50mm (121.5 million) was greater than the BSFRF abundance estimate in the study area (113.6 million) (Table 3).

The abundance of male crab in the entire Bering Sea survey for 2009 was greatest in the 30 – 60mm size range (Figure 29). 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 30). 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. (this meeting). 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 42 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.

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. 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 an essential control 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 5). 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 99^{th} percentile of the distribution of ages in an unexploited population if observable. Under negative exponential depletion, the 99^{th} percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method an M=0.23 corresponds to a maximum age of 18 years (Table 6). 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,

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

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

Growth

Very little information exists on growth for Bering Sea snow crab. 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.

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. No growth measurements exist for Bering Sea snow crab females. North Atlantic growth data indicate growth is slightly less for females than males.

Growth was modeled using a linear function to estimate the mean width after molting given the mean width before molting (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. 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.

A new growth curve was estimated by Somerton (pers. Comm.) from snow crab males collected in 2011 combined with data from Rugolo(pers.Comm.) as a three parameter equation (Figure 55),

post-molt CW = -0.75 + 1.39 Premolt CW – 0.0015 * (Premolt CW)^2

Model scenarios 8, 9 and 10 use the above growth curve fixed in the 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*,

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

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

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

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

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

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

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 14.

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 study area) 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.

Fishery cpue in average number of crab per pot lift.

$$\sum_{t=1}^{tf} \left[\frac{\log(CPUE_t) - \log(\hat{C}PUE_t)}{sqrt(2) * s.d.(\log(CPUE_t))} \right]^2$$

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.

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

No penalty was used when immature M was estimate.
Growth parameters were estimated in the model using a penalty which assumes a normal distribution,

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

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).

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

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

There were a total of 276 to 323 parameters estimated in the model, depending on scenario (Table 16) for the 34 years of data (1978-2011). The 96 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 34 recruitment parameters estimated in the model, one for the mean recruitment, 33 for each year from 1979 to 2011 (male and female recruitment were fixed to be equal). There were 8 fishery selectivity parameters that did not change over time as in previous assessments. Survey selectivity was estimated for three different periods resulting in 9 parameters for males and 9 parameters for females estimated. There were 12 survey selectivity parameters were estimated for the study area BSFRF male and female logistic availability curves. 22 parameters for each year (2009 and 2010) and sex were estimated for the availability curve for BSFRF in model scenarios 4, 5 and 6. One or two parameters for natural mortality (depending on scenario) and 3 growth parameters were also estimated, except for models 8, 9 and 10 were the new growth curve was fixed.

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 13). 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 parameters estimated in the model. The alpha parameter of the distribution was fixed at 11.5 and the beta parameter was 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 assumed to be 50% for this assessment. 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 analysis presented here builds on earlier analyses by addressing key recommendations from the February 2011 crab modeling workshop, the SSC April and June 2011 and May 2011 CPT recommendations. The CPT and SSC in 2010 and 2011, recommended the use of the BSFRF 2009 and 2010 survey data as an alternative survey in the assessment model to inform estimates of survey selectivity. Table 7 contains a description of all model scenarios.

The model used in the September 2010 assessment estimated natural mortality for 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. Small crab (<40mm) were removed from the2009 study area data to allow the use of three parameter logistic curves to estimate survey selectivity and obtain a good fit to length data. The removal of small crab solves the problem of lack of fit of very small crab confounding estimates of selectivity of larger crab. While a survey that has a consistent catchability of small crab is desirable for recruitment estimation, the purpose of the surveys in the study area was mainly to inform survey selectivity of mature and larger crab.

Following the recommendation of the CPT and SSC, abundance estimates by length as well as survey biomass for the study area for the BSFRF tows as well as the NMFS tows were added to the stock assessment model as an additional survey. Survey selectivities were estimated using logistic curves for males and females for the NMFS standard survey in the entire Bering Sea area and the BSFRF tows in the study area (Model scenarios 1,2,3,7,8,9,10, Table 7). Model scenarios 4,5,and 6 use a smooth function for the BSFRF availability for male crab in the study areas. 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 Model scenarios presented here include a formulation of the NMFS study area survey selectivity that has been revised from the September 2010 assessment model.

The maximum selectivity in the September 2010 assessment for the NMFS study area was estimated by the product of the Q for the NMFS Bering Sea area and the Q for the BSFRF survey in the study area. The Q for the BSFRF survey in the study area was assumed to represent the fraction of crab available in the study area relative to the entire Bering Sea. The maximum catchability of the BSFRF net in the study area was assumed to be 1.0. 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.

The survey selectivity for the NMFS net in the study area in the September 2010 model was formulated as,

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

$C_l^s =$ numbers by length for NMFS net in the study area (s)

$S_l^s =$ vector of selectivity by length in study area for 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

The revised formulation used in this assessment and recommended by the February 2011 Crab Modeling Workshop was,

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

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

A_l = 2 parameter logistic 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 and the BSFRF availability were estimated using a 3 parameter logistic function (scenarios 1,2,3,7,8,9,10),

$$\text{Selectivity}_1 = \frac{Q}{1+e^{\left\{\frac{-\ln(19)(l-l_{50\%})}{(l_{95\%}-l_{50\%})}\right\}}}$$

The BSFRF availability was estimated as a smooth function (23 parameters, 1 parameter for each length bin(22) and Q for model scenarios 4,5, and 6.

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

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

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

Model scenarios 0, 0.1 and 0.2 are the September 2010 model with the same data as scenarios 1-10, except scenario 0 does not have the 2010 study area data. Scenario 0.1 is scenario 0 with the 2010 study area data, and scenario 0.2 is scenario 0 with the change in formulation of NMFS selectivity in the study areas.

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,

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

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

The temporal autocorrelation error (ε_t) was estimated as,

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

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,

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

$B_t^{'}$ mature male biomass in year t with implementation error input to the harvest control rule,

B_t mature male biomass in year t,

ρ_I temporal autocorrelation for implementation error, set at 0.6 (estimated from the recruitment time series),

σ_I standard deviation of φ which determines the magnitude of the implementation error.

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

RESULTS

The authors preferred model is Model 7, where natural mortality for all crab is fixed at 0.23, which is consistent with data on longevity of snow crab. Mature male M in model 2 was estimated at 0.33, which corresponds to longevity less than about 15 years, which is not consistent with Canadian tagging data. Without a prior constraint on M, the best fit is obtained at a higher value than the estimation of 0.33 in model 2, indicating that there is not sufficient information in the data to estimate M reliably.

The total mature biomass increased from about 353,600 t in 1978 to the peak biomass of 762,000 t in 1990 for model scenario 7 (Table 4a). Biomass declined sharply after 1997 to about 256,100 t in 2003. Total mature biomass increased to 412,900 t in 2010 (Table 4a scenario 7, Table 4b scenario 2 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 discard catch mortality for 1978 to 2008 was estimated to be about 16.7% of the retained catch (with 50% mortality applied), similar to the average observed discards from 1992 to 2008 (15.5%) (Tables 1a and 1b, and Figure 58). Parameter estimates are listed in Table 13. Estimates of observed discard mortality ranged from 6% of the retained catch to 32% of the retained catch (assuming 50% discard mortality). Discard mortality has declined over the last three years from 12.9% in 2008/09 to 9.4% in 2009/10 and 4.2% in 2010/11.

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 2, Tables 4a and 4b, Figures 62 and 64). Model estimates (scenario 7) of mature male biomass increased from 154,200 t in 2006 to 239,400 t in 2009, and then declined to 223,400 t in 2011. Observed survey mature male biomass increased from 141,300 t in 2009 to 157,300 t in 2010 and 167,400 t in 2011. Model estimates of mature female biomass has an increasing trend from 120,400 t in 2009 to 189,500 t in 2011. Mature female biomass observed from the survey increased about 93% from 145,100 t in 2010 to 280,000 t in 2011.

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 2010 assessment Q for the 1989 to present period was estimated at 0.75 for male crab (Turnock and Rugolo 2010). 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 Q for male crab, 1989 to present, depends on the estimation of natural mortality (Table 8 and Figure 102).

Q estimates ranged from 0.55 (scenario 3, immature M estimated at 0.320 and mature male M = 0.315), to 0.753 (scenario 10, M fixed at 0.23, new growth curve). The results when using a smooth function for BSFRF availability were slightly higher Q values and lower natural mortality (scenarios 4, 5 and 6). The survey selectivity curves estimated for model 5 are shown in Figures 120 and 121.

Model scenario 0 (September 2010 model, no 2010 study area data, includes other data through 2011) estimated Q at 0.699 (lower than the September 2010 assessment) and mature male M = 0.309 (higher than the September 2010 assessment). The addition of the 2010 study area data to model scenario 0 (scenario 0.1) resulted in a decrease in Q (0.647) and an increase in mature male M (0.326). Scenario 0.2 (scenario 0 with change in formulation of NMFS study area selectivity) estimated Q lower than scenario 0 at 0.628 and mature male M higher (0.324).

The total likelihood declines from M=0.18 to about M=0.25, reaches the lowest likelihood at 0.326, then increases at higher M (Figure 117) (Model scenario 2, prior on M included in the likelihood). The likelihood is similar at M=0.25 and M=0.38. The total likelihood declines with decreasing Q to a low at Q=0.60 (using Model scenario 2). The likelihood is relatively flat from about Q=0.7 to 0.55, then increases at Q<0.55 (Figure 118).

The estimated number of males > 101mm generally follows the observed survey abundance estimates (Figure 73). The observed survey estimate of males greater than 101 mm has been increasing since 2008 and increased from 137.6 million crab in 2010 to 150.7 million crab in 2011(Table 2). The estimated 95% confidence interval for the observed survey large males in 2011 was +/-24% of the estimate. Model estimates of large males show a decreasing trend from 232.6 million in 2008 to 196.9 million in 2011.

Two main periods of above average recruitment were estimated by the model, in 1979-1981, 1983, 1987 and 2004 (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 1988 to 1998, 2000 to 2003 and 2006. The 1998-1999 and 2004 year classes appear to be about average recruitment that has resulted in an increase in biomass in recent years. The 2004 year class is estimated to higher in this assessment than in September 2010, since the 2011 survey data continue to indicate an above average recruitment has entered the stock. The recruitment from the 2004 year class has entered the mature female biomass and resulted in a large increase in biomass in 2011 from 2010. The recruits to the model may enter the mature stock after about 2 year to 7 years depending on whether they are male or female. The spread of years is large as male crab mature over a wide range of sizes.

The size at 50% selected for the pot fishery for total catch (retained plus discarded) was 103.3 mm for males (shell condition combined, Figure 56). The size at 50% selected for the retained catch was 105.6 mm. The fishery generally targets 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 0.14 to 2.69 (Figure 85 and Table 4a). Fishing mortality rates ranged from 0.60 to 2.69, 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 0.22 to 0.59, with F estimated at 0.29 in 2010/11.

Model estimates (Model 7) of mature male biomass at mating decreased from 184,900 t in 2009/10 to 179,000 t in 2010/11 (110% of B35% (162,190 t), Figure 87). MMB at mating for scenario 7 was above B35% in 2008/09, 2009/10 and 2010/11. MMB at mating for all model scenarios (1-10) was estimated to be above B35% in the last three years (Figure 103).

Likelihood values for the alternative model scenarios are shown in Tables 16 and 17.

Survey selectivity curves estimated for model scenario 7 are shown in Figures 90 to 97.

Model scenario 7 fits to the length frequency in the 2009 and 2010 study areas are shown in Figure 98.
Model scenario 7 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 model scenario 7 estimates the 2010/11 F to be below the overfishing level and MMB at mating above B35%(Figure 101).

Fits to data for model scenario 2 are shown in Figures 106 to 116.

Harvest Strategy and Projected Catch

Current Rebuilding Harvest Strategy

The harvest strategy described here is the current rebuilding strategy 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 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.

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

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).

$$
F = \begin{cases} Bycatch\ only,\ Directed\ F = 0, & if\ \dfrac{B_t}{B_{REF}} \le \beta \\[2ex] \dfrac{F_{REF}\left[\dfrac{B_t}{B_{REF}} - \alpha\right]}{(1-\alpha)} & if\ \beta < \dfrac{B_t}{B_{REF}} < 1 \\[2ex] F_{REF} & if\ B_t \ge B_{REF} \end{cases} \qquad (12)
$$

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 2009 and mature male biomass per recruit fishing at F35%.

Biomass and catch projections based on $F_{REF} = F_{35\%}$ and Bref = $B_{35\%}$ were used to estimate the catch OFL, 75%F35% and the ACL for model scenarios 1-10 in 2011/12 (Tables 9, 10 and 11. The OFL was estimated as the median of the distribution of OFLs from the stochastic projection model described earlier. OFL in 2011/12 ranged from 47,200 t to 79,400 t depending on model scenario. Model scenario 7 OFL was 52,800 t (retained 48,000 t). Average total catch from 1978/79 to 2010/11 was 52,030 t (43,900 t retained catch average), which includes periods of high and low stock abundance. 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. Higher catches from 1978/79 to 1998/99 may have contributed to the decline of the stock and resulting low levels of abundance over the last 10 years, and therefore would not be considered sustainable.

MMB at mating in 2011/12 fishing at the OFL ranged from 88% to 92% of B35%. The ACL was estimated based on a probability of overfishing of 49% from the projection model with a cv on 2010/11 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 12). Fishing at 75%F35% the total catch ranged from 39,200 t to 69,200 t (Table 11).

F35% in the September 2010 assessment was estimated at 1.24 and B35% at 133,246 t. F35% ranged from 0.71 to 1.65 for model scenarios 1-10. F35% was 0.89 for model scenario 7. B35% ranged from 135,630 t to 173,750 t for model scenarios 1-10. B35% for model scenario 7 was 162,190 t.

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 2011 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, 0.62 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 2011 mature male biomass projected forward to the time of mating time (Feb. 2012), 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 model scenario 7 with multipliers on the F35% control rule of 1.0 and 0.75. The rebuilding strategy implemented in 2000 (ADFG strategy) was also run for comparison. Steepness of the Beverton and Holt spawner recruit curve used in projections was estimated at 0.744 and R_0 at 1.660 billion crab, by equating F35% with Fmsy and B35% with Bmsy

The rebuilding strategy implemented in 2000/01 was developed for use with observed survey data and includes reference points based on observed survey data, not based on the current assessment model.

Median biomass values are projected to decline in 2011/12 fishing at the OFL, 75%F35% or at the ADFG strategy, then projected to increase (Tables 12a, 12b and 12c). MMB at mating relative to B35% is estimated in 2011/12 is estimated at 88.9%, 93.9% and 101.9% fishing at the OFL, 75% F35% and the ADFG harvest strategy respectively.

Figure 112. History of exploitation rate on mature male biomass relative to the exploitation rate corresponding to fishing at F35%.
Figure 113. Log of recruits/MMB at mating with a 5 yr lag for recruitment and mature male biomass at mating.

Conservation concerns

- Discard mortality has been assumed to be 50%, however there is a high level of uncertainty in this parameter. While sensitivity studies have shown only small differences in long term catch and biomass with different assumptions on discard mortality, higher discard mortality would necessitate lower retained catches in the short term.

- 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.

A full management strategy evaluation of the snow crab model has been funded by NPRB for the period 2008-2011.

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Table 1a. 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 2010/11 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(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	0.68	21.80	33.10
2010/11	24.67	2.05	26.72	2010	0.19	24.62	44.40

Table 1b. Model estimates of catch (1,000 t) for Bering Sea snow crab. Model estimates of pot fishery discards include a 50% mortality and groundfish discard 80% mortality.

Year	Model estimate of male retained (1000 t)	Model estimate of male discard(50% 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	23.80	1.10	0.10	3.80	24.80	28.70
1979/80	34.10	1.40	0.10	3.10	35.50	38.60
1980/81	30.50	3.30	0.10	2.20	33.80	36.10
1981/82	13.40	3.90	0.10	0.70	17.20	18.00
1982/83	11.90	2.60	0.10	0.20	14.50	14.80
1983/84	12.20	1.30	0.10	0.40	13.50	13.90
1984/85	30.00	2.40	0.00	0.40	32.40	32.80
1985/86	44.50	3.20	0.00	0.40	47.70	48.10
1986/87	46.30	4.20	0.10	1.80	50.50	52.40
1987/88	61.50	10.30	0.10	0.20	71.90	72.10
1988/89	67.90	15.50	0.10	0.50	83.40	84.10
1989/90	73.60	16.10	0.10	0.70	89.60	90.50
1990/91	149.40	29.20	0.10	0.60	178.60	179.30
1991/92	143.30	32.10	0.20	1.90	175.50	177.50
1992/93	105.00	28.00	0.30	1.70	133.00	135.00
1993/94	67.90	9.90	0.20	1.70	77.80	79.70
1994/95	34.30	6.30	0.20	3.50	40.60	44.20
1995/96	29.80	9.80	0.10	1.20	39.70	41.00
1996/97	54.70	10.80	0.20	0.80	65.40	66.40
1997/98	114.40	11.20	0.00	1.40	125.60	127.10
1998/99	88.30	7.80	0.00	0.90	96.10	97.00
1999/00	15.10	1.20	0.00	0.40	16.40	16.80
2000/01	11.50	0.90	0.00	0.30	12.50	12.80
2001/02	15.00	1.80	0.00	0.20	16.90	17.10
2002/03	13.00	1.90	0.00	0.10	14.90	15.10
2003/04	10.90	1.10	0.00	0.50	12.00	12.50
2004/05	11.30	0.90	0.00	0.70	12.20	12.90
2005/06	16.90	1.60	0.00	0.20	18.50	18.70
2006/07	16.60	2.40	0.00	0.60	19.00	19.60
2007/08	28.60	4.40	0.00	0.30	33.00	33.40
2008/09	26.60	3.10	0.00	0.20	29.80	30.00
2009/10	21.80	1.80	0.00	0.50	23.60	24.20
2010/11	24.60	1.80	0.00	0.20	26.40	26.60

Table 2. 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	0.2	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	0.12	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	0.115	209.5	0.105	466.5	63
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	0.20	147.3	52.3
2004/05	84.5	0.28	75.8	0.16	160.3	56
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	97.7
2009/10	103.8	0.22	141.3	0.12	245	125.9
2010/11	145.1	0.156	157.3	0.142	302.4	137.6
2011/12	280.0	0.178	167.4	0.12	447.4	150.7

Table 3a. 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 3b. 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 4a. Model 7 estimates of population biomass (1000t), population numbers, male, female and total mature biomass(1000t) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs. * Numbers by length estimated in the first year, so recruitment estimates start in second year.

Year	Biomass (1000t 25mm+)	numbers (million crabs 25mm+)	Female mature biomass (1000t)	Male mature biomass (1000t)	Total mature biomass (1000t)	Number of males >101mm (millions)	Recruit-ment (millions, 25 mm to 50 mm)	Male mature biomass at mating time(Feb of survey year+1) (1000t)	Full selection fishing mortality	Exp.rate of total male catch on mature male biomass
1978/79	479.4	6,759.9	145.8	207.8	353.6	167.6		145.0	0.35	0.15
1979/80	498.5	6,898.2	171.5	167.2	338.7	122.9	788.0	98.3	0.84	0.27
1980/81	531.3	6,832.2	225.2	124.0	349.2	65.6	710.0	66.8	2.17	0.37
1981/82	558.6	6,253.9	241.2	113.2	354.4	40.2	453.3	78.6	1.27	0.21
1982/83	592.7	5,273.5	229.7	170.0	399.6	105.0	177.2	129.2	0.34	0.11
1983/84	633.3	5,594.1	204.4	264.1	468.5	240.1	717.9	207.0	0.14	0.06
1984/85	668.6	6,681.9	188.9	312.8	501.7	311.3	1,131.2	224.5	0.28	0.13
1985/86	701.5	8,107.1	197.0	302.8	499.8	300.2	1,427.3	210.2	0.43	0.19
1986/87	802.1	11,533.7	224.5	266.8	491.3	239.0	2,585.7	176.8	0.60	0.22
1987/88	877.3	9,870.5	285.9	256.2	542.1	195.9	398.2	156.6	1.15	0.32
1988/89	1,014.2	12,629.2	310.5	282.1	592.6	198.7	2,458.6	166.0	1.39	0.35
1989/90	1,067.2	10,010.6	339.6	340.1	679.7	247.9	71.6	215.6	1.08	0.31
1990/91	1,070.6	8,387.3	335.5	426.7	762.1	356.6	304.3	205.7	1.99	0.50
1991/92	909.6	6,978.2	296.2	381.9	678.1	298.8	330.2	169.9	2.69	0.55
1992/93	855.9	11,818.5	254.0	303.6	557.6	214.9	3,312.8	151.7	2.55	0.51
1993/94	817.1	10,361.9	294.2	259.2	553.4	186.6	621.2	152.9	1.48	0.35
1994/95	821.7	9,033.5	329.6	217.8	547.4	113.5	473.1	149.9	1.06	0.22
1995/96	840.5	7,293.4	314.9	238.6	553.5	112.3	101.7	176.8	0.87	0.19
1996/97	843.7	5,825.8	272.6	349.2	621.8	266.7	58.2	248.0	0.66	0.22
1997/98	763.9	4,690.2	225.1	434.2	659.3	419.2	93.4	258.5	0.94	0.33
1998/99	580.0	4,490.4	183.9	330.8	514.7	298.1	489.0	193.4	1.04	0.34
1999/00	440.4	4,253.0	161.0	216.6	377.6	166.8	423.1	171.4	0.25	0.09
2000/01	395.6	3,646.3	150.7	179.3	330.0	132.2	147.6	137.2	0.24	0.08
2001/02	363.7	3,153.3	137.3	153.5	290.8	105.1	139.2	116.9	0.41	0.13
2002/03	346.9	3,196.1	120.0	146.2	266.2	103.4	360.0	113.1	0.36	0.12
2003/04	358.0	4,003.1	109.3	155.8	265.1	128.6	745.2	123.5	0.23	0.09
2004/05	394.3	5,083.2	115.1	157.5	272.5	137.4	962.1	124.2	0.22	0.09
2005/06	426.2	4,812.9	135.8	150.8	286.6	123.5	397.9	113.0	0.38	0.14
2006/07	458.7	4,655.9	146.8	154.2	300.9	115.9	431.5	116.1	0.41	0.14
2007/08	477.3	3,874.7	145.3	186.0	331.3	150.0	105.1	132.0	0.59	0.20
2008/09	473.4	3,715.7	132.5	220.3	352.9	198.9	348.3	163.9	0.39	0.16
2009/10	527.0	6,829.9	120.4	239.4	359.9	232.6	1,964.6	184.9	0.26	0.11
2010/11	573.8	6,848.2	154.0	235.9	389.9	228.1	730.6	179.0	0.29	0.13
2011/12	613.7	6,378.7	189.5	223.4	412.9	196.9	490.2	NA	NA	NA

Table 4b. Model 2 estimates of population biomass (1000t), population numbers, male, female and total mature biomass(1000t) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs. * Numbers by length estimated in the first year, so recruitment estimates start in second year.

Year	Biomass (1000t 25mm+)	numbers (million crabs 25mm+)	Female mature biomass (1000t)	Male mature biomass (1000t)	Total mature biomass (1000t)	Number of males >101mm (millions)	Recruit-ment (millions, 25 mm to 50 mm)	Male mature biomass at mating time(Feb of survey year+1) (1000t)	Full selection fishing mortality	Exp.rate of total male catch on mature male biomass
1978/79	502.4	8,744.8	166.4	146.2	312.6	198.1		87.1	0.34	0.22
1979/80	572.4	9,077.3	205.7	139.0	344.7	159.7	1,097.2	68.2	0.69	0.34
1980/81	655.7	9,217.7	292.6	111.6	404.3	90.7	1,046.6	53.3	1.42	0.39
1981/82	722.5	8,534.9	324.0	127.1	451.2	64.9	656.7	83.5	0.77	0.18
1982/83	774.7	7,149.4	313.0	213.5	526.5	146.2	229.4	152.3	0.27	0.09
1983/84	817.9	7,532.7	279.9	324.6	604.5	298.5	975.2	237.4	0.13	0.05
1984/85	845.6	8,823.2	258.4	370.8	629.2	367.3	1,472.3	247.2	0.26	0.12
1985/86	875.8	10,586.0	266.9	350.1	617.0	343.7	1,858.4	230.4	0.42	0.17
1986/87	995.3	14,757.2	300.2	305.1	605.3	265.0	3,253.9	192.1	0.60	0.21
1987/88	1,080.5	12,435.7	374.7	297.6	672.3	212.3	442.1	176.7	1.16	0.30
1988/89	1,242.7	15,804.4	401.3	337.2	738.5	219.8	3,076.5	191.6	1.38	0.32
1989/90	1,294.4	12,481.1	433.5	408.4	842.0	277.7	103.4	251.2	1.05	0.27
1990/91	1,280.9	10,476.7	426.3	499.8	926.1	395.3	432.9	236.2	1.95	0.46
1991/92	1,085.3	8,734.3	377.6	441.5	819.1	328.6	448.8	192.3	2.66	0.51
1992/93	1,047.8	15,486.1	325.6	347.6	673.1	236.8	4,511.2	170.2	2.46	0.47
1993/94	1,025.8	13,580.8	383.4	296.8	680.2	209.8	822.7	170.3	1.40	0.32
1994/95	1,050.8	11,969.5	433.7	258.1	691.8	129.5	710.0	171.9	0.99	0.19
1995/96	1,077.4	9,625.5	418.2	297.1	715.4	133.0	153.2	213.6	0.79	0.16
1996/97	1,070.1	7,619.4	364.8	433.4	798.1	320.1	85.1	298.8	0.59	0.18
1997/98	952.7	6,083.1	302.5	519.9	822.5	495.4	138.8	305.9	0.84	0.30
1998/99	726.9	6,020.9	247.9	388.5	636.4	354.4	758.8	223.8	0.92	0.30
1999/00	561.8	5,769.4	219.7	251.0	470.7	204.3	616.3	188.7	0.22	0.08
2000/01	502.2	4,921.5	208.6	199.1	407.7	153.9	215.5	141.8	0.23	0.08
2001/02	461.5	4,233.6	191.7	167.7	359.4	116.6	200.9	120.9	0.40	0.12
2002/03	445.1	4,414.9	168.2	164.5	332.7	118.5	565.6	120.9	0.34	0.11
2003/04	462.2	5,474.1	154.7	179.4	334.2	152.9	1,020.3	135.1	0.21	0.08
2004/05	509.4	6,880.5	163.1	180.2	343.2	160.2	1,299.7	134.9	0.21	0.08
2005/06	550.6	6,504.1	190.0	172.9	363.0	138.9	553.2	123.6	0.37	0.13
2006/07	590.9	6,179.3	203.8	183.5	387.3	131.7	547.2	132.4	0.40	0.13
2007/08	607.7	5,097.6	200.1	226.1	426.2	174.7	140.7	155.4	0.55	0.18
2008/09	593.5	4,846.9	181.4	264.7	446.1	231.3	460.6	189.1	0.36	0.14
2009/10	648.1	8,699.7	163.9	277.5	441.4	263.4	2,483.7	204.0	0.25	0.10
2010/11	695.3	8,721.1	203.8	262.7	466.4	246.4	956.6	189.1	0.30	0.12
2011/12	738.8	8,136.0	247.1	243.8	490.9	200.9	658.1	NA	NA	NA

Table 5. 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 6. 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

Table 7. Model scenarios. Female mature M is fixed at 0.23 for all models.

Model Scenario		BSFRF Availability	Immature M (males and females)	Mature male M
1		Logistic	estimate	0.23
2		Logistic	0.23	Estimate w/prior
3		Logistic	estimate	Estimate w/prior
4		Smooth	estimate	0.23
5		Smooth	0.23	Estimate w/prior
6		Smooth	estimate	Estimate w/prior
7		Logistic	0.23	0.23
8	New male growth fixed	Logistic	estimate	0.23
9	New male growth fixed	Logistic	0.23	Estimate w/prior
10	New male growth fixed	Logistic	0.23	0.23
0	Sept 2010 model	Logistic	0.23	Estimate w/prior
0.1	Model 0 with 2010 study area data	Logistic	0.23	Estimate w/prior
0.2	Model 0 with change in formulation of NMFS study area selectivity. Without 2010 study area data	Logistic	0.23	Estimate w/prior

Table 8. Immature M, mature female M, mature male M and survey Q for males 1989-Present for model scenarios 1-10, 0, 0.1 and 0.2.

scenario	Immature M(male and female)	Mature Female M (fixed)	Mature Male M	Q, males 1989-Present
1	0.367	0.230	0.230	0.572
2	0.230	0.230	0.326	0.604
3	0.320	0.230	0.315	0.554
4	0.353	0.230	0.230	0.612
5	0.230	0.230	0.325	0.604
6	0.319	0.230	0.299	0.583
7	0.230	0.230	0.230	0.714
8	0.405	0.230	0.230	0.649
9	0.230	0.230	0.310	0.699
10	0.230	0.230	0.230	0.753
0	0.230	0.230	0.309	0.699
0.1	0.230	0.230	0.326	0.647
0.2	0.230	0.230	0.324	0.628

Table 9. 2011/12 projected catch (1000t) fishing at 75%F35% for model scenarios 1-10.

scenario	Total	retained	MMB/B35%	Prob above B35%	F35%	B35%
1	59.2(46.8,68.4)	53.6(42.5,62)	97.4(87.2,109.5)	0.347	1.20	173.75
2	63.9(51.1,73.1)	57.3(45.9,65.6)	98.5(88.6,110.9)	0.406	1.49	141.73
3	69.2(55.5,79.6)	62(49.9,71.3)	97.9(88,110)	0.374	1.65	148.57
4	53.6(42.3,62.8)	48.9(38.6,57.2)	96.1(85.9,107.5)	0.259	1.04	167.50
5	64.6(51.7,74.1)	58.2(46.6,66.7)	98.3(88.5,110.6)	0.398	1.46	141.08
6	63.7(50.8,73.8)	57.5(46,66.6)	97(87.2,108.6)	0.312	1.42	147.48
7	44.2(34.7,52.9)	40.3(31.6,48.2)	93.9(83.8,104.5)	0.162	0.89	162.19
8	46.8(36.8,55.4)	42.2(33.1,49.9)	95(84.9,106.1)	0.205	0.89	163.04
9	48.8(38.6,56.8)	43.5(34.5,50.6)	96.8(86.8,108.5)	0.308	0.96	135.63
10	39.2(30.6,47.5)	35.3(27.6,42.8)	92.7(82.7,103)	0.107	0.71	158.43

Table 10. 2011/12 projected catch (1000t) fishing at 100%F35%(OFL) for model scenarios 1-10.

scenario	total	retained	MMB/B35%	Prob above B35%	F35%	B35%
1	69.4(55.4,83.8)	62.7(50.1,75.5)	91.9(82.6,101.2)	0.071	1.20	173.75
2	73.6(59.3,88.1)	65.7(53.1,78.4)	92.2(83.2,101.2)	0.072	1.49	141.73
3	79.4(64.1,95.2)	70.7(57.3,84.5)	91.6(82.7,100.4)	0.061	1.65	148.57
4	63.3(50.3,77.1)	57.5(45.8,69.9)	90.6(81.4,99.4)	0.038	1.04	167.50
5	74.5(60,89.4)	66.7(53.9,79.9)	91.9(83,100.7)	0.063	1.46	141.08
6	73.5(59.2,88.7)	66.1(53.4,79.5)	90.7(81.9,99.3)	0.032	1.42	147.48
7	52.8(41.7,64.7)	48(37.9,58.7)	88.9(79.7,97.8)	0.021	0.89	162.19
8	55.7(44.1,68.1)	50(39.6,61)	89.9(80.6,98.8)	0.027	0.89	163.04
9	57.4(45.7,69.8)	51(40.7,61.9)	90.9(81.9,99.6)	0.039	0.96	135.63
10	47.2(37.1,58)	42.4(33.4,52)	88(78.8,96.8)	0.015	0.71	158.43

Table 11. 2011/12 projected catch (1000t) fishing at ACL (Probability of overfishing = 49%) for model scenarios 1-10.

scenario	Total Catch	Retained Catch
1	69.29	62.60
2	73.46	65.57
3	79.23	70.54
4	63.13	57.34
5	74.30	66.52
6	73.38	66.00
7	52.68	47.89
8	55.55	49.86
9	57.23	50.85
10	47.06	42.27

Tables 12a-c. Projections using a multiplier on the F35% control rule for 2011/12 to 2019/20 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%, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is full selection fishing mortality and exploitation rate is total male catch relative to mature male biomass at the time of the fishery. Base model $B_{35\%}$ = 168,000 t. $F_{35\%}$ = 1.01. All projections have rebuilding strategy (multiplier) in effect until rebuilt, then strategy switches to a 0.98 multiplier.

a) Model 7, 100% $F_{35\%}$ B35% = 162,190 t F35%=0.89

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Prob MMB> B35%**	**Full Selection Fishing Mortality**
2011/12	52.8(41.7,64.7)	48(37.9,58.7)	88.9(79.7,97.8)	0.021	0.78
2012/13	39.9(25.2,57.3)	33.1(21.1,46.7)	88.2(76.6,99.8)	0.061	0.74
2013/14	65.4(41.4,83)	54.5(35.1,68.1)	107.7(90.9,125.9)	0.764	0.87
2014/15	82.9(57.7,104.9)	73.6(51.7,92.4)	122.9(100.5,149.9)	0.958	0.87
2015/16	73.1(48.1,96.2)	63.9(43.2,82.2)	117.8(89.5,159.6)	0.965	0.85
2016/17	65.4(37,119.2)	56.1(32.5,96.9)	115.7(79.6,194)	0.966	0.84
2017/18	68.9(28.6,167.7)	59(25.3,142.5)	119.5(73.6,248.7)	0.977	0.82
2018/19	72.1(24.2,187)	61.9(20.8,164.6)	122.4(67.7,279.6)	0.981	0.82
2019/20	72(20.2,195.5)	61.7(17.2,170.7)	124(63.5,286.1)	0.986	0.81
2020/21	71.1(18.4,192.2)	61.9(16.2,171.5)	126.7(59.6,289.6)	0.986	0.8

b) Model 7, 75% $F_{35\%}$ B35% = 162,190 t F35%=0.89

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Prob MMB> B35%**	**Full Selection Fishing Mortality**
2011/12	44.2(34.7,52.9)	40.3(31.6,48.2)	93.9(83.8,104.5)	0.162	0.62
2012/13	36(22.3,49.7)	30.2(18.8,41.4)	94.8(82.6,107.5)	0.261	0.6
2013/14	55.4(36.4,71.5)	46.9(31.3,59.8)	117.7(101.1,136.2)	0.956	0.66
2014/15	71.8(52.5,92.9)	64.4(47.2,82.8)	138.1(115.6,165.6)	0.999	0.65
2015/16	66.4(46.7,87.1)	58.9(42.3,76.6)	134.3(104.6,176.8)	0.999	0.64
2016/17	60.2(37.4,106.1)	52.9(33.3,88.6)	130.7(92.7,217.8)	0.999	0.64
2017/18	63(29.7,147.4)	54.9(26.7,126.9)	135.9(84,278)	0.999	0.63
2018/19	65.6(23.8,165.3)	57.4(21.3,148)	139.6(76.5,316.9)	0.999	0.64
2019/20	66.4(19.3,174.6)	58.3(17.1,153.8)	141.5(70.4,329)	0.999	0.63
2020/21	65.1(17.8,180.1)	57.3(16,156)	145.6(67.4,331.3)	0.999	0.62

c) Model 7, ADFG harvest strategy, B35% = 162,190 t F35%=0.89

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Prob MMB> B35%**	**Full Selection Fishing Mortality**
2011/12	30.5(24.2,37.6)	27.9(22.1,34.4)	101.9(89.9,113.6)	0.605	0.4
2012/13	32.3(19,45.2)	27.7(15.7,41)	103.5(89.5,117.2)	0.727	0.46
2013/14	45.9(25.4,80.8)	39.9(21.2,73.9)	129.3(108.8,149.5)	0.994	0.48
2014/15	57.2(31.1,105.5)	51.3(27.2,103.5)	153.9(128.4,180.7)	1	0.45
2015/16	58.1(30.1,92.7)	52(26.6,89.5)	153.5(125.8,188)	1	0.49
2016/17	55.9(27.3,122)	50.2(24,106.6)	149.3(114.7,215.3)	1	0.5
2017/18	59.6(23.3,176.6)	53.1(20.6,162.3)	151.2(105.3,273.1)	1	0.52
2018/19	61.5(21.6,186)	54.7(18.9,173.2)	155.3(96.9,297.5)	1	0.53
2019/20	59.7(18.2,181.6)	53.4(16,160.1)	157.9(88.5,310.6)	1	0.51
2020/21	59.4(17.2,182.7)	52.8(15.3,166.9)	158.6(84.2,318.5)	1	0.51

Table 13. Model 7 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	0.23		N	
Natural Mortality mature females and males	0.23		N	
Female intercept (a) growth	7.35	0.25	set equal to male	
Male intercept(a) growth	7.35	0.25	Y	
Female slope(b) growth	1.06	0.01	Y	
Male slope (b) growth	1.13	0.01	Y	
Alpha for gamma distribution of recruits	11.50		N	
Beta for gamma distribution of recruits	4.00		N	
Beta for gamma distribution female growth	0.75		N	
Beta for gamma distribution male growth	0.75		N	
Fishery selectivity total males slope	0.16	0.00	Y	
Fishery selectivity total males length at 50%	105.58	0.15	Y	
Fishery selectivity retention curve males slope	0.40	0.02	Y	
Fishery selectivity retention curve males length at 50%	96.88	0.15	Y	
Pot Fishery discard selectivity female slope	0.36	0.01	Y	
Pot Fishery discard selectivity female length at 50%			Y	
Trawl Fishery selectivity slope	0.09	0.00	Y	
Trawl Fishery selectivity length at 50%	94.46	1.67	Y	
Survey Q 1978-1981 male	1.00	0.00	Y	
Survey 1978-1981 length at 95% of Q male	56.99	3.04	Y	
Survey 1978-1981 length at 50% of Q male	38.36	1.45	Y	
Survey Q 1978-1981 Female	1.10	0.04	Y	
Survey 1978-1981 length at 95% of Q female	56.99	3.04	Set equal to Male	
Survey 1978-1981 length at 50% of Q female	38.36	1.45	Set equal to Male	
Survey Q 1982-1988 male	0.71	0.05	Y	
Survey 1982-1988 length at 95% of Q male	61.69	4.08	Y	
Survey 1982-1988 length at 50% of Q male	38.53	1.45	Y	
Survey Q 1982-1988 female	0.77	0.02	Y	
Survey 1982-1988 length at 95% of Q female	61.69	4.08	Set equal to Male	
Survey 1982-1988 length at 50% of Q female	38.53	1.45	Set equal to Male	

Table 13 cont. Model 7 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	0.71	0.03	Y	
Survey 1989-present, length at 95% of Q male	46.92	2.12	Y	
Survey 1989-present length at 50% of Q male	33.15	0.87	Y	
Female Survey Q 1989-present	0.78	0.02	Y	
Female Survey 1989-present, length at 95% of Q	47.15	1.78	Y	
Female Survey 1989-present length at 50% of Q	33.83	0.79	Y	
Male BSFRF 2009 Study area Q (availability)	0.25	0.05	Y	
Male BSFRF 2009 Study area length at 95% of Q	74.51	4.05	Y	
Male BSFRF 2009 Study are length at 50% of Q	63.86	2.01	Y	
Female BSFRF 2009 Study area Q (availability)	0.75	0.13	Y	
Female BSFRF 2009 Study area length at 95% of Q	60.99	2.54	Y	
Female BSFRF 2009 Study are length at 50% of Q	53.06	1.29	Y	
male BSFRF 2010 Study area Q (availability)	0.75	0.07	Y	
male BSFRF 2010 Study area length at 95% of Q	25.03		N	
male BSFRF 2010 Study are length at 50% of Q	25.00		N	
Female BSFRF 2010 Study area Q (availability)	1.71	0.16	Y	
Female BSFRF 2010 Study area length at 95% of Q	25.03		N	
Female BSFRF 2010 Study are length at 50% of Q	25.00		N	

Table 14. Weighting factors for likelihood equations.

Likelihood component	Weighting factor
Retained catch	10
Retained catch length comp	1
Total catch	10
Total catch length comp	1
Female pot catch	10
Female pot fishery length comp	0.2
Trawl catch	10
Trawl catch length comp	0.25
Survey biomass	survey cv by year
Survey length comp	1
Recruitment deviations	1
Fishing mortality average	1
Fishing mortality deviations	0.1
Initial length comp smoothness	1
Fishery cpue	0.14 (cv = 5.0)

Table 15. Model 7 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			145.0	9.9
1979/80	788.1	163.9	98.3	6.7
1980/81	710.0	149.8	66.8	5.0
1981/82	453.3	118.6	78.6	5.5
1982/83	177.2	77.8	129.2	9.2
1983/84	717.9	125.7	207.0	14.2
1984/85	1131.2	173.9	224.5	16.2
1985/86	1427.3	209.2	210.2	16.3
1986/87	2585.7	221.1	176.8	14.2
1987/88	398.2	150.1	156.6	11.8
1988/89	2458.6	74.0	166.0	10.9
1989/90	71.6	28.4	215.6	11.7
1990/91	304.3	43.0	205.7	10.0
1991/92	330.2	72.8	169.9	8.2
1992/93	3312.8	155.3	151.7	7.8
1993/94	621.2	97.5	152.9	8.1
1994/95	473.1	62.0	149.9	8.4
1995/96	101.7	32.4	176.8	10.1
1996/97	58.2	20.3	248.0	13.4
1997/98	93.4	32.2	258.5	14.9
1998/99	489.0	67.2	193.4	13.5
1999/00	423.1	62.7	171.4	11.9
2000/01	147.6	39.0	137.2	9.9
2001/02	139.2	40.2	116.9	9.1
2002/03	360.0	63.8	113.1	8.7
2003/04	745.2	99.1	123.5	8.8
2004/05	962.1	109.3	124.2	8.6
2005/06	397.9	86.9	113.0	8.1
2006/07	431.5	74.5	116.1	8.3
2007/08	105.1	40.4	132.0	9.8
2008/09	348.3	81.4	163.9	12.1
2009/10	1964.6	235.6	184.9	13.5
2010/11	730.6	128.3	179.0	13.9
2011/12	490.2	159.9		

Table 16. Likelihood values for model scenarios 1-7 (see table 7 for description).

Likelihood Component	1	2	3	4
Recruitment	33.26	32.45	32.03	33.16
Initial numbers old shell males small length bins	0.12	0.12	0.12	2.44
ret fishery length	-2023.49	-2042.39	-2043.26	-2055.39
total fish length	685.81	679.90	680.98	682.61
female fish length	155.58	154.64	155.42	155.03
survey length	3174.14	3174.57	3159.83	3176.16
trawl length	216.04	223.46	221.39	218.15
2009 BSFRF length	-92.01	-92.40	-91.54	-88.79
2009 NMFS study area length	-78.97	-79.74	-78.45	-79.08
M prior	0.00	29.97	23.25	0.00
maturity smooth	46.41	51.12	48.62	48.97
growth a	2.26	2.76	2.64	1.90
growth b	0.05	0.04	0.05	0.05
2009 BSFRF biomass	0.09	0.11	0.09	0.15
2009 NMFS study area biomass	0.07	0.09	0.06	0.08
retained catch	3.28	2.77	2.97	3.05
discard catch	127.94	103.45	113.50	121.42
trawl catch	11.07	11.31	10.75	11.61
female discard catch	3.74	3.83	3.84	3.63
survey biomass	188.82	171.52	175.12	166.78
F penalty	79.41	78.00	78.01	78.65
2010 BSFRF Biomass	0.45	0.66	0.36	0.75
2010 NMFS Biomass	1.84	2.47	1.50	2.46
initial numbers fit	519.40	518.11	518.66	516.02
2010 BSFRF length	-66.29	-66.15	-66.08	-71.04
2010 NMFS length	-85.79	-84.89	-85.78	-86.03
male survey selectivity smooth constraint	0.00	0.00	0.00	3.70
init nos smooth constraint	23.98	23.60	23.82	55.04
Total	2927.21	2899.38	2887.89	2901.47
Q	0.572	0.604	0.554	0.612
no. par	282	282	283	322
immat M	0.367	0.23	0.32	0.353
M mature females	0.23	0.23	0.23	0.23
M mature males	0.23	0.326	0.315	0.23

Table 16 Cont.. Likelihood values for model scenarios 1-7 (see table 7 for description).

Likelihood Component	5	6	7
Recruitment	32.14	32.07	34.31
Initial numbers old shell males small length bins	0.12	2.33	0.12
ret fishery length	-2042.60	-2061.67	-2018.11
total fish length	679.82	679.52	684.34
female fish length	154.17	154.90	154.44
survey length	3174.34	3160.61	3210.91
trawl length	222.75	221.54	219.69
2009 BSFRF length	-90.40	-88.34	-93.32
2009 NMFS study area length	-79.49	-78.60	-81.05
M prior	29.23	15.53	0.00
maturity smooth	51.58	49.04	46.42
growth a	2.47	2.15	2.17
growth b	0.04	0.04	0.05
2009 BSFRF biomass	0.14	0.14	0.18
2009 NMFS study area biomass	0.07	0.06	0.17
retained catch	2.74	2.86	3.04
discard catch	103.32	111.94	112.62
trawl catch	11.08	11.09	12.38
female discard catch	3.82	3.74	3.70
survey biomass	174.30	162.24	184.68
F penalty	77.70	78.15	79.78
2010 BSFRF Biomass	0.78	0.52	1.44
2010 NMFS Biomass	2.47	2.00	4.07
initial numbers fit	518.14	514.92	518.28
2010 BSFRF length	-70.94	-71.06	-66.22
2010 NMFS length	-85.77	-85.91	-84.12
male survey selectivity smooth constraint	3.79	3.77	0.00
init nos smooth constraint	23.61	53.23	23.44
Total	2899.42	2876.83	2953.43
Q	0.604	0.583	0.714
no. par	322	323	281
immat M	0.23	0.319	0.23
M mature females	0.23	0.23	0.23
M mature males	0.325	0.299	0.23

Table 17. Likelihood values for model scenarios 0, 0.1, 0.2, 8, 9 and 10 (see table 7 for description). Scenarios 8, 9 and 10 use male growth fixed at the values estimated by Somerton for the 2011 growth study.

Likelihood Component	0	0.1	0.2
Recruitment	33.3683	32.8789	32.7383
Initial numbers old shell males small length bins	2.37776	0.123938	0.123938
ret fishery length	-2059.33	-2040.28	-2040.74
total fish length	677.601	679.375	679.605
female fish length	155.062	154.249	154.318
survey length	3178.53	3173.97	3174.86
trawl length	227.665	225.831	224.586
2009 BSFRF length	-100.241	-100.311	-92.3168
2009 NMFS study area length	-88.1308	-87.8913	-79.7531
M prior	20.4561	29.8323	28.6042
maturity smooth	50.0563	50.3606	50.1809
growth a	2.19013	1.86612	1.92223
growth b	0.042286	0.042944	0.042042
2009 BSFRF biomass	0.106554	0.083435	0.131566
2009 NMFS study area biomass	2.31907	2.54236	0.116716
retained catch	2.70201	2.78085	2.77884
discard catch	99.4939	101.808	102.786
trawl catch	12.6955	11.8113	11.5035
female discard catch	3.63494	3.72838	3.77804
survey biomass	151.792	169.368	171.092
F penalty	78.6925	78.2743	78.0787
2010 BSFRF Biomass	1.03157	0	0
2010 NMFS Biomass	8.9583	0	0
initial numbers fit	567.317	518.132	518.183
2010 BSFRF length	-65.0431	0	0
2010 NMFS length	-85.8137	0	0
male survey selectivity smooth constraint	0	0	0
init nos smooth constraint	48.9242	23.644	23.6284
Total	2926.458	3032.22	3046.247
Q	0.699	0.647	0.628
no. par	290	280	276
immat M	0.23	0.23	0.23
M mature females	0.23	0.23	0.23
M mature males	0.309	0.326	0.324

Table 17 Cont.. Likelihood values for model scenarios 0, 0.1, 0.2, 8, 9 and 10 (see table 7 for description). Scenarios 8, 9 and 10 use male growth fixed at the values estimated by Somerton for the 2011 growth study.

Likelihood Component	8	9	10
Recruitment	35.3104	33.126	34.9603
Initial numbers old shell males small length bins	0.123938	2.42097	0.123938
ret fishery length	-2006.4	-2048.96	-2001.5
total fish length	690.754	686.205	690.64
female fish length	156.42	154.596	154.493
survey length	3180.77	3195.93	3230.14
trawl length	221.258	225.662	221.853
2009 BSFRF length	-89.1255	-89.1945	-90.1704
2009 NMFS study area length	-78.3186	-79.9115	-80.9199
M prior	0	20.8361	0
maturity smooth	46.449	52.9964	48.2517
growth a	0.009091	0.052985	0.065353
growth b	0.040061	0.033659	0.041965
2009 BSFRF biomass	0.150115	0.198491	0.272051
2009 NMFS study area biomass	0.160721	0.223759	0.301716
retained catch	4.4159	3.67513	3.94134
discard catch	175.858	144.54	152.391
trawl catch	11.3347	11.6535	12.0323
female discard catch	3.7207	3.75456	3.68877
survey biomass	186.126	159.468	186.448
F penalty	82.3191	77.3308	78.6398
2010 BSFRF Biomass	0.701864	1.16674	1.89399
2010 NMFS Biomass	2.88277	4.07654	5.46822
initial numbers fit	518.295	513.984	517.239
2010 BSFRF length	-63.4587	-63.4423	-63.6781
2010 NMFS length	-85.3413	-83.827	-83.1308
male survey selectivity smooth constraint	0	0	0
init nos smooth constraint	24.2267	55.1101	23.5863
Total	3018.682	2981.705	3047.073
Q	0.6493	0.6989	0.753
no. par	277	277	276
immat M	0.405	0.23	0.23
M mature females	0.23	0.23	0.23
M mature males	0.23	0.31	0.23

Table 18. Changes in the September 2011 model and data from the September 2010 assessment.

Model Scenario	Description
Data	BSFRF 2010 study are data , biomass and length frequencies for BSFRF net and NMFS net in the study area. 2011 survey biomass and length frequencies 2010/11 directed fishery retained and discard catch and length frequencies. Groundfish discard length frequency data 2008-2010. 2010 groundfish discard catch
Model	Formulation of survey selectivity for NMFS net in the 2009 and 2010 study areas revised (see text). Revised code for estimation of growth transition matrix (bug in mfexp function) and truncated distribution 40mm above premolt bin. Growth curve estimated from 2011 growth study used in some scenarios (see text)

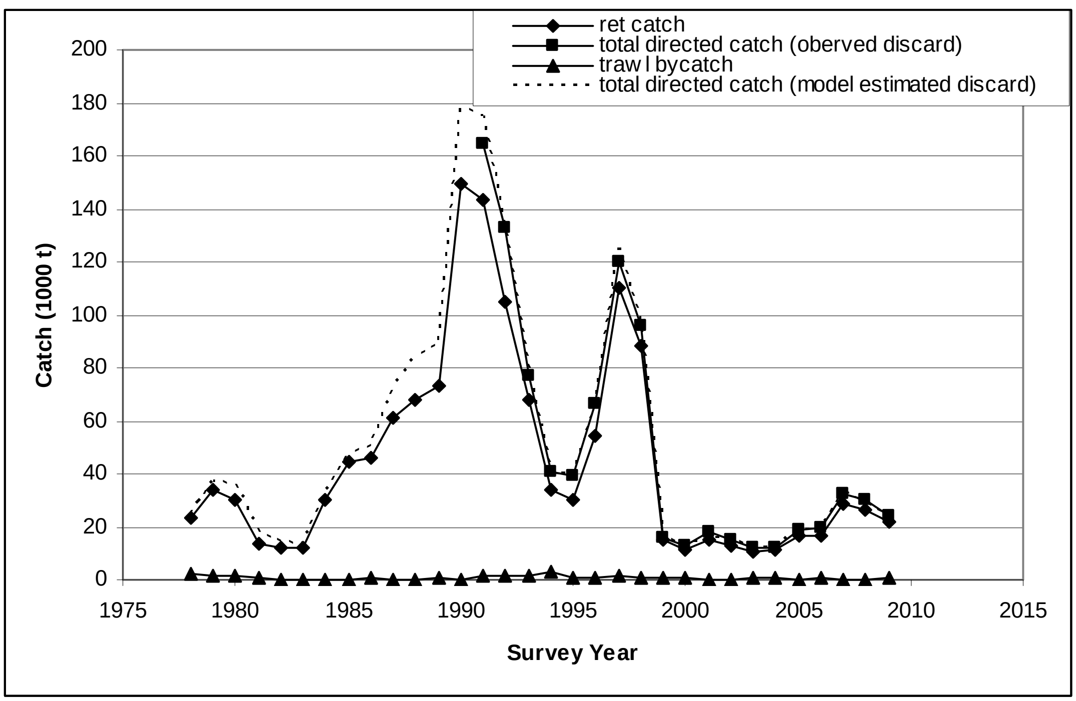

Figure 1. Catch (1000 t) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch is retained catch plus discarded catch after 50% discard mortality was applied. Discard catch was estimated from observer data 1992 to present. Discard for 1978 to 1991 was estimated in the model. Trawl bycatch 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.

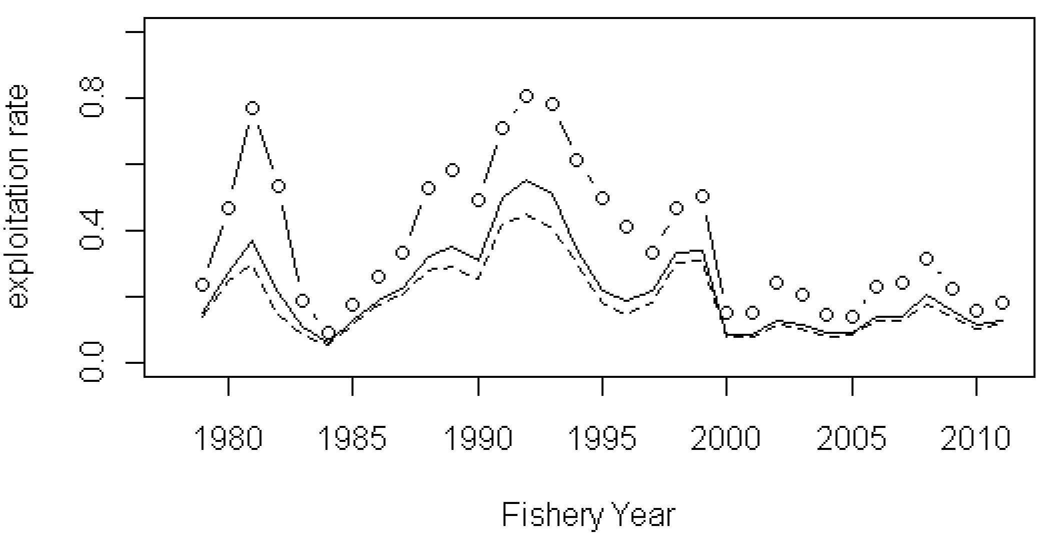

Figure 3. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line is total and dotted line is retianed). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the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

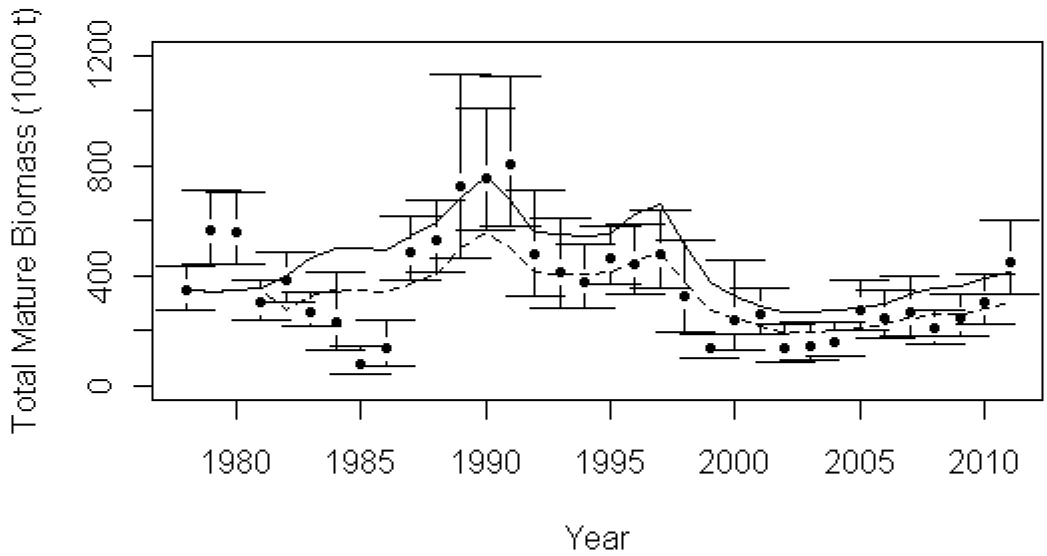

Figure 4. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

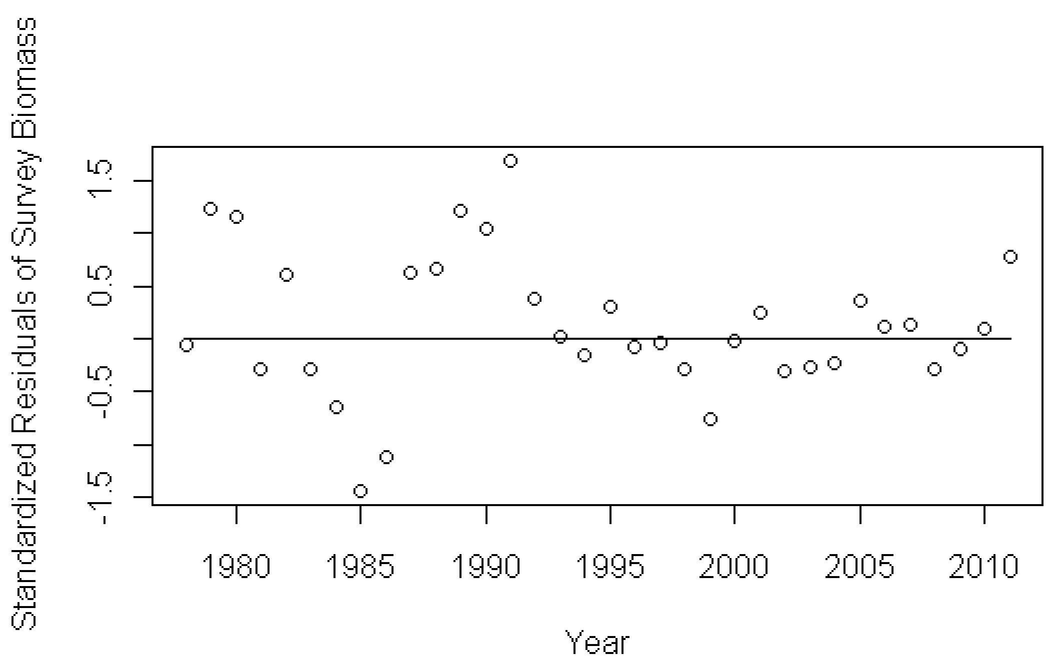

Figure 5. Standardized residuals for model fit to total mature biomass from Figure 4.

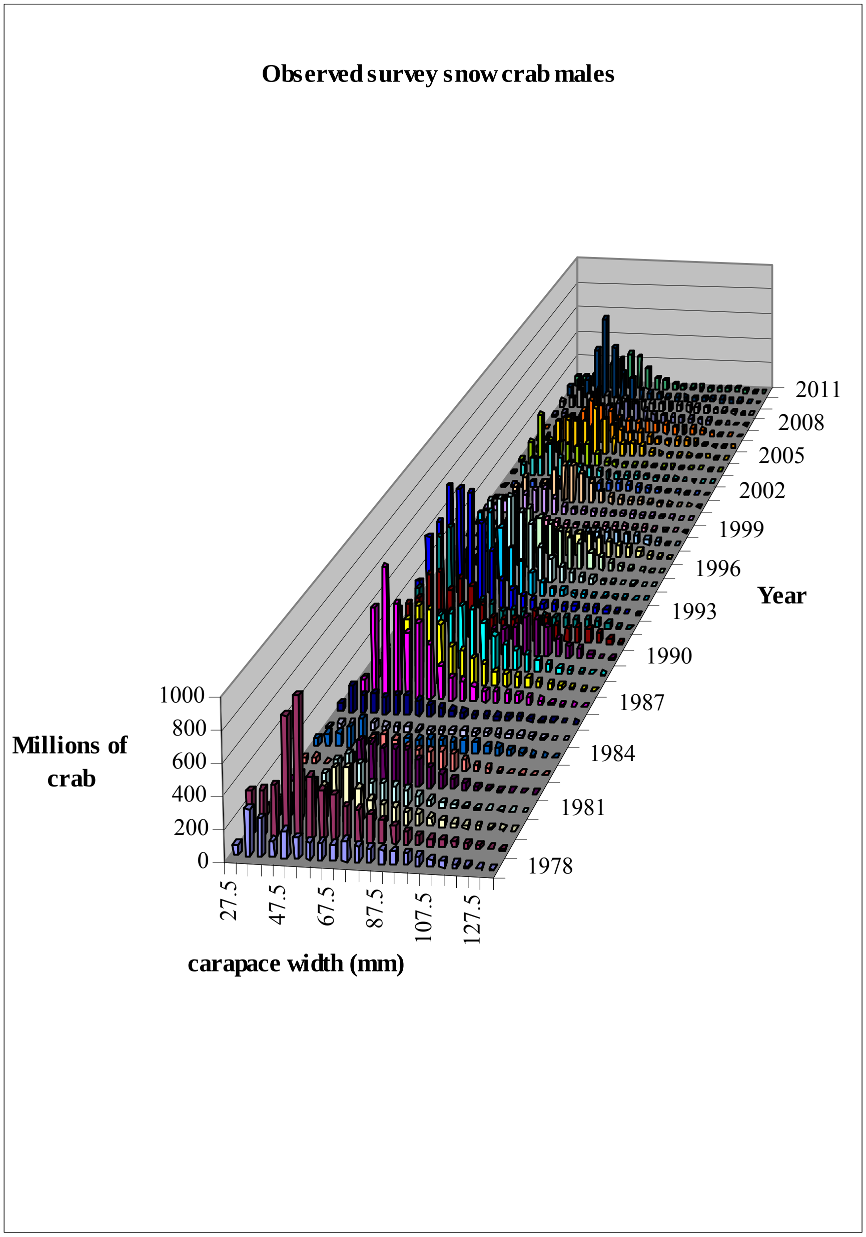

Figure 6. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

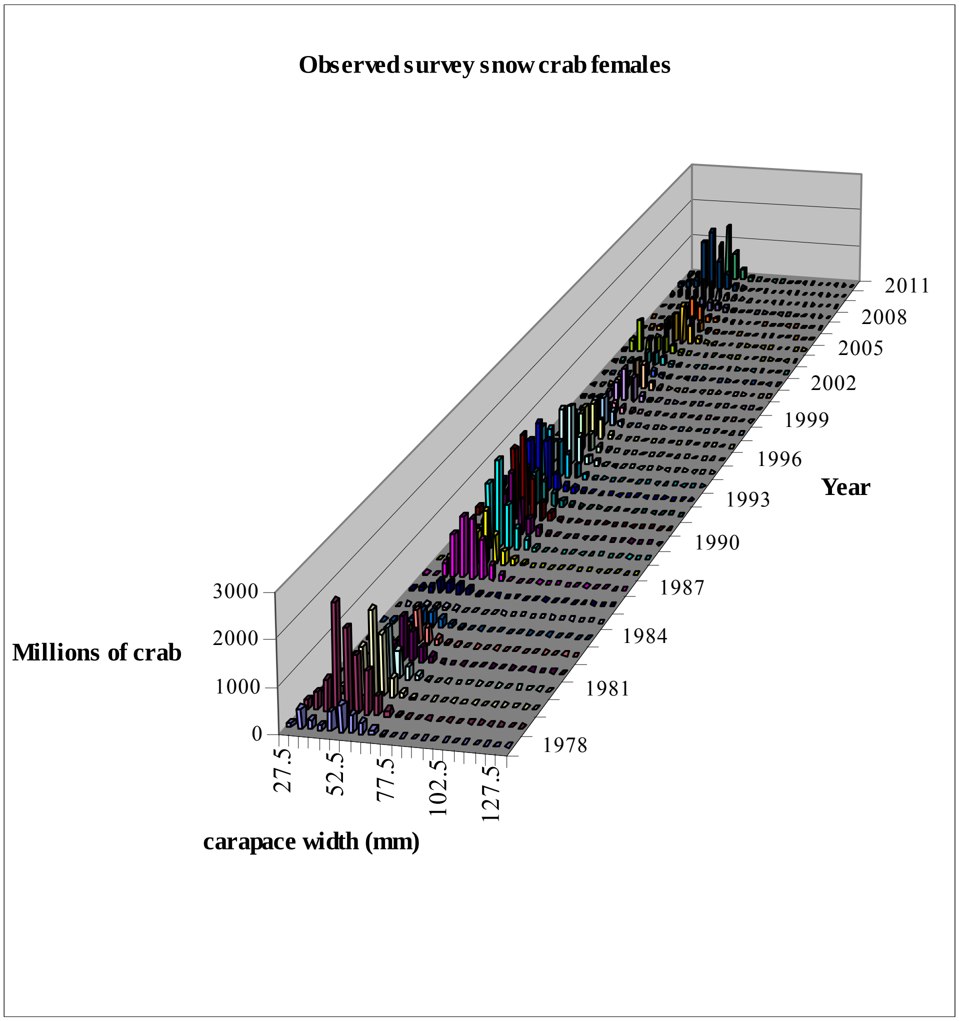

Figure 7. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

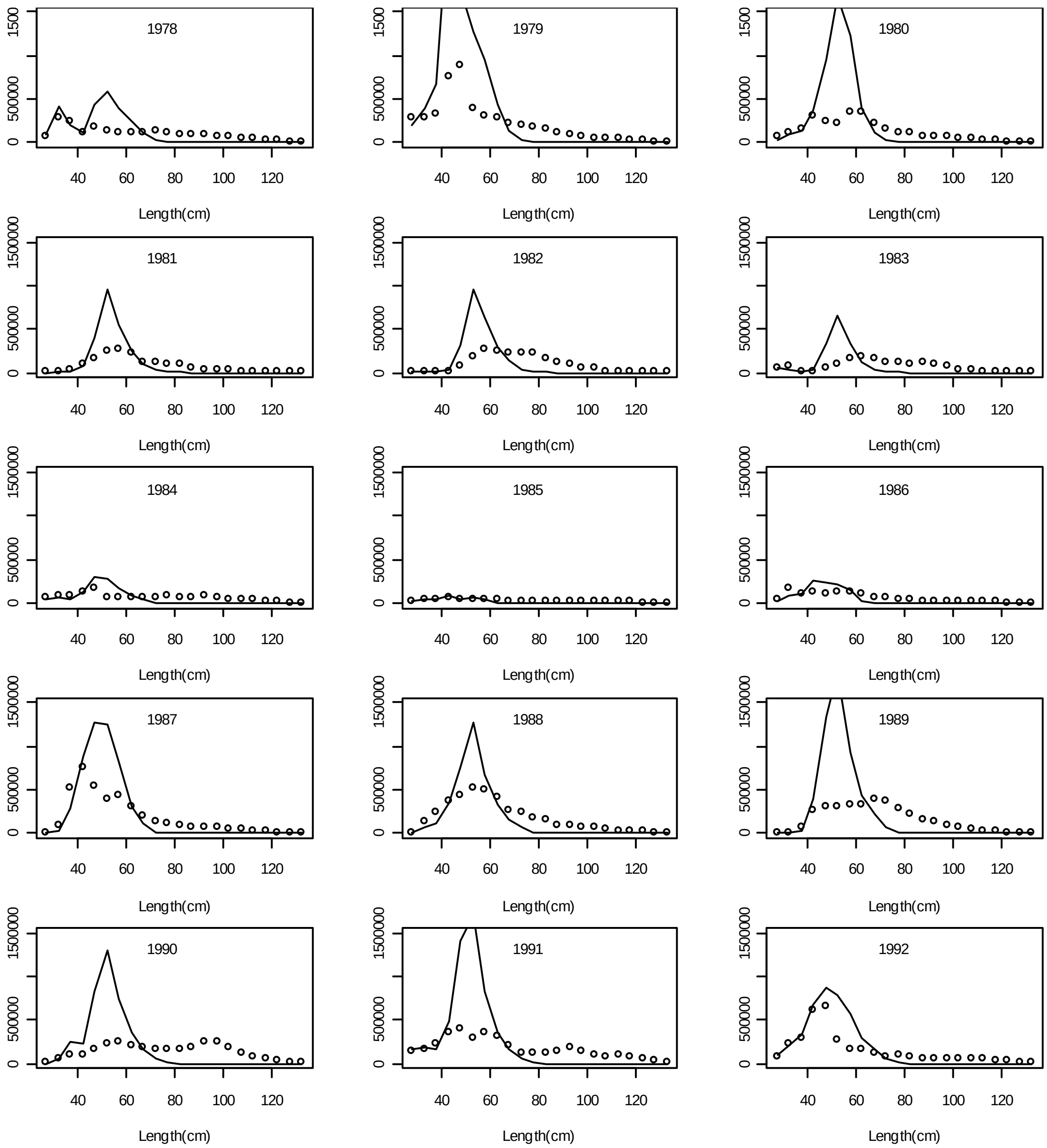

Figure 8. Observed survey numbers 1978 to 1992 by length, males circles, females solid line.

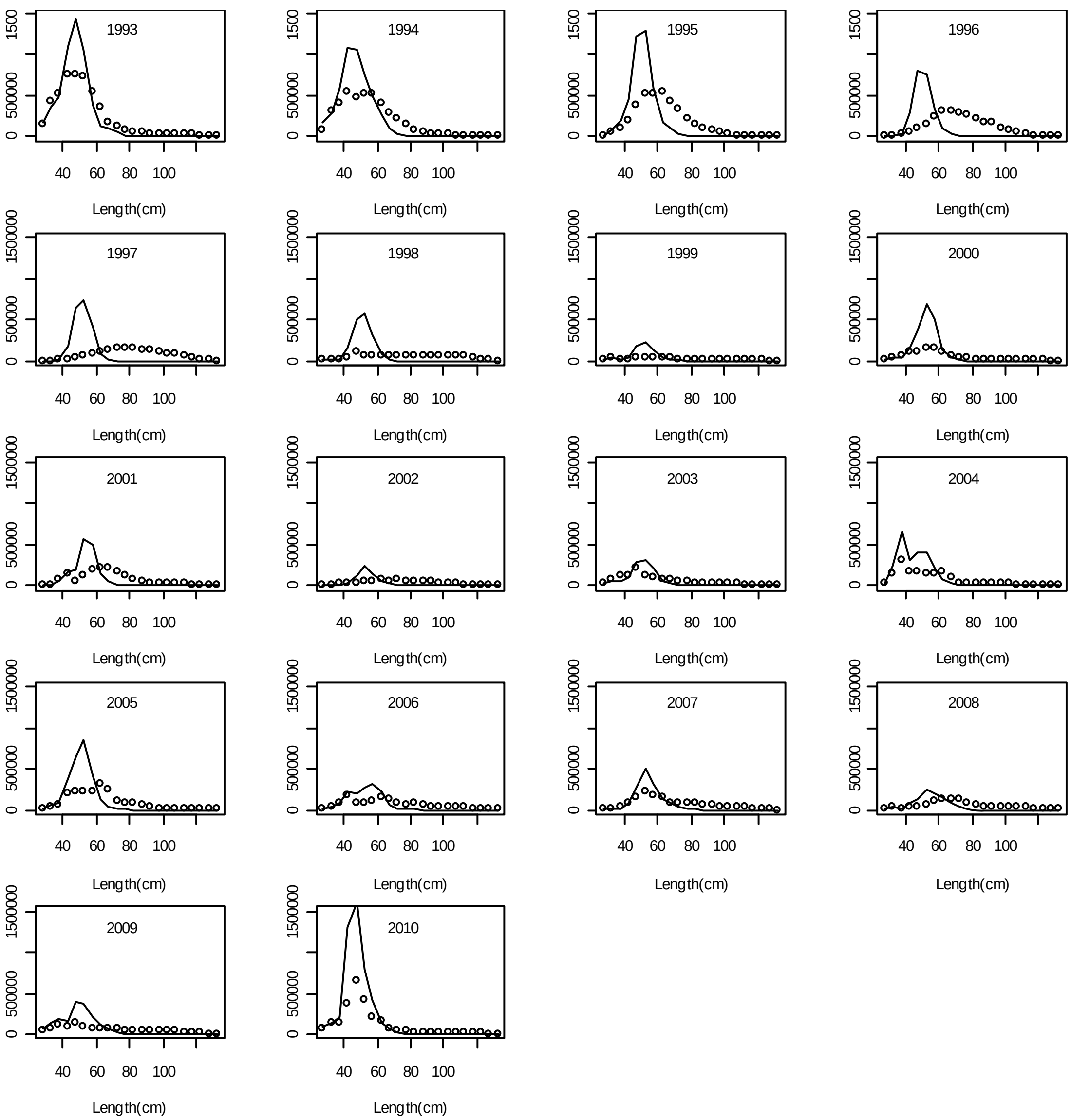

Figure 8 continued. Observed survey numbers 1993 to 2010 by length, males circles, females solid line.

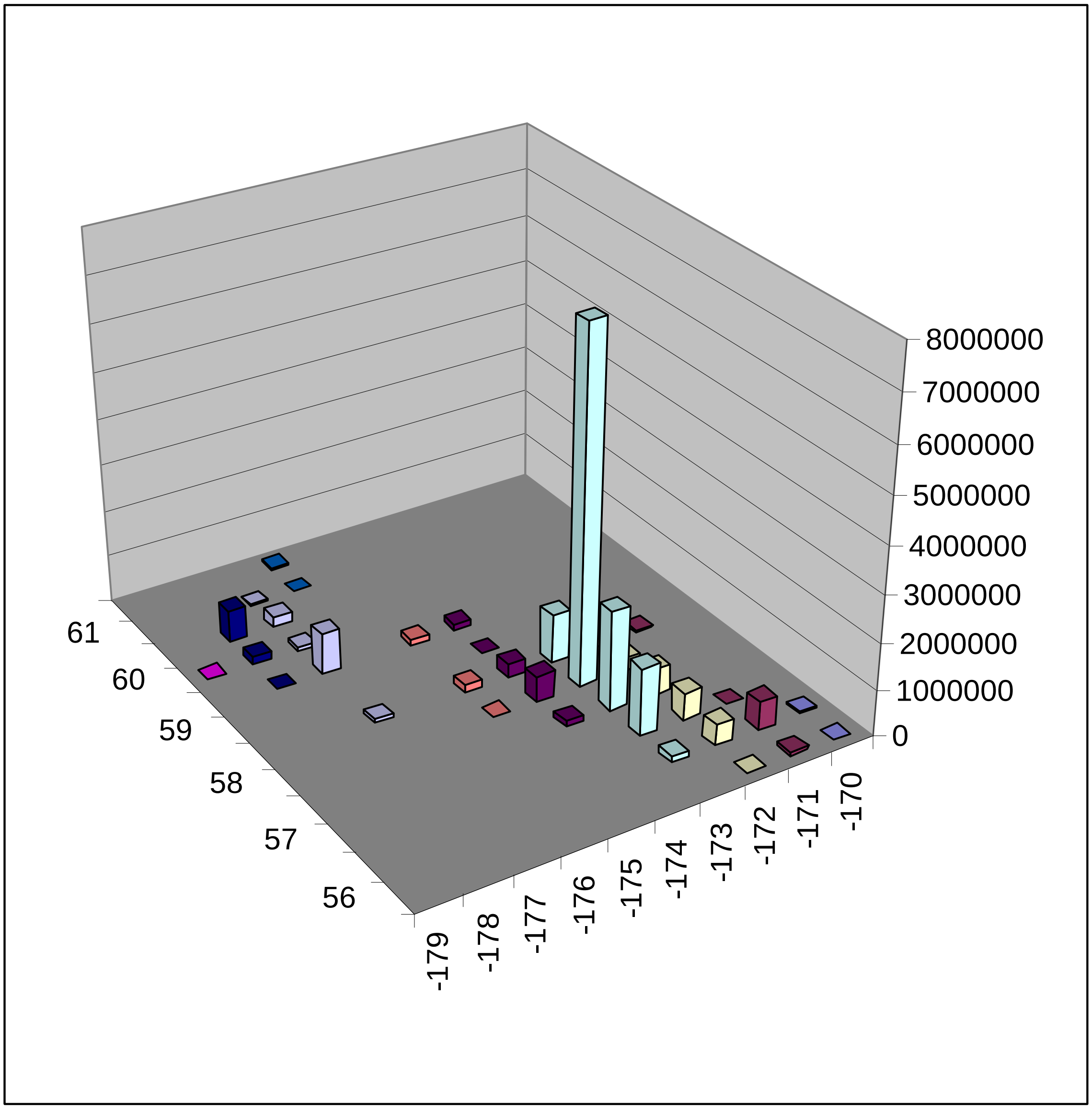

Figure 9. 2003/04 pot fishery retained catch in numbers by statistical area. Longitude in negative degrees. Areas are 1 degree longitude by 0.5 degree latitude.

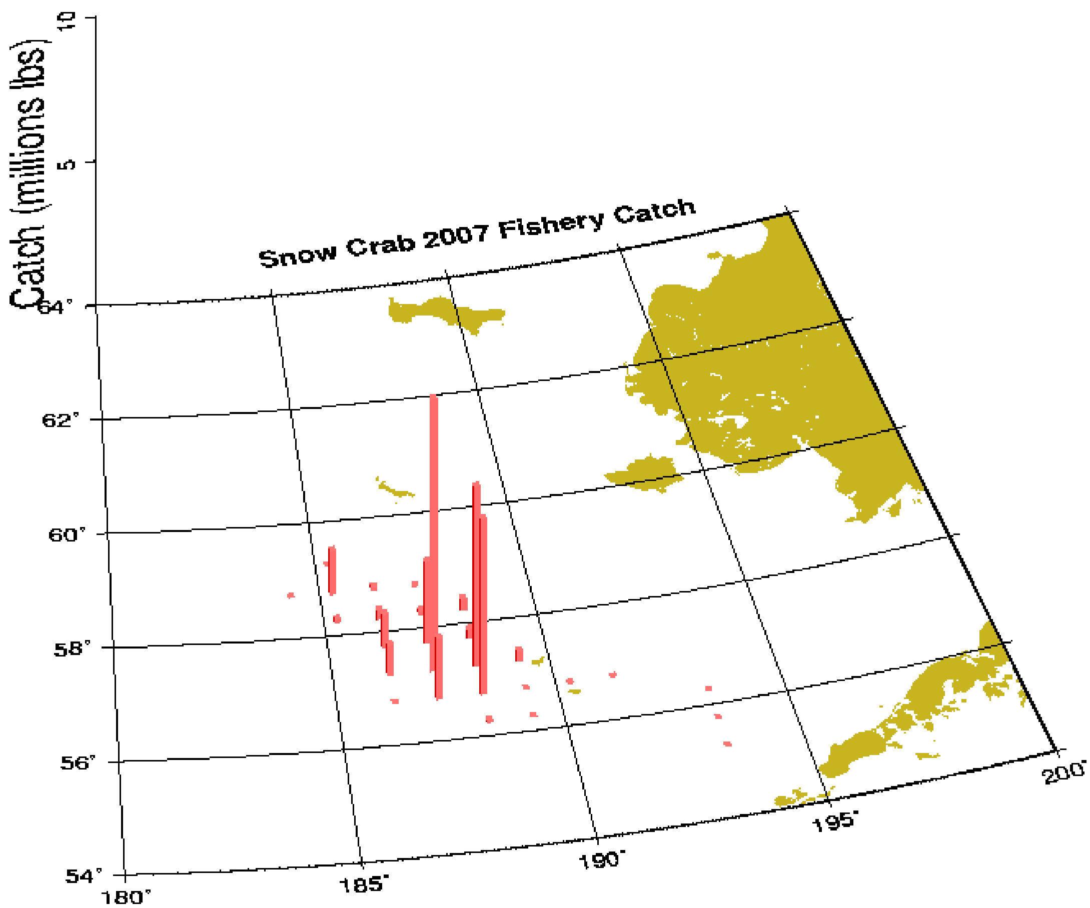

Figure 10. 2006/07 snow crab pot fishery retained catch(million lbs) by statistical area. Longitude increases from west to east (190 degrees = 170 degrees W longitude). Areas are 1 degree longitude by 0.5 degree latitude.

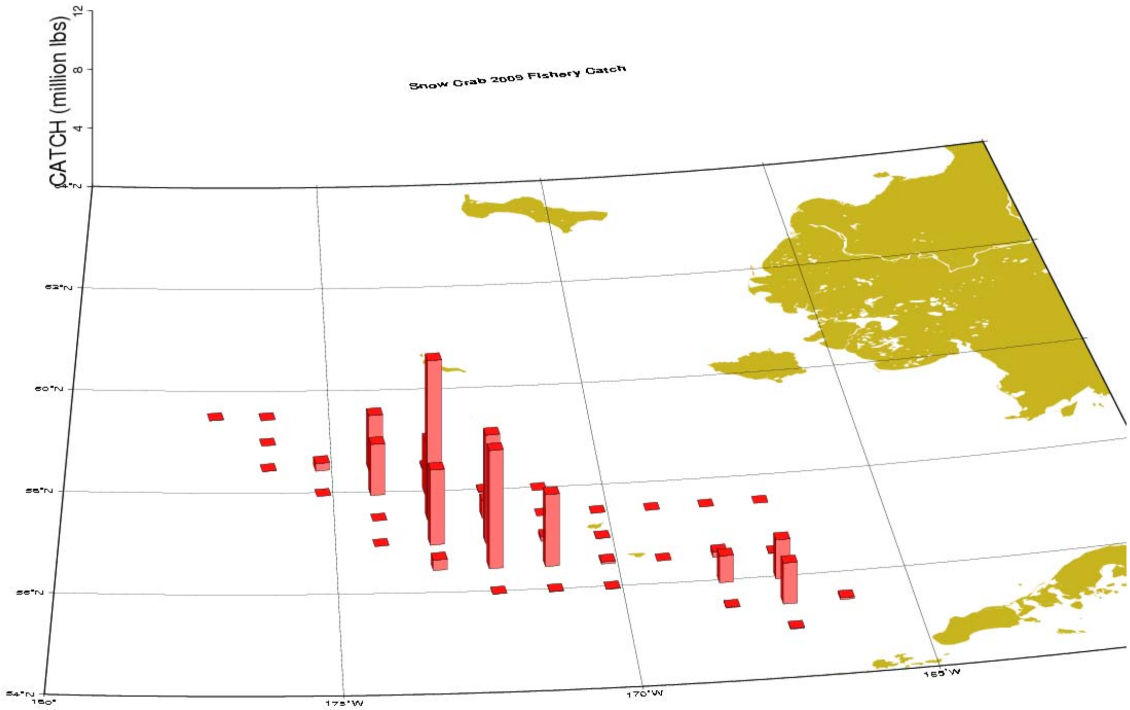

Figure 11. 2008/09 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

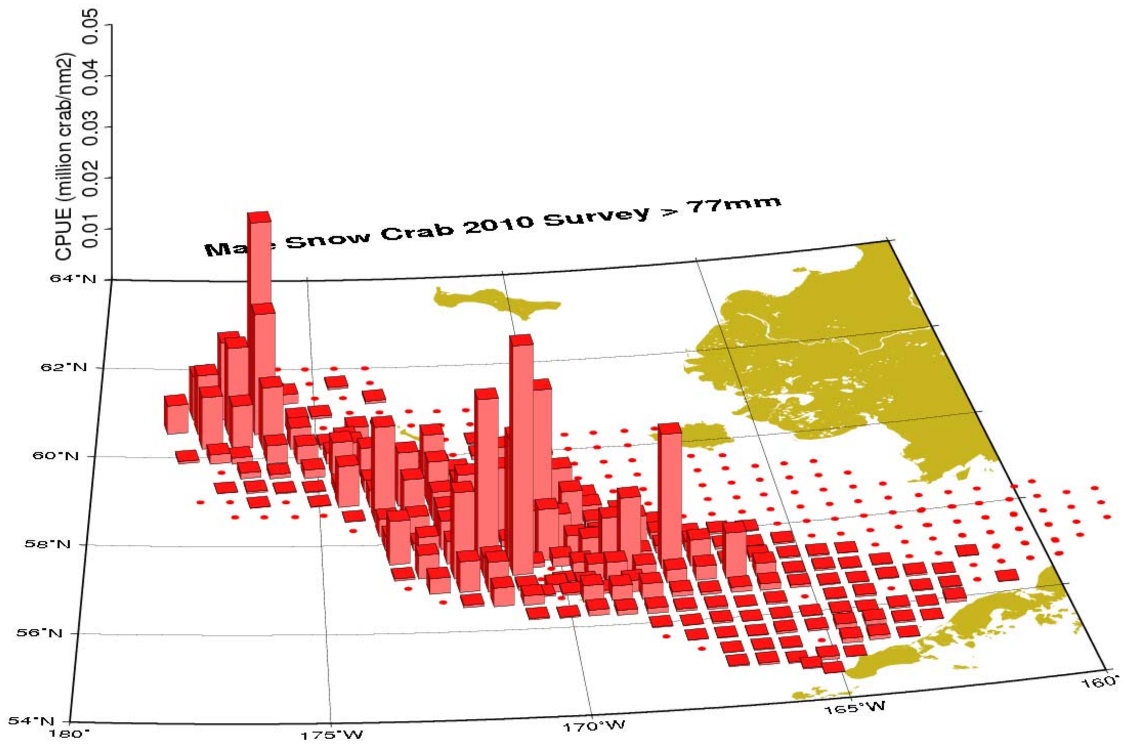

Figure 12. 2010 Survey CPUE (million crab per nm2) of males > 77 mm by tow. Filled circles are tows with 0 cpue.

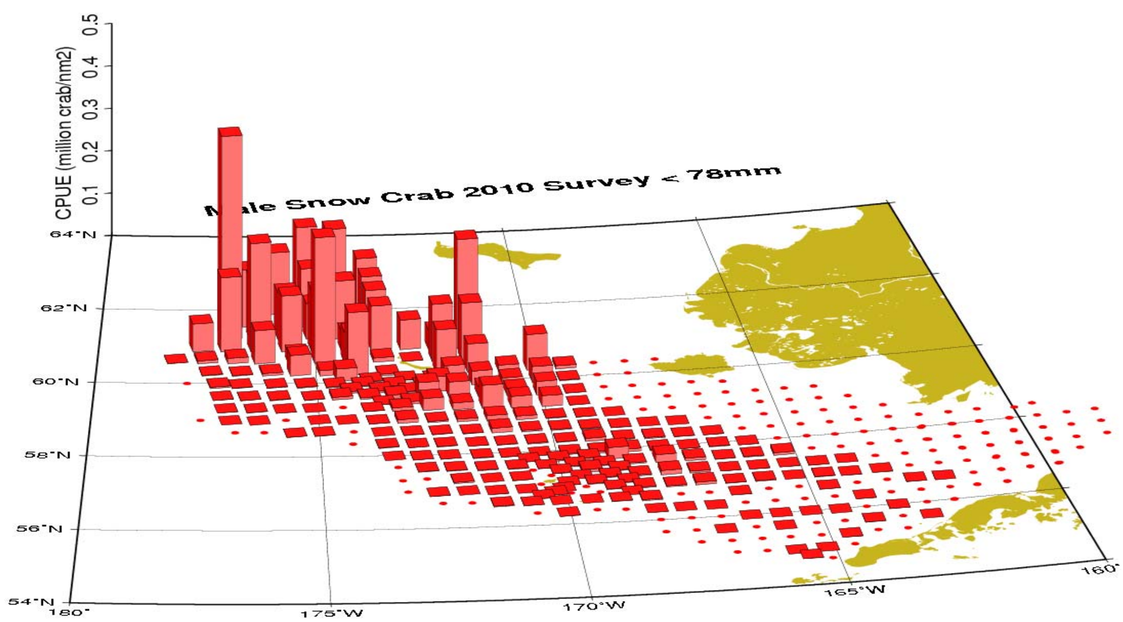

Figure 13. 2010 Survey CPUE (million crab per nm2) of males < 78 mm by tow. Filled circles are tows with 0 cpue.

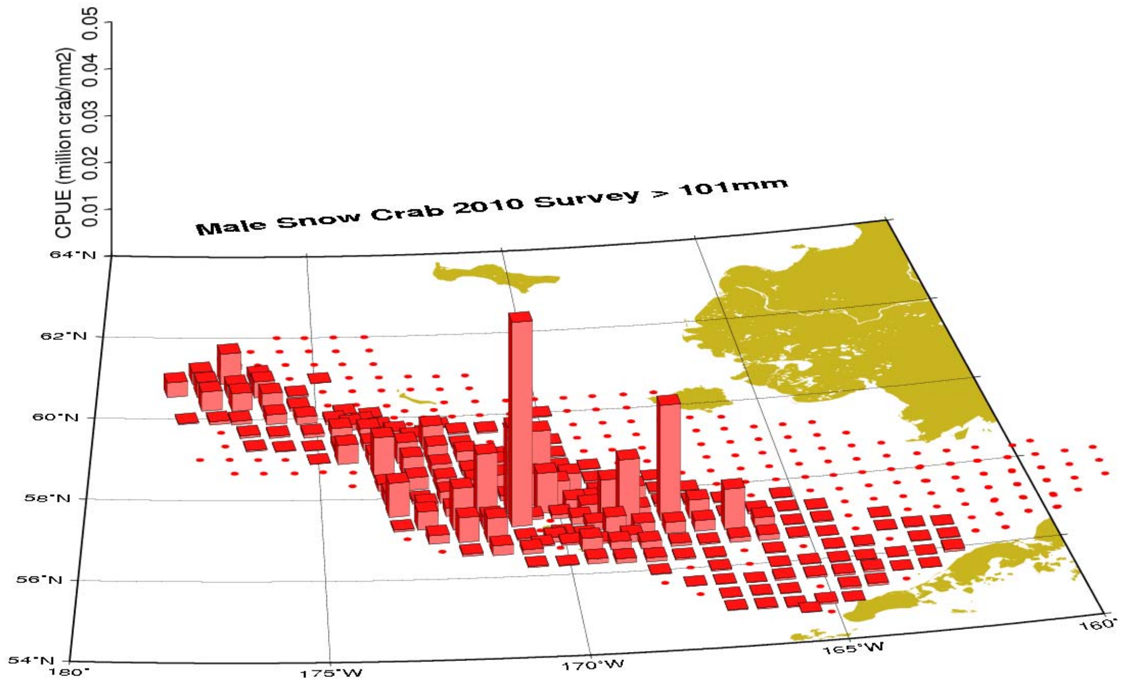

Figure 14. 2010 Survey CPUE (million crab per nm2) of males > 101 mm by tow. Filled circles are tows with 0 cpue.

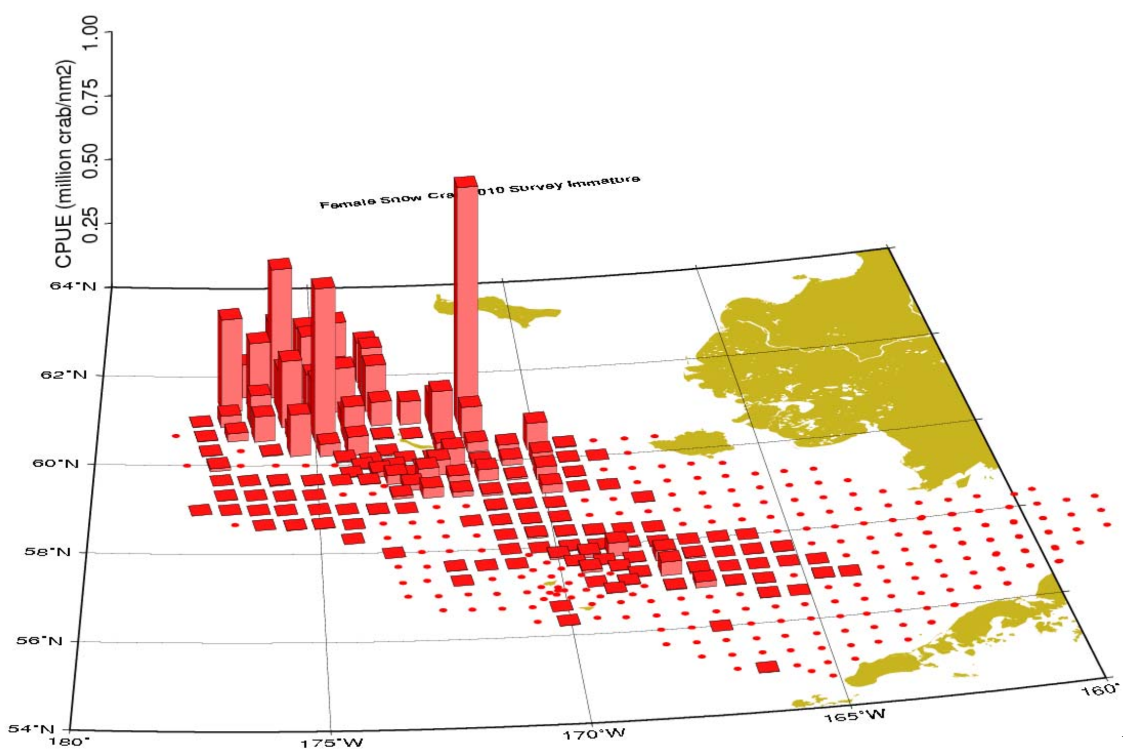

Figure 15. 2010 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

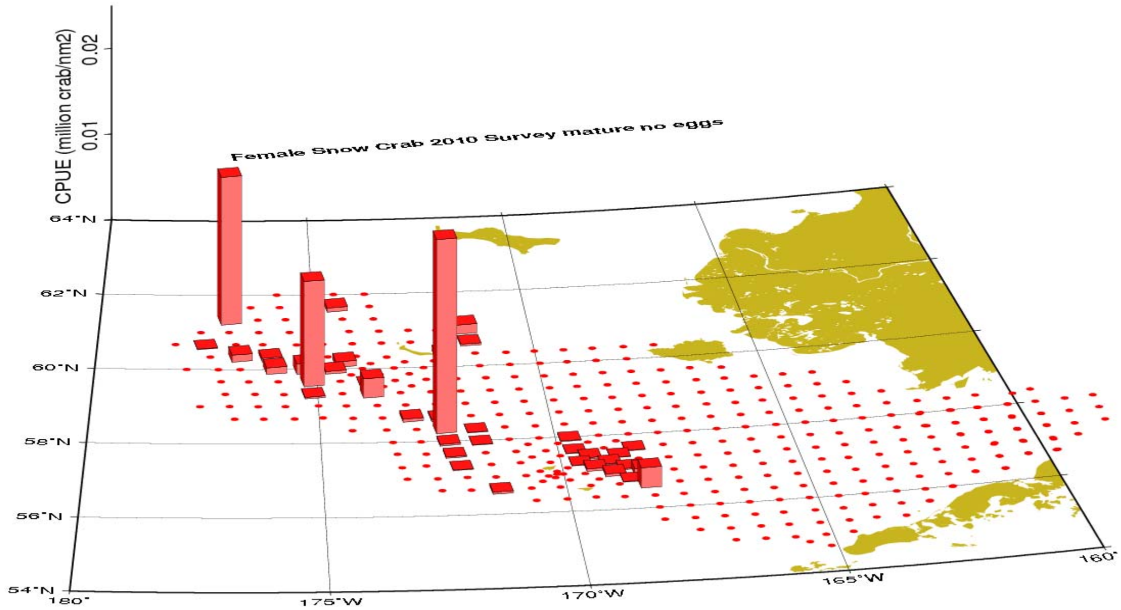

Figure 16. 2010 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

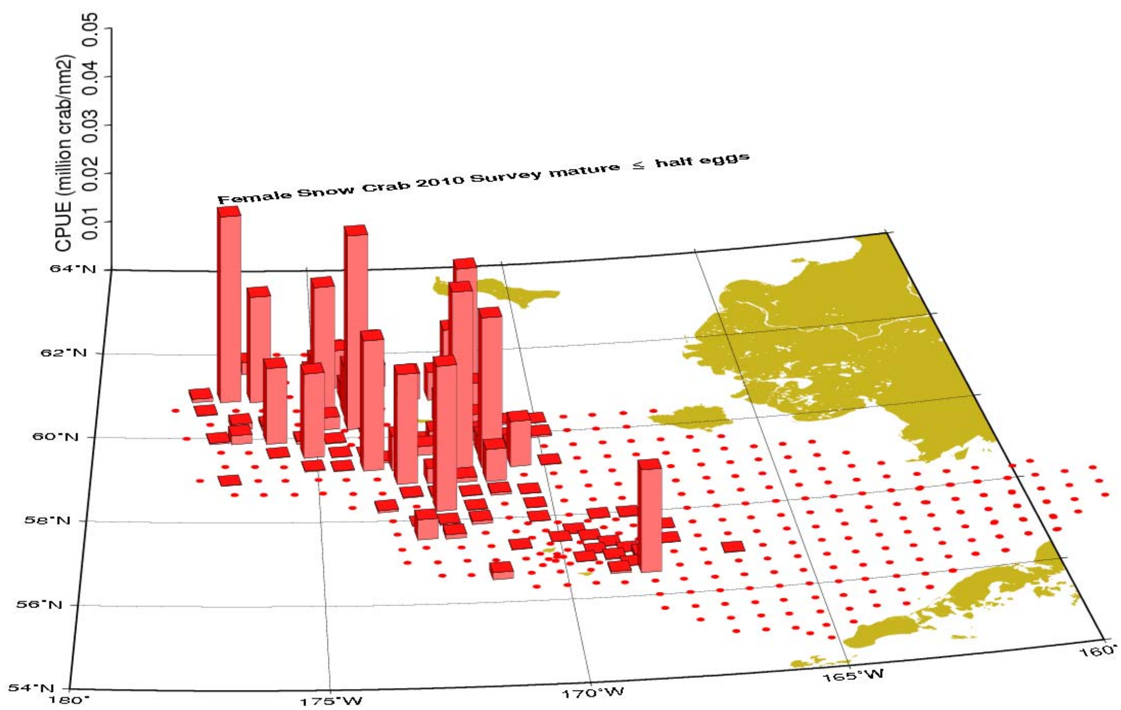

Figure 17. 2010 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

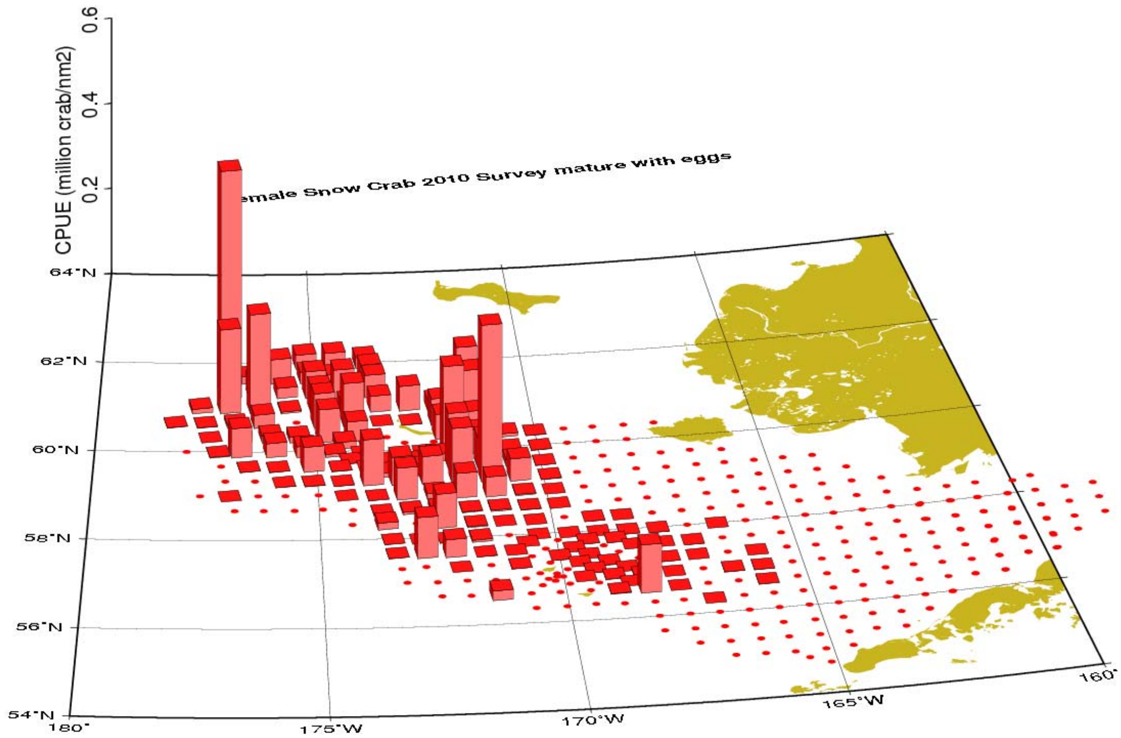

Figure 18. 2010 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

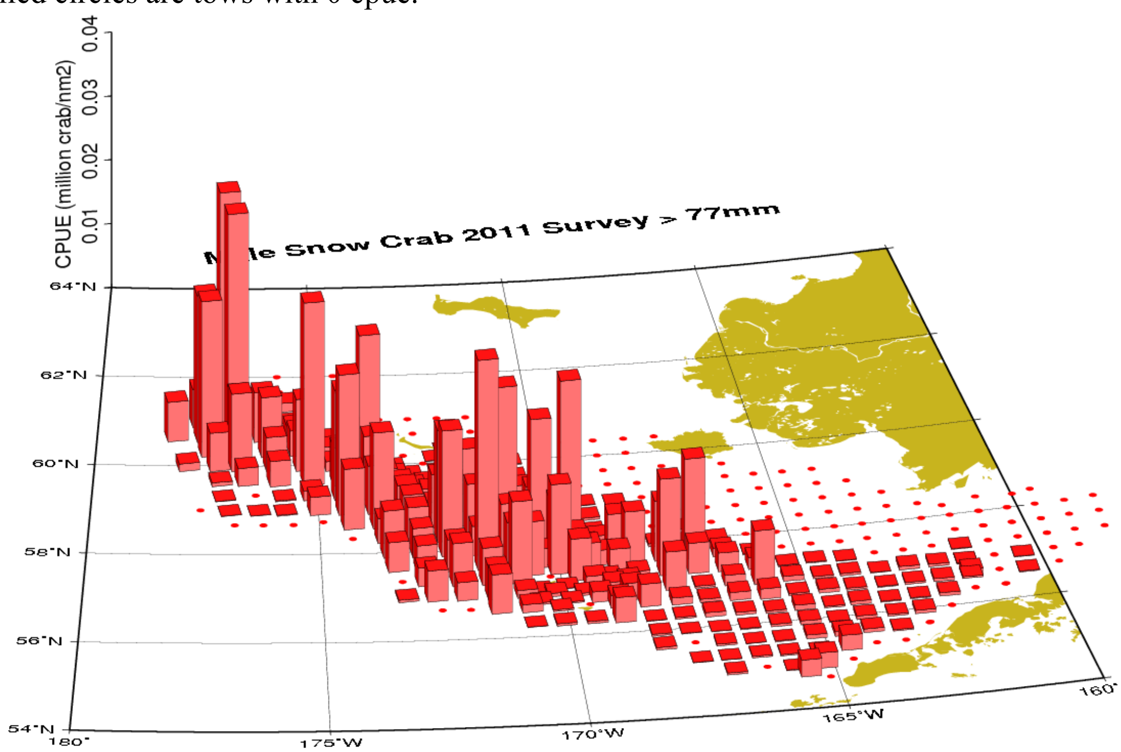

Figure 19. 2011 Survey CPUE (million crab per nm2) of males > 77 mm by tow. Filled circles are tows with 0 cpue

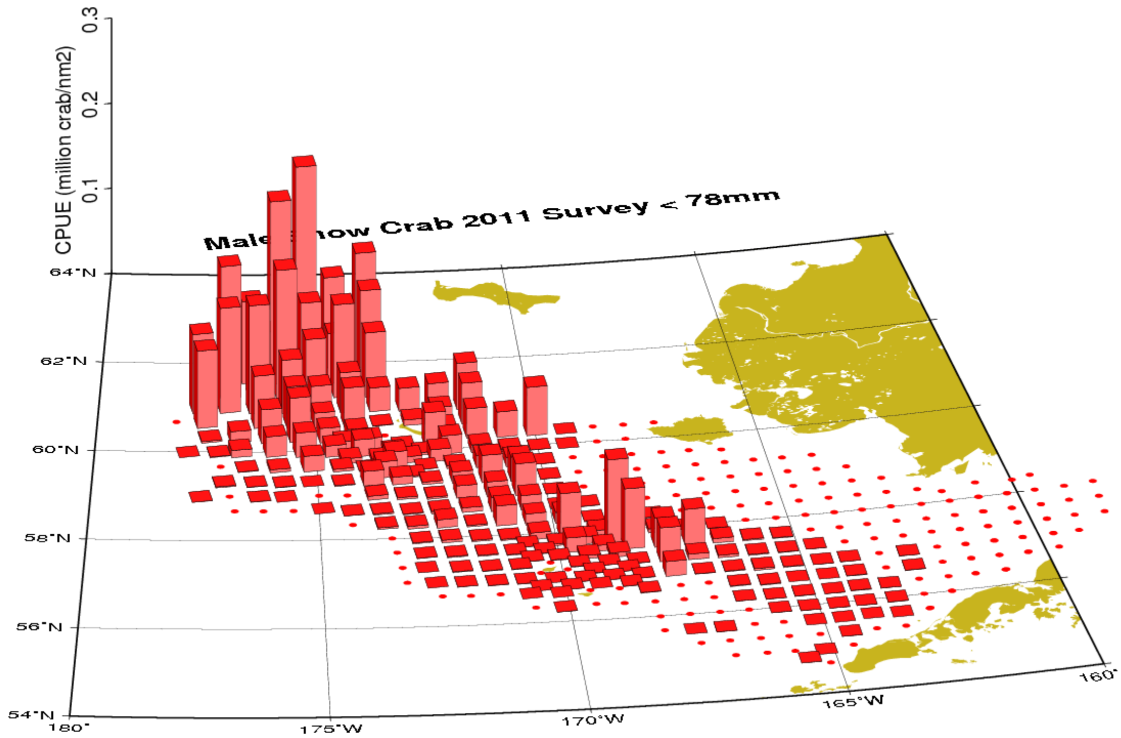

Figure 20. 2011 Survey CPUE (million crab per nm2) of males < 78 mm by tow. Filled circles are tows with 0 cpue.

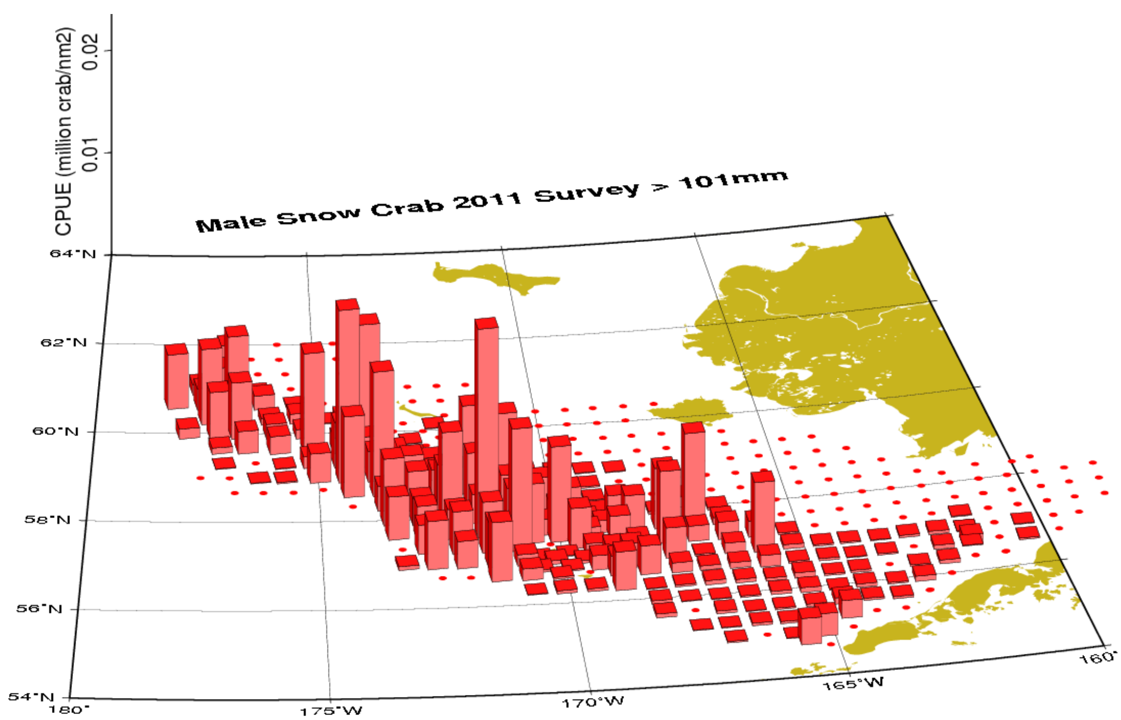

Figure 21. 2011 Survey CPUE (million crab per nm2) of males > 101 mm by tow. Filled circles are tows with 0 cpue

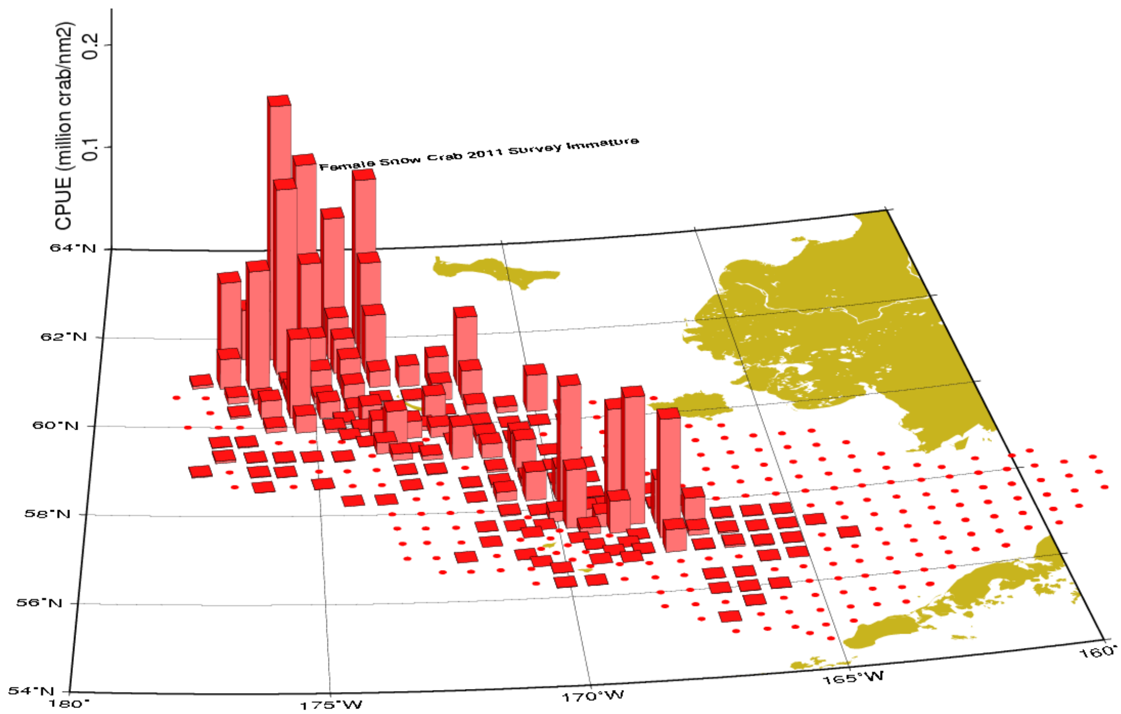

Figure 22. 2011 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue

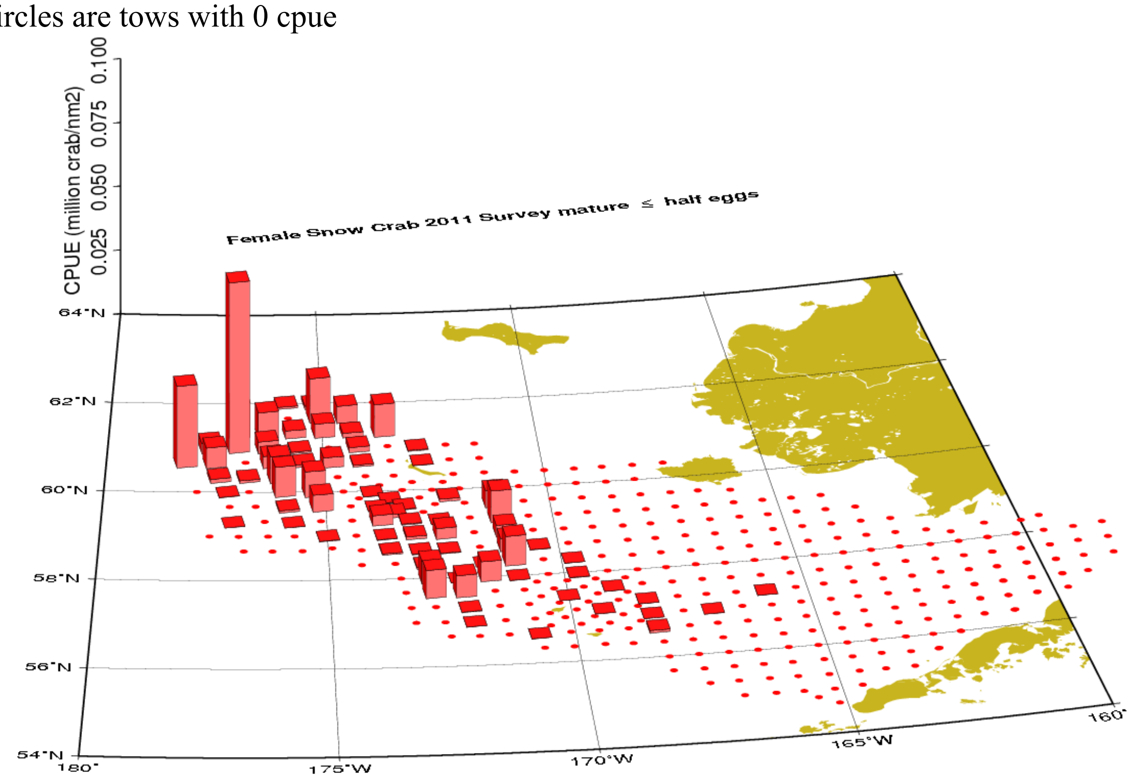

Figure 23. 2011 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

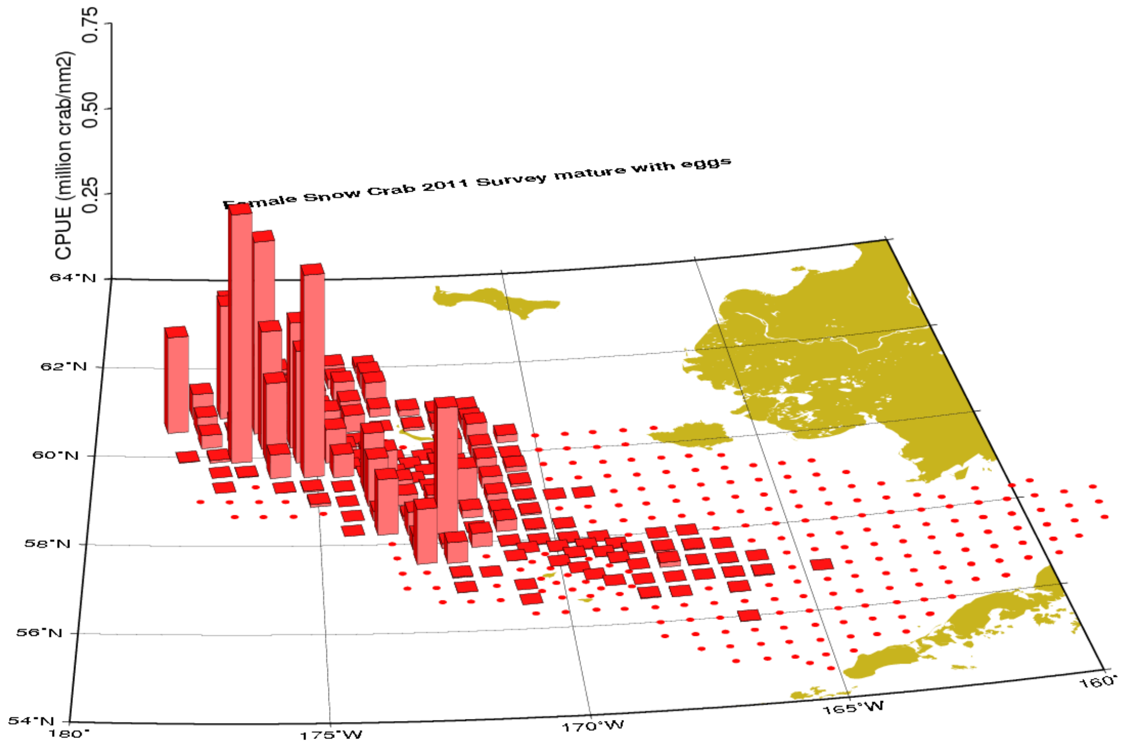

Figure 24. 2011 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

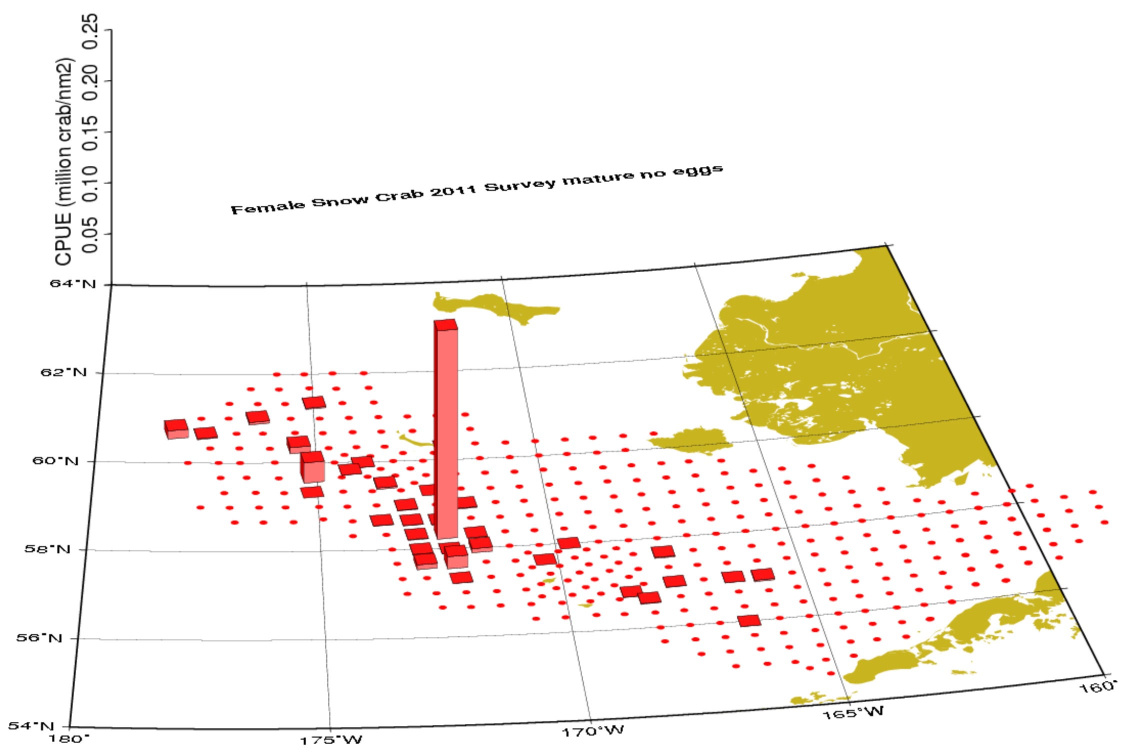

Figure 25. 2011 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

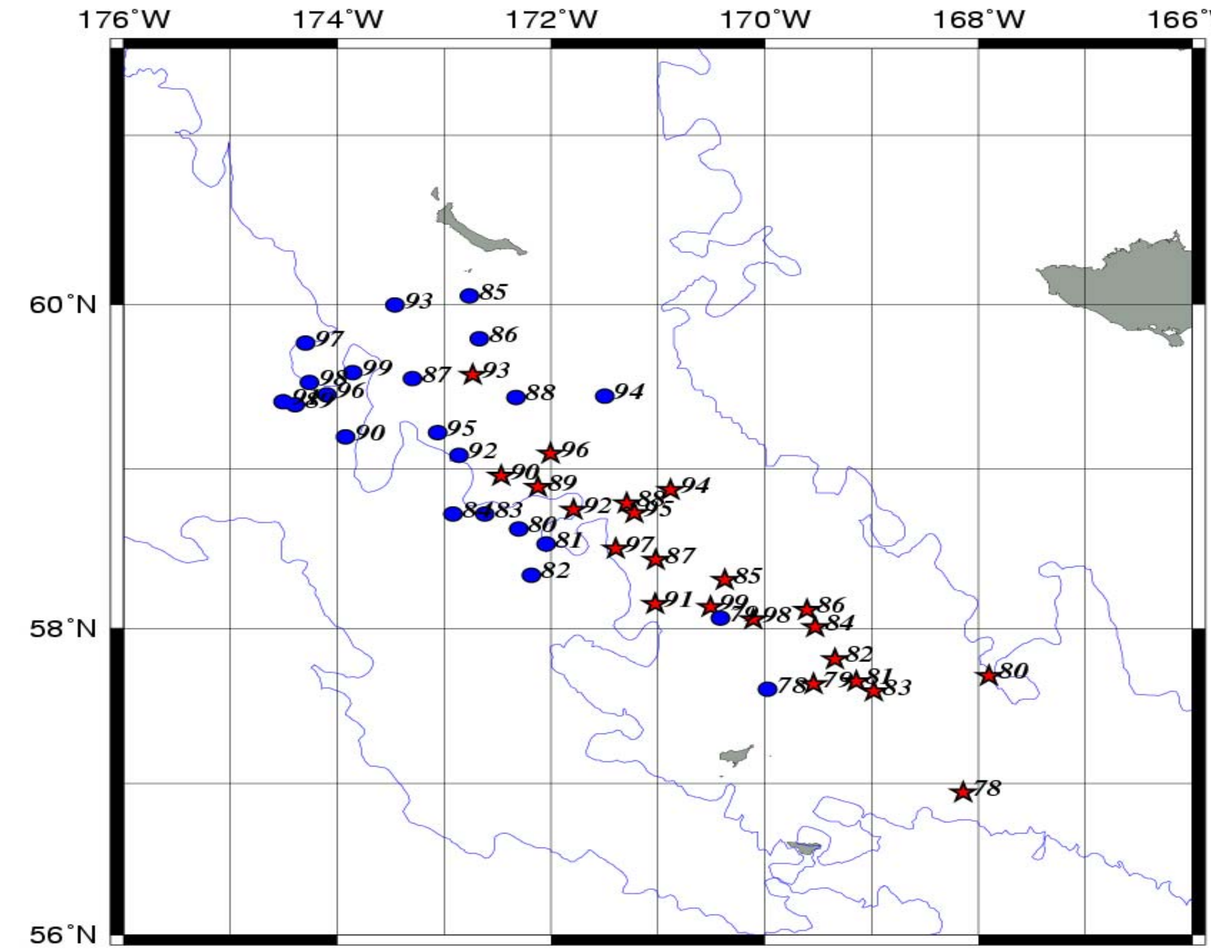

Figure 26. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars (Ernst, et al. 2005).

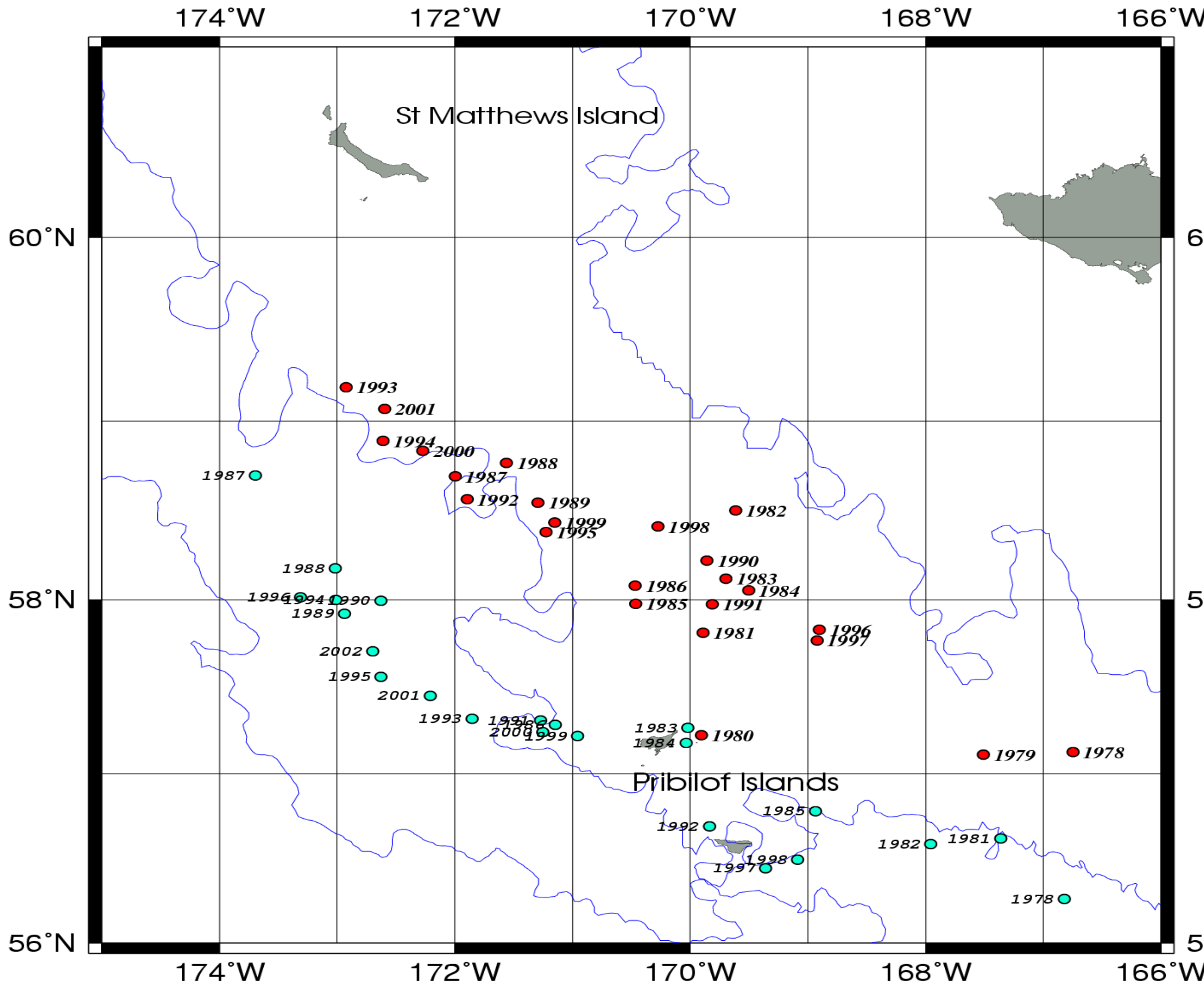

Figure 27. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green) (Ernst, et al. 2005).

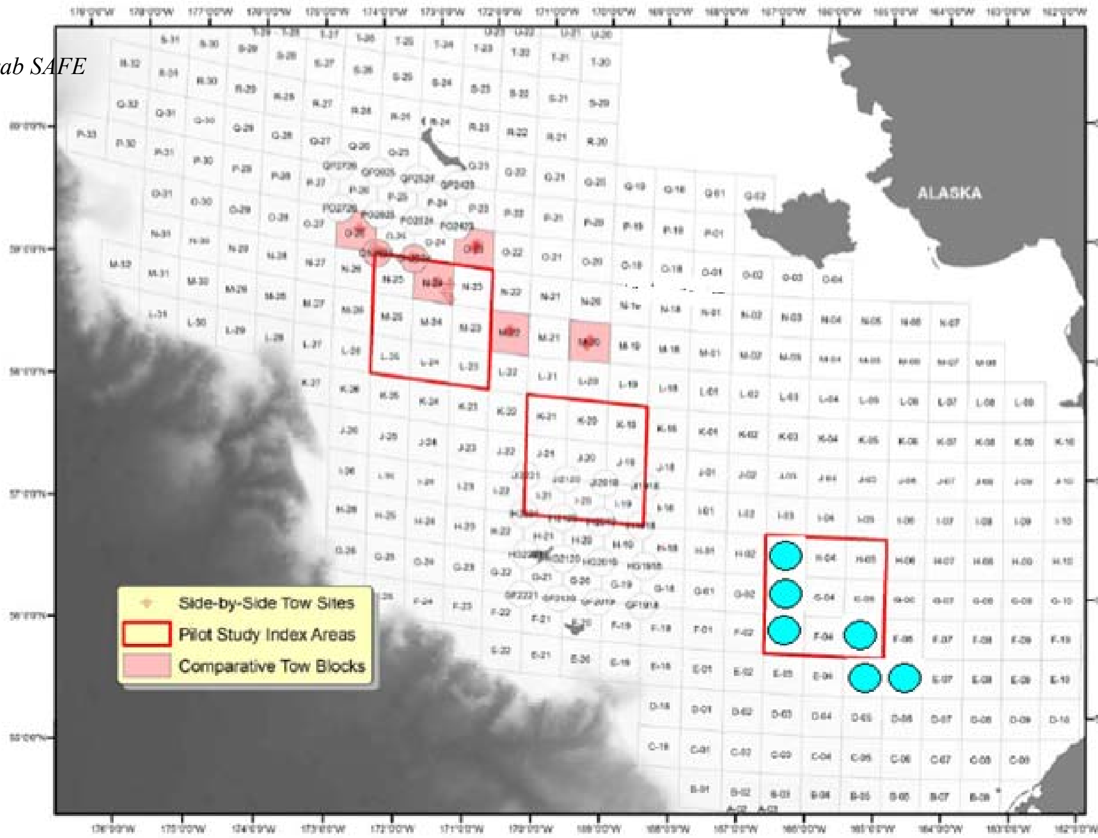

Figure 28. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas are the blue circles.

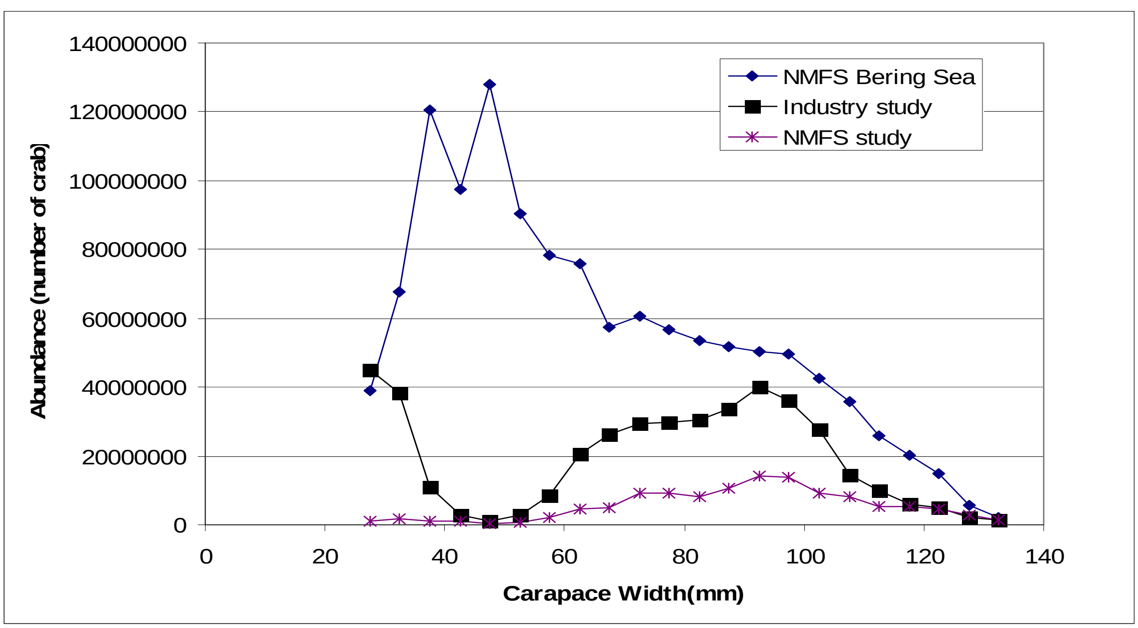

Figure 29. Abundance estimates of male snow crab by 5 mm carapace width(>=25mm) for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

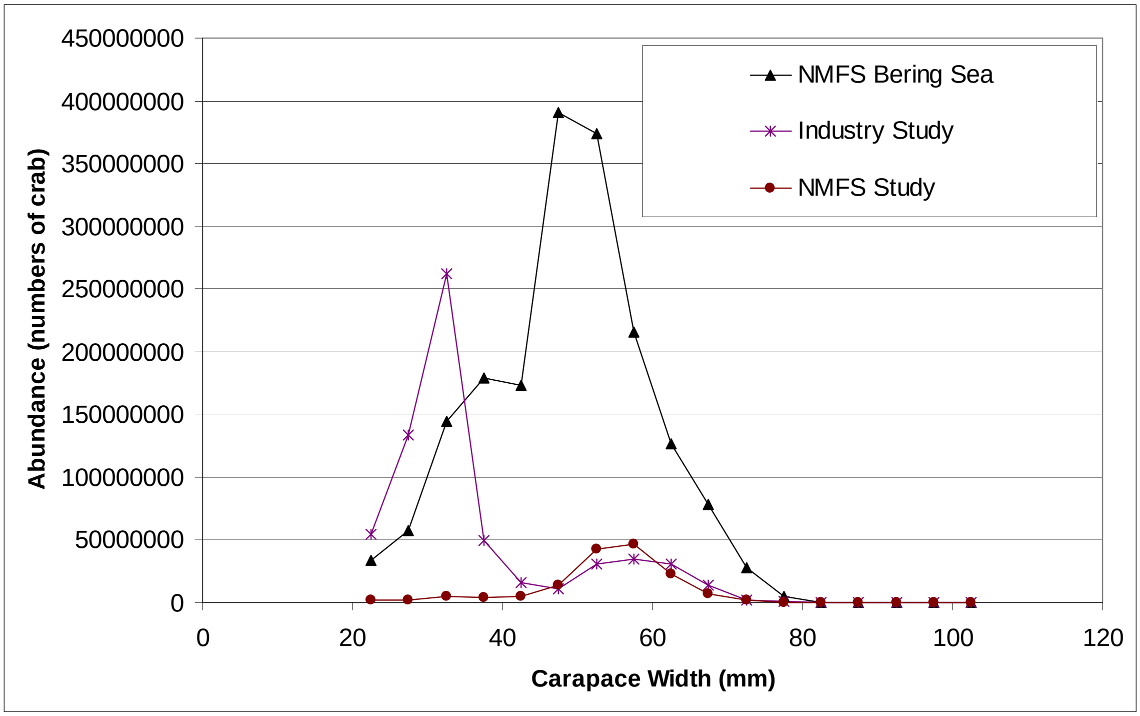

Figure 30. Abundance estimates of female snow crab by 5 mm carapace width for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

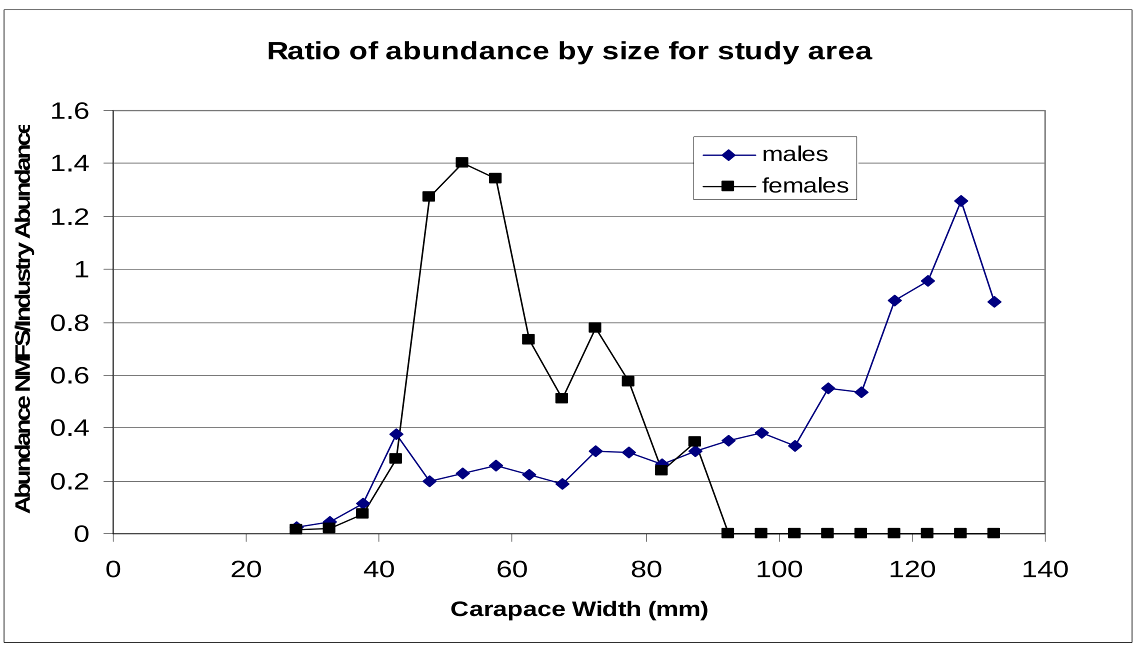

Figure 31. Ratio of abundance in the 2009 study area from the NMFS net to the BSFRF net for male and female crab.

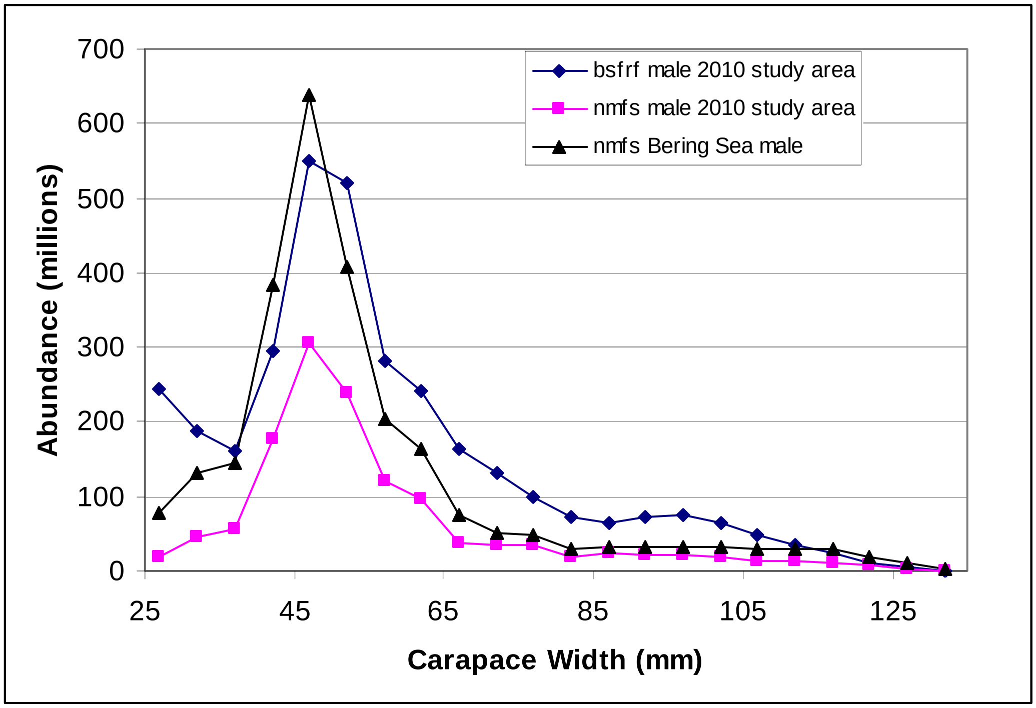

Figure 32. 2010 study area Male abundance.

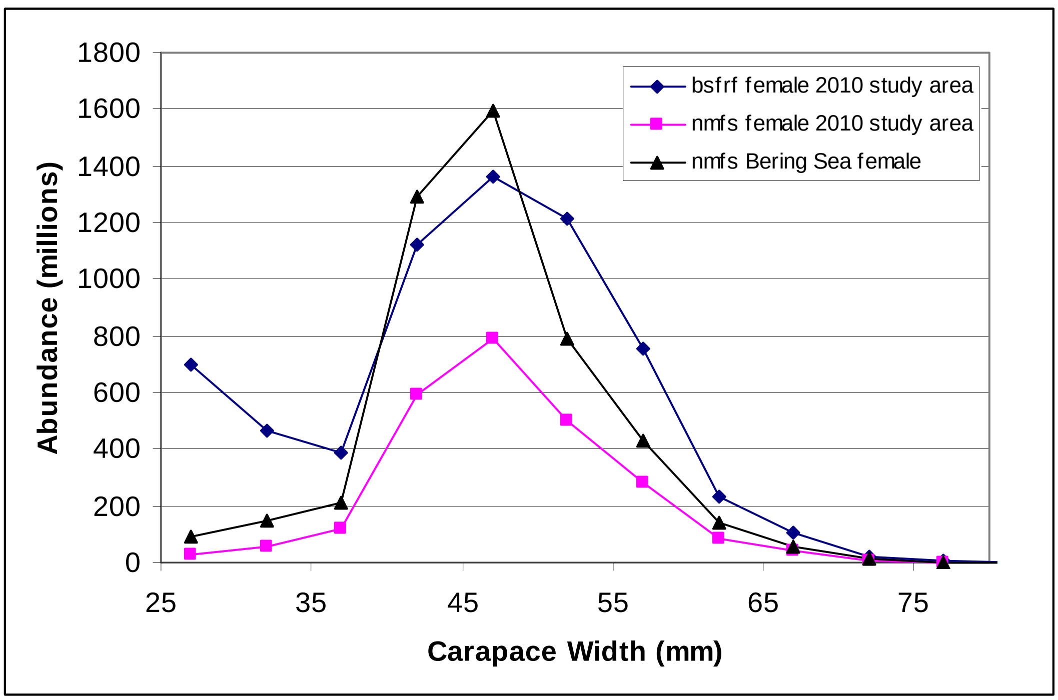

Figure 33. 2010 study area Female abundance.

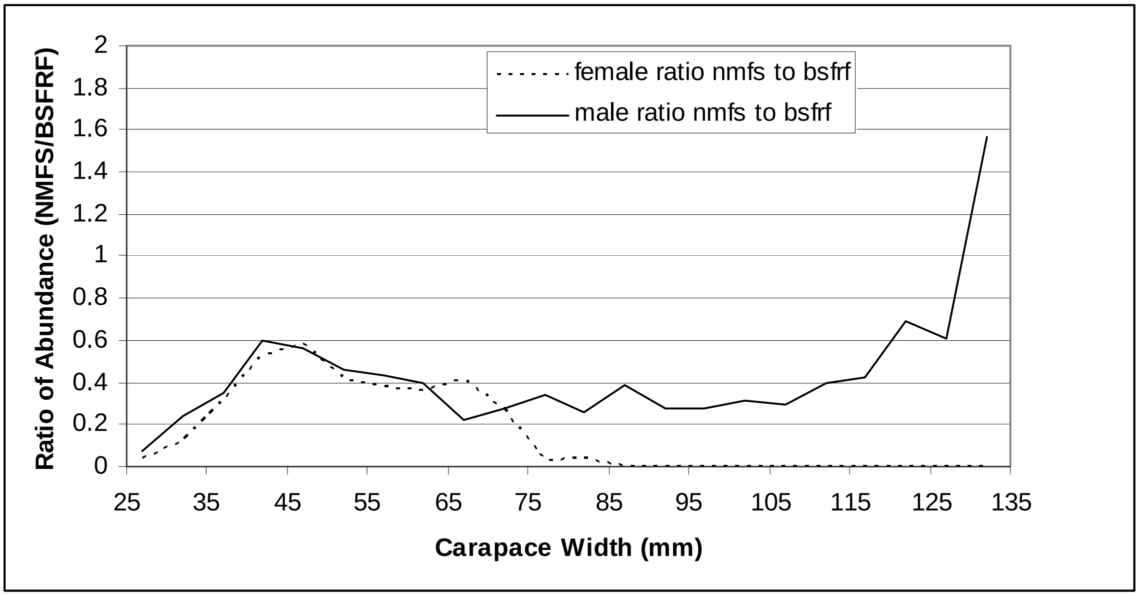

Figure 34. 2010 study area ratio of abundance

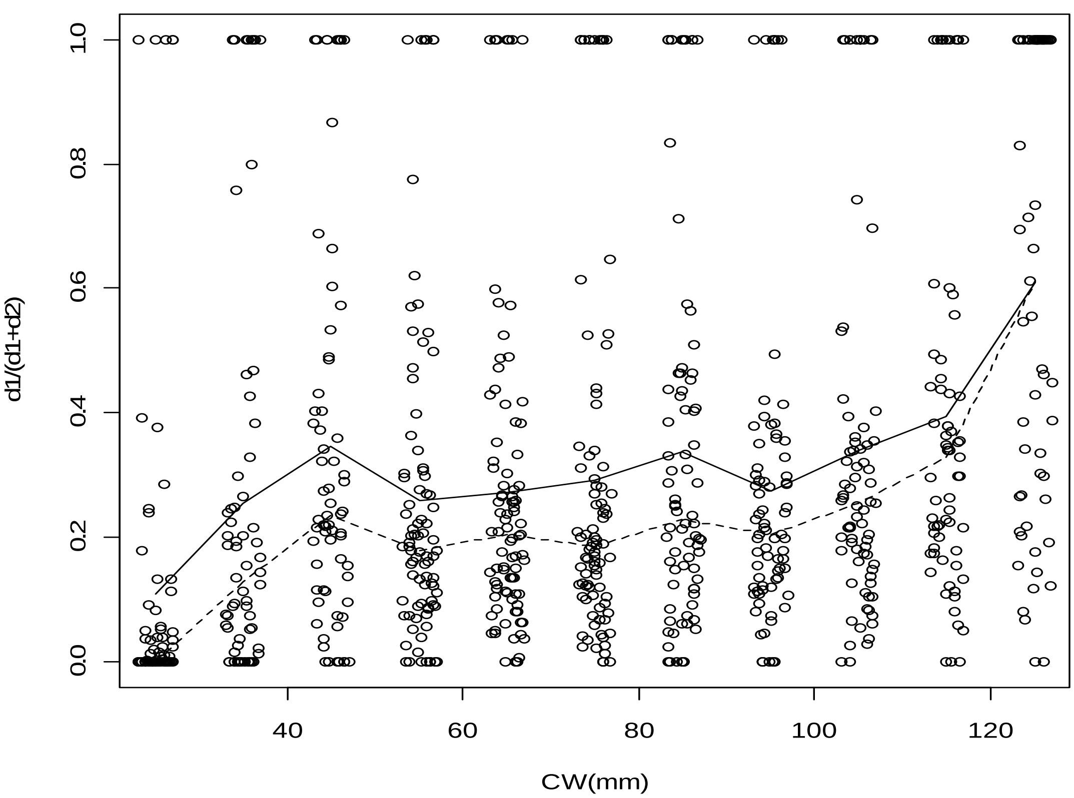

Figure 35. Male crab. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is unweighted mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

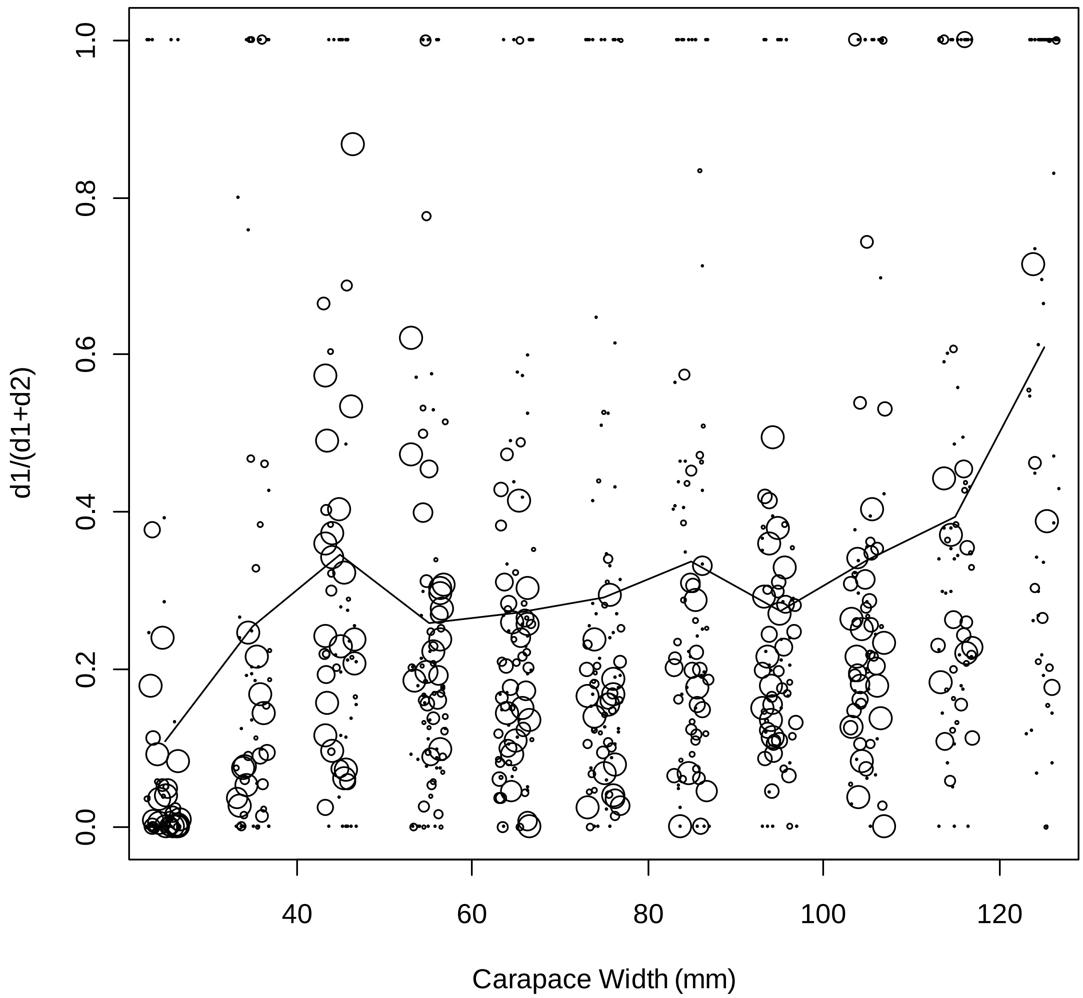

Figure 36. Density of NMFS tow (d1) divided by the sum of the density of the NMFS tow (d1) and the Industry tow (d2). The radius of the circle at each point is proportional to the sum of the catch in numbers where the Industry numbers are adjusted by the ratio of the NMFS area swept to the Industry area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

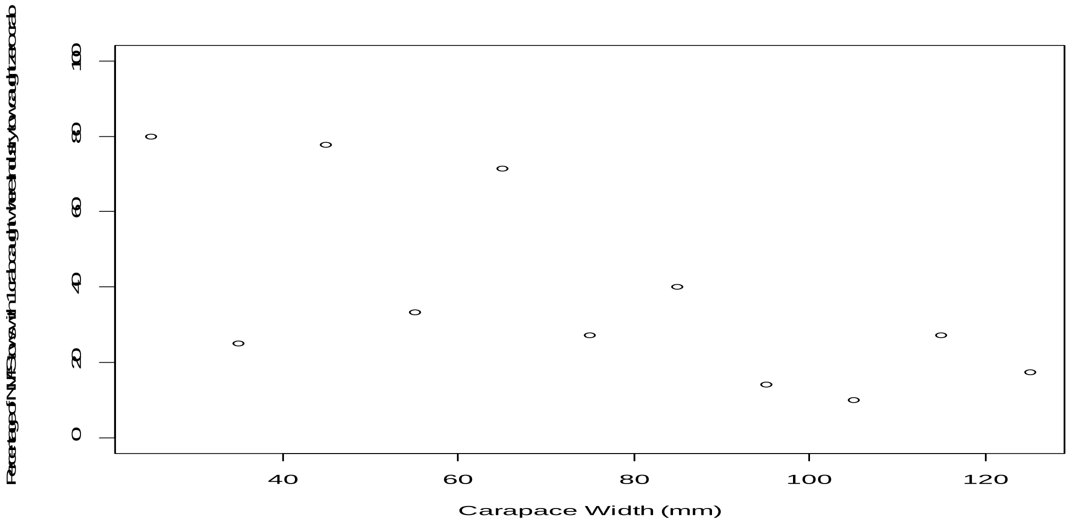

Figure 37. Percentage of paired tows where BSFRF caught no crab and NMFS caught only 1 crab.

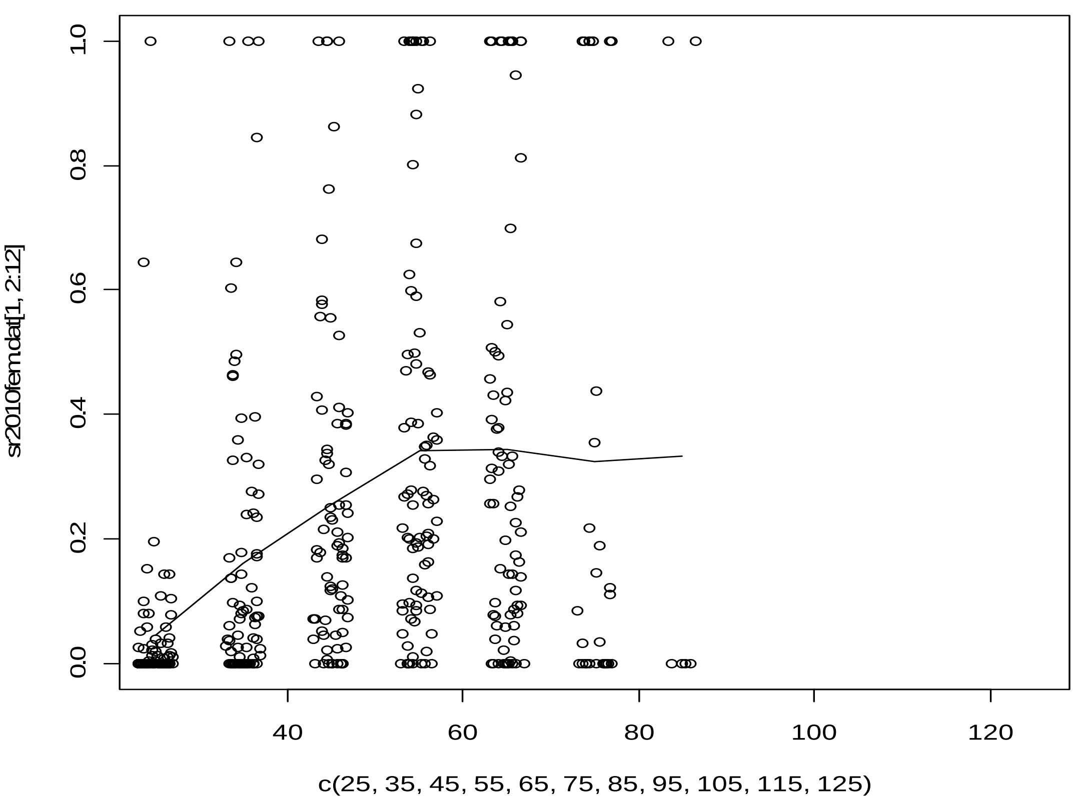

Figure 38. Female d1/(d1+d2) with mean. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

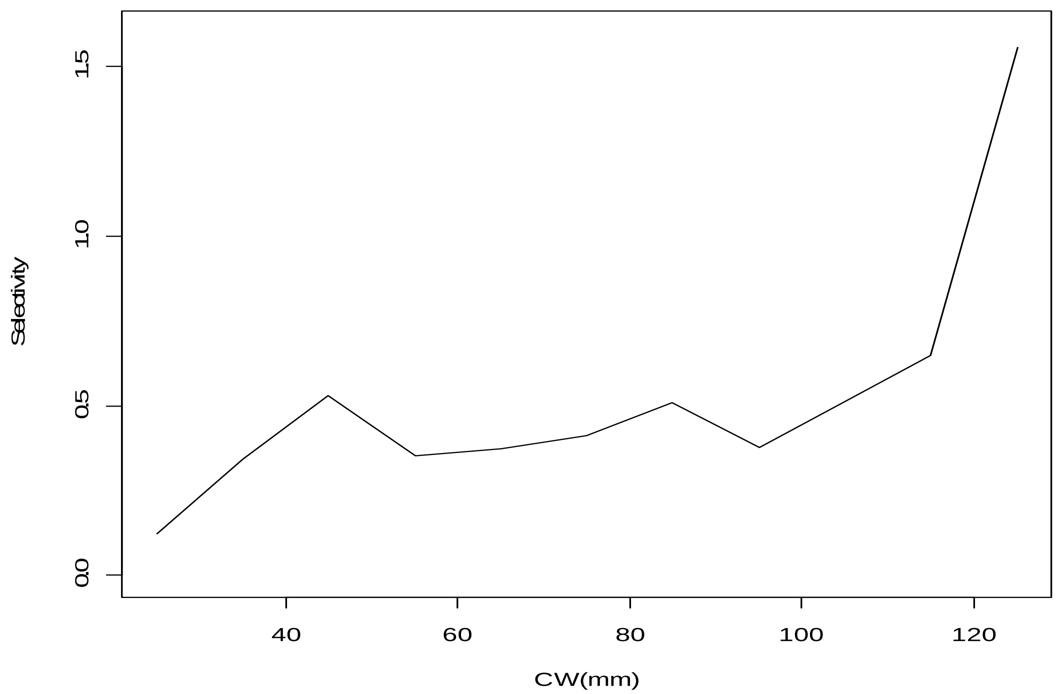

Figure 39. Mean from Figure 9 translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2)).

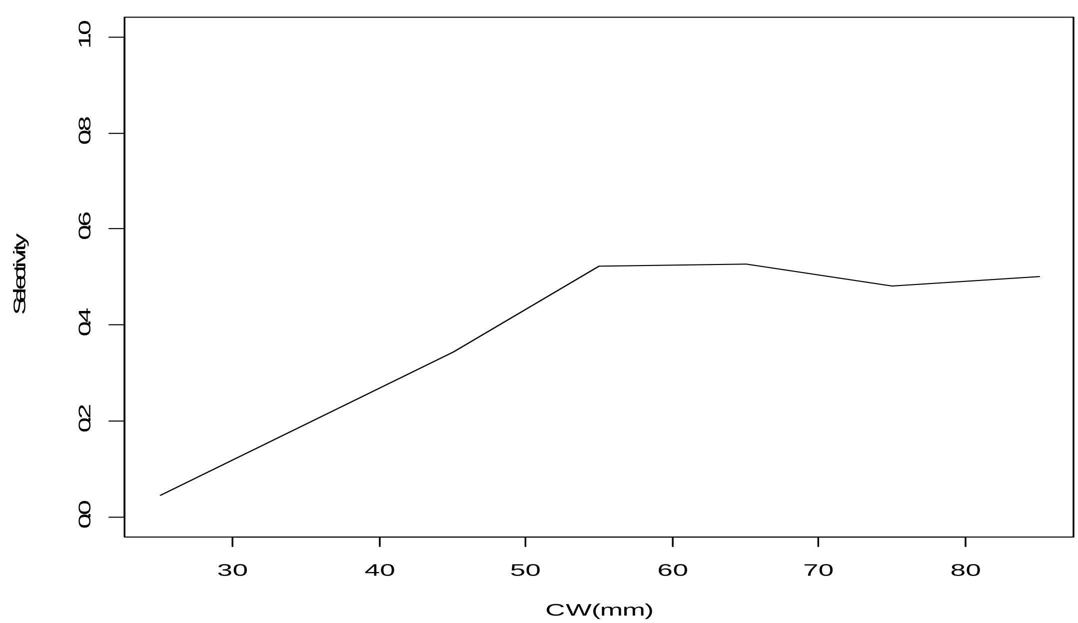

Figure 40. Mean from Figure 38, female crab translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2))

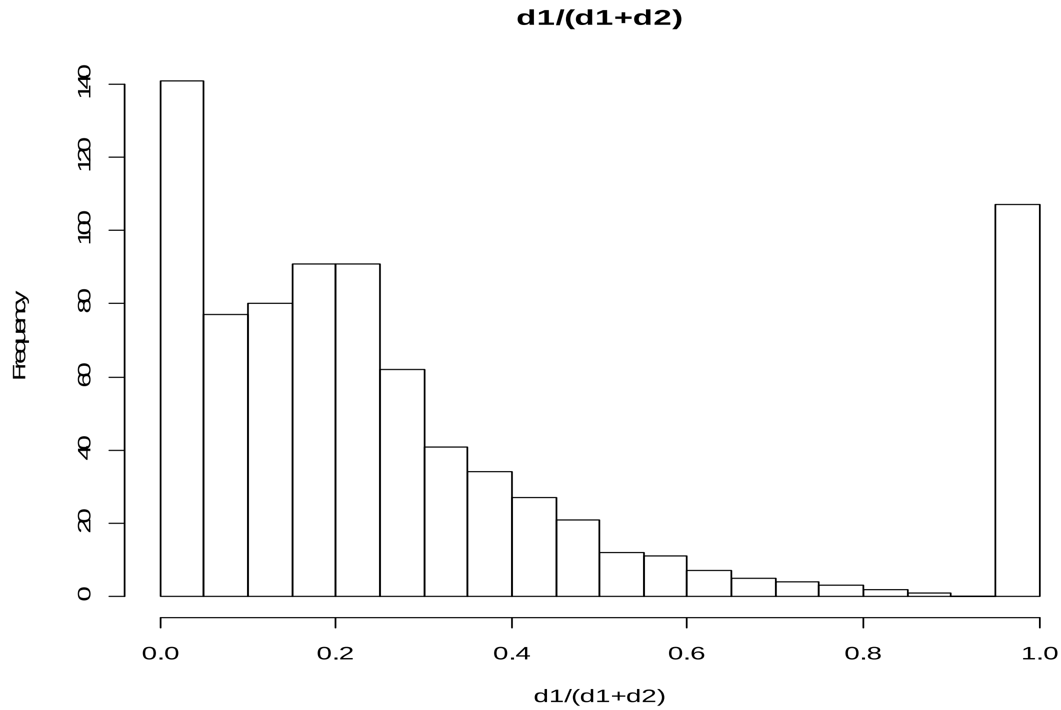

Figure 41. Histogram of d1/(d1+d2) over all sizes and tows. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

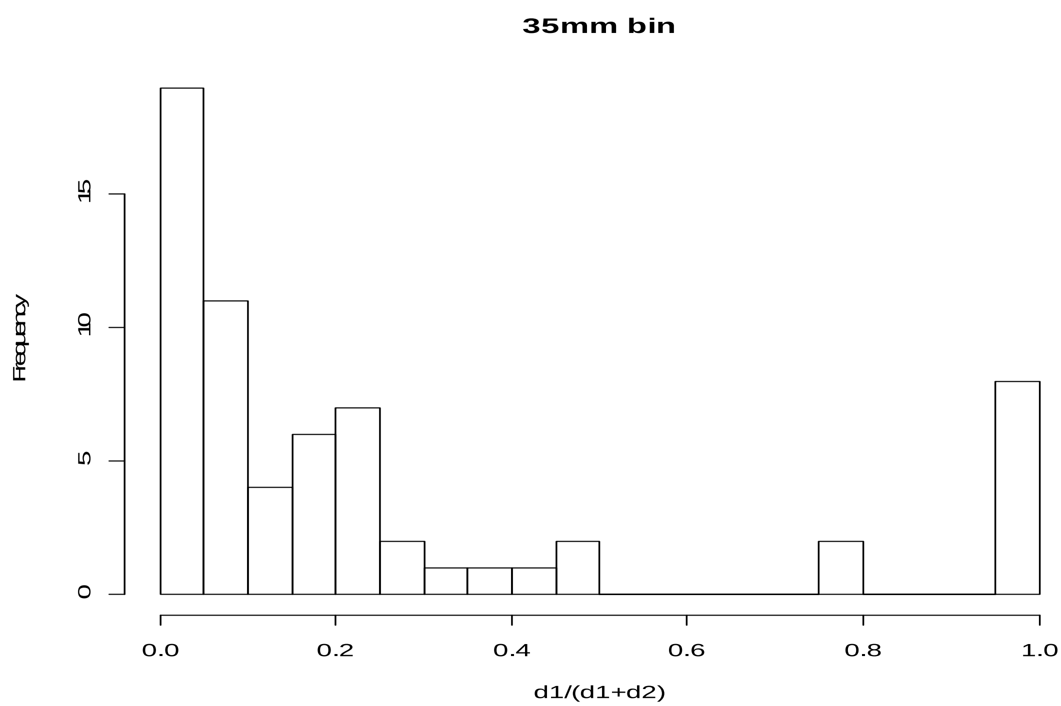

Figure 42. Histogram of d1/(d1+d2) for the 30 to 40 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

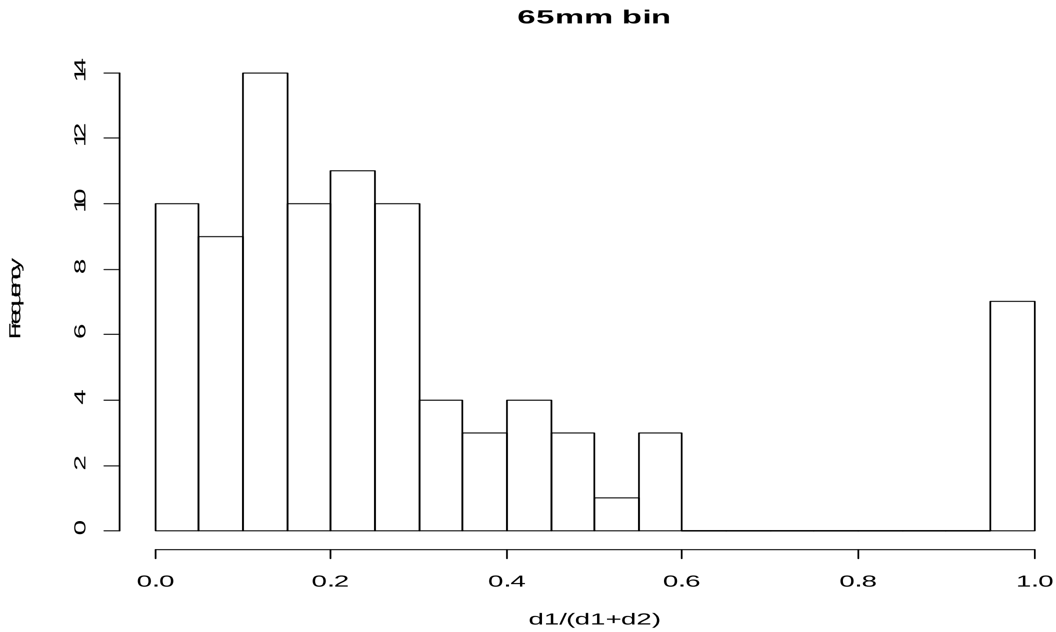

Figure 43. Histogram of d1/(d1+d2) for the 60 to 70 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

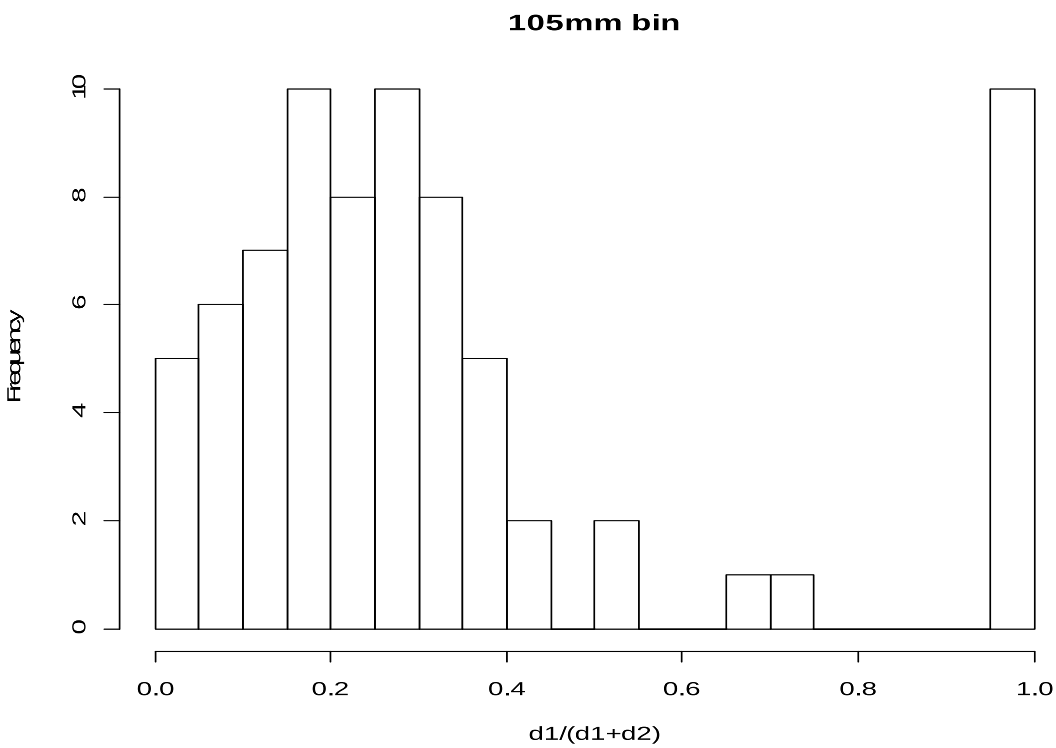

Figure 44. Histogram of d1/(d1+d2) for the 100 to 110 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

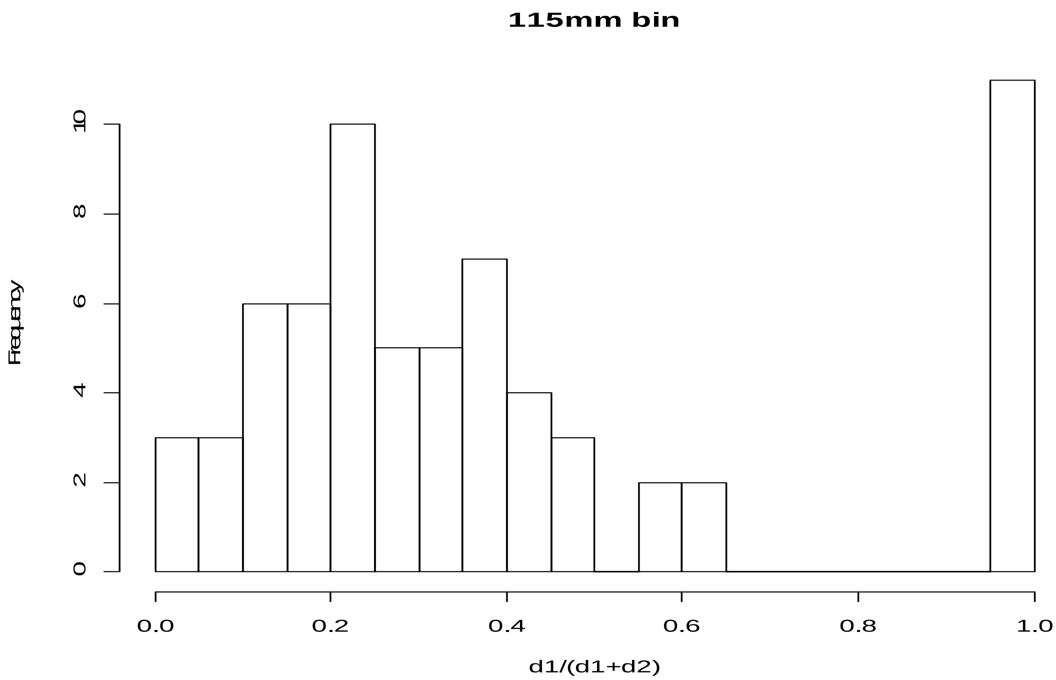

Figure 45. Histogram of d1/(d1+d2) for the 100 to 120 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

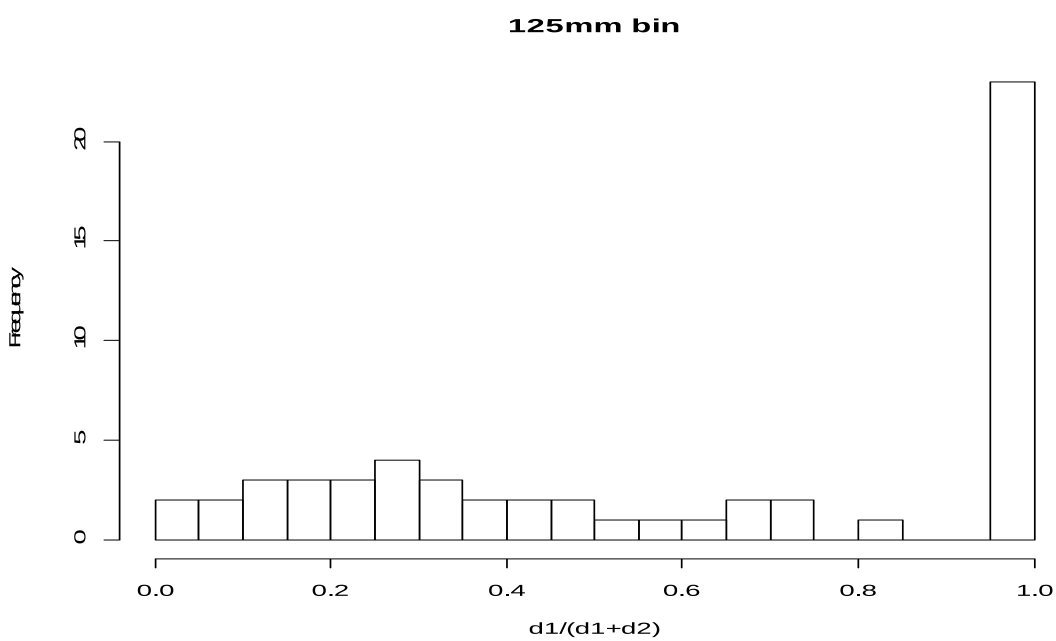

Figure 46. Histogram of d1/(d1+d2) for the 120+mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

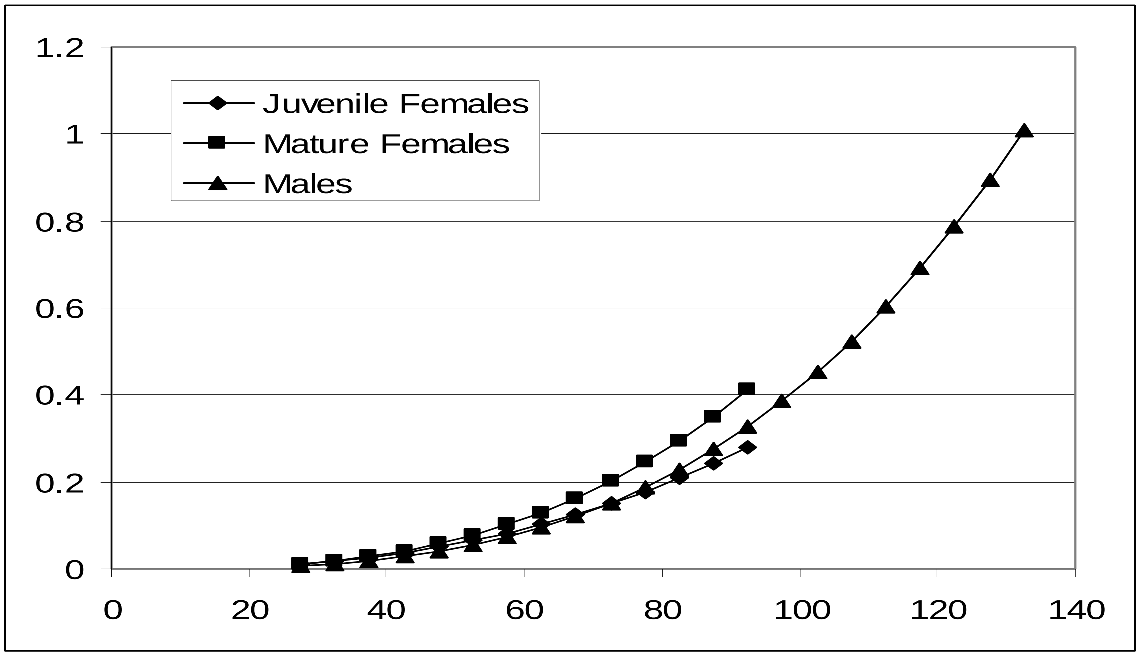

Figure 47. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

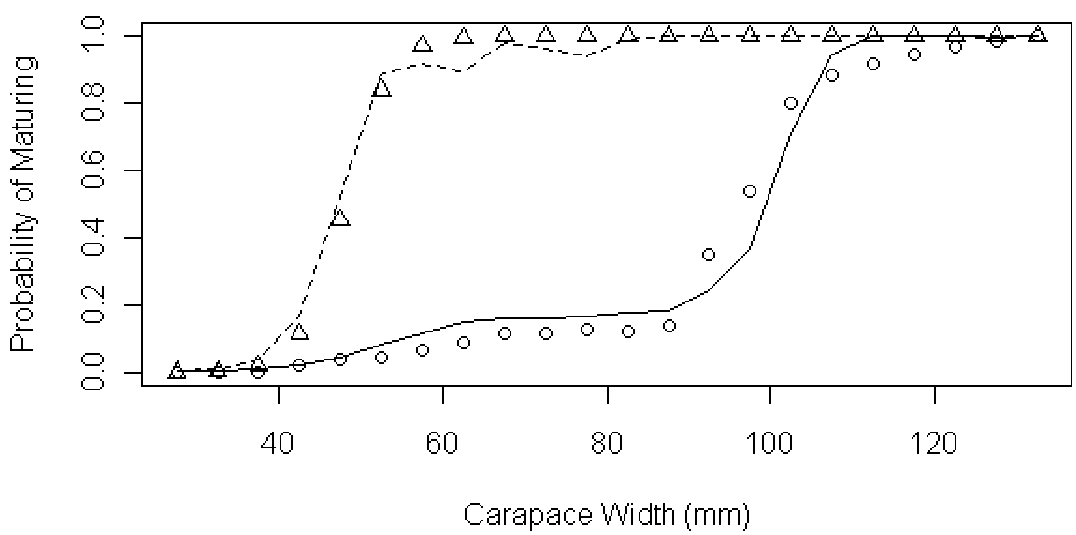

Figure 48. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (<u>not</u> the average fraction mature). Triangles are values for females used in the 2009 assessment. Circles are values for males used in the 2009 assessment.

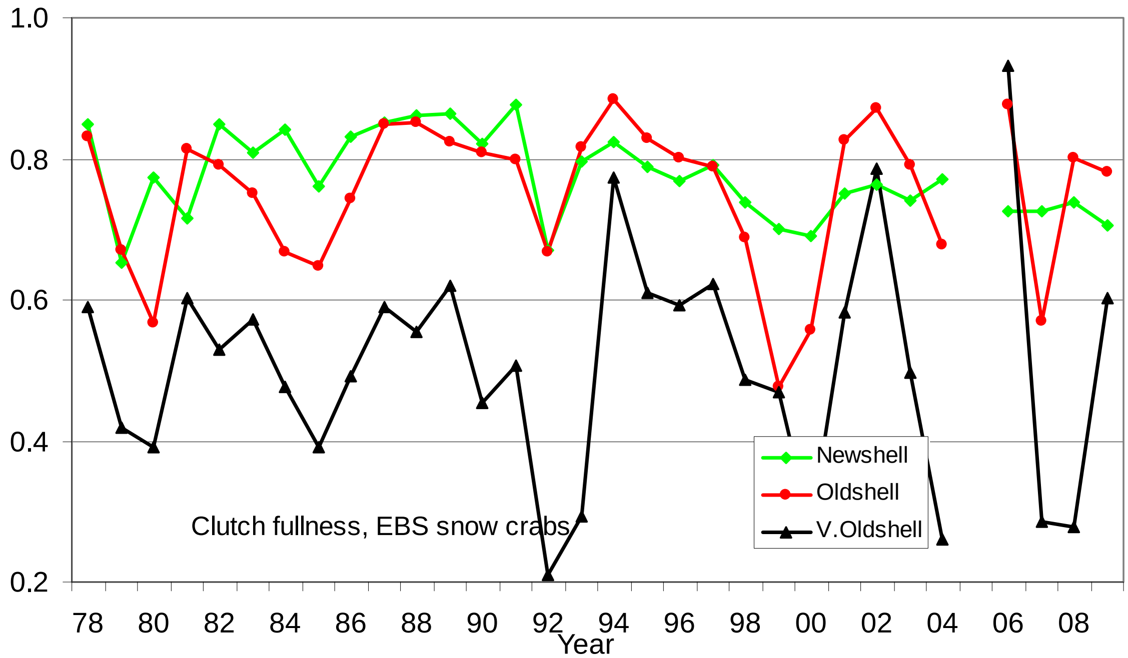

Figure 49. Clutch fullness for Bering Sea snow crab survey data by shell condition for 1978 to 2009.

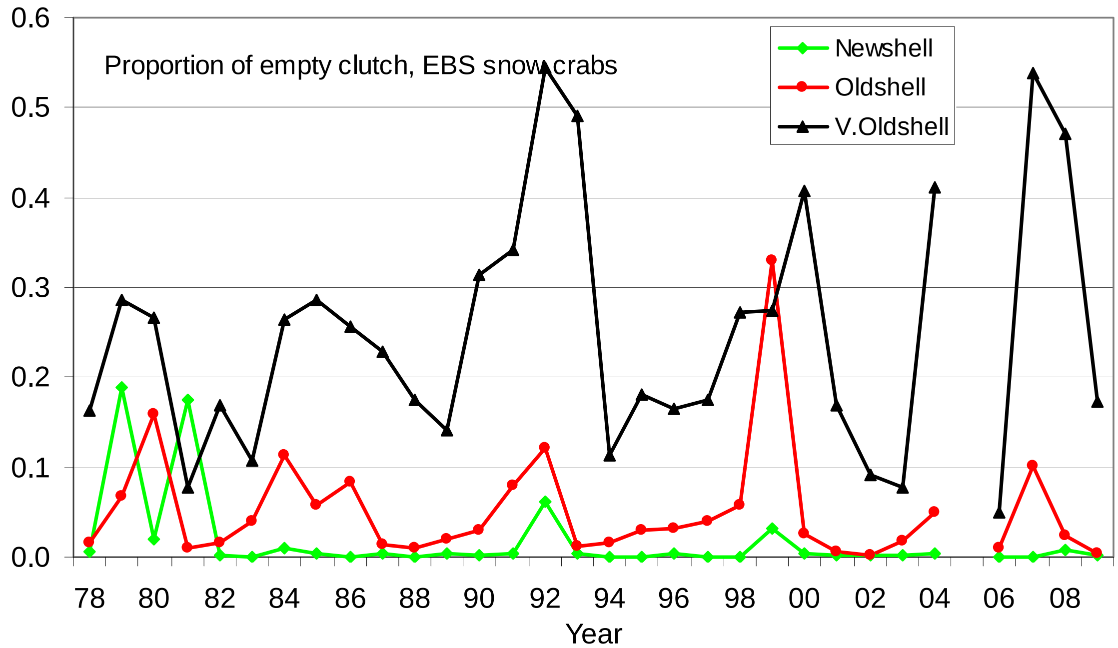

Figure 50. Proportion of barren females by shell condition from survey data 1978 to 2009.

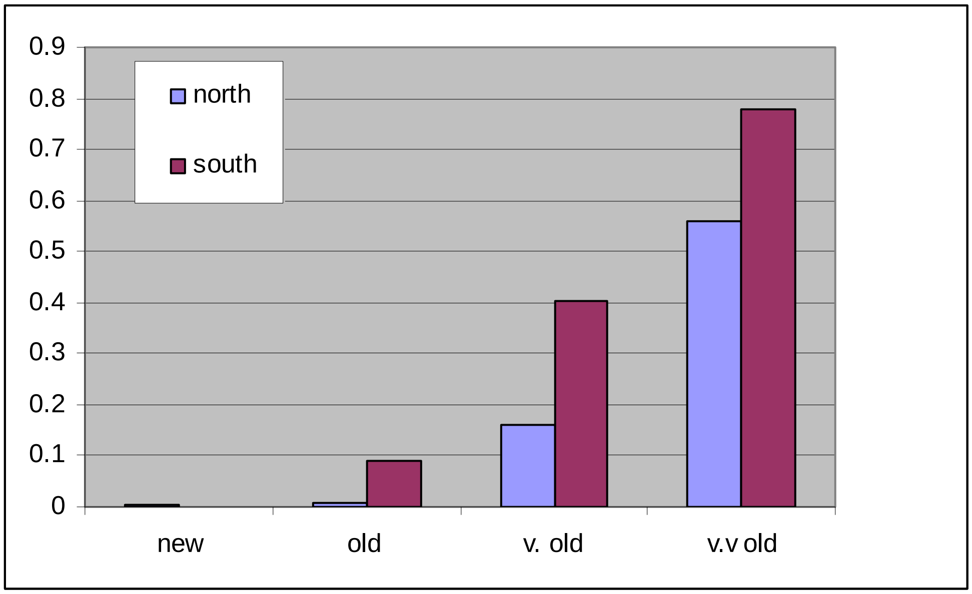

Figure 51. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

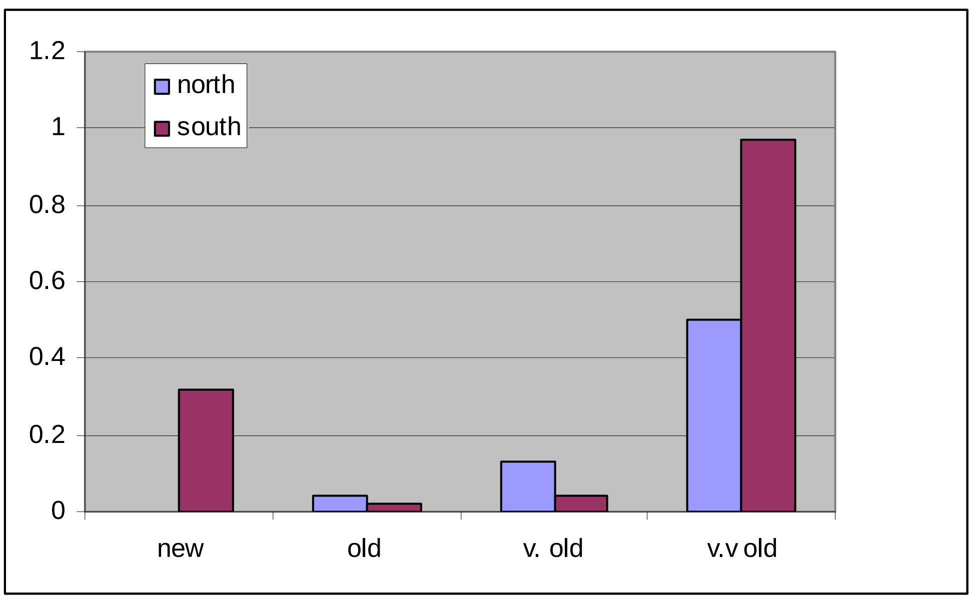

Figure 52. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

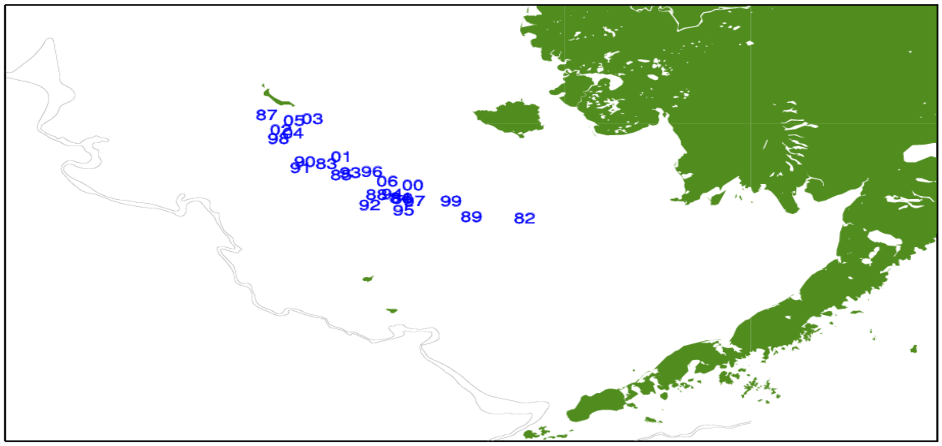

Figure 53. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

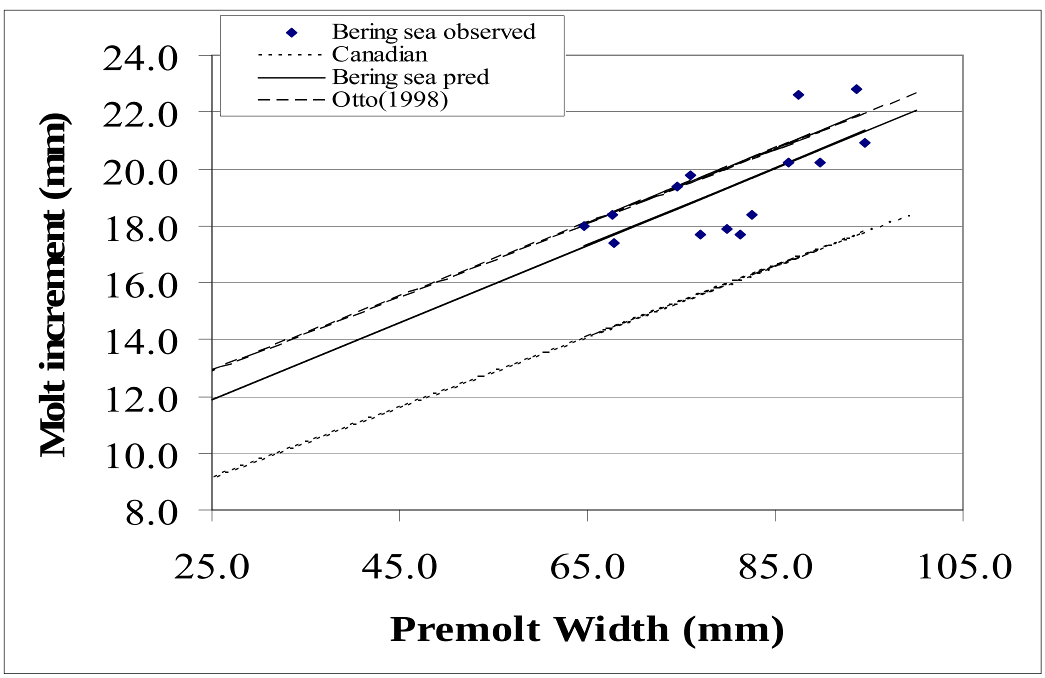

Figure 54. Growth increment as a function of premolt size for male snow crab. Points labeled Bering Sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering Sea pred is the predicted line from the Bering Sea observed growth, which is used as a prior for the growth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

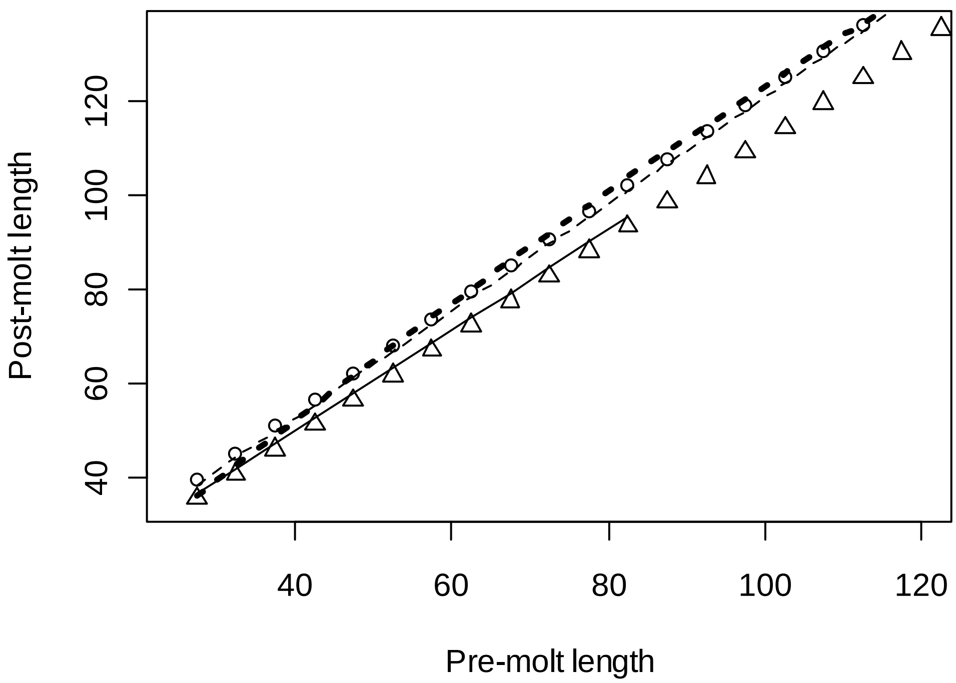

Figure 55. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the model (Model 7). Circles are the observed growth curve. Heavy dotted line is the growth curve estimated by Somerton from the 2011 growth study (post-molt CW = -0.75 + 1.39 Premolt CW – 0.0015 * (Premolt CW)^2. (Models 8,9 and 10)

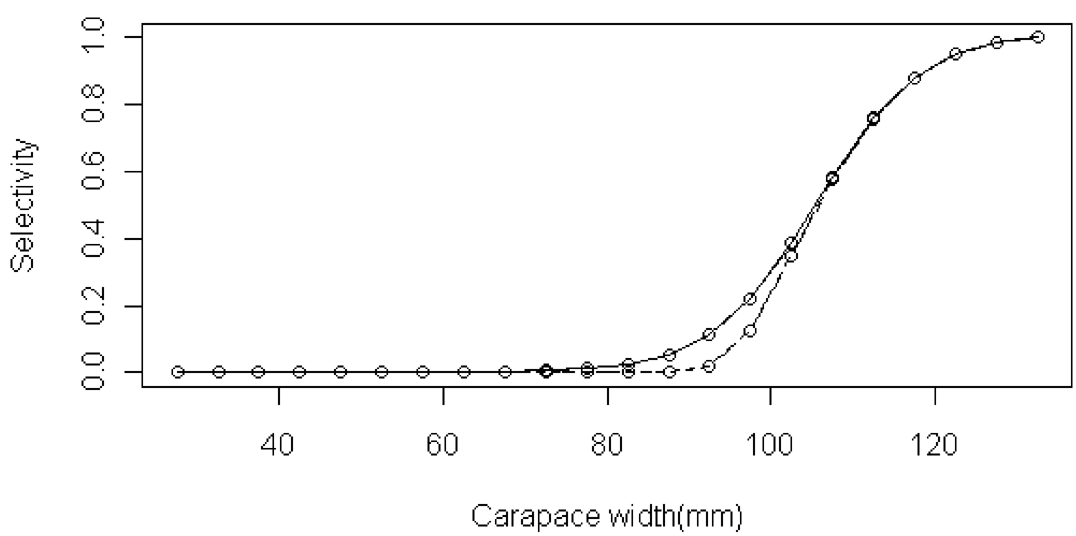

Figure 56. Model 7. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

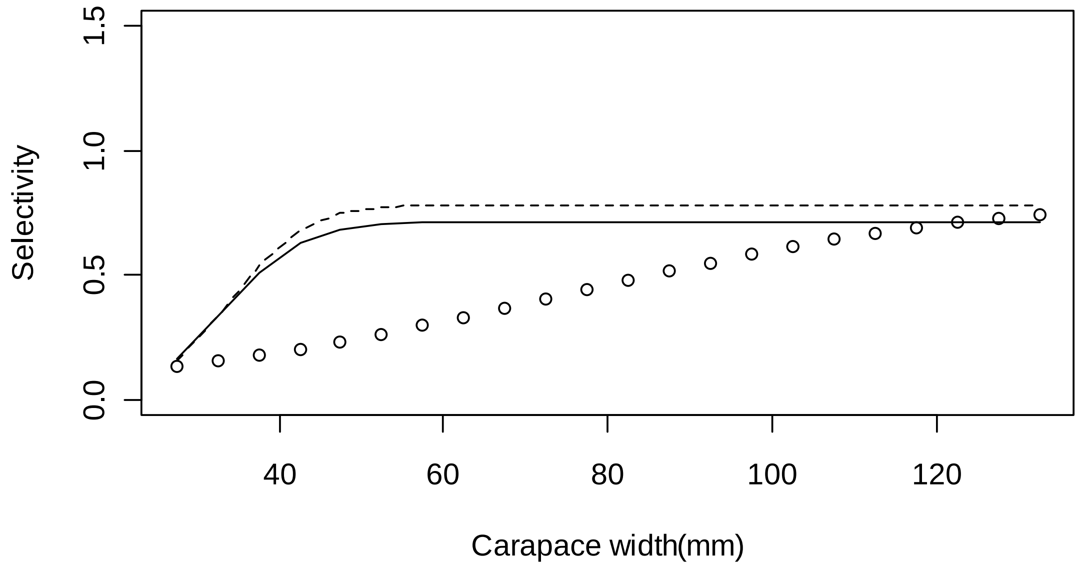

Figure 57. Model 7. Survey selectivity curves for female (dotted lines) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton from 2009 study area data (2010) are the circles.

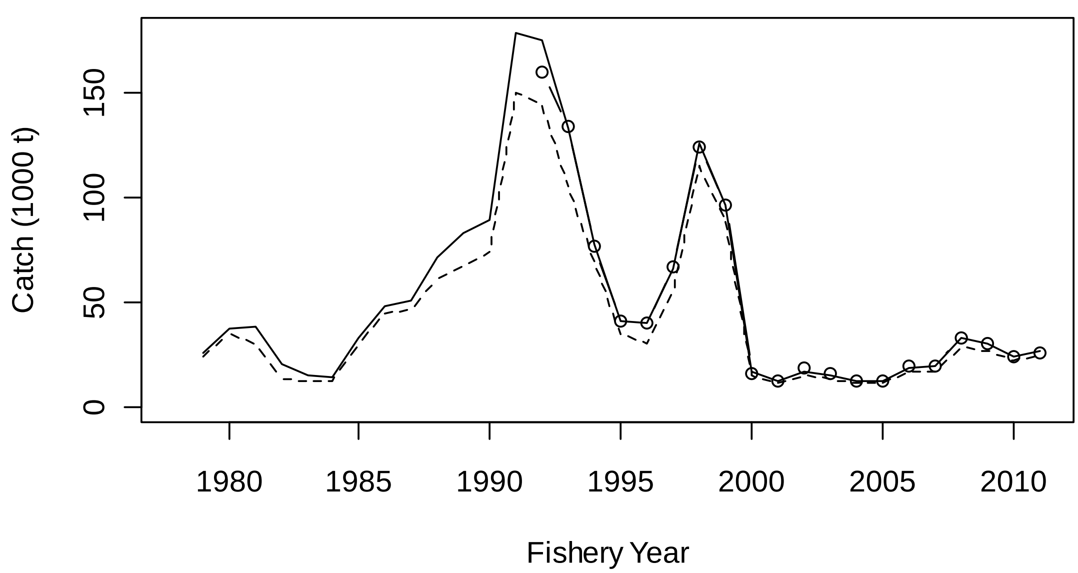

Figure 58. Model 7. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 50% mortality of discarded crab) and observed retained catch (dotted line) for 1979 to 2008 fishery seasons.

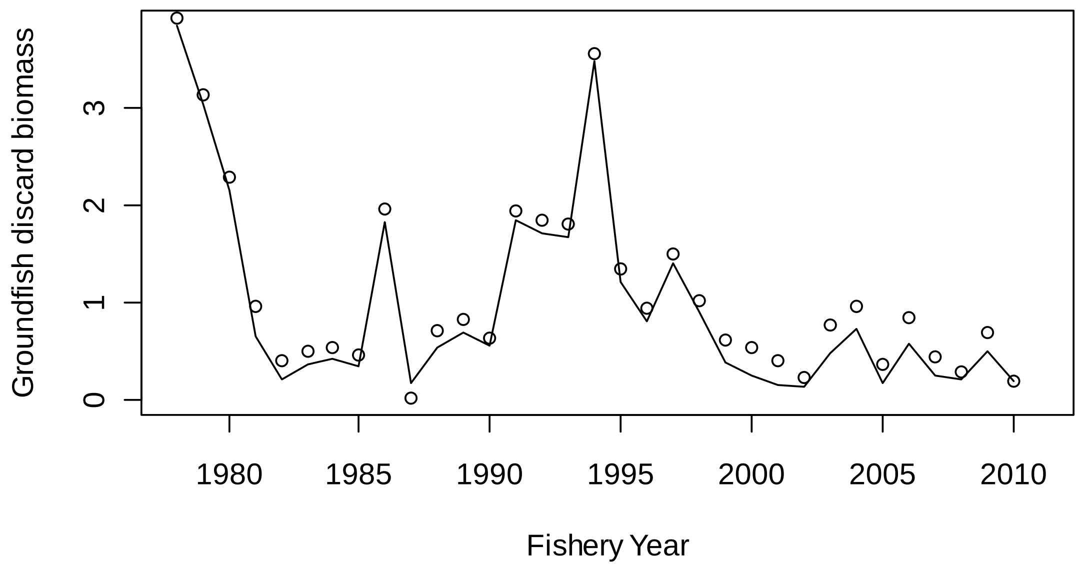

Figure 59. Model 7. Model fit to groundfish bycatch from 1978 to 2010. Circles are observed catch, line is model estimate.

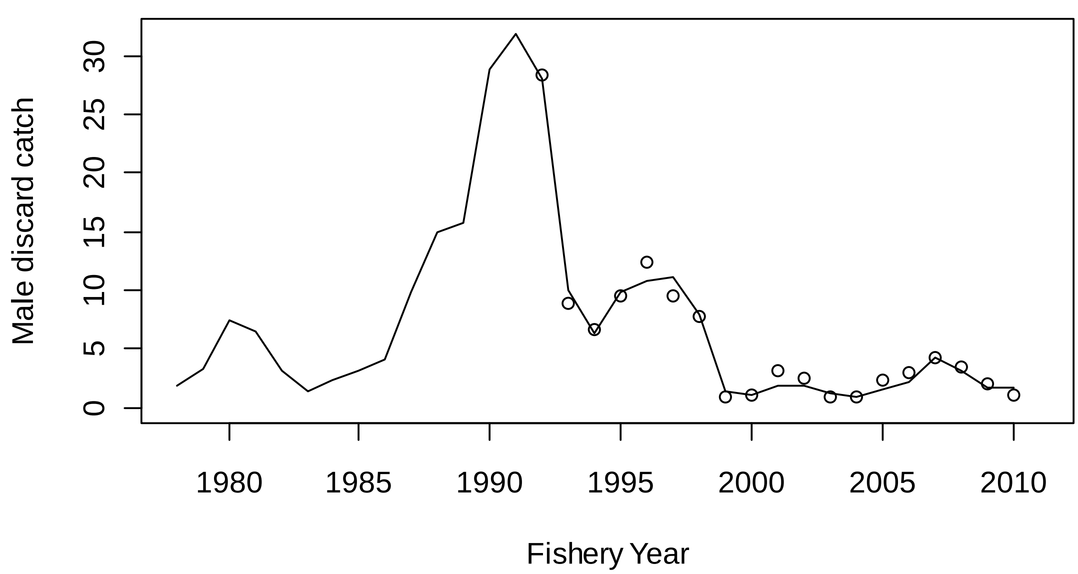

Figure 60. Model 7. Model fit to male directed discard catch for 1992/93 to 2010/11 and estimated male discard catch from 1978 to 1991.

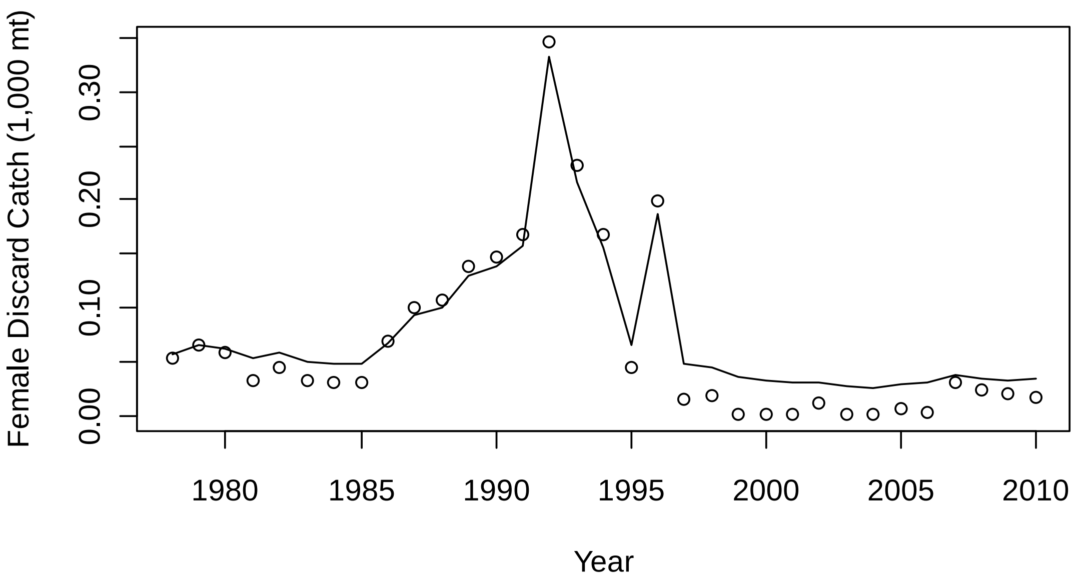

Figure 61. Model 7. Model fit to female discard bycatch in the directed fishery from 1992/93 to 2010/11 and model estimates of discard from 1978 to 1991.

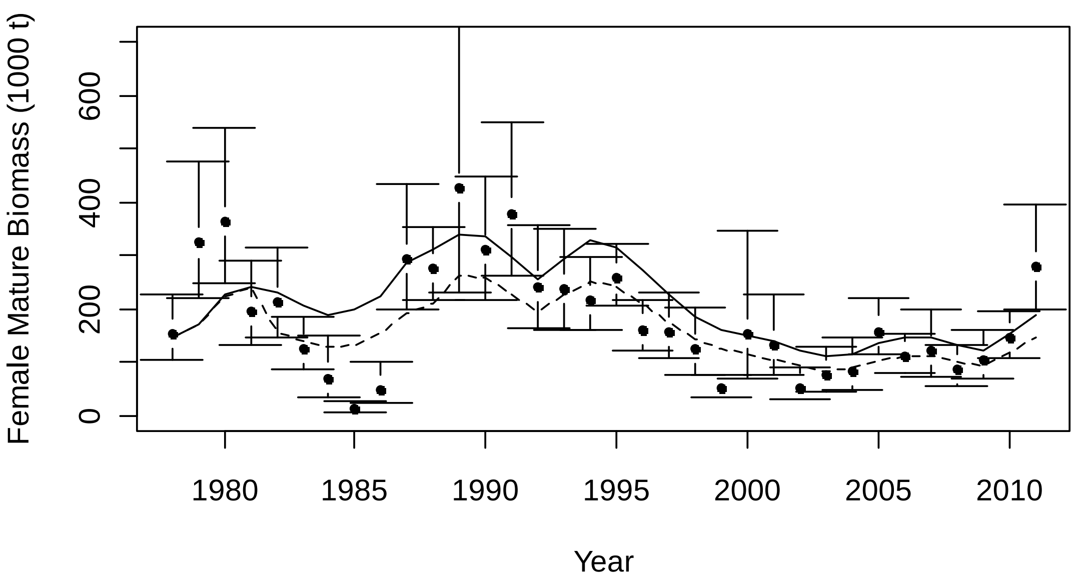

Figure 62. Model 7. Population female mature biomass (1000 t, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

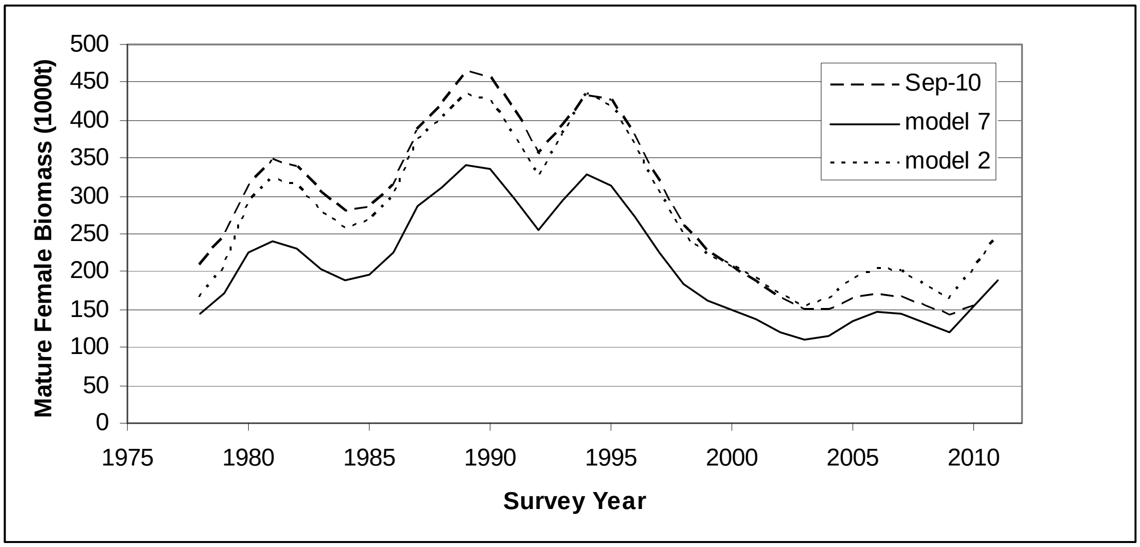

Figure 63. Population female mature biomass from the September 2010, Model 7 and Model 2.

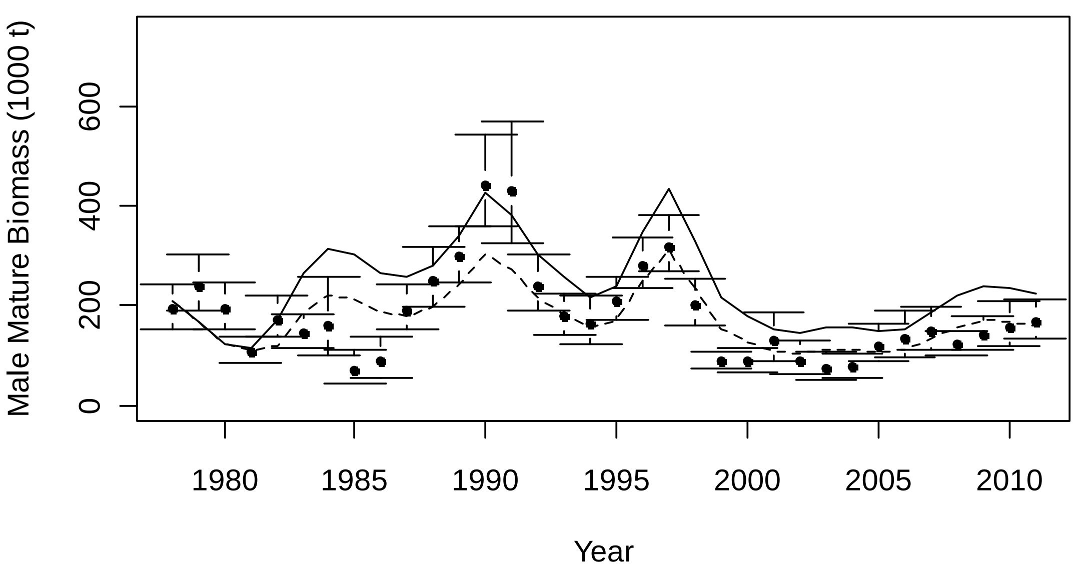

Figure 64. Model 7. Population male mature biomass (1000 t, solid line), model estimate of survey male mature biomass (dotted line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

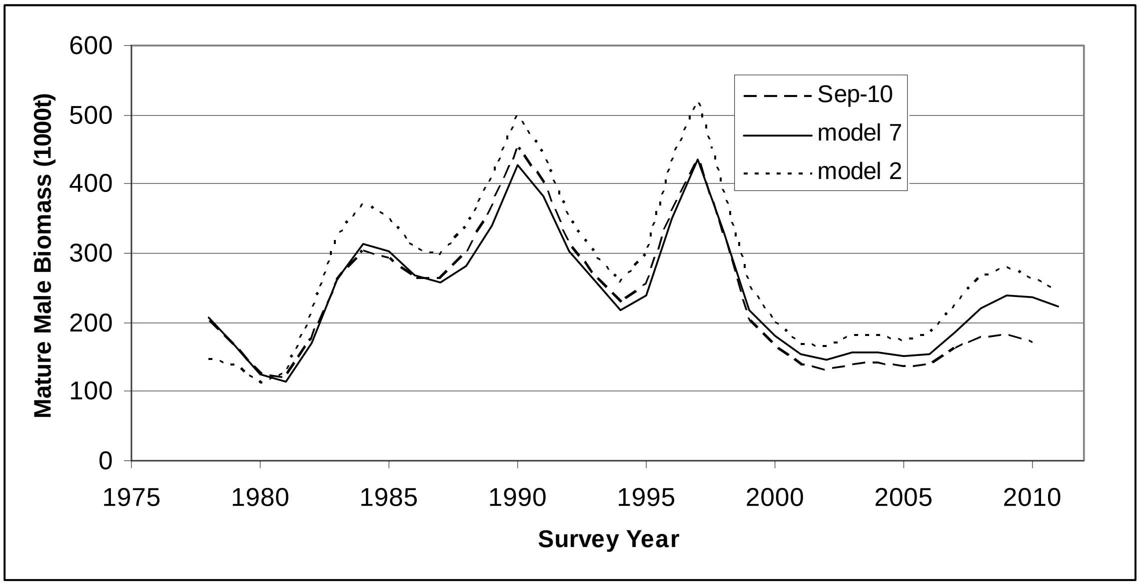

Figure 65. Population male mature biomass from the September 2010 assessment, Model 7 and Model 2.

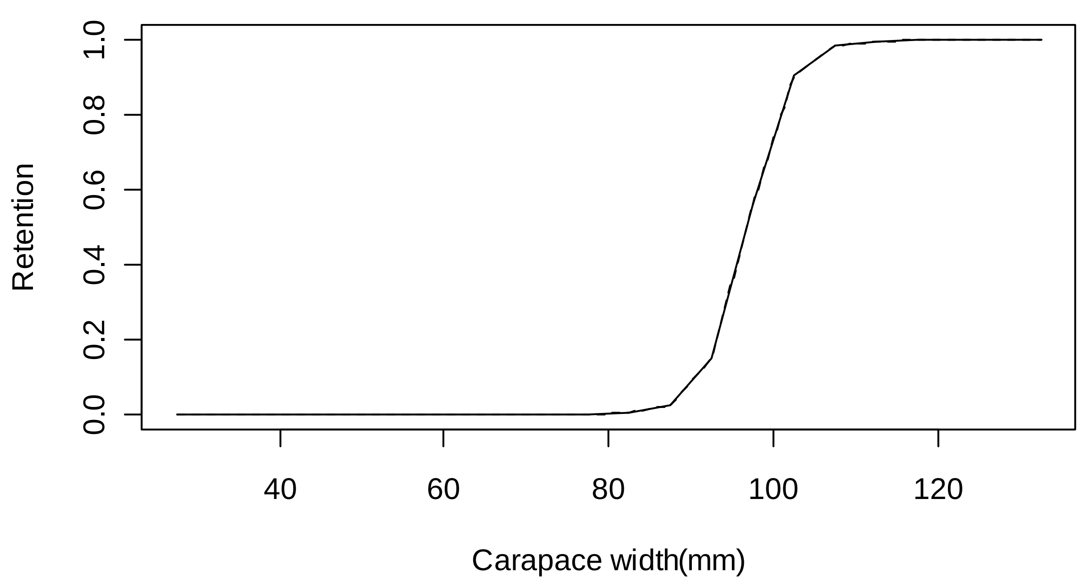

Figure 66. Model 7. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

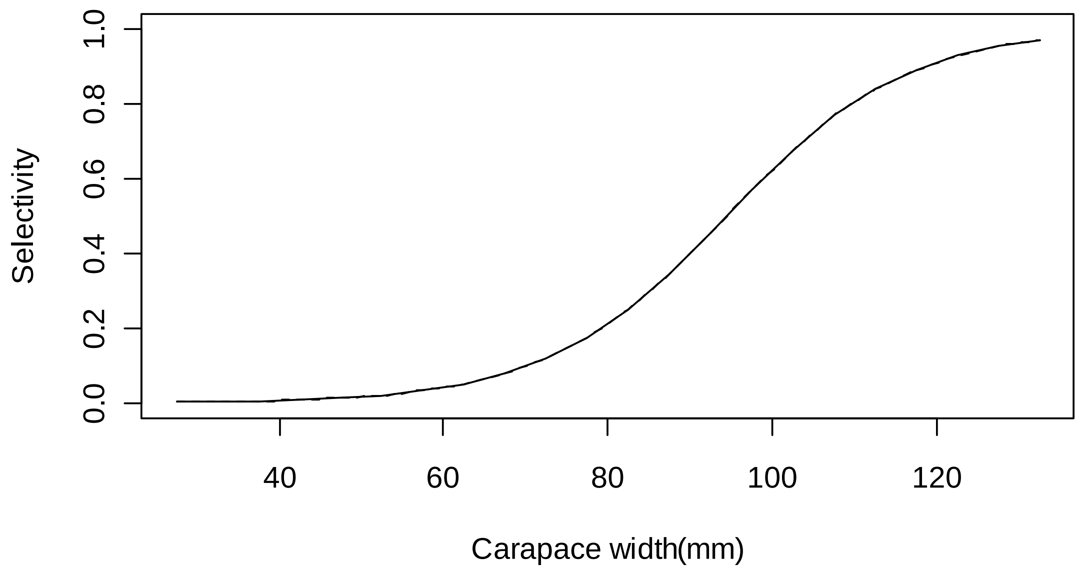

Figure 67. Model 7. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

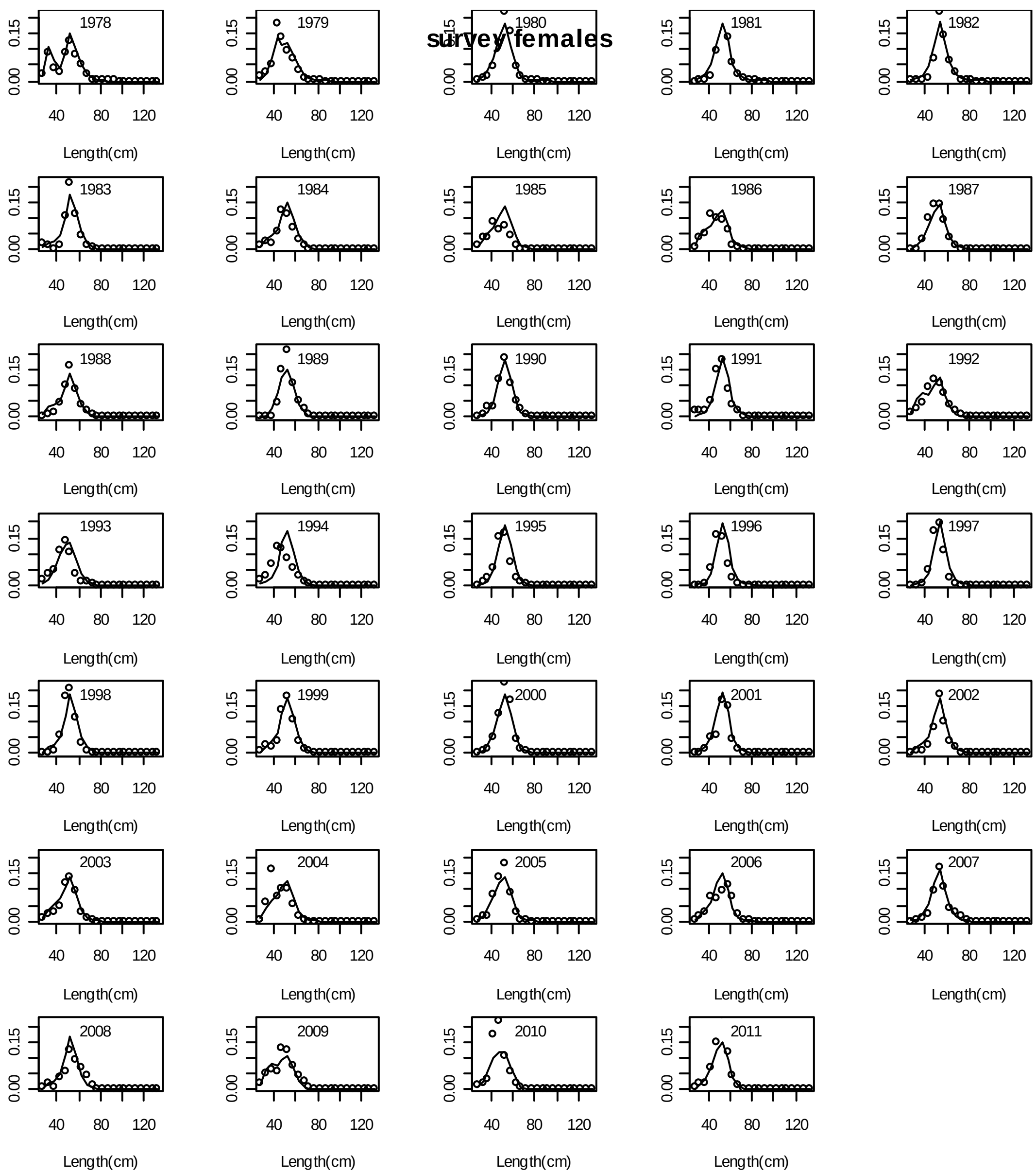

Figure 68. Model 7. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

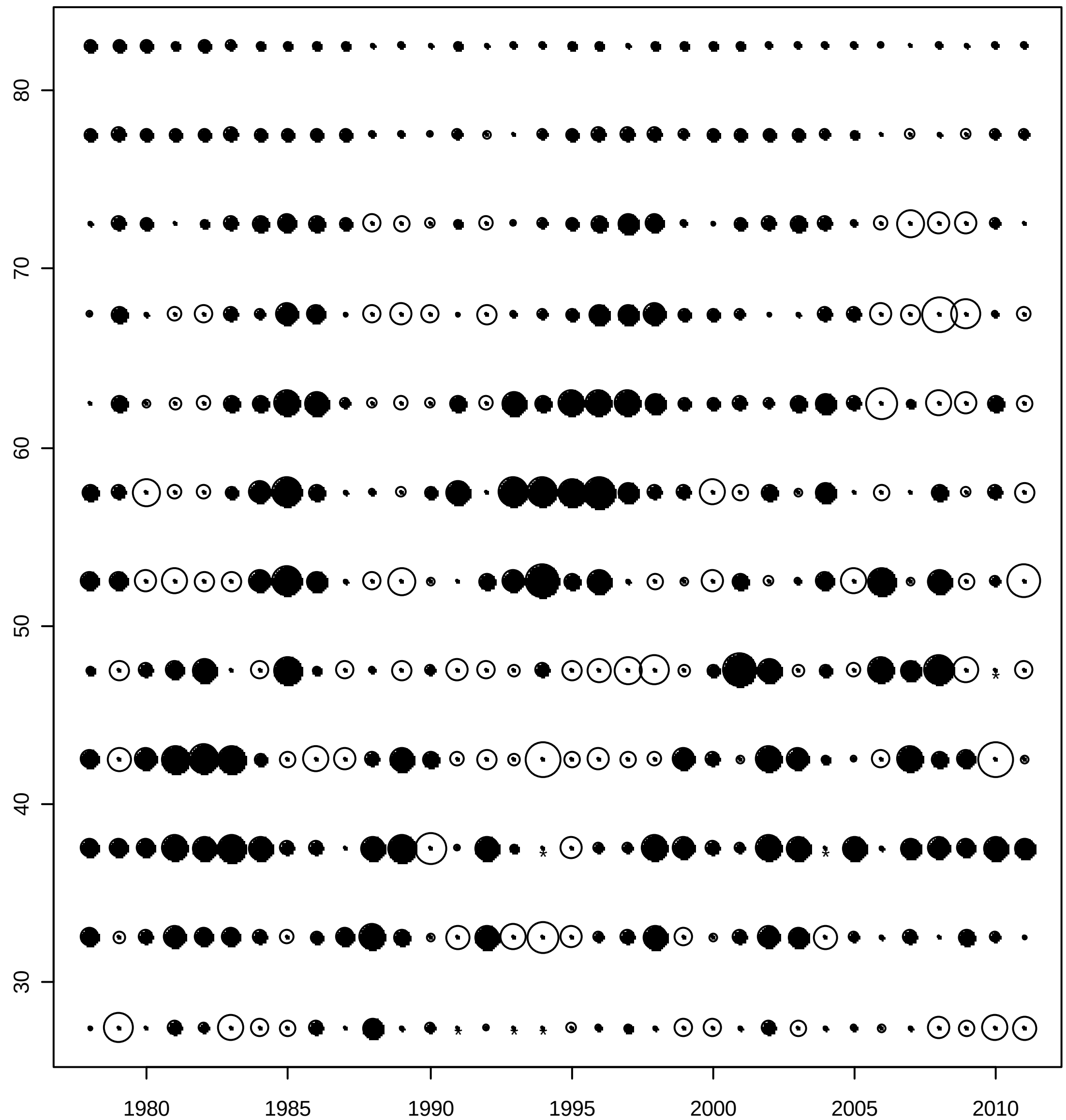

Figure 69. Model 7. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

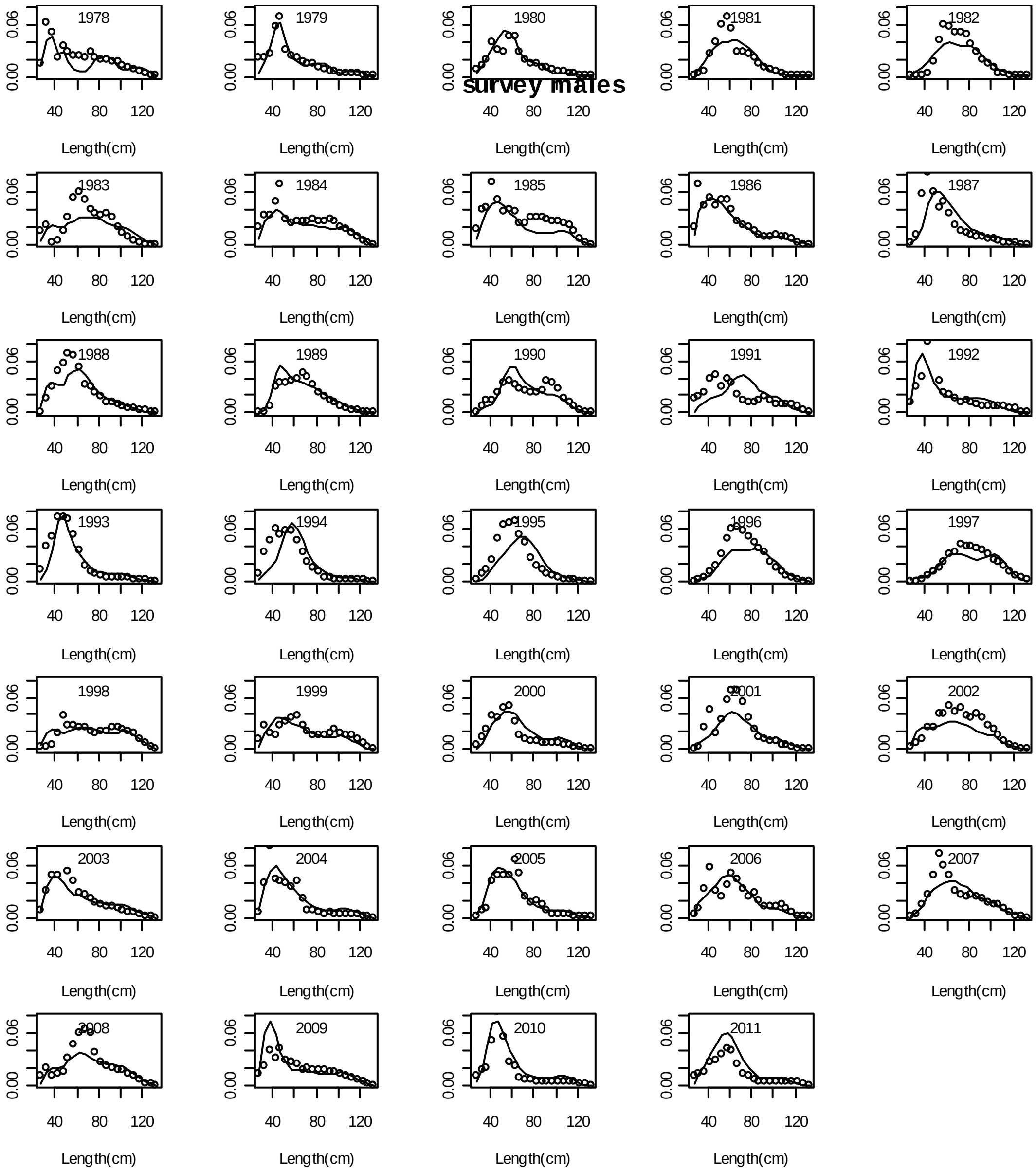

Figure 70. Model 7. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

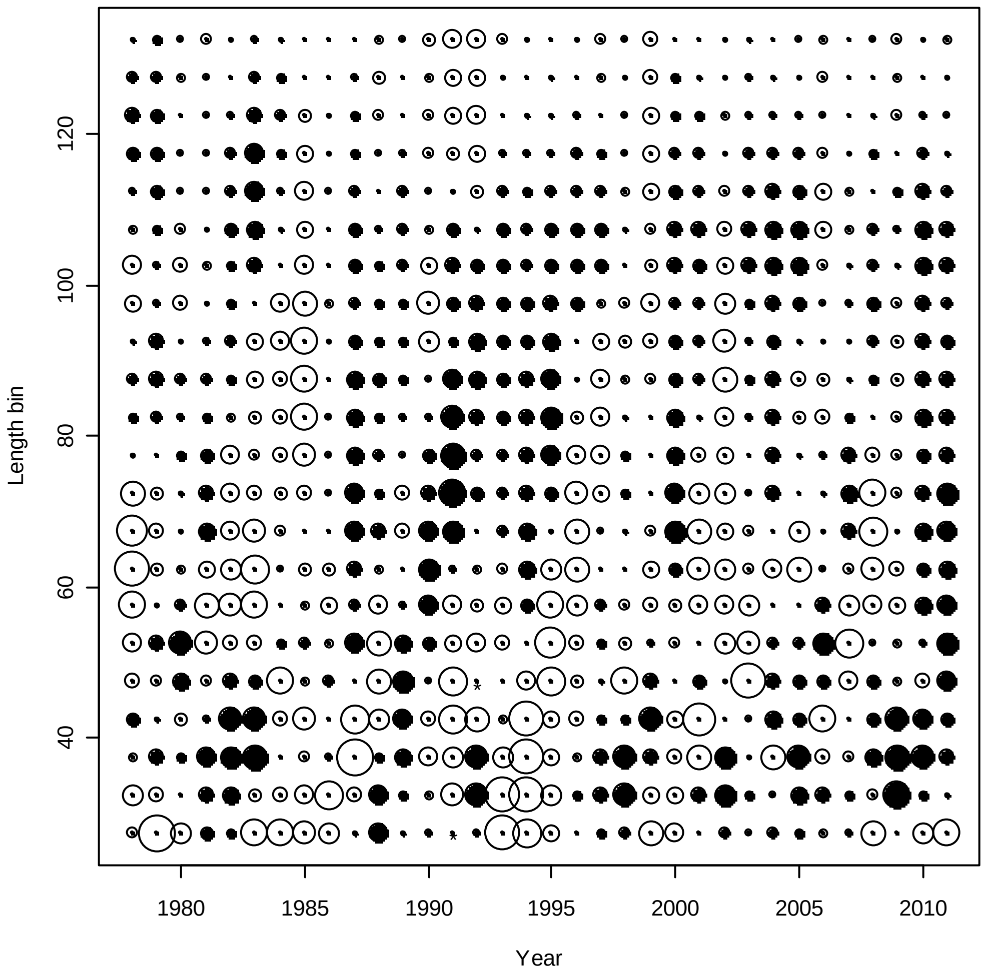

Figure 71. Model 7. Residuals for fit to survey male size frequency. . Filled circles are negative residuals (predicted higher than observed).

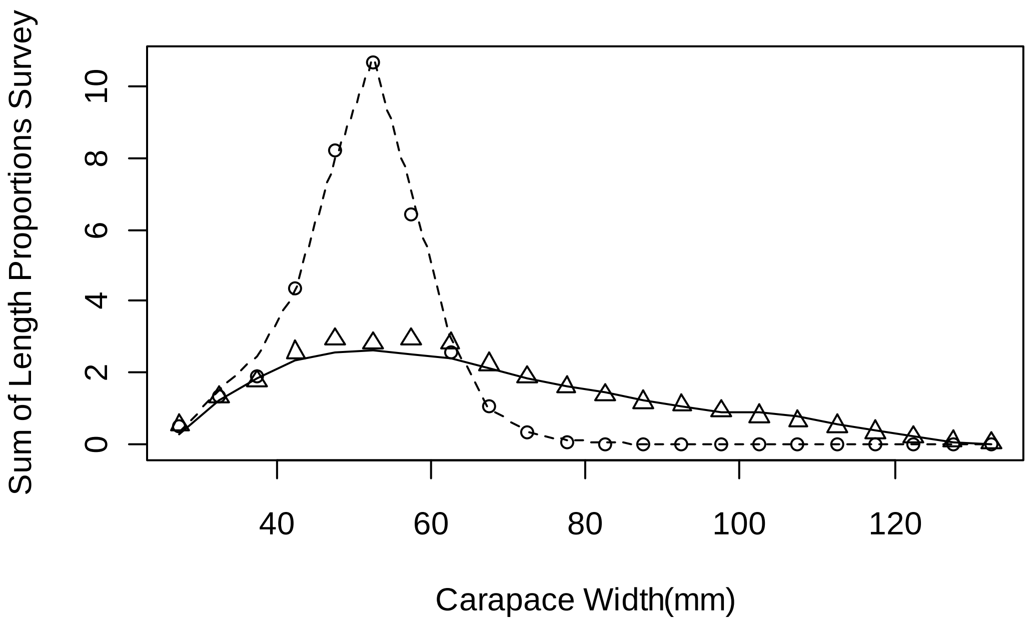

Figure 72. Model 7. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

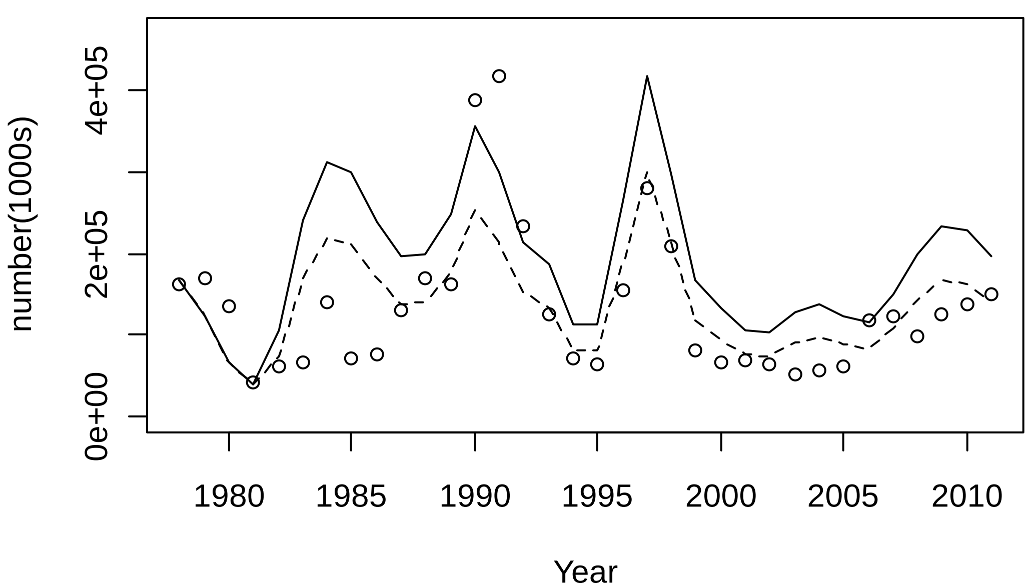

Figure 73. Model 7. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

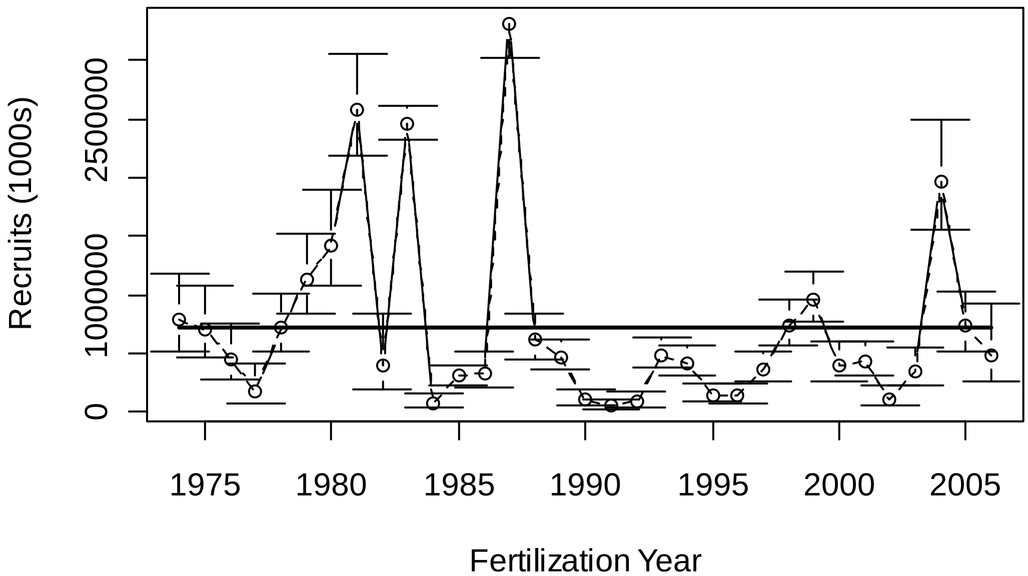

Figure 74. Model 7. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

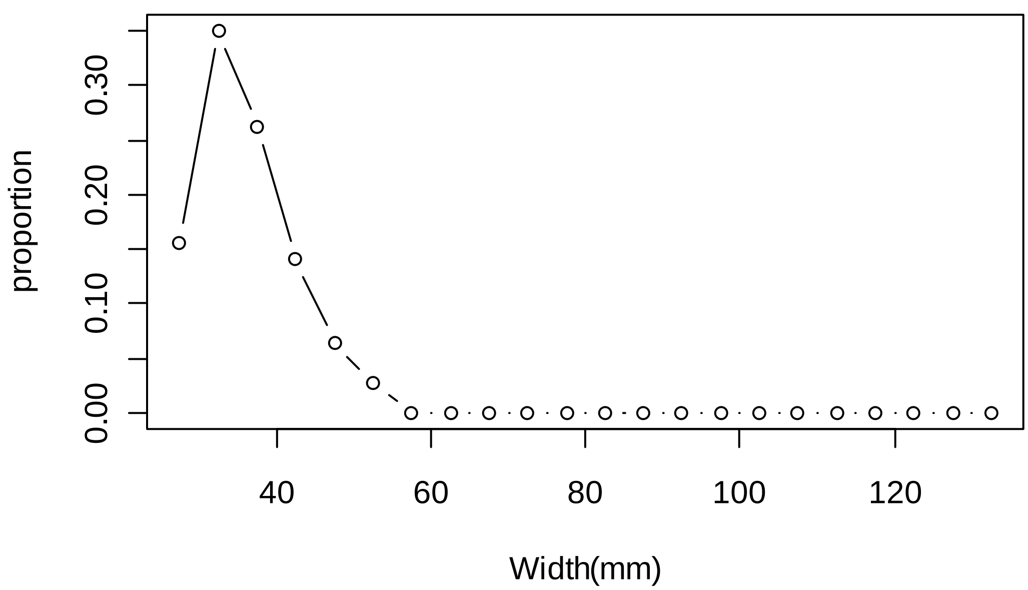

Figure 75. Model 7. Distribution of recruits to length bins estimated by the model.

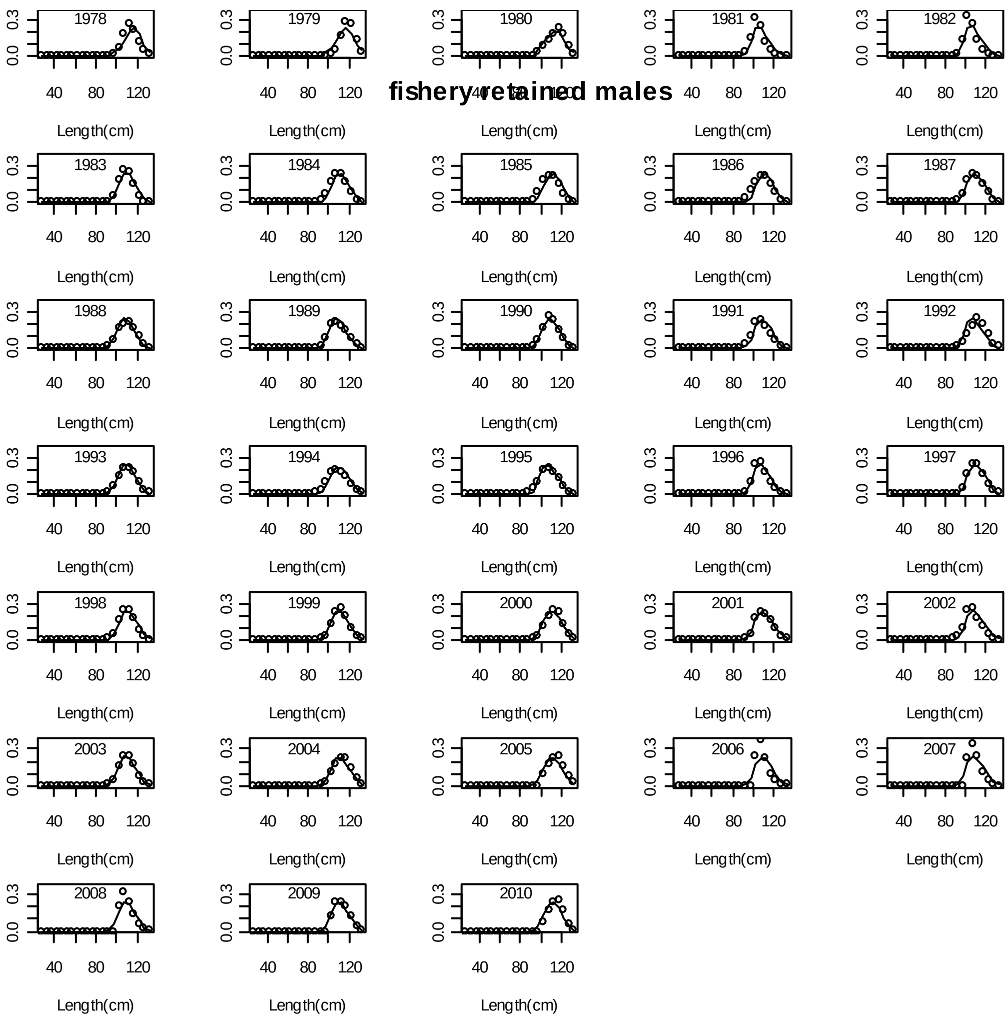

Figure 76. Model 7. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

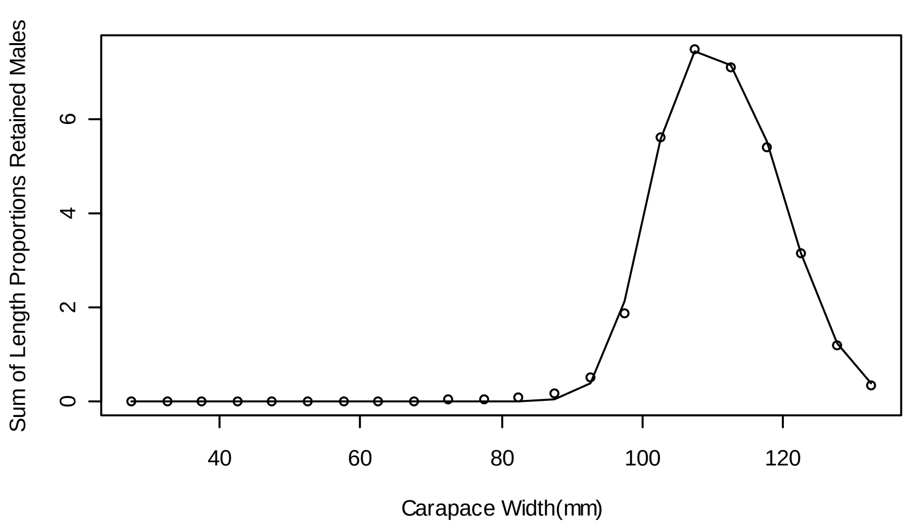

Figure 77. Model 7. Summary fit to retained male length.

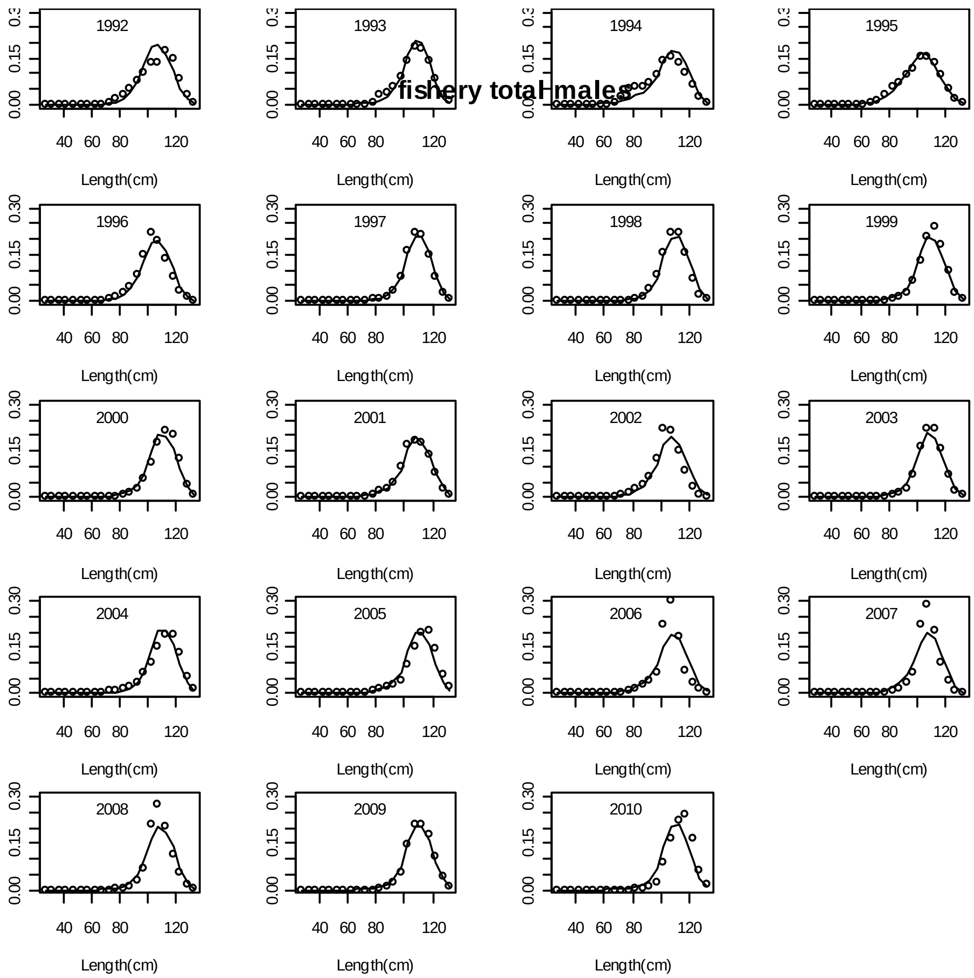

Figure 78. Model 7. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

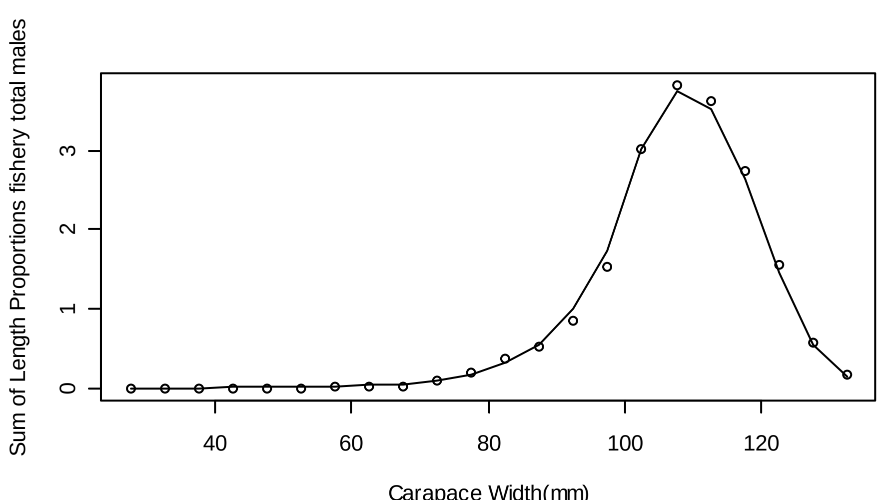

Figure 79. Model 7. Summary fit to total length frequency male catch.

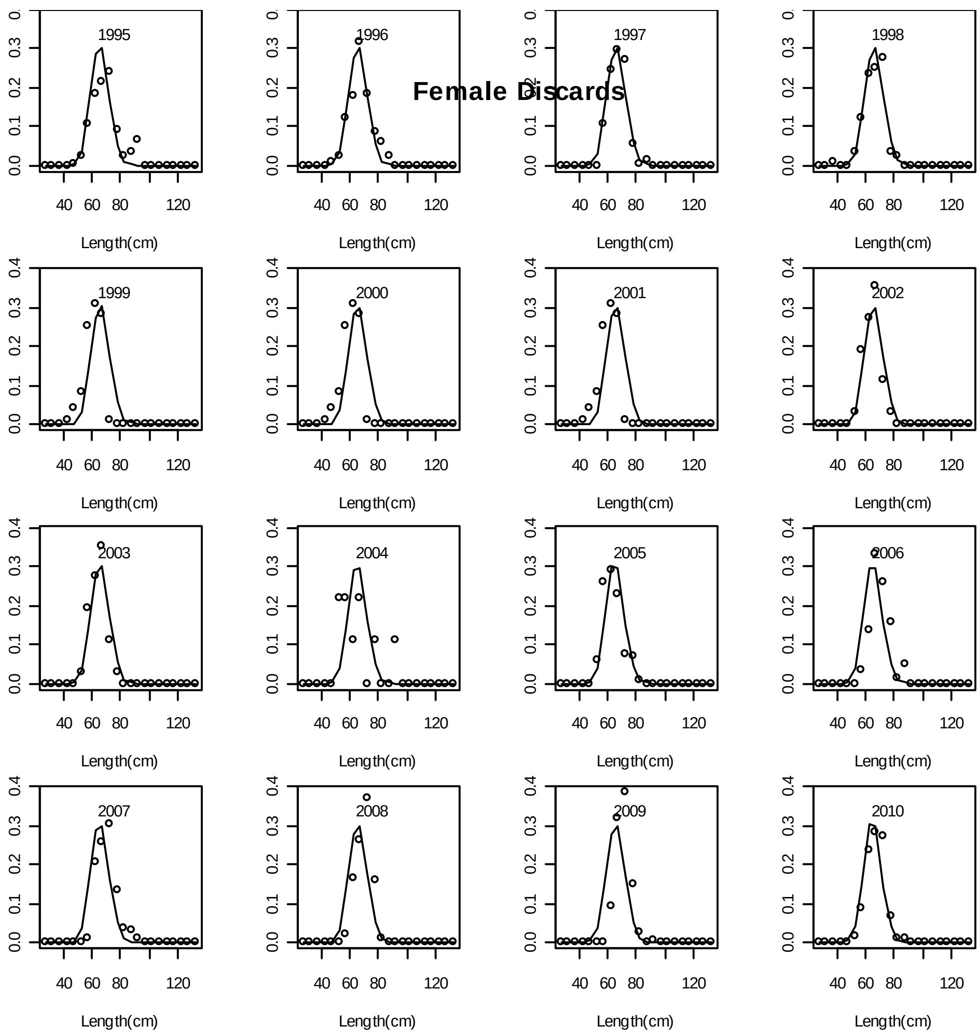

Figure 80. Model 7. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

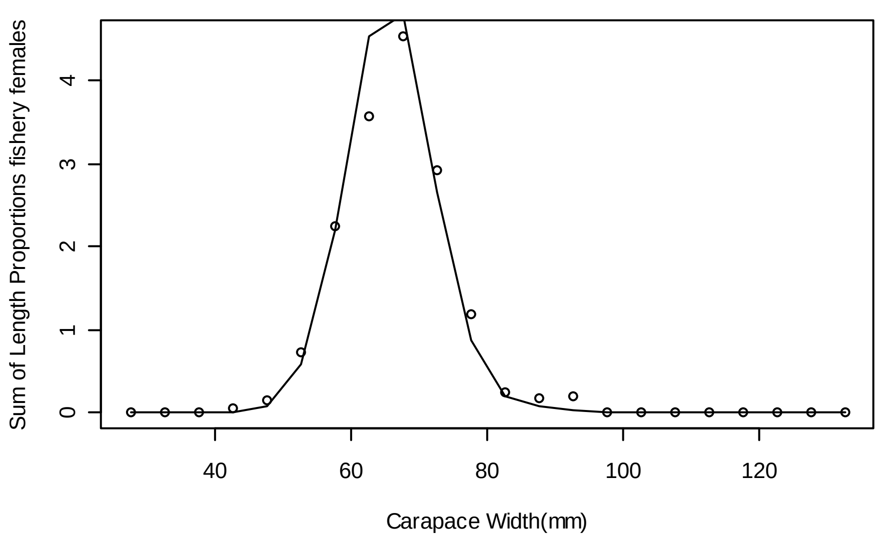

Figure 81. Model 7. Summary fit to directed fishery female discards.

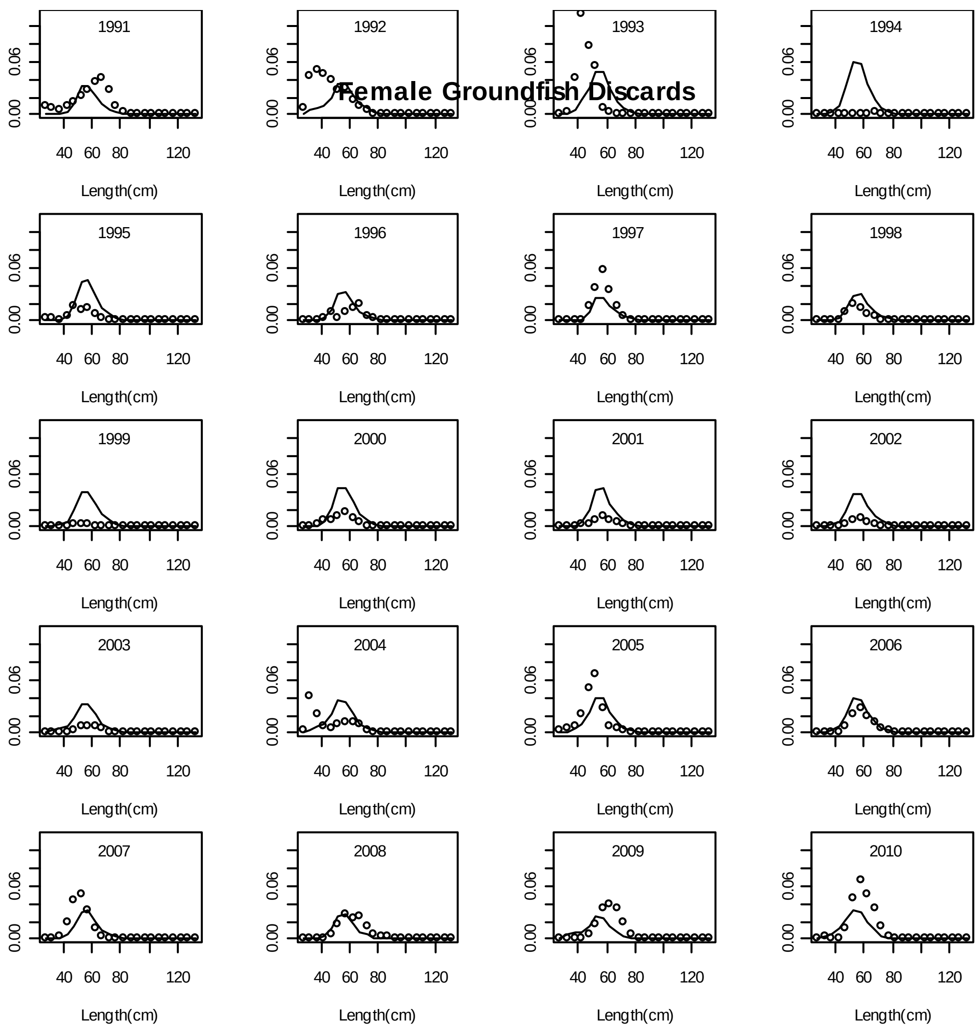

Figure 82. Model 7. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

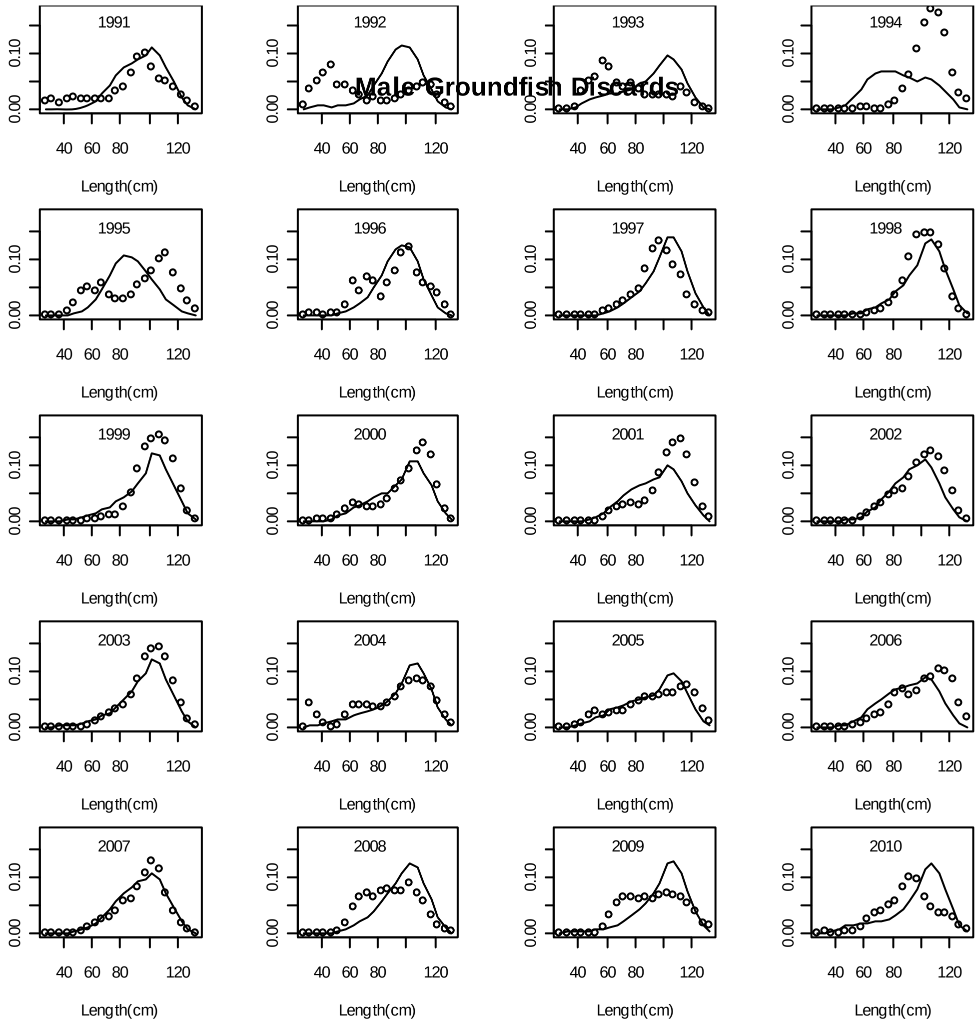

Figure 83. Model 7. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

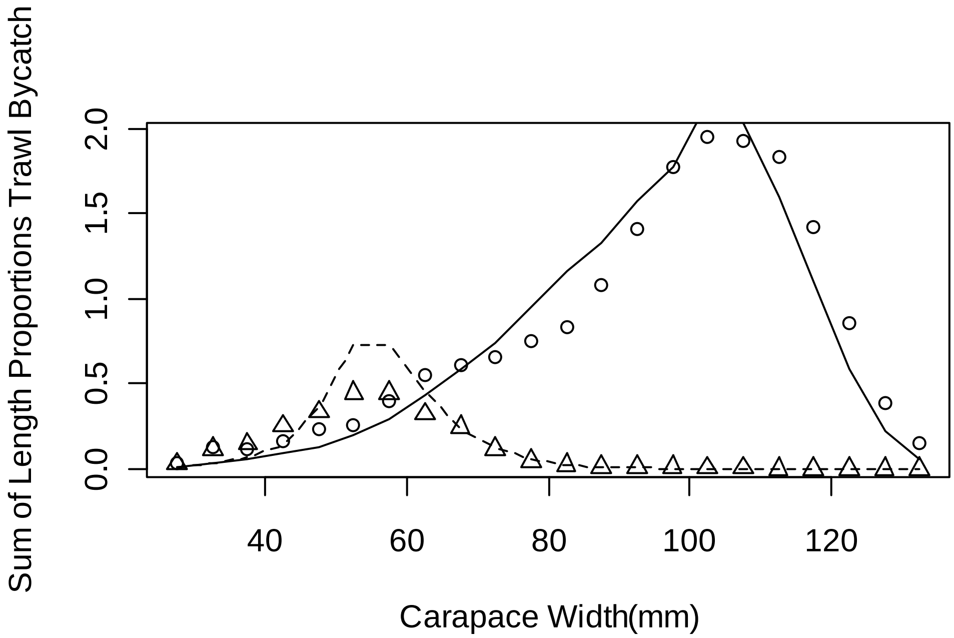

Figure 84. Model 7. Summary fit to groundfish length frequency.

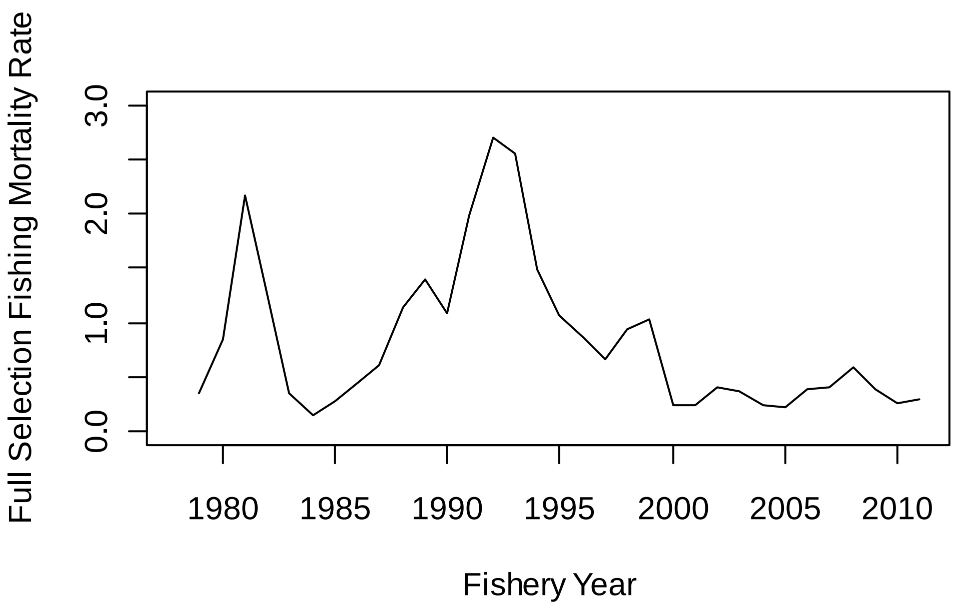

Figure 85. Model 7. Full selection fishing mortality estimated in the model from 1978/79 to 2010/11 fishery seasons (1978 to 2010 survey years).

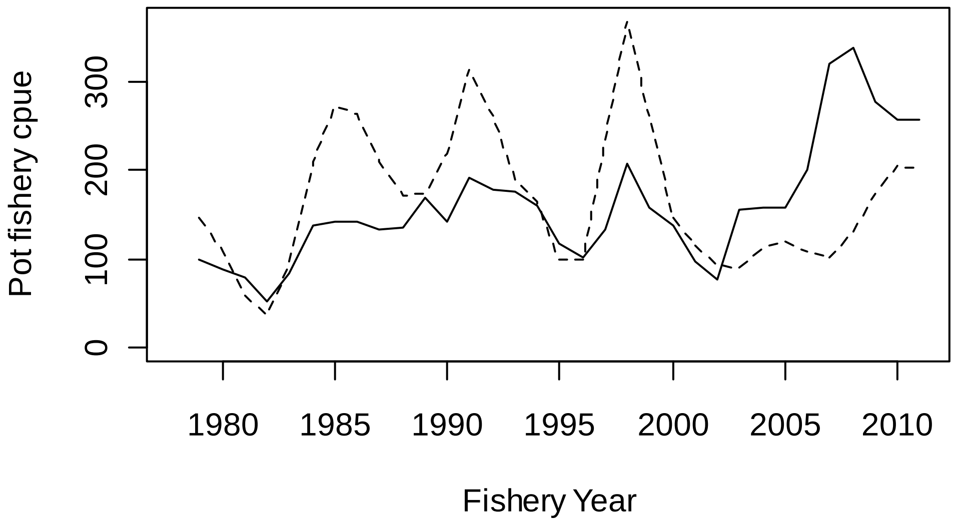

Figure 86. Model 7. Fit to pot fishery cpue for retained males (q is fixed in model). Solid line is observed fishery cpue, dotted line model fit.

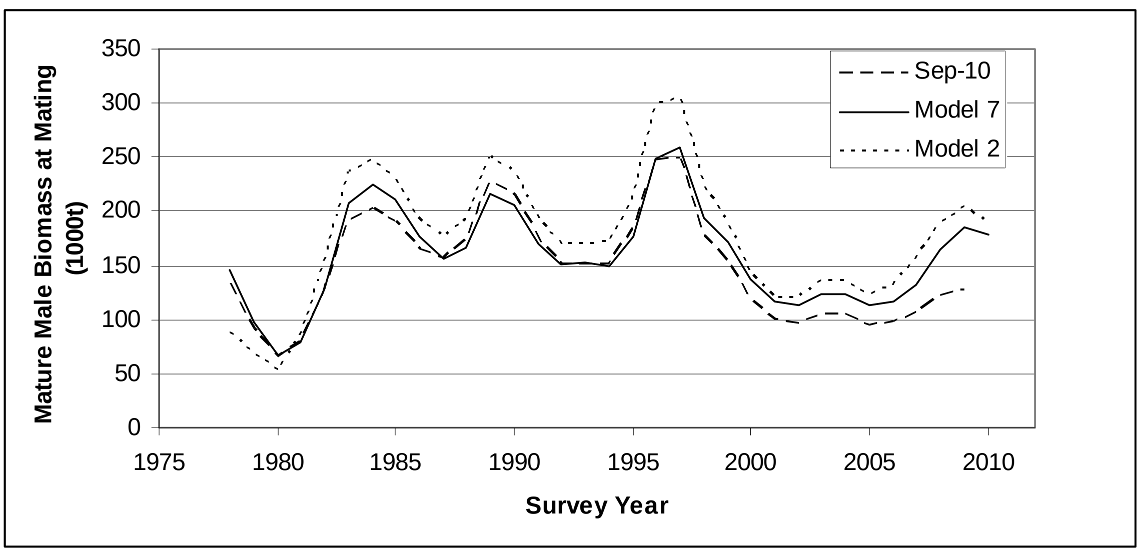

Figure 87. Mature male biomass at mating for the September 2010 model, Model 7 and Model 2.

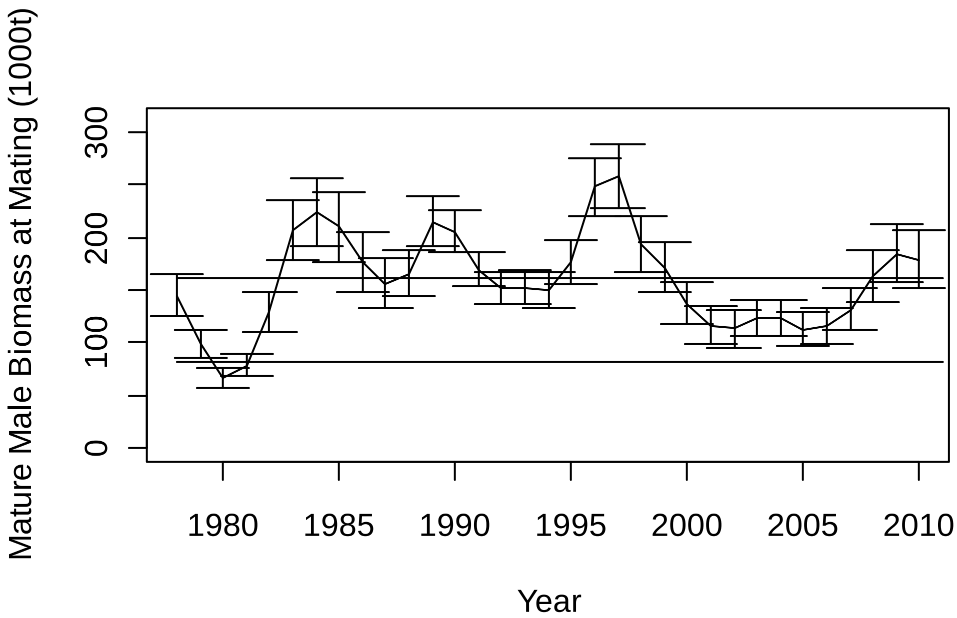

Figure 88. Model scenario 7. Mature Male Biomass at mating with 95% confidence intervals. Top horizontal line is B35%, lower line is ½ B35%.

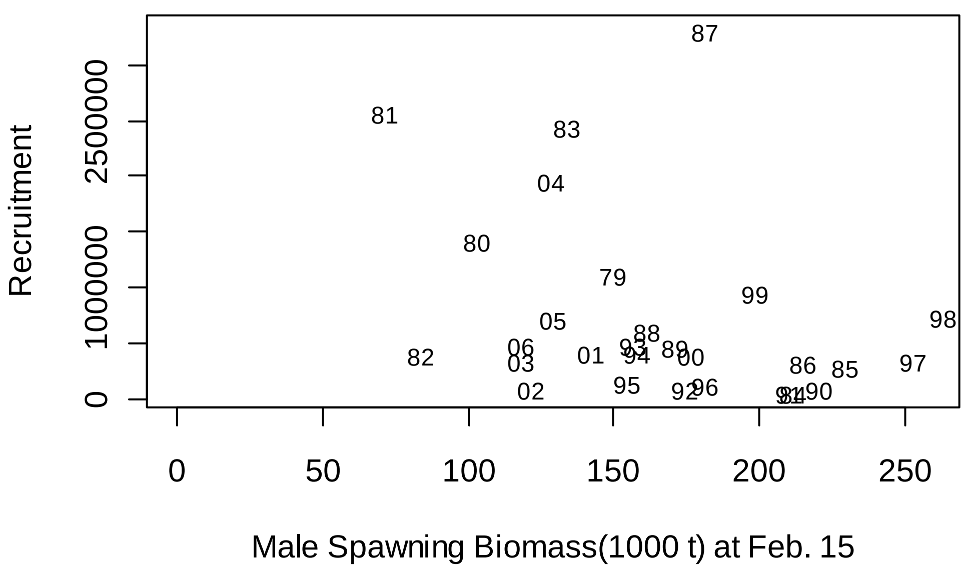

Figure 89. Model 7. Spawner recruit estimates using male mature biomass at time of mating (1000t). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

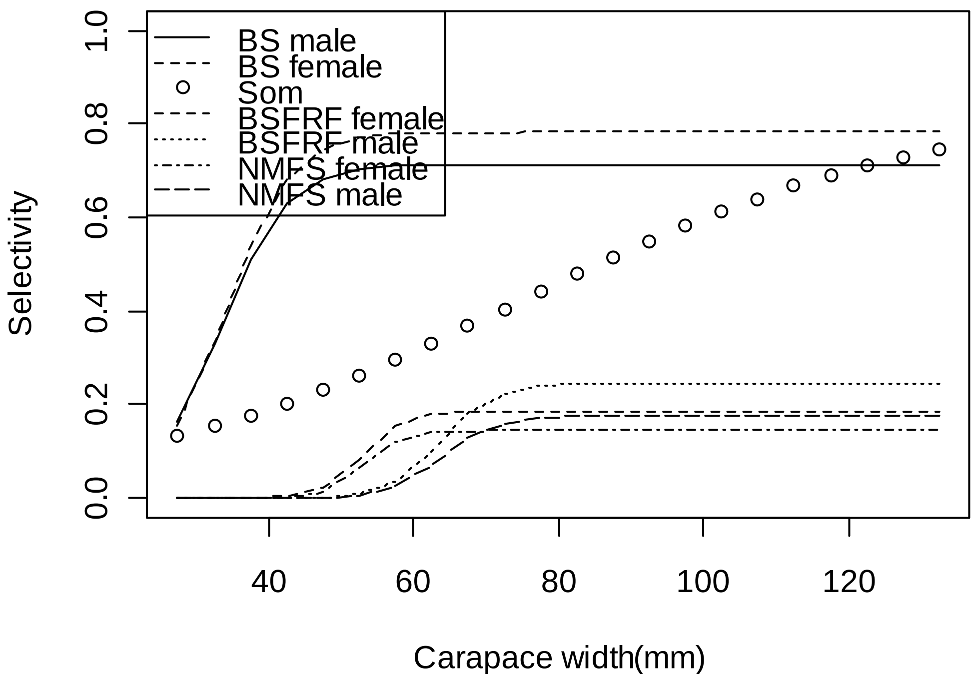

Figure 90. Model 7. Survey selectivity curves entire Bering Sea survey for female (upper dashed line) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton(2010) from 2009 study area data are the circles. Lower lines are survey selectivities in the study area for BSFRF male and female crab and NMFS male and female crab.

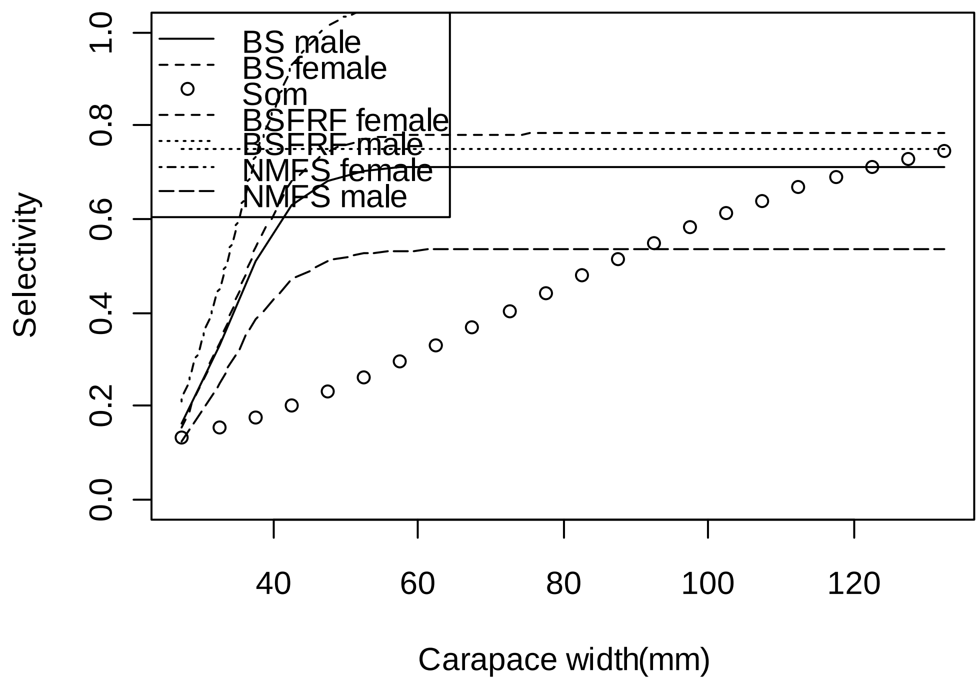

Figure 91. Model 7. 2010 study area survey selectivity curves (BSFRF and NMFS). BS are survey selectivity curves for the entire Bering Sea. Som is the selectivity curve estimated by Somerton from the 2009 study area data.

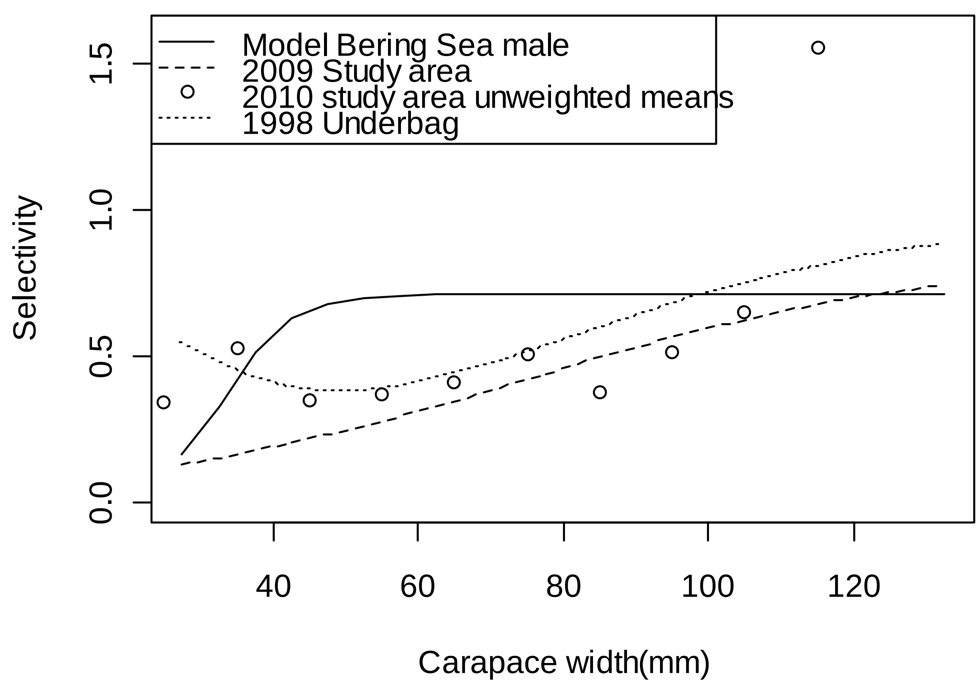

Figure 92. Model 7. Survey selectivity for male crab 1989- present (Model Bering Sea male), with selectivity curves estimated outside the model. 2009 study area is the curve estimated by Somerton from the 2009 study area data.

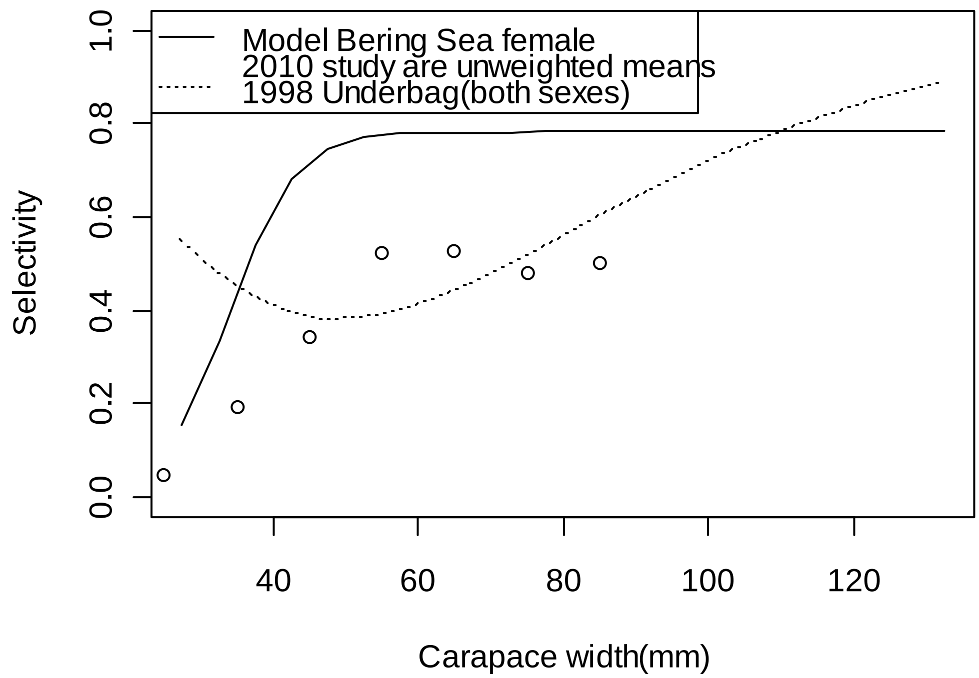

Figure 93. Model 7. Survey selectivity for female crab 1989- present (Model Bering Sea female),

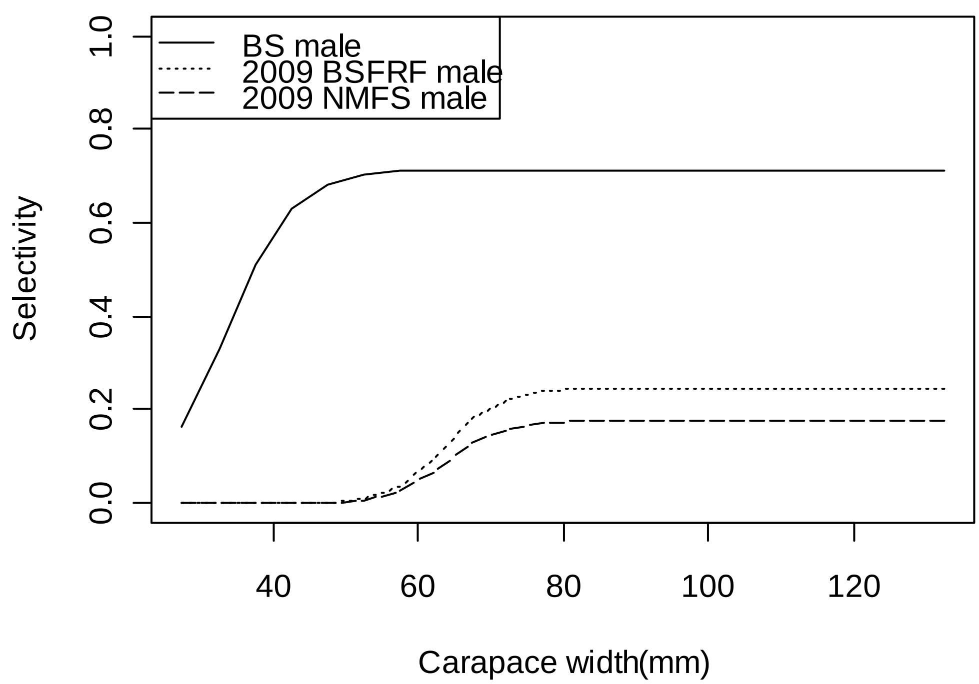

Figure 94. Model 7. Survey selectivity curves for male crab in the entire Bering sea 1989- present (BS male), 2009 study area BSFRF male and 2009 study area NMFS male.

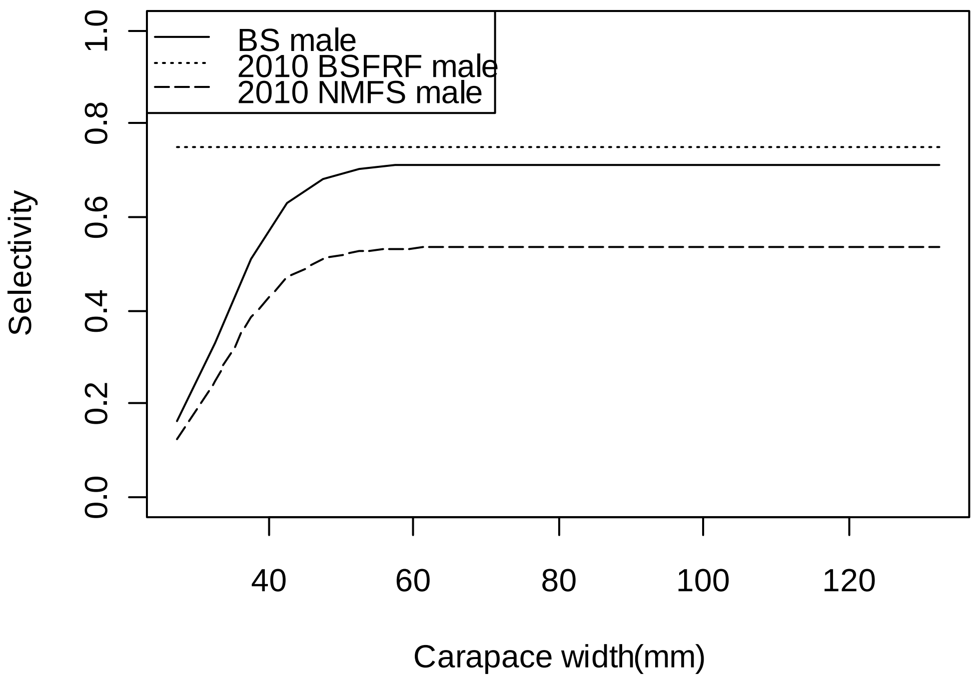

Figure 95. Model 7. Survey selectivity curves for male crab in the entire Bering sea 1989-present (BS male), 2010 study area BSFRF male and 2010 study area NMFS male.

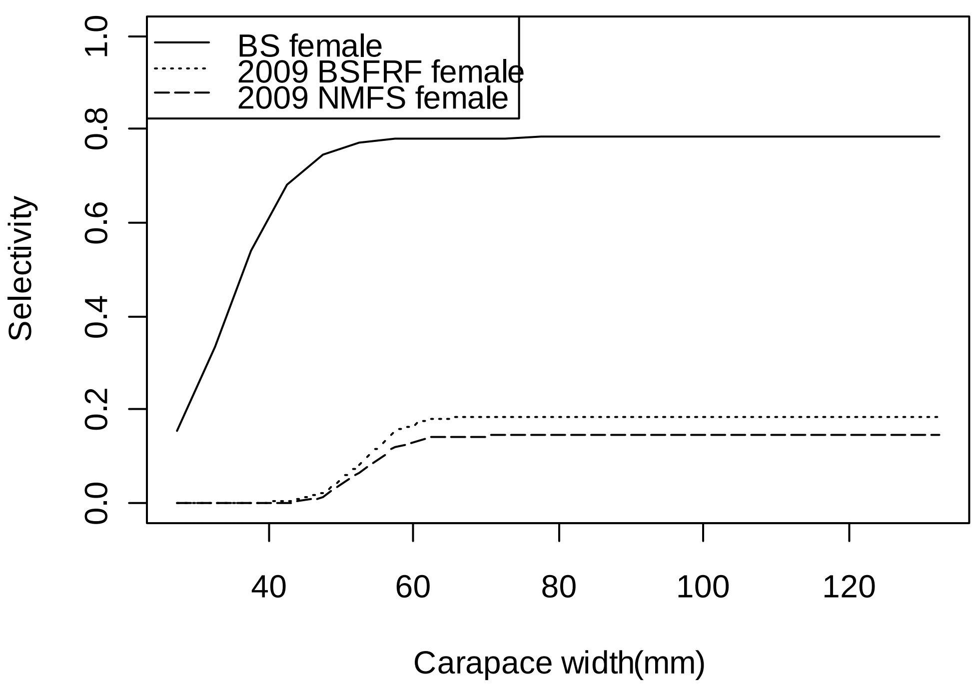

Figure 96. Model 7. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2009 study area BSFRF female and 2009 study area NMFS female.

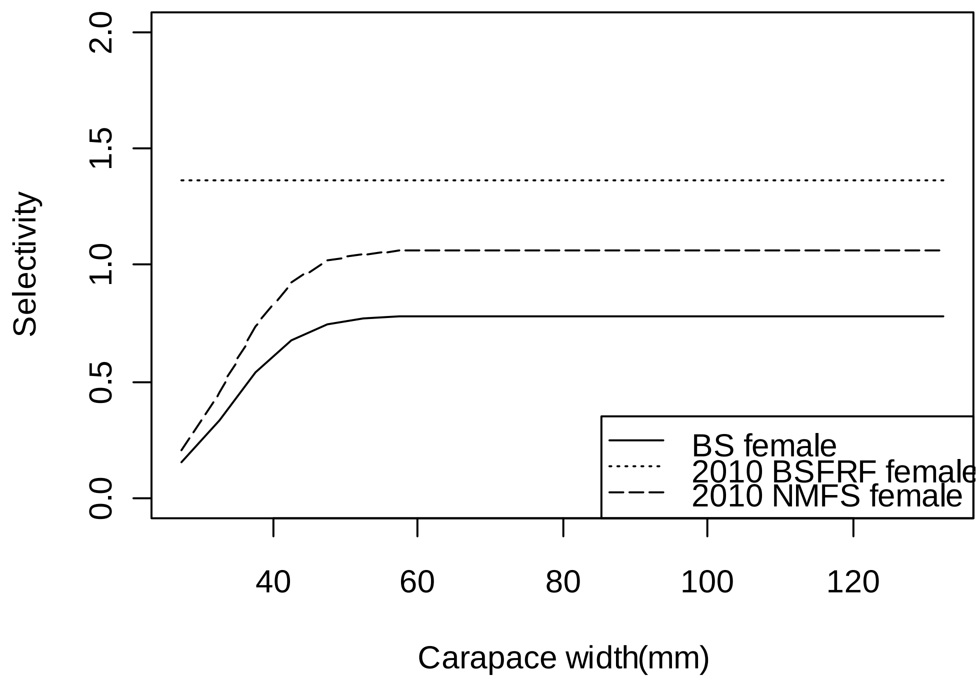

Figure 97. Model 7. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2010 study area BSFRF female and 2010 study area NMFS female.

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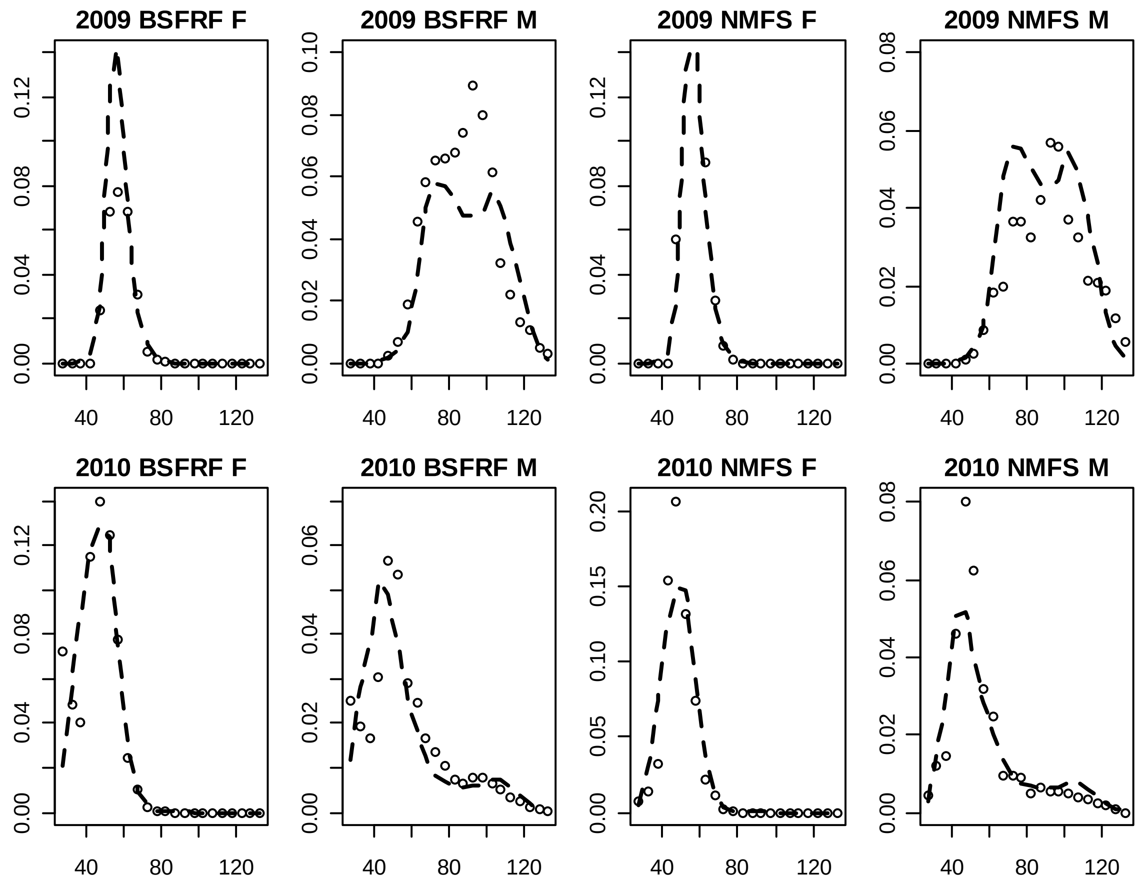

Figure 98. Model 7. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

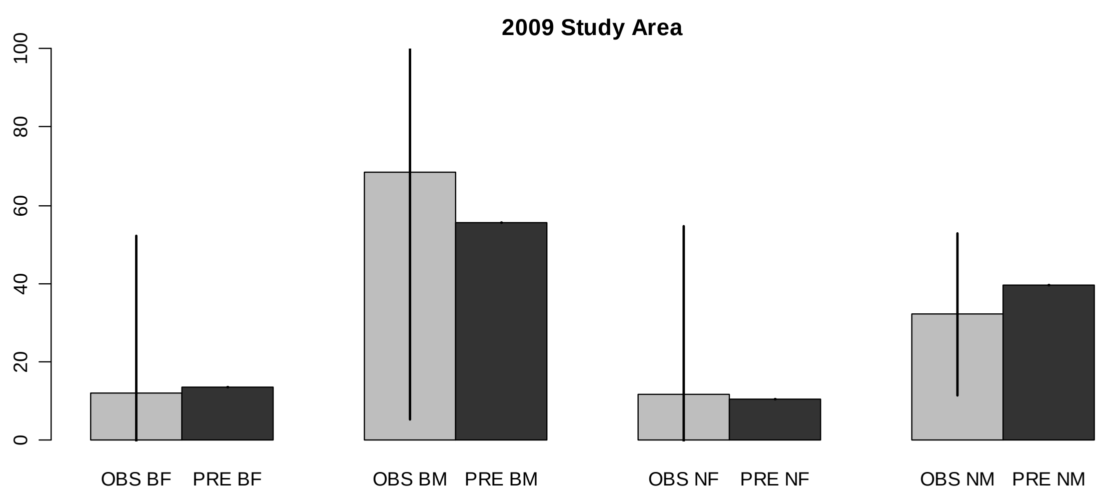

Figure 99. Model 7. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

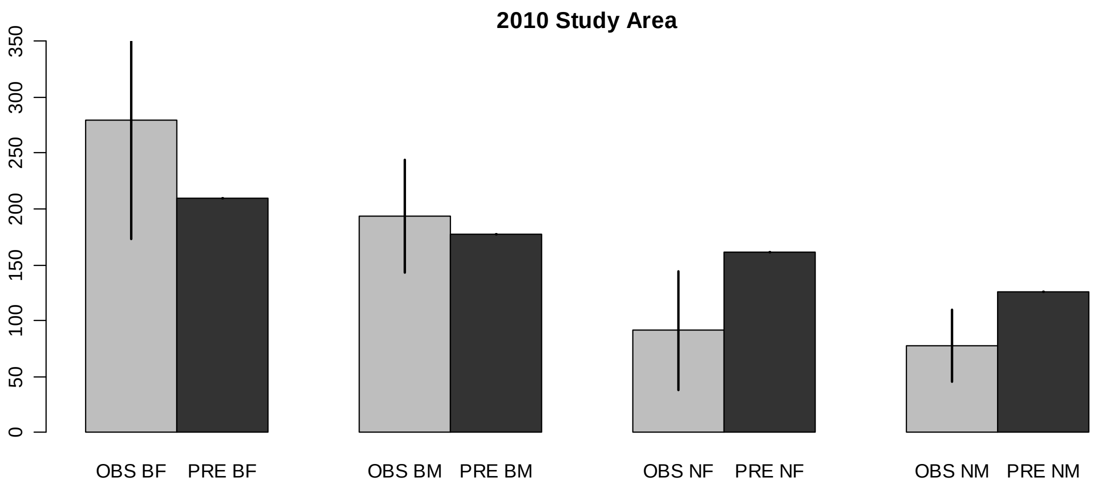

Figure 100. Model 7. Fits to 2010 study area mature biomass by sex for BSFRF and NMFS data.

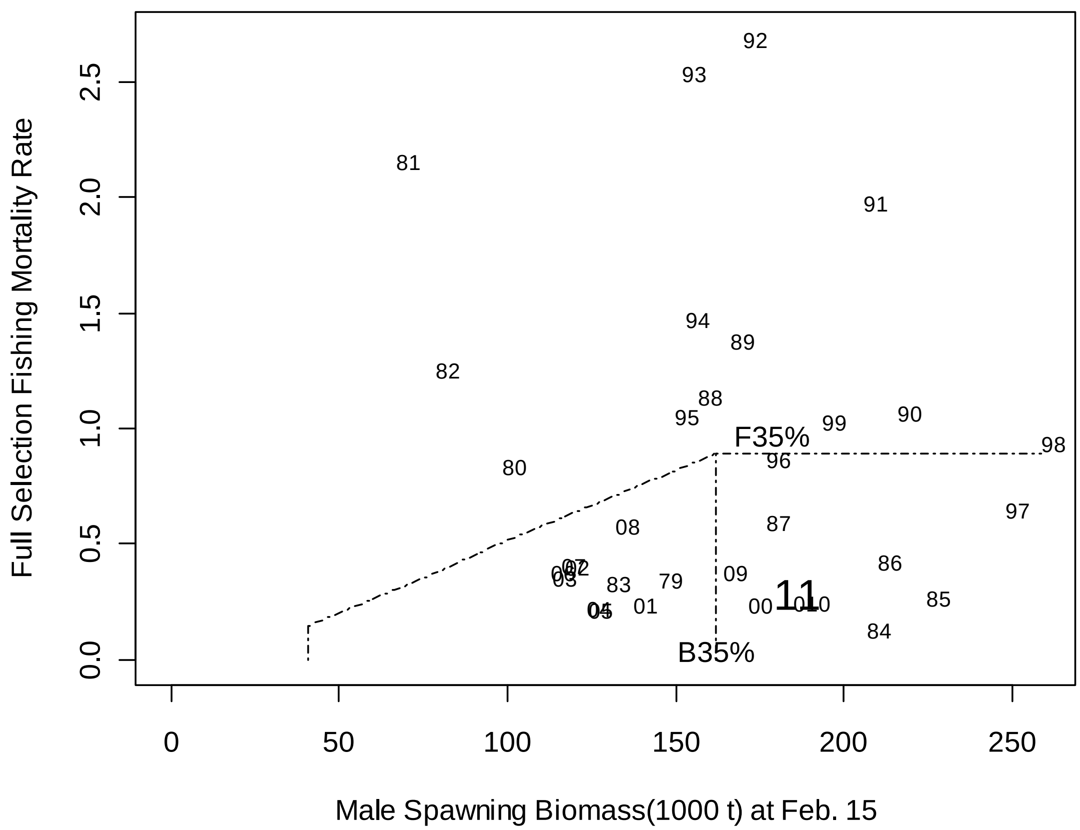

Figure 101. Model 7. Fishing mortality estimated from fishing years 1979 to 20010/11 (labeled 11 in the plot). The OFL control rule (F35%) is shown for comparison. The vertical line is B35%, estimated from the product of spawning biomass per recruit fishing at F35% and mean recruitment from the stock assessment model.

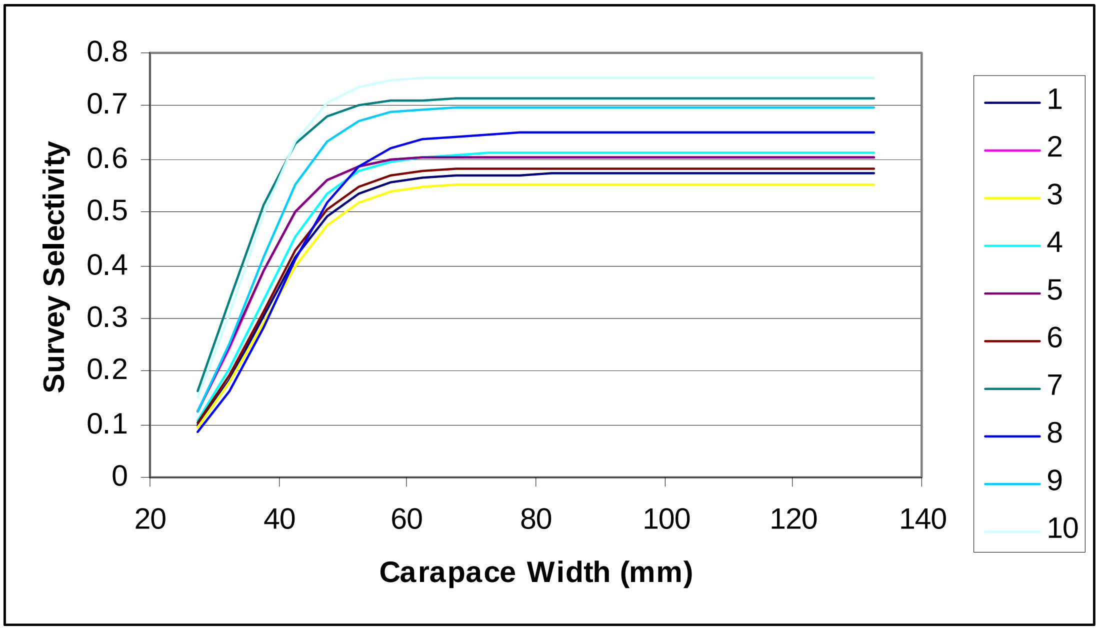

Figure 102. Male survey selectivity for 1989-Present for models 1-10.

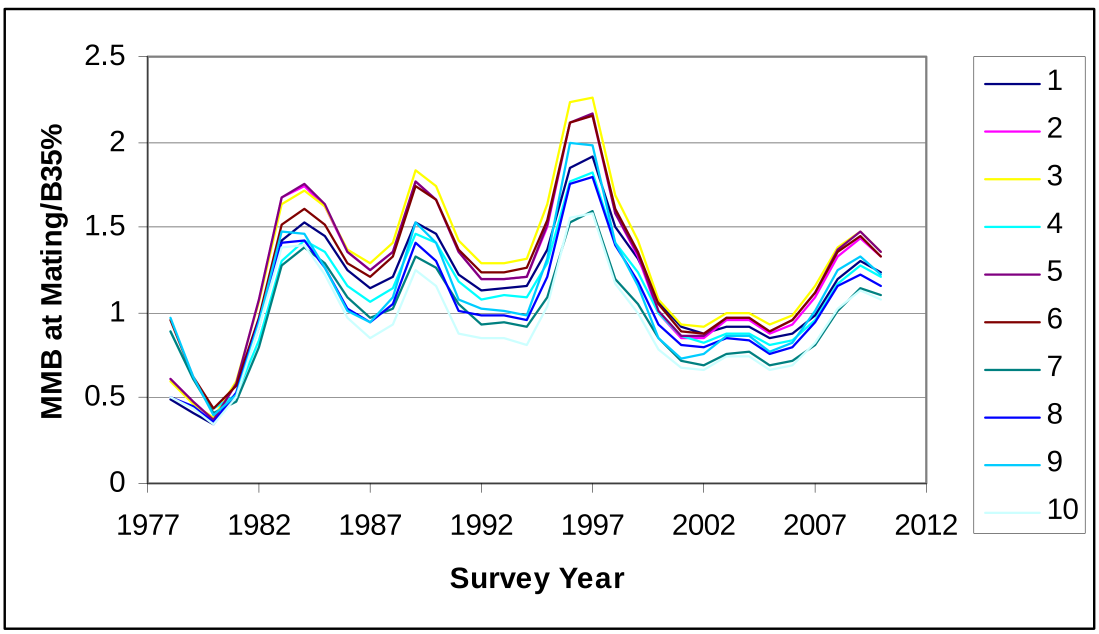

Figure 103. MMB at Mating/B35% from 1978/79 to 2010/11 for models 1-10.

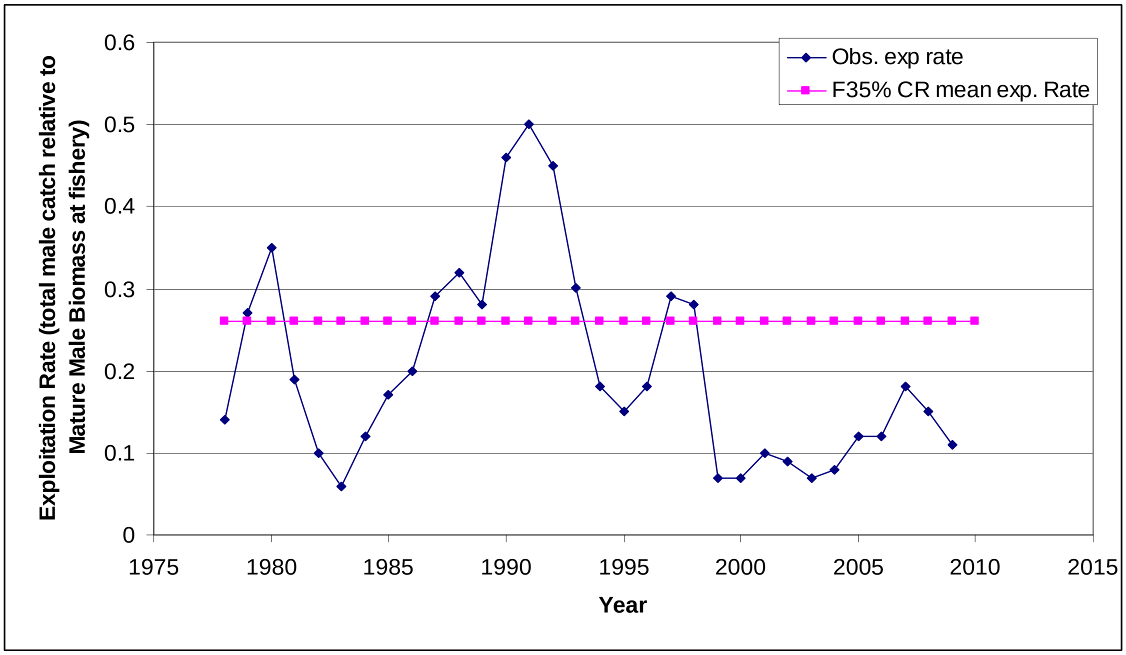

Figure 104. History of exploitation rate on mature male biomass relative to the exploitation rate corresponding to fishing at F35%.

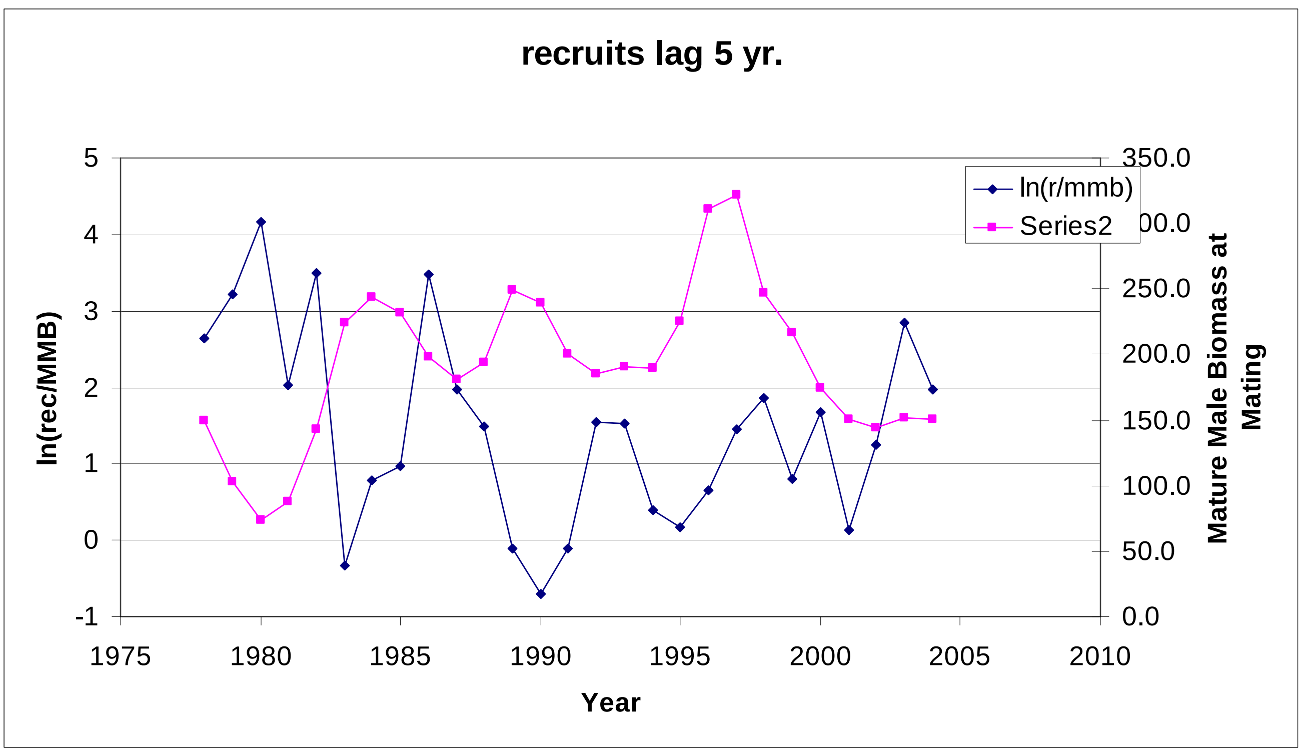

Figure 105. Log of recruits/MMB at mating with a 5 yr lag for recruitment and mature male biomass at mating.

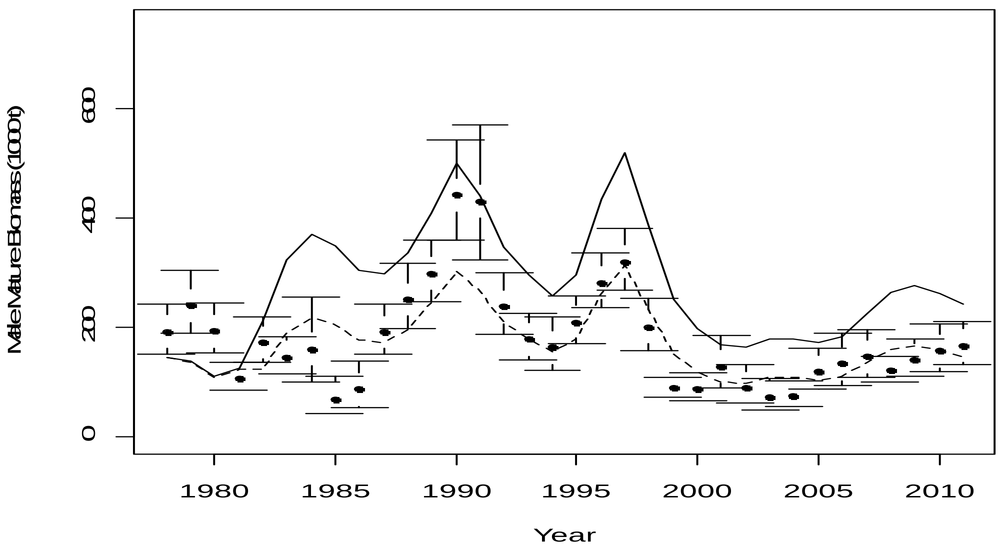

Figure 106 Model 2. Population male mature biomass (1000 t, solid line), model estimate of survey male mature biomass (dotted line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

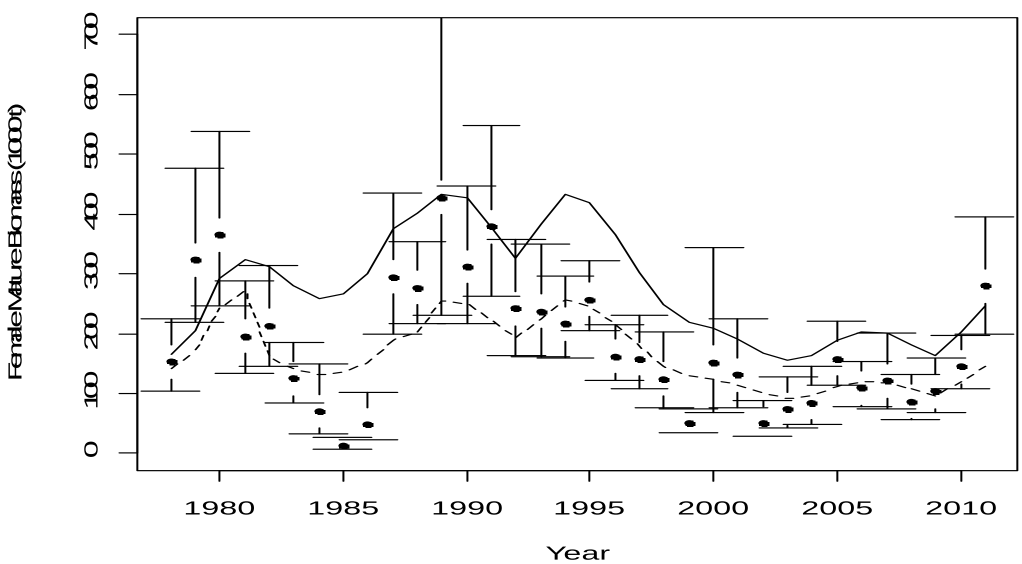

Figure 107. Model 2. Population female mature biomass (1000 t, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

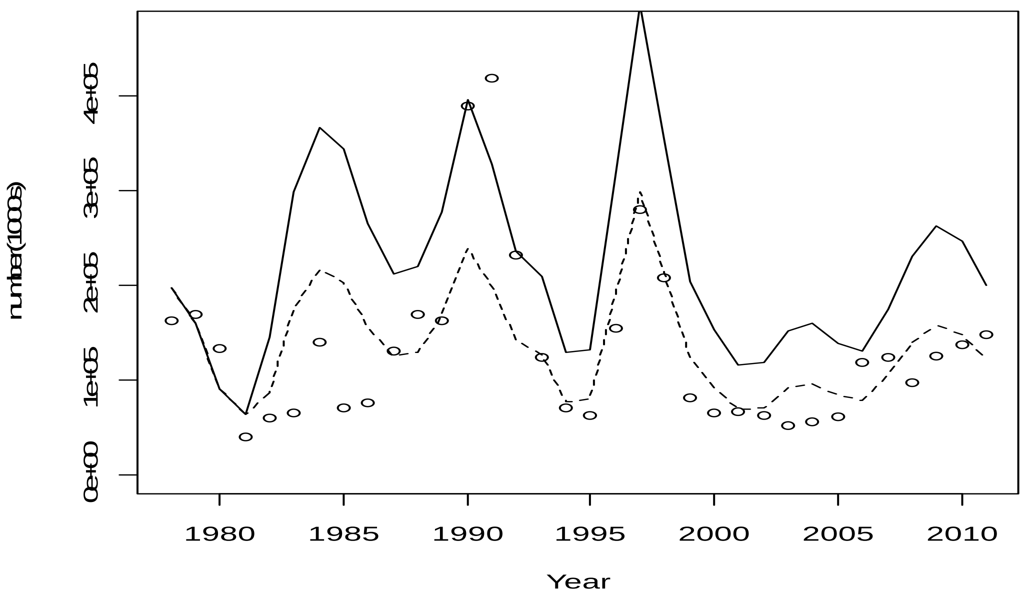

Figure 108. Model 2. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

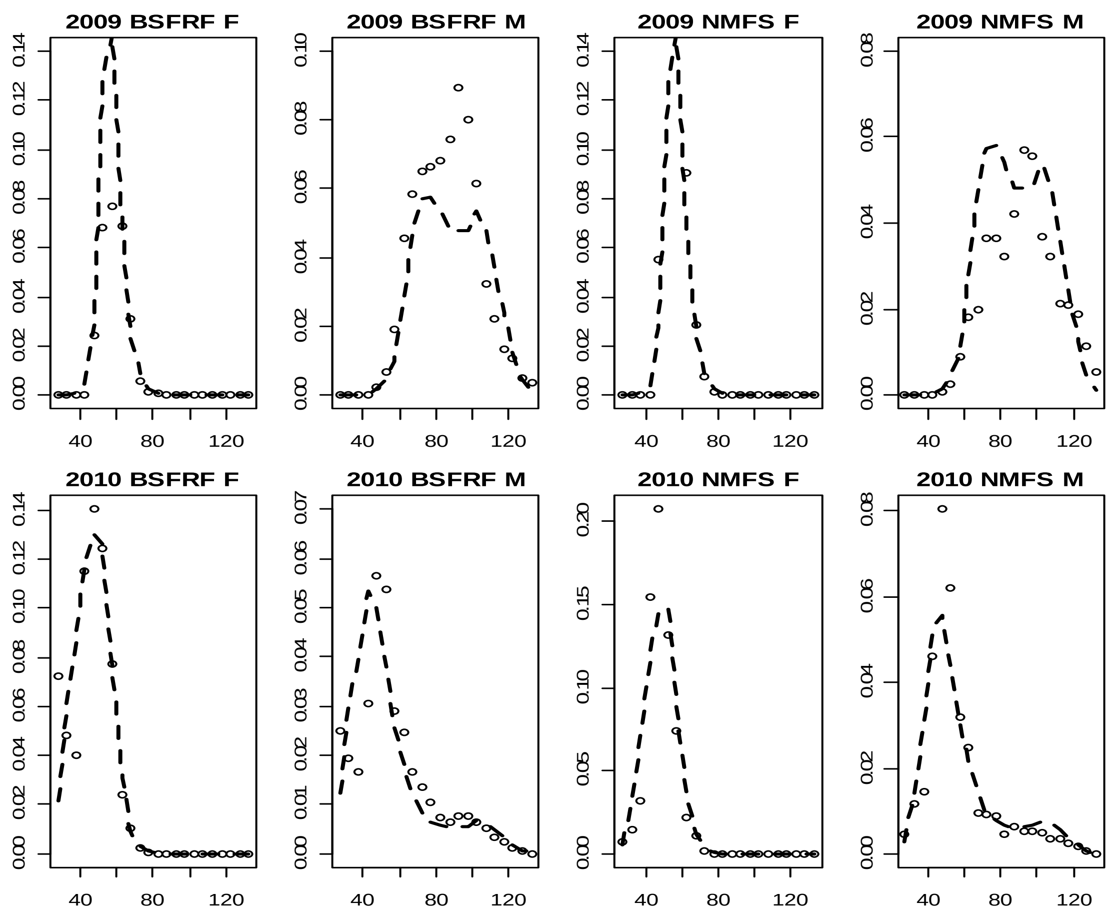

Figure 109. Model 2. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

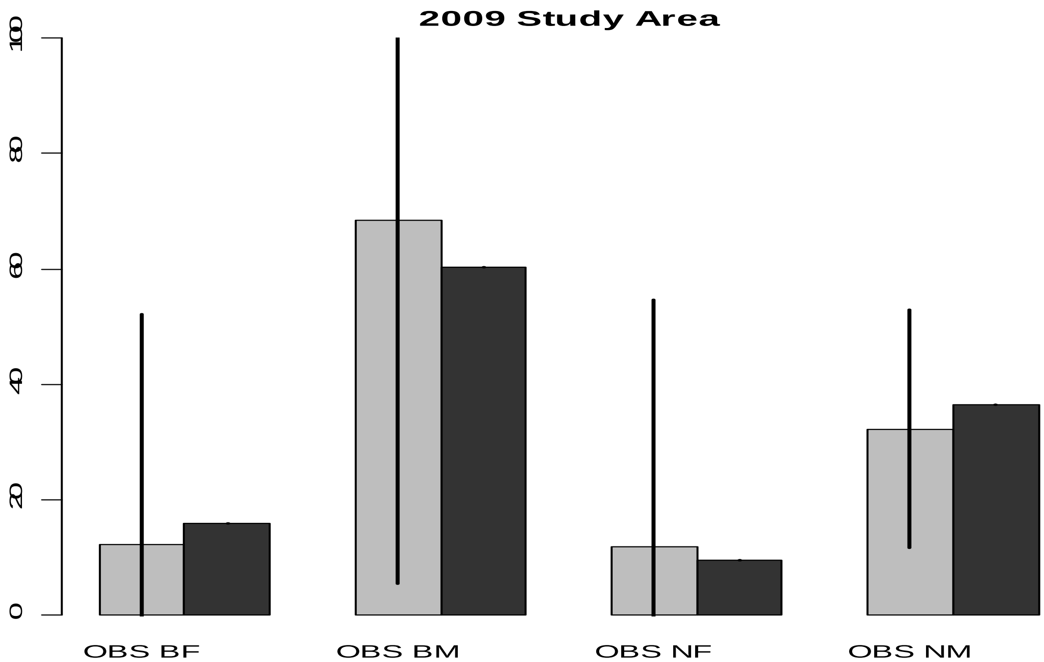

Figure 110. Model 2. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

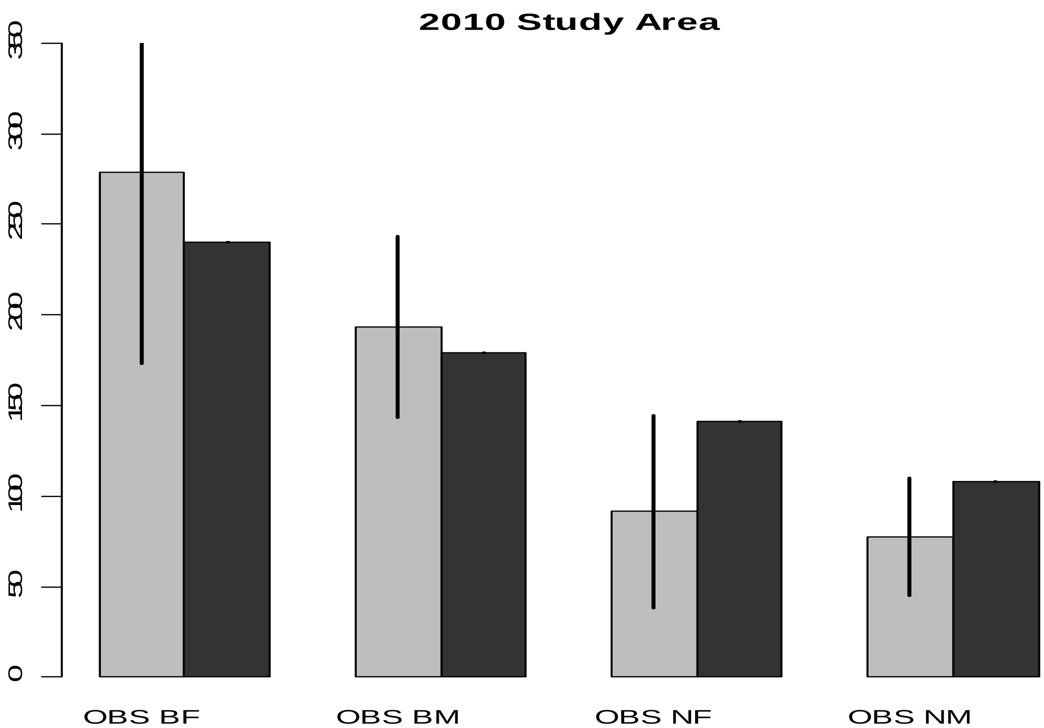

Figure 111. Model 2. Fits to 2010 study area mature biomass by sex for BSFRF and NMFS data.

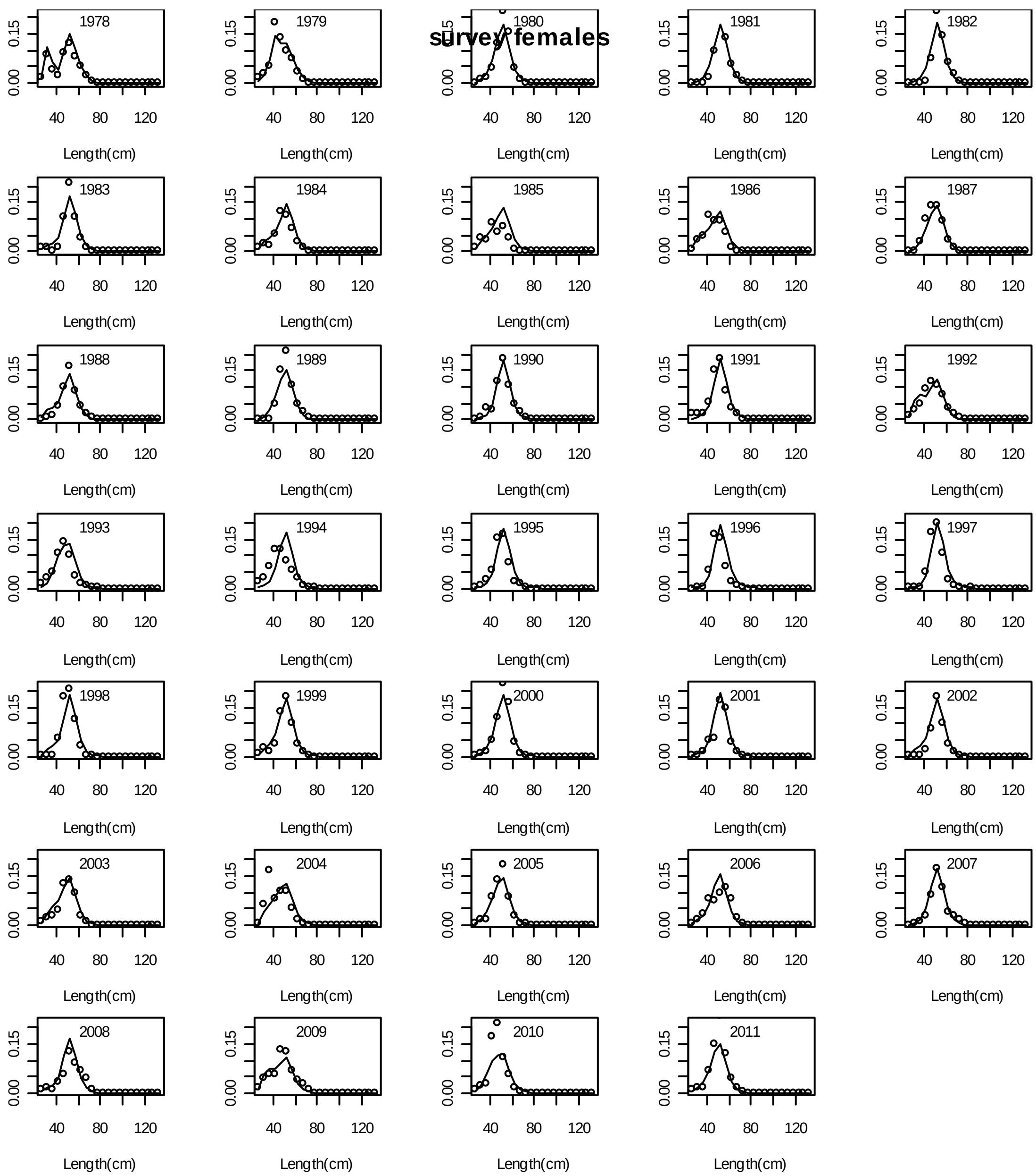

Figure 112. Model 2. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

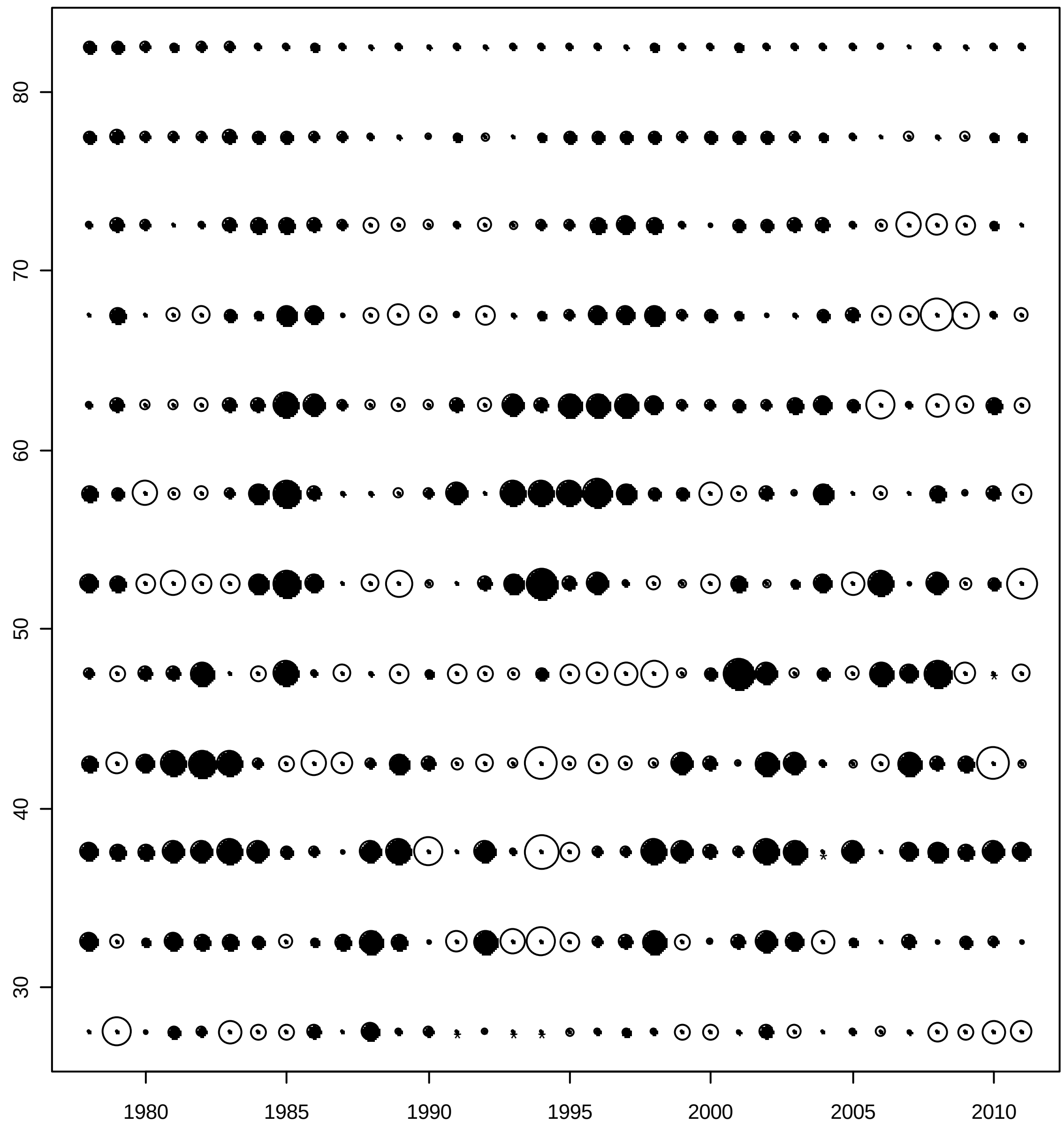

Figure 113. Model 2. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

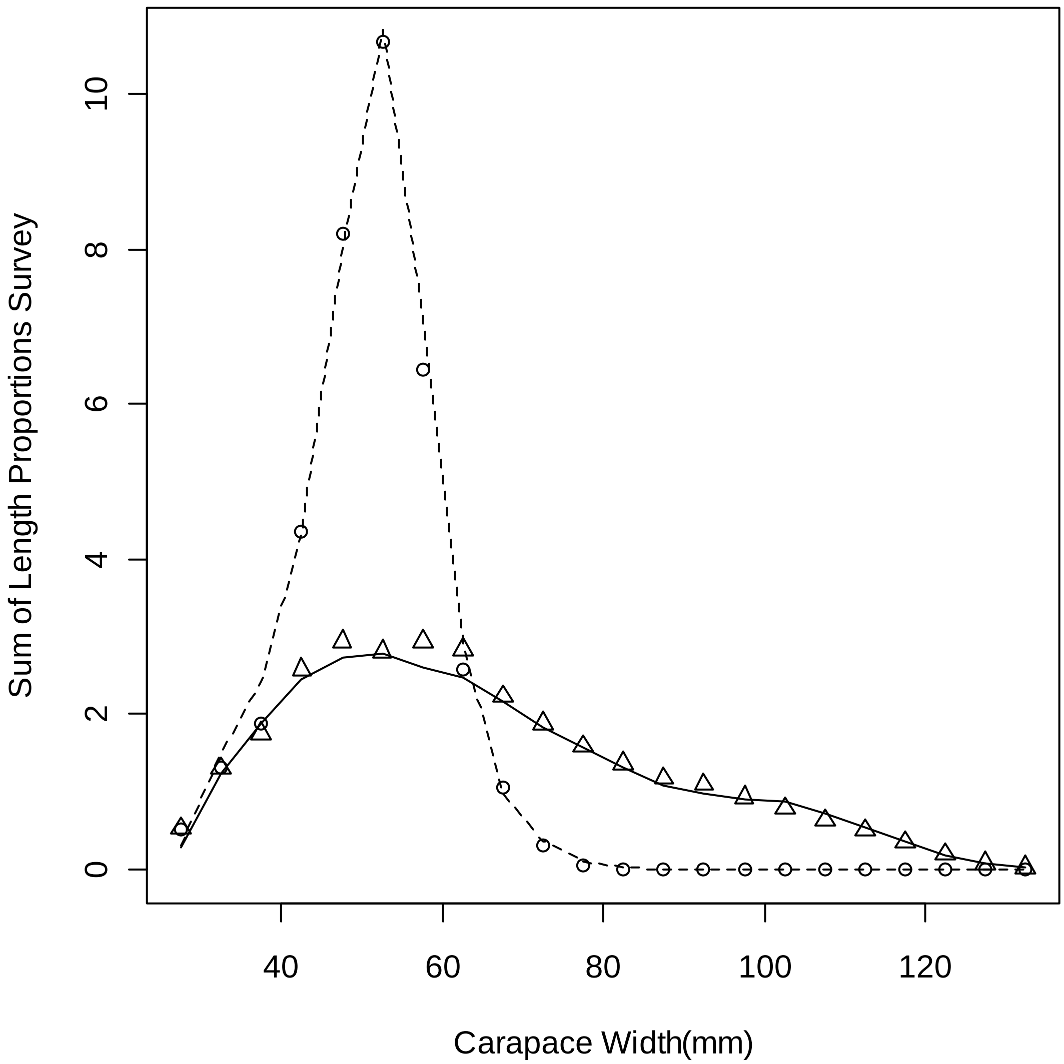

Figure 114. Model 2. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

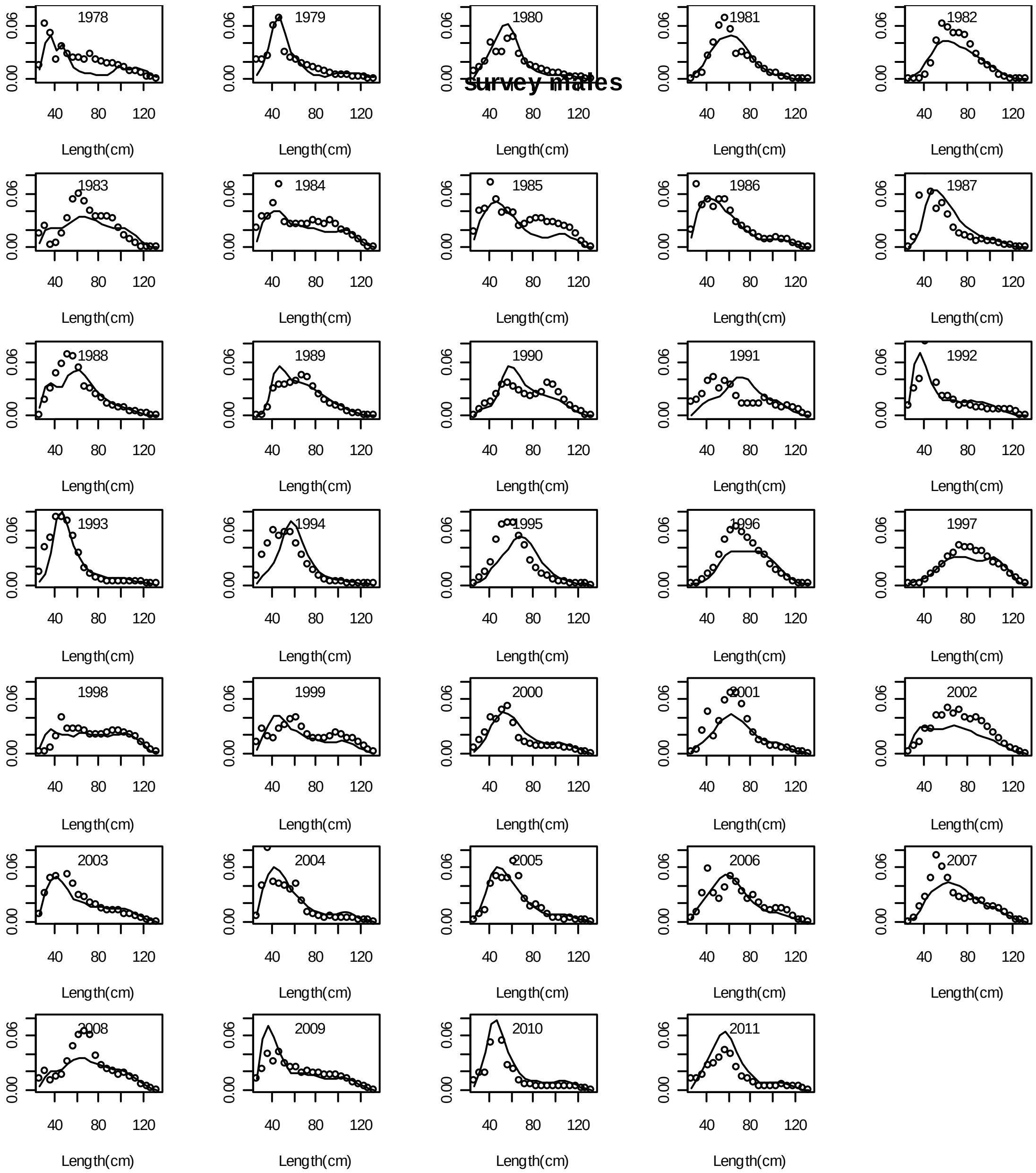

Figure 115. Model 2. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

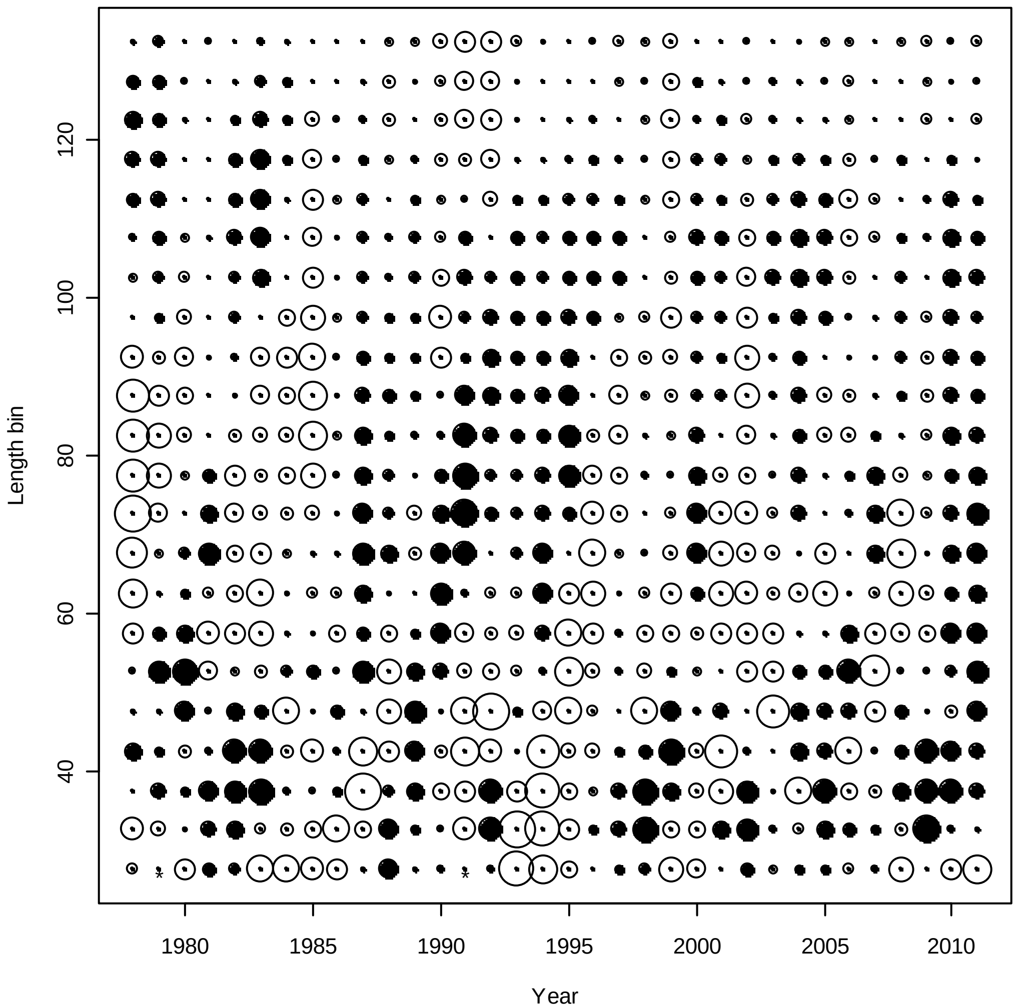

Figure 116. Model 2. Residuals for fit to survey male size frequency. . Filled circles are negative residuals (predicted higher than observed).

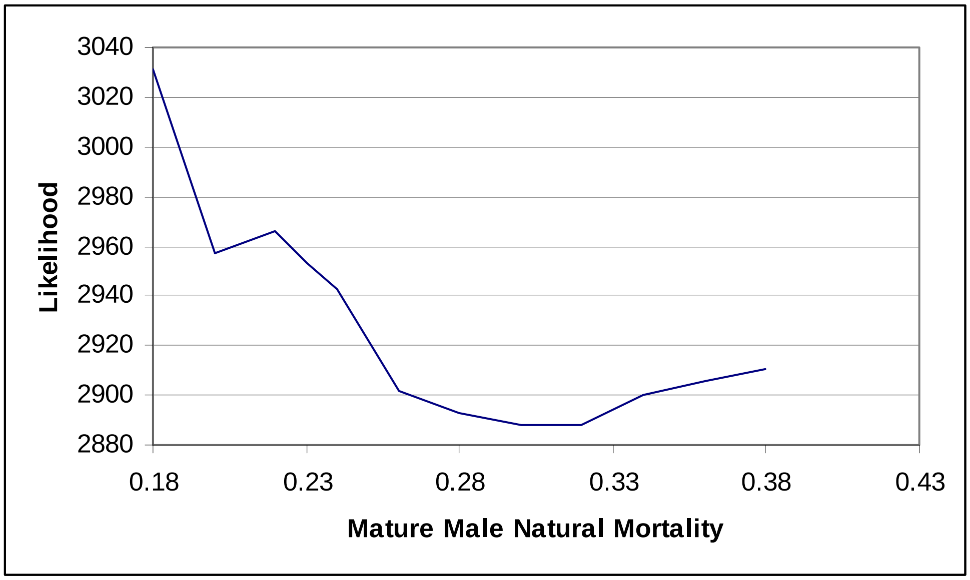

Figure 117. Total Likelihood and mature male natural mortality, using model scenario 2.

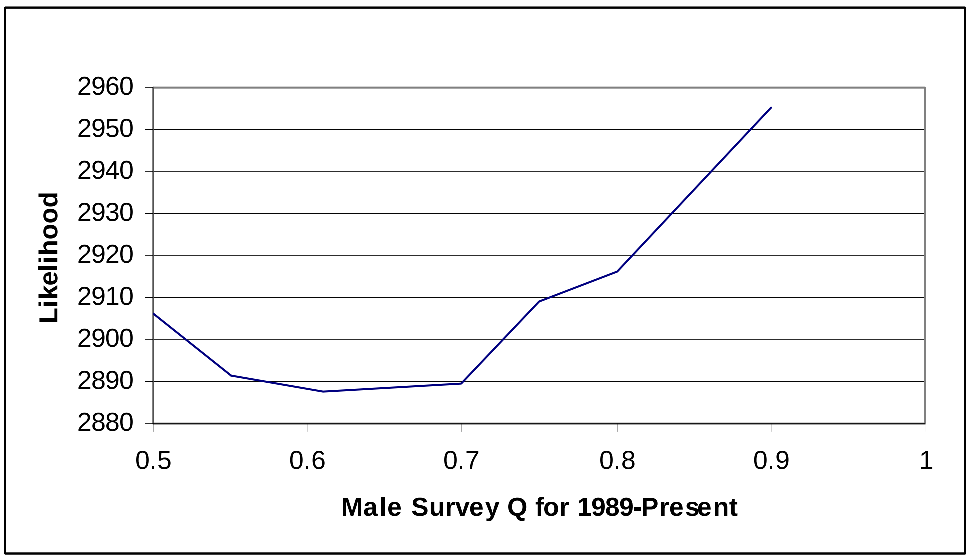

Figure 118. Total Likelihood and male survey Q for 1989-Present using model scenario 2.

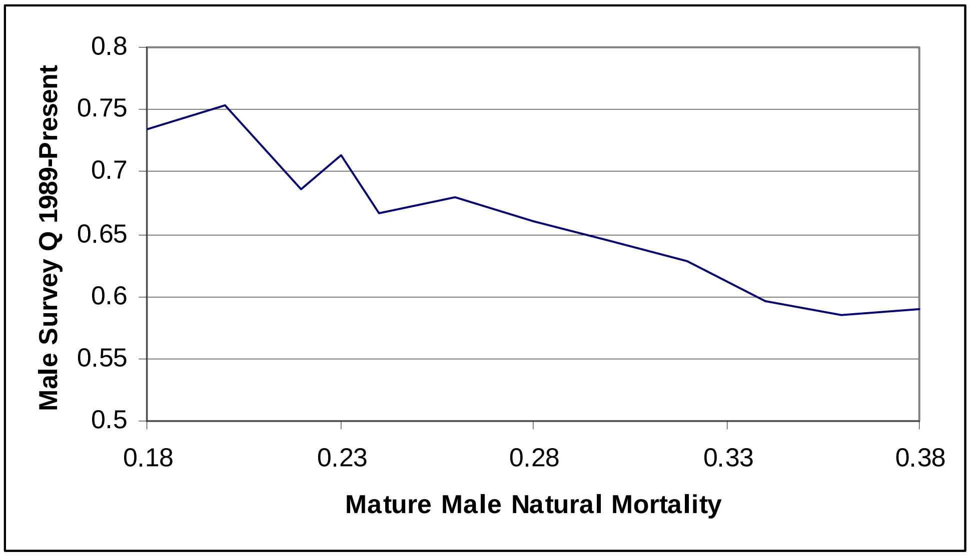

Figure 119. Male survey Q 1989-Present estimated at fixed values of mature male natural mortality from 0.18 to 0.38.

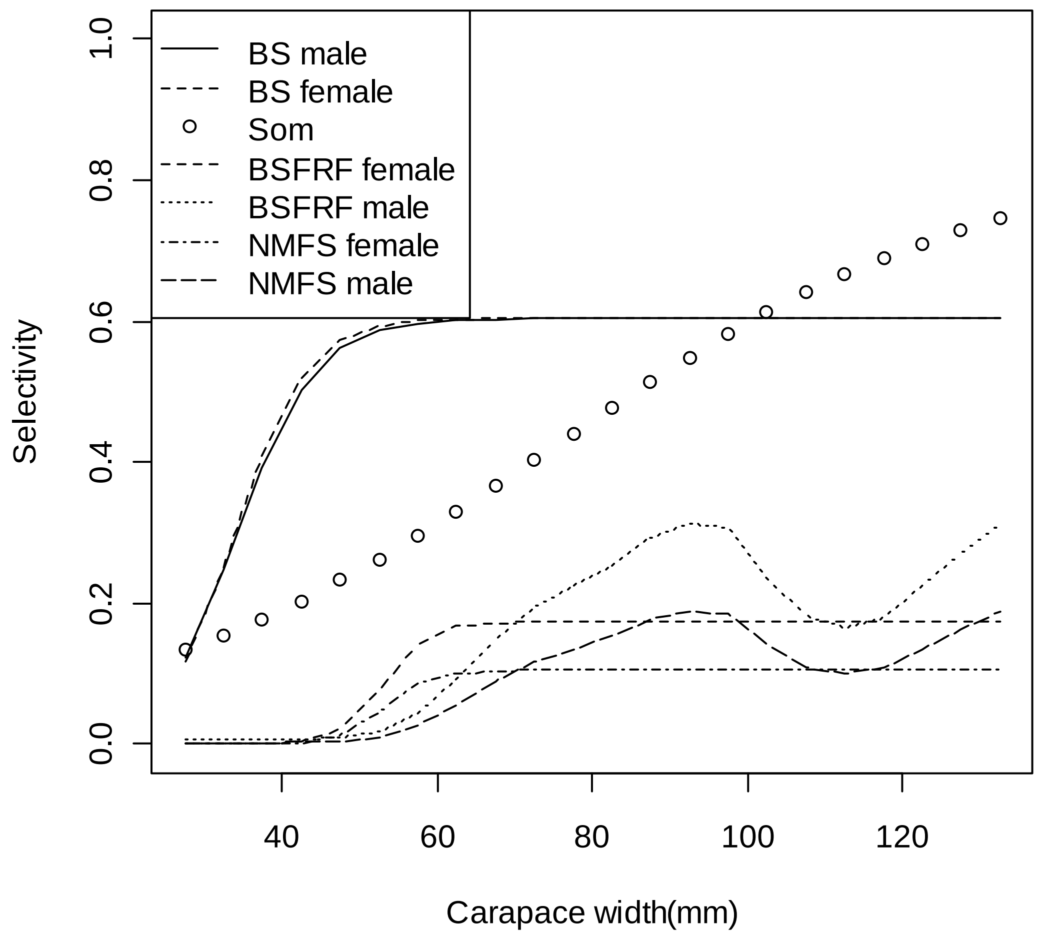

Figure 120. Survey selectivitys for model scenario 5 with smooth availability (BSFRF) for male crab in the 2009 study area. BS is all Bering Sea 1989-Present, BSFRF and NMFS are for the 2009 study area.

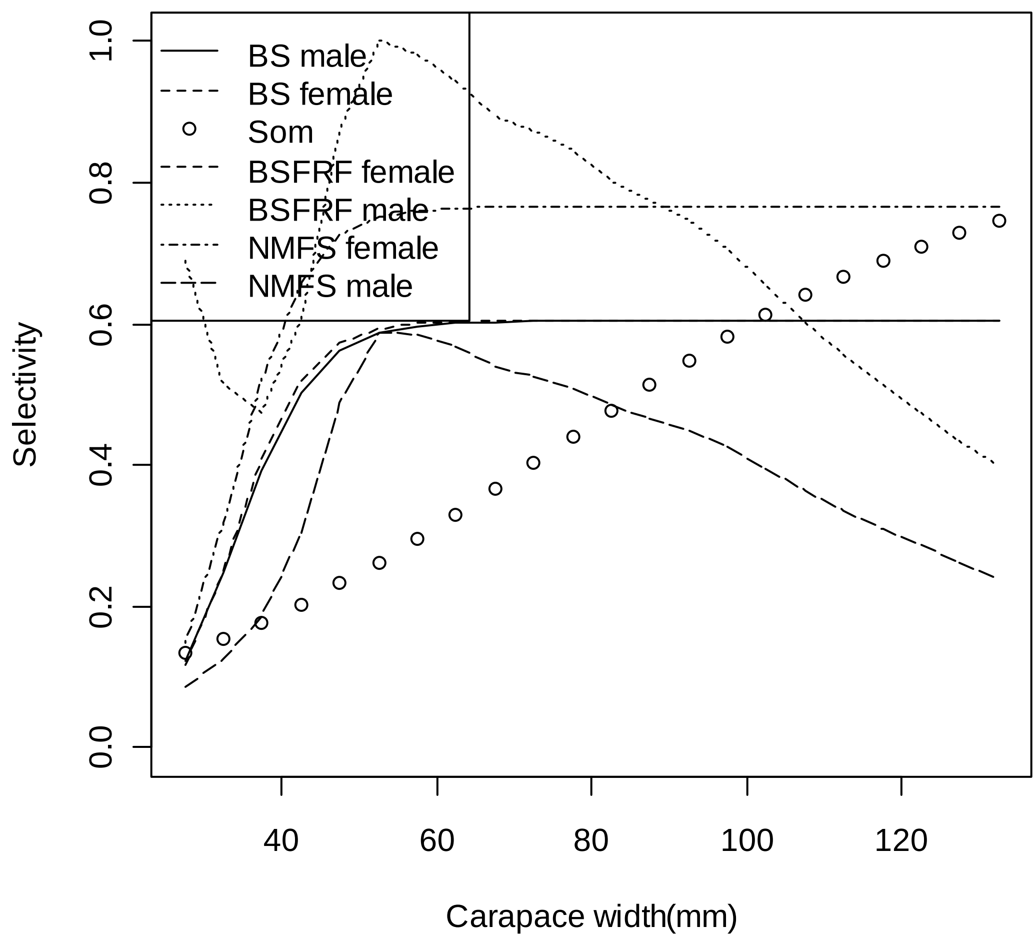

Figure 121. Survey selectivitys for model scenario 5 with smooth availability (BSFRF) for male crab in the 2010 study area. BS is all Bering Sea 1989-Present, BSFRF and NMFS are for the 2010 study area.

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2011

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Executive Summary

1. Stock: red king crab (RKC), *Paralithodes camtschaticus,* in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades. Catches during recent years were among the high catches in last 15 years. The retained catch was about 1 million lbs (454 t) less in 2010/11 than in 2009/10. 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 20 years with mature females being 2.9 times more abundant in 2011 than in 1985 and mature males being 2.2 times more abundant in 2011 than in 1985.
4. Recruitment: Estimated recruitment was high during 1970s and early 1980s and has generally been low since 1985 (1979 year class). During 1984-2011, only estimated recruitment in 1984, 1995, 2002 and 2005 was above the historical average for 1969-2011. Estimated recruitment was extremely low during the last 5 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		29.76[D]	NA	NA	NA	8.80	7.19

The stock was above MSST in 2010/11 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		65.6[D]	NA	NA	NA	19.39	15.84

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

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

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

Average recruitments during four periods were used to estimate $B_{35\%}$: 1969-1983, 1969-present, 1984-present, and 1995-present. We recommend using the average recruitment during 1984-present, corresponding to the 1976/77 regime shift. Note that recruitment period 1995-present was used during 2008-2010 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 4.433 during brood years 1968-1977 and 0.806 during 1978-2005. The two-tail t-tests with unequal variances show that ln(recruitment) and ln(recruitment/mature male biomass) between brood years 1968-1977 and 1978-2005 are strongly, statistically different with p values of 0.0000000005676 and 0.0002189, 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 2011 and the 2011 summer trawl survey data were added.

3. Changes to the assessment methodology:

Twelve model scenarios are evaluated. In this report, only results for scenario 7ac are presented. The results for all other scenarios were presented in the SAFE report in May 2011. These 12 scenarios are:

Scen.	Var formula for size comp. LL	Initial year proportion estimates	Treatment of re-tow survey data
0	Est[prop]	No	Standard + retow for males & retow for females
1	Obs[prop]	No	Standard + retow for males & retow for females
1a	Obs[prop]	Yes	Standard + retow for males & retow for females
1b	Obs[prop]	No	Standard data only for both males and females
1c	Obs[prop]	No	Standard data for males & retow for females

Sc.	M	Additional mortality (one level for♂, two levels for ♀)	BSFRF survey data, 07 &08	Var formula for size comp. LL	NMFS survey 'Q'	Others	Others
0	0.18	1980-1984 ♂ 76-79&85-93, 80-84♀ (periods selected based Zheng et al. 1995)	Include	Est[prop]	0.896 & Est[Q] for 1970-72		
1	0.18	1980-1984 ♂ 76-79&85-93, 80-	Include	Obs[prop]	0.896 & Est[Q] for 1970-72		

3

		84♀					
2	0.18	1980-1984 ♂ 76-79&85-93, 80-84♀	Include	Obs[prop]	Above with annually varying multiplying factor (0.8 -1) for 0.896 ♀		
3	0.18	1980-1984 ♂ 76-79&85-93, 80-84♀	Include	Obs[prop]	0.896 & Est[Q] for 1970-72	Three levels of molting prob for ♂	
4	0.18	Predation mortality only on newshell. 1980-1984 high; 76-79&85-93 low	Include	Obs[prop]	0.896 & Est[Q] for 1970-72		
5	0.18	1980-1984 ♂ 76-79&85-93, 80-84 ♀	Include	Obs[prop]	Above with annually varying multiplying factor (0.8 -1) for 0.896 ♀	Three levels of molting prob for ♂	
6	0.18	1980-1984 ♂ 76-79&85-93, 80-84 ♀	Include	Obs[prop]	0.896 & Est[Q] for 1970-72	Three levels of molting prob for ♂	High bycatch rates before 90 from RKC &Tanner fisheries
7	0.18	1980-1984 ♂ 76-79&85-93, 80-84 ♀	Include	Obs[prop]	0.896 & Est[Q] for 1970-72	Three levels of molting prob for ♂	Estimate effective sample size from observed

Scenario 7ac: Combination of scenarios 7, 1a and 1c, that is, scenario 7 plus standard survey data for males and retow data for females and estimating initial year length compositions.

4. Changes to assessment results:

Male abundance from the 2011 summer trawl survey was lower than expected. Estimated mature male abundance and biomass in 2011 were about 10% lower than those in 2010. Estimated crab abundance and biomass during recent five years were lower than those estimated in 2010.

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 2010)

"The CPT ***recommended*** *the following changes to the document: fixing the MSST and MMB values in the summary table; highlighting the most recent year in the plot of F against MMB; and ensuring that the tables and figures in the CIE review transfer correctly to this SAFE chapter."*

These are done.

"The assessment author noted that most of the recent CPT and SSC recommendations will be addressed for the May 2011 CPT meeting. A response to the CIE review will be prepared and submitted to the CPT for the May 2011 meeting. In the fishing mortality/MMB figure, the most recent year should be highlighted. The CPT noted that in the model, the retow and standard survey biomass data were averaged for males and only the retow data were used for female biomass in the model. In May 2011, only the standard survey should be used for males and the retow survey data for females to be consistent with the intent of the retow survey."

The response to the CIE review is included. Due to time constraint, only one scenario (1c) uses the standard tows for males and retows for females. Scenario 1b uses only standard tows for both males and females. All other scenarios use the both standard and retow data for males and retow data for females.

Response to CPT Comments (from May 2011)

"*More information should be provided why it is reasonable that assuming the bycatch rate in the 1980s equaled the two highest bycatch rates can address the question of whether high bycatch mortality in the 1980s caused the drop in abundance."*

Good information for estimating bycatch rates in the early 1980s is not available. From the responses to the CIE comments below, the only observed data in the early 1980s from Griffin et al. (1983) did not show very high bycatch rates relative to the survey abundance. The two highest observed bycatch rates represent the high end of bycatch rates we have data on.

"Page 175 – the text relative to the assumption being conservative should not be included in text; rather it should be made clear that this is the best estimate."

Remove the wording of "conservative assumption"

"Additional justification for differential mortality rates for males and females should be provided because, at present, the model fits the data, but the mechanisms for, for example, sex-specific natural mortality over different periods is unclear. "

The following text was added to the report: These additional mortalities could be due to increase in natural mortality or unknown fishing mortality. Predation mortality could result in different natural mortalities for males and females because predation for mature crab is mainly on soft shell crab and mature females molt yearly.

"The fraction of the female stock outside survey area in each year needs to be linked to something. It is possible that the differences in abundance between legs 3 and 1 relate to the proportion outside of the survey area. There are survey data indicating that the proportion of animals outside of survey area in a cold year. These data could be used as an index. The hot spot issue should be identified as research priority along with the need for tagging data."

We also think this is an important issue because estimated recruitments for males and females are forced to be similar to each other each year. It is not easy to find a good index to link to. We will continue to examine this in the future.

"How the BSFRF data are incorporated in the assessment should be re-evaluated in conjunction with scientists from BSFRF; specifically, the assessment currently ignores the length data from the BSFRF surveys as well as the female data. This could be a topic for a modeling workshop."

We will look into this in the future.

"The estimates of time-trajectories of mature biomass are computed from the output of the model because "maturity" is not explicitly represented in the model. The equation for the population dynamics should be modified to indicate that growth (for females) changes over time."

Done. The description of the female model includes change of the growth matrix over time.

"Indicate the MLE on the graph for OFL"

Done.

"The team recommends additional runs for the September assessment which combine model configurations 7 and 1a (the 'recommended' model). Model configurations 7 a,c should also be included in the September assessment."

The "configurations 7 and 1a (the 'recommended' model)" conflicts with the CPT position that the standard survey data are used for male abundance estimates (see the CPT recommendation in September 2010 above). Scenario 7ac, the combination of scenarios 7, 1a and 1c, is used as the CPT recommended model for this report (based on my note from the May CPT meeting).

Response to SSC Comments specific to this assessment (from March 2011)

"To address concerns over population-level effects of fishing on recruitment, the SSC recommends that the Crab Plan Team review the basis for the current baseline used to determine productivity of RKC (1995-2010). *In particular, if fishing has contributed to the decline in RKC recruitment after the 1970s, the recent baseline period may not be representative of the productivity of the stock. "*

We support the SSC recommendation on research efforts to understand the effects of the regime shift of 1976/77 and fishing on Bristol Bay red king crab productivity. In the SAFE report, we report the different productivity levels before and after the 1976/77 regime shift, which is the basis for the current baseline. Four different periods are compared for this report. When new results on these effects are available, the baseline can be modified.

Response to SSC Comments specific to this assessment (from Oct. 2010)

"The SSC is still puzzled by one result in the previous SAFE. Namely, Model 5, which set additional mortality for females to 0, had a higher likelihood than Model 3. This should not be possible, because Model 5 had one less parameter. The authors restated that Model 5 had the lowest likelihood but did not explain why this could be the case. The SSC would appreciate receiving an explanation for this result."

We agree with this comment that if it were the case, it would be impossible. However, nowhere in the May 2010 SAFE report does Model 5 have a higher likelihood value than Model 3. In the May 2010 SAFE report, Model 5 has the lowest log likelihood (55180) among all models (ranging from 55180 to 55806) (See the Table in The Summary of Major Changes).

"The SSC agrees with CPT recommendations about items to be addressed by May 2011. First, the authors have not addressed reviewer comments from the June 2009 CIE review. CPT informed the SSC that the author will present a response to the CIE comments during a proposed modeling workshop during February 15-18, 2011. The SSC looks forward to seeing the assessment author's response and plan team recommendations at the April 2011 Council meeting."

The CIE comments were addressed during the Stock Assessment Workshop in Feb. 2011 and the response is included in the report.

"Second, the CPT recommended that the standard survey should be used for the male abundance index and the re-tow survey be used for females, because the standard survey is the baseline and the re-tow survey is intended to address the problem of delayed female molt timing. However, the SSC would be interested to see an evaluation of model results using the standard survey only versus standard plus re-tow survey results for males for reasons similar to the rationale to include BSFRF survey data in the snow crab assessment. For instance, the selection of the best data to be used in the assessment could involve a sensitivity analysis in which model fit statistics are examined. This could evaluate datasets are most consistent with model projections from one

year to the next. In any case, it is important to determine the dataset(s) to be used in the assessment a priori, not post hoc."

Scenario 1b uses only standard survey data and is compared with scenario 1 (both standard and re-survey data) and scenario 1c (standard survey data for males and re-survey data for females, CPT option). The likelihood value is much higher for Scenario 1 than scenarios 1b and 1c.

"Third, further sensitivity analysis should be done with respect to data weighting, catchability parameters, and mortality parameters. Also, rationale for model choices should be enhanced. Finally, the extent of expansion of the population northward should be examined. In that light, consideration should be given as to whether a tagging study in the north would be useful to estimate movement probability."

Data weighting was examined during the past SAFE reports. Due to time constraint, the only data weighting examined in this report is effective sample sizes. Different scenarios are used to examined catchability parameters and mortality parameters. We do not have time to examine the expansion of the population northward. A tagging study in the north would understand crab migration. Few mature crab occur in the north outside of the current stock definition. We need to understand whether the northern crab participate in the stock reproductivity before including them in the model. This issue is similar to snow crab, which are found all way to Norton Sound.

Response to SSC Comments specific to this assessment (from June 2011)

"The Plan Team made several suggestions to improve document clarity and recommended reevaluating the treatment of the BSFRF data by including length data and data for females. The Team also requested two additional scenarios: (1) a scenario combining (1a) with (7), and (2) a scenario combining (1c) with (7). The Team also developed 4 possible time periods for the baseline for calculating reference biomass. The SSC concurs with these recommendations."

See the responses to the CPT comments in May 2011.

3. Responses to the recommendations from the Stock Assessment Workshop in Feb. 2011:

"1) Justify why the choice of switching the variance terms in the robust multinomial likelihood to the observed proportions-at-length for all scenarios, rather than switching back to the base scenario that used the predicted proportions-at-length. Bubble plots of the residual patterns using either formulation should be shown sideby-side for comparative purposes. There is some concern that very small sample sizes may create large residuals."

Switching the variance terms are suggestions from the CIE review and the CPT. The likelihood value is much higher with the variances from the observed proportions than estimated proportions. The plots of residual patterns are following each other, although they are not side-by-side.

"2) Provide a table of model parameters and describe which parameters are fixed and which are estimated (as per terms of reference) as well as the corresponding parameter bounds assumed. If fixed then please justify the fixed value."

The fixed parameters are listed in Table 4(0) for scenario 0. Most other scenarios have the same fixed parameters. These fixed parameters are explained in the Appendix (section of Parameters Estimated Independently). Estimated parameters are listed in Table 5 for scenario 0.

3) A suggestion to run a sensitivity analysis with and without retow data. The retow data should be treated consistently in both the survey abundance estimate and the population assessment model."

Scenario 1b is the scenario with only standard survey data, which can be compared with scenario 1 with both standard and re-tow data for males and re-tow data for females and scenario 1c with only standard data for males and re-tow data for females.

"4) The model is initialized with the 1968 size distribution data; the model should be run with estimated initial conditions and evaluate the effects on management quantities."

Scenario 1a estimates initial length/sex proportions, which has similar abundance estimates with scenario 1. Scenario 1a has additional 36 parameters and its log likelihood also increases, but the increase is much less relative to other scenarios with high numbers of parameters.

4. Responses to the recommendations from the Stock Assessment Workshop in Feb. 2011:

WEAKNESSES

Dr. Billy Ernst

• Some relevant fisheries data were omitted from the stock assessment. The time series of catch-per-unit effort (catch-per-pot) was not used in the stock assessment, and it would have been useful to have a second index of relative abundance.

Reply: If survey data were not available, catch-per-potlift data would have to be used as a relative abundance index. Because soak times are not available for most years and changes occurred in pot limits and escapement rings over time, it is difficult to standardize the catch-per-potlift data.

• There is a potential bias with inter-annual variability in the EBS NMFS trawl survey abundance estimates due to timing of the survey, spatial dynamics and environmental variability.

Reply: Good point. Scenario 2 addresses some of these problems.

• Parameter uncertainty in fixed model quantities was not appropriately addressed in the stock assessment document.

Reply: When relatively good information is available, we tend to fix the parameter values to reduce parameter confounding. Sensitivity analysis can be used to examine the uncertainty.

• There is a lack of a general conceptual model that integrates life history and spatial dynamics. This would help to interpret the survey data, model configuration and relevant statistics for management.

Reply: The general conceptual model for recruitment has been developed (Tyler and Kruse, 1996). It is difficult to formulate a spatial model at this point in time because appropriate data are not available to estimate parameters.

• There is a lack of theoretical support for variable natural mortality scenarios. These might be replaced by more mechanistic bycatch mortality scenarios.

Reply: This is a good point, and scenarios 4 and 6 are used to examine high predation and high bycatch mortality rates. SAFE reports in 2009 and 2010 examined scenarios with extreme high bycatch.

• The stock assessment document is extensive but incomplete in describing all model equations and formulations.

Reply: The SAFE report has been revised in 2010 to document all equations and formulations in response to this concern (Appendix A and text in the main stock assessment document for spring 2011).

• The selection of recruitment time series interval for reference points calculations is debatable.

Reply: Good point, agree, and it is a hot topic for the CPT too.

Dr. Nick Caputi:

• The use of different natural mortality rates for different periods appears to be justified to explain the declines in abundance in the early 1980s which may be linked to regime shifts, predation, bycatch or effects of trawling. The changes in the mortality rates for males and females for different time periods provides a better fit to the data but it is not clear what the biological processes may be to justify this assumption.

Reply: The SAFE reports in 2009 and 2010 discussed potential biological explanations: predation, older ages, and diseases; however, we acknowledge that specific explanations are difficult to verify,

• The model has been developed for the whole stock which hides some interesting spatial dynamics that is occurring in the fishery such as (a) differential rates of migration between inshore and offshore; and (b) changes in the spatial distribution of the spawning stock that may have affected the recruitment abundance and distribution.

Reply: Agree. A spatial model may be an improvement from the current model. However, due to lack of data, it is difficult to develop a detailed spatial model at this point in time.

• The complex state/federal decision rule framework is a weakness in the stock assessment process. The step function being used in the Alaskan state decision framework for setting quotas (Fig.1 of Zheng and Siddeek 2009) may make it difficult if the biological estimates are close to the threshold levels given there is some uncertainty associated with these estimates. A slope

function between the harvest rate and biomass may provide a better representation for the decision rule.

Reply: This is a good recommendation for consideration by the Alaska Board of Fisheries. There are pros and cons for the state harvest strategy in term of assessment errors. Under the state harvest strategy, the impact of errors would be bigger if the estimated abundance is close to the threshold levels and would be less if the estimated abundance is away from the threshold levels.

• *The stock assessment process does not utilize the fishing effort and catch rate (CPUE) information for the pot fishery. This may be a valuable data set that may enhance the stock assessment process. Further comments on this analysis are provided below.*

Reply: if survey data were not available, catch-per-potlift data would have to be used as a relative abundance index. Because soak times are not available for most years and changes occurred in pot limits and escapement rings over time, it is difficult to standardize the catch-per-potlift data.

• *Potential underestimates of the Tanner and RKC fisheries bycatch of RKCs that may affect the estimate of natural mortality. Consideration should be given to the effect that: (a) rate of retention for undersize in traps may be greater during periods of high catch rate as escape gaps may not function as well; and (b) higher bycatch mortality rate may be associated with handling in periods of high catch rate.*

Reply: Agree. Scenario 6 was added to address this problem.

• *One of the hotspots of abundance of RKCs from the annual trawl survey regularly occurs on the boundary of the trawl area near the coast. This could result in a significant underestimate of the biomass if there is a high abundance in the non-surveyed areas along the coast.*

Reply: Agree. This case could occur for mature female and juvenile crabs. Scenario 2 was added to address the female catchability issue. Survey selectivity deals with the juvenile crabs.

• *A useful addition to the stock assessment document would be a description of the life cycle that provides an understanding of the key biological processes taking place over time and space. This should include time and place of primiparous and multiparous mating, hatching, larval period and movement, settlement period and location, growth, time and size at maturity, time to legal size, molt frequency and timing, migration patterns of males and females. Some of this information is directly relevant to the stock assessment and other information may be supplementary to the stock assessment process. Development of a spatial-temporal conceptual model of the life history of RKC and the fisheries affecting it would be useful.*

Reply: Agree. Life history has been added to the SAFE report for 2010. A more complete spatial-temporal conceptual model can be added in the future.

ToRs 2 and 3: Recommendations of alternative model assumptions and estimators

Dr. Billy Ernst:

(a) *Re-analyze EBS NMFS trawl survey data using an alternative likelihood based geostatistical approach (Roa and Niklitschek 2007). If the same approach is used, the criteria for estimating abundance and its variance across the entire time series should be unified.*

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Reply: Agree. NMFS scientists conduct area-swept estimates of the trawl survey data. We encourage NMFS scientists to examine this approach for Bristol Bay red king crab data as well as other crab stock data.

(b) Include new mechanistic scenarios that address more clearly the decline in female and male abundance during the early 1980s (use Griffin et al. 1983 bycatch rates to complete the time series).

Reply: Different scenarios were made to investigate this issue. The most difficult task is to deal with the crab abundances in the 65-120 mm size range that were highly abundant with low bycatch selectivity, but disappeared quickly during the early 1980s. The estimated bycatches based on Griffin et al. (1983) study were low relative to the area-swept abundance (Figure 1r) and the selectivity was similar to the current model estimates. These bycatch rates could not explain the abundance decline. Some NMFS scientists suggested using the ratio of bycatch to the number of legal males in 1982 and assumed all other years have the same ratio to estimate bycatches. This approach requires a steady population state assumption during the 1970s and early 1980s. Under this assumption and ignoring the stock length structures, estimated bycatches could explain the abundance decline by a certain degree for male crabs but failed to explain the female abundance decline. Unfortunately, the stock changed dramatically during late 1970s and early 1980s and was far from a steady state (Figures 2r and 3r). The length structure in 1982 was extremely different from the other years (Figure 2r).

We investigated a scenario of high predation mortality for newshell crabs (scenario 4) and high bycatch rates (scenario 6) in the current updated SAFE report.

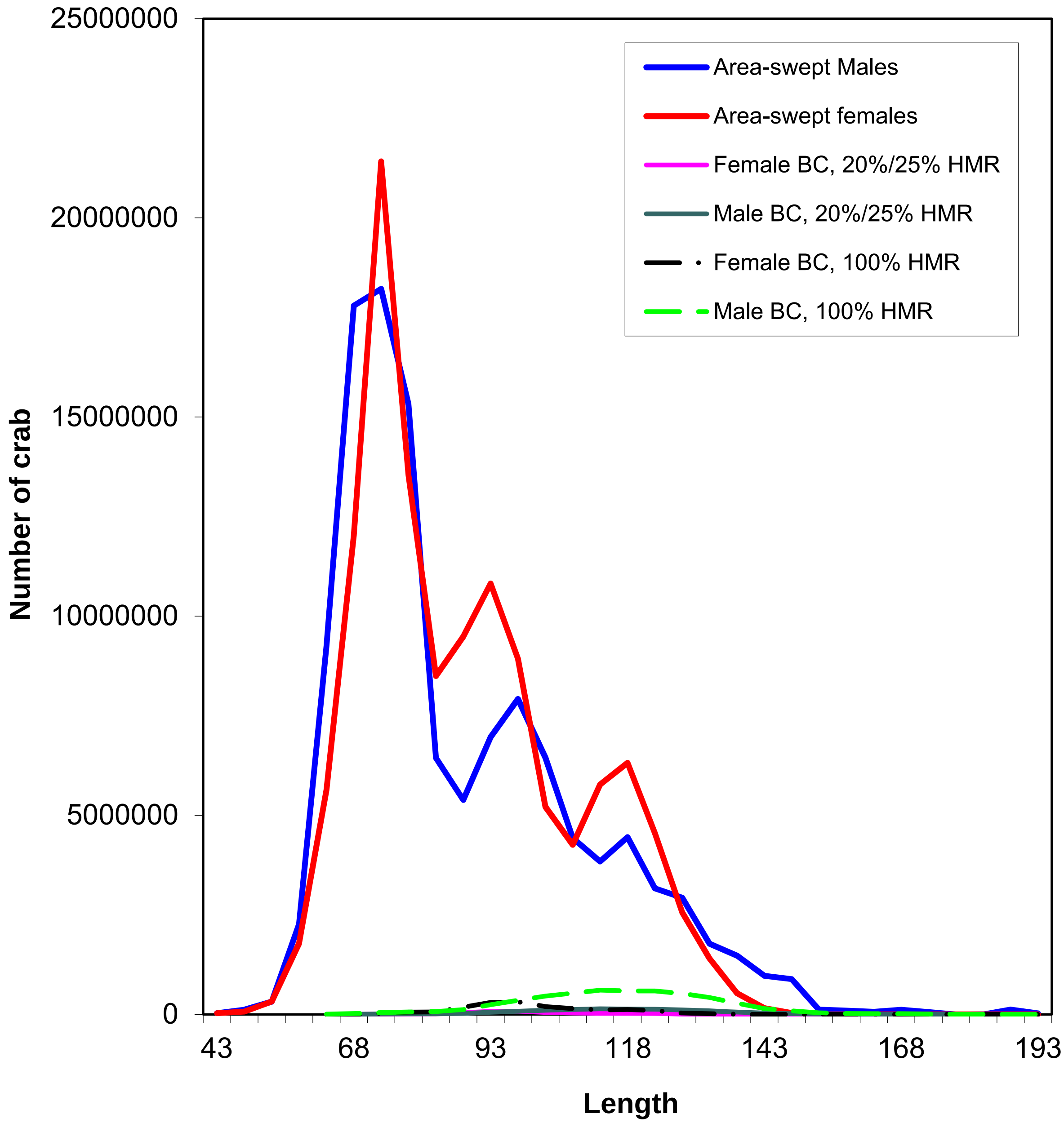

Figure 1r. Comparison of area-swept estimates of abundance and estimates of bycatch mortality (Griffin et al., 1983) in 1982. Two bycatch mortality rates are used: 20% for the red king fishery and 25% for the Tanner crab fishery and 100% for both red king and Tanner crab fisheries. Estimated bycatches were a very small proportion of the survey abundance.

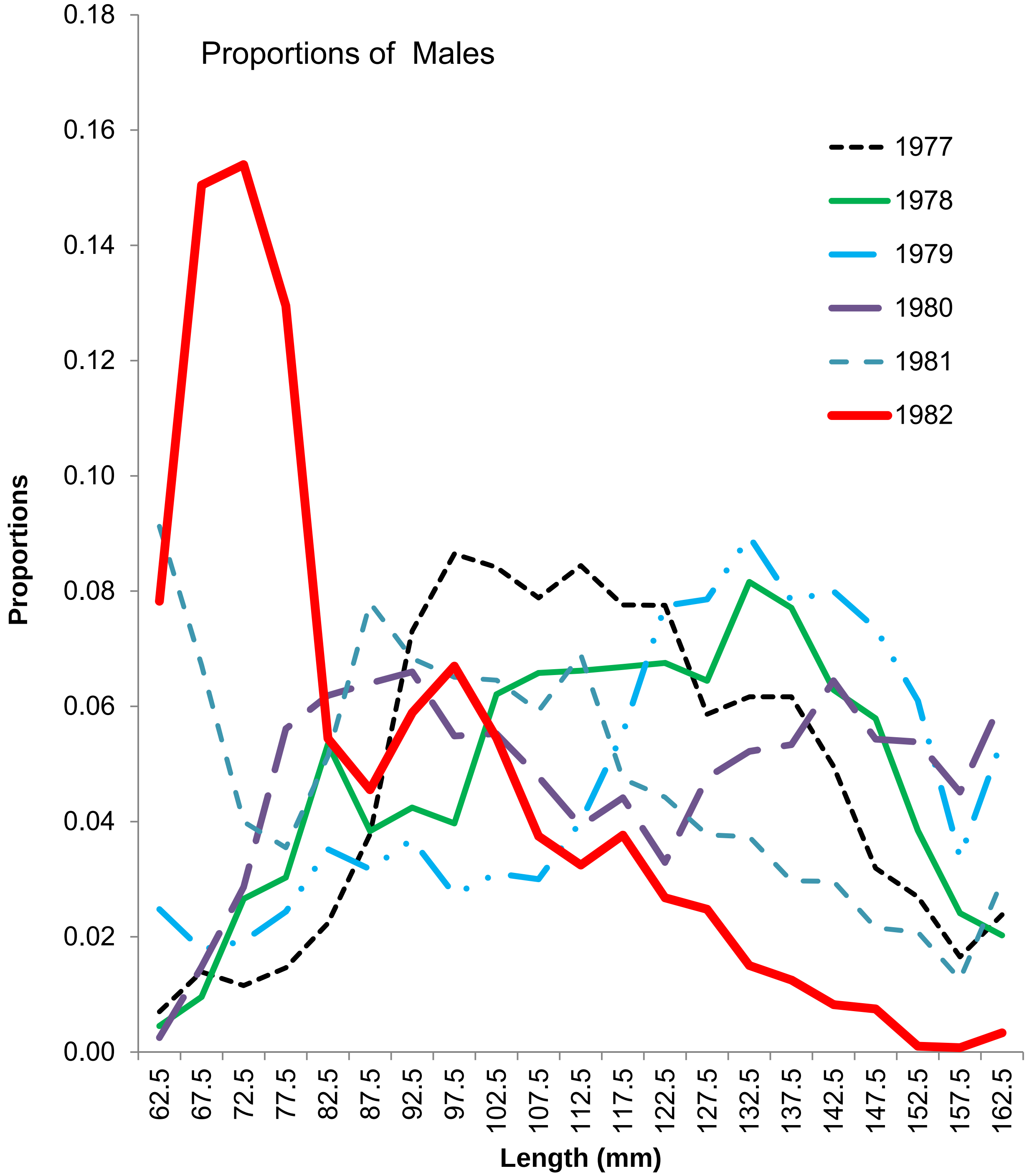

Figure 2ra. Length compositions of area-swept estimates of male crabs during 1977-1982. Length structure in 1982 was completely different from the other years. It is invalid to assume that the length structures are about the same during these years.

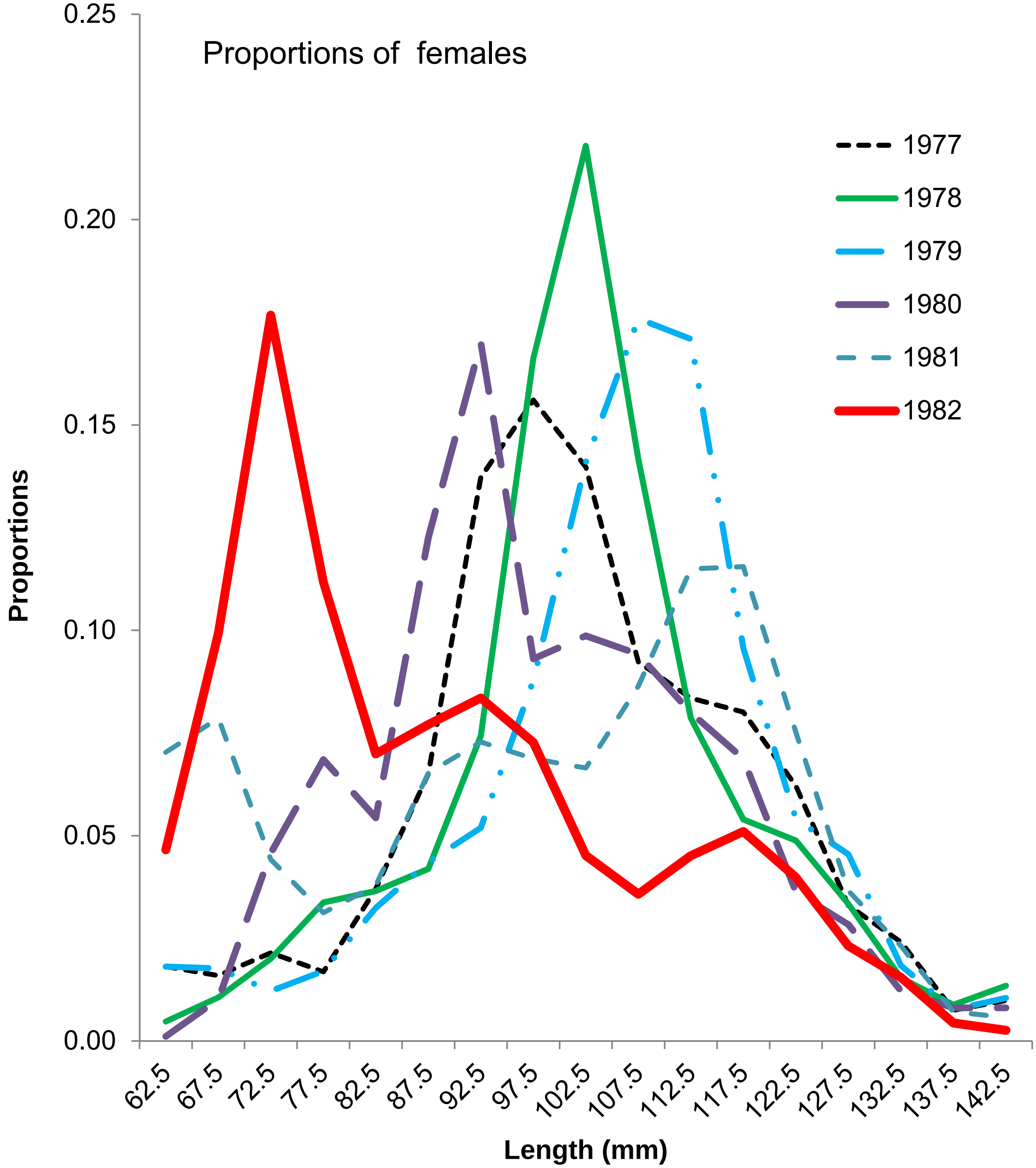

Figure 2rb. Length compositions of area-swept estimates of female crabs during 1977-1982. Length structure in 1982 was completely different from the other years. It is invalid to assume that the length structures are about the same during these years.

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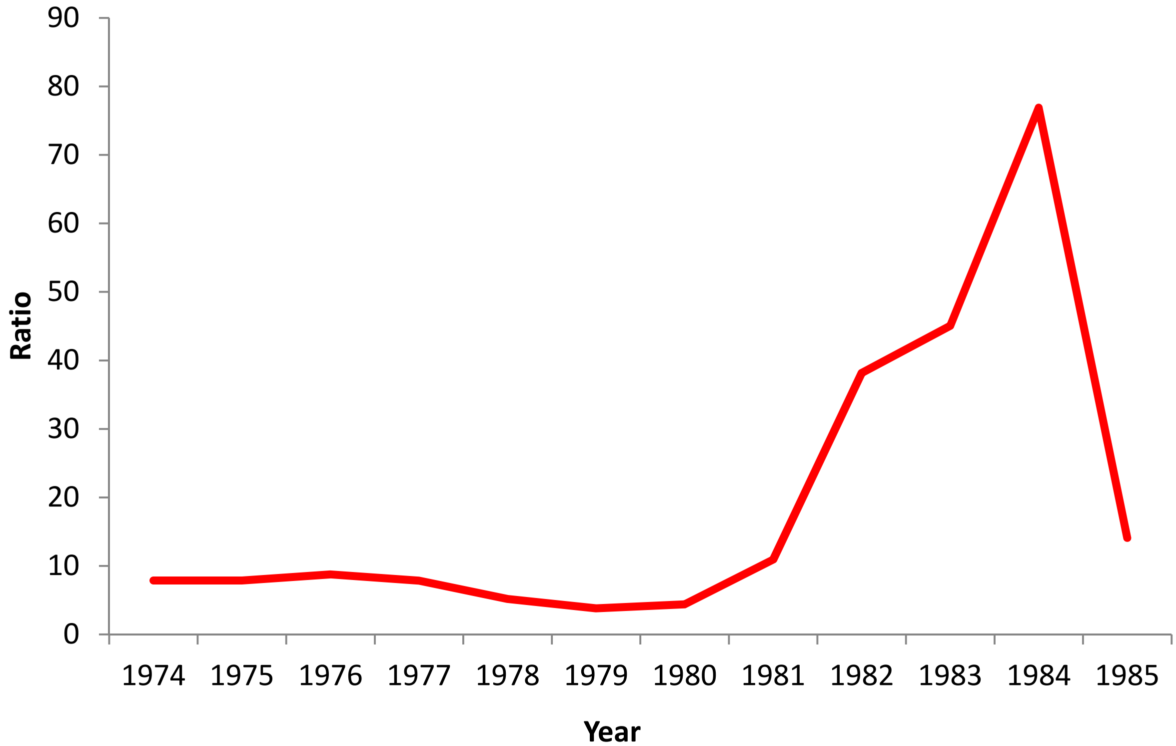

Figure 3r. Ratios of survey abundance of 80-134 mm males and 70+ mm females divided by survey legal male abundance. Although some bycatches are smaller than 70 mm for females and smaller than 80 mm for males, 80-134 mm males and 70+ mm females basically represent the bycatch population. The ratio in 1982 was much higher than those before 1982. It is invalid to assume that the length structures are about the same during these years.

(c) Explore alternative configurations for initial conditions and evaluate their effects on the assessment parameters.

Reply: Initial conditions for different parameters were varied when the model was developed to check the robustness of the likelihood optimization.

(d) Improve diagnostics and comparative analyses of different model configuration results (scenarios), including fixed parameter values, effect of likelihood weights, initial conditions.

Reply: A good suggestion. Effects of likelihood weights were examined and reported in the 2009 SAFE report. Eight scenarios are compared in the current updated SAFE report.

(e) *More precisely assess the effect of including and excluding the BSFRF survey, with an emphasis on current biomass estimates (males and females) and likelihood value of different pieces of information.*

Reply: This was done in the 2010 SAFE Fall report.

(f) *Use observed proportions as opposed to predicted ones in the variance term of the normal likelihood function.*

Reply: Good suggestion. We implemented it in scenario 1.

(g) *Compute implicit sample sizes and variances for each piece of information and compare it to the ones used in the assessment.*

Reply: Effective sample sizes have been estimated and compared with the assumed values. In scenario 7, we examined a new approach to estimate effective sample sizes.

(h) *Consider a formal statistical approach to estimate the male size transition matrix externally, using historical tagging data (Punt et al., 2009).*

Reply: The current approach is a statistical approach. Different assumptions are needed for using the approaches by Punt et al (2009). We may examine different approaches in the future.

(i) *If male molting probabilities are estimated outside of the model (from tagging data), then there should be no need to use old shell and new shell categories in the dynamics of the model. This would simplify model assumptions and the number of parameters to be estimated.*

Reply: Good point, one that we have thought about before. The problem is that the tagging data are primarily from 1960s and early 1970s, and during these periods, oldshell crab abundances were low and estimated molting probabilities were much higher than those during 1980s-2000s. We examined a scenario with three levels of molting probabilities over time (scenario 3).

(j) *Assess mature male molting time. If a fraction of mature males are not capable of mating during the survey time (Dew 2009), then the current calculation of mature males available for mating (>120 mm) would be overestimated.*

Reply: Dew (2009) assumed that oldshell mature males stay inshore for mating. The re-tow data during the last 12 years did not support this assumption.

(k) *Because an unknown fraction of the population remains unsampled in the survey and this proportion varies from year to year, it would be appropriate to implement a scenario that allows for inter-annual variation in survey availability. Ideally this variation could be modeled based on oceanographic data during the survey, or available year around from ROMs outputs.*

Reply: Good point. However, this mainly applies to females. This can be tried by allowing some variation of annual survey selectivities. The difficulty is knowing how much variation should be allowed. We examined a scenario of varying survey catchabilily of females over time (scenario 2).

(l) *Implement a management strategy evaluation to assess harvest rates under different productivity scenarios.*

Reply: This is a good idea. This will be a task to consider in the near future.

Dr. Nick Caputi:
Recommendations for alternative model configurations and assumptions are:

(a) *The move to crab rationalization has resulted in improved economic data collection that can be used to set harvest rate targets for improved profitability of the fishery.*

Reply: This requires economists' expertise. We will explore this with our economists.

(b) *Average recruitment during 1968-2008, 1985-2008, 1995-2008 were considered in setting overfishing limits - the choice of B35% should take into account the stock-recruitment relationship so that the level of mature biomass is sufficiently high that if good environmental conditions occur then good recruitments will occur.*

Reply: The S-R relationships were used for determining the current state harvest strategy (target harvest).

(c) *The assessment of the mature male biomass (MMB) contributing to the mating each year should take into account the decline in molting probability with size which means that the larger males may be contributing proportionally more to mating than smaller males that are molting most years.*

Reply: Because large males are heavier than small males, the mature male biomass estimate more or less takes this into account. The state harvest strategy (target harvest) provides further weighting for large males. How many mature females a mature male can mate during a mating season will affect the effective spawning biomass. The number of mature females a mature male can mate increases with the size of mature male (see Zheng et al. 1995). This is currently an area of debate.

(d) *Alternative hypotheses for cause of mortality in the early 1980s should be explored e.g. an additional mortality at different time periods, bycatch in the RKC and/or Tanner crab fisheries. Information on size structure should be taken into account to obtain improved estimates of bycatch when observer data was not available as well the effectiveness of the escape gaps and bycatch mortality rates at different levels of catch rate.*

Reply: We have investigated some scenarios on this line. In the current updated SAFE report, we examined two scenarios, scenario 4 for high predation mortality and scenario 6 for high bycatch rates.

(e) *Sensitivity analysis of trawl survey catchability estimates.*

Reply: We examined variation of trawl survey catchability over time for females (scenario 2). This issue will be examined further when new data become available.

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 2010/2011 and the 2011 summer trawl survey.

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.

(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 $\approx$140,000 nm^2. Since 1972 the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2011 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 statons (2011) 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 and 2011, 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) 1982-2011 (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 1994-2011). 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:

Eleven scenarios were compared for this report following September 2010 CPT request, the response to CIE review, and the response to the Stock Assessment Workshop recommendations.

Scenario 0: We called the base scenario as Scenario 0 and other scenarios as Scenarios 1-7. Scenario 0 is the original scenario 3 in the September 2010 SAFE report. The base scenario is: constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 (one parameter) and for females during 1976-1993 (one parameter for period 1980-1984 and another parameter for periods 1976-1979 and 1985-1993), and including the Bering Sea Fisheries Research Foundation (BSFRF) survey data. These additional mortalities could be due to increase in natural mortality or unknown fishing mortality. Predation mortality could result in different natural mortalities for males and females because predation for mature crab is mainly on soft shell crab and mature females molt yearly.

Scenario 1: The same as scenario 0 except for using observed proportions in the variance formula for size composition.

Scenario 1a: The same as scenario 1 except estimating initial abundance by length and sex. An additional 36 parameters from scenario 1 are estimated. An additional likelihood component is added from the length compositions in the first year:

$$f = \sum_{l,sex}(observed\ length\ proportions - estimated\ length\ proportions)^2$$

Scenario 1b: The same as scenario 1 except only the standard survey data are used for estimating survey male and female abundances.

Scenario 1c: The same as scenario 1 except only the standard survey data are used for estimating survey male abundance and re-tow data are used for female abundance (the CPT option).

Scenario 2: The same as scenario 1 except for survey catchability for females changes annually. Specifically, an annual variable within the range, 0.8 to 1.0, is estimated within the model and multiplied by the fixed survey catchability of 0.896 for females. A penalty term with a CV of 0.1 is used to estimate this variable. This scenario illustrates the effects of annual variation on population and parameter estimates. Due to lack of data, it is difficult to estimate annual catchability. An additional 43 parameters from scenario 1 are estimated.

Scenario 3: The same as scenario 1 except for three levels of molting probabilities for males over time. The years grouped into three groups are from the results from the ADF&G stock assessment model (Zheng et al. 1995). Group 1 consists of 1968-79; group 2 consists of 1980-84, 1992-94, 1997, 1999, 2001, 2007-2010; and group 3 consists of 1985-91, 1995-96, 1998, 2000, and 2002-2006. Four additional parameters from scenario 1 are estimated.

Scenario 4: The same as scenario 1 except for replacing additional mortality parameters with assumed predation mortality. Predation moralities are assumed to occur on newshell crab only with the same predation mortality rate for both males and females. One parameter is predation mortality during 1980-1984 and the second parameter is for predation mortality during 1976-1979 and 1985-1993. Data is lacking for estimating predation mortalities. These two predation mortality rates are estimated in the model as two parameters. One less parameter from scenario 1 is estimated.

Scenario 5: Combination of scenarios 1, 2 and 3. An additional 47 parameters from scenario 1 are estimated.

Scenario 6: The same as scenario 3 except for assuming high bycatch rates before 1990. The average of the highest two observed bycatch rates during 1990-2006 from the directed pot and the average of top 2 bycatch rates from the Tanner crab fishery during 1991-1994 are used to estimate bycatch before 1990. This scenario assumes bycatch mortality rates before 1990 are equal to the high ends of bycatch rates estimated from the available observer data after 1990. Four additional parameters from scenario 1 are estimated.

Scenario 7: The same as scenario 3 except for estimating effective sample size (ESS) using observed sample sizes. Four additional parameters from scenario 1 are estimated. Effective sample sizes are estimated through two steps:

(1) 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.

(2) 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.

Following the recommendation of the CPT in May 2011, Scenario 7ac is developed for the stock assessment in this report. Scenario 7ac is a combination of scenarios 7, 1a and 1c, that is, scenario 7 plus standard survey data for males and retow data for females and estimating initial year length compositions.

Only the results for scenario 7ac are presented in this report. The results for all other scenarios were presented in the SAFE report in May 2011.

b. Progression of results: NA.

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 scenario 0-6, we assumed constant effective sample sizes for the length/sex composition data. Estimated effective sample sizes were computed 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. Estimated effective sample sizes vary greatly over time. For scenario 7ac, 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 scenario 7ac are summarized in Tables 4 and 5.

ii. Abundance and biomass time series are provided in Table 6 for scenario 7ac.

iii. Recruitment time series for scenario 7ac 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 scenario 7ac.

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 scenario 7ac, estimated molting probabilities during 1968-2011 (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 2010 and 2011 (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 20 years with mature females being 2.9 times more abundant in 2011 than in 1985 and mature males being 2.2 times more abundant in 2011 than in 1985 (Figure 10b).

iii. Estimated recruitment time series are plotted in Figure 11 for scenario 7ac.

iv. Estimated harvest rates are plotted against mature male biomass in Figure 12 for scenario 7ac.

The average of estimated male recruits from 1995 to 2011 (Figure 11) and mature male biomass per recruit were used to estimate $B_{35\%}$. Alternative periods of 1968-present and 1985-present were compared in our previous 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, 2007-2009 but below the $F_{35\%}$ limits in the other post-1995 years.

Estimated full pot fishing mortalities ranged from 0.00 to 1.09 during 1968-2010, 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 4.433 during 1968-1977 and 0.806 during 1978-2011.

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 (scenario 7ac) 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 2011 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 2011 estimates as the baseline values, we can also evaluate how well the model had done in the past. The 2011 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 2011 model includes sequentially excluding one-year of data. The model with scenario 7ac performed reasonably well during 2004-2010 with a lower terminal year estimate in 2004 and higher estimates during 2005-2010 (Figure 28).

Overall, both historical results and the 2011 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 2009-2011, the model was extended to the data through 1968. No weight factors were used for the NMFS survey biomass during 2009-2011 assessments.

f. Uncertainty and sensitivity analyses

i. Estimated standard deviations of parameters are summarized in Table 5 for scenario 7ac. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for mature male biomass and exploitable male biomass in 2011 are illustrated in Figure 30 for scenario 7ac using the mcmc method with 1,000,000 replicates. The confidence intervals are quite narrow for two values.

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.

Scenario 7 statistically fits the data better than all other scenarios. The biggest improvements of scenario 7 over other scenarios are better fitting the survey length compositions and retained catch biomass. Mature male abundance estimate with scenario 7 in 2008 falls into the 95% confidence interval of BSFRF survey estimates. Scenario 4 with model estimated predation mortalities during late 1970s and 1980s does not fit the data as well as the other scenarios.

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

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

c) $\frac{B}{B^*} \le \beta$ 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 2010 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 1990-2010. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2007-2010 than in 2005 after the fishing industry minimized discards of legal males. Thus, the average of retained selectivities and discard male selectivities during 2009-2010 were used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2000-2010 were used for per recruit analysis and projections.

Average recruitments during four periods were used to estimate $B_{35\%}$: 1969-1983, 1969-2011, 1984-2011, and 1995-2011 (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 1995-present was used during 2008-2010 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 4.433 during brood years 1968-1977 and 0.806 during 1978-2005 (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 1978-2005 are strongly, statistically different with p values of 0.0000000005676 and 0.0002189, 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 1984-2011 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 mcmc procedure is used to generate probability distribution for the OFL (Figure 31a). To adjust the retrospective bias of the 2011 model, the 2011 model estimates of MMB during 2006-2010 is regressed against the terminal year estimates of MMB during 2006-2010 with the intercept equal to 0 (Figure 31b). The slope (0.817) is used to multiply the OFL 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		29.76[D]	NA	NA	NA	8.80	7.19

The stock was above MSST in 2010/11 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		65.6[D]	NA	NA	NA	19.39	15.84

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

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2011, the biological reference points were estimated as follows:

Scenario 7ac

$B_{35\%}$ = 60.082 million lbs, or 27,252.6 t

$F_{35\%}$ = 0.32

$F_{40\%}$ = 0.25

Based on $B_{35\%}$ and $F_{35\%}$, the retained catch and total catch limits (OFL) for 2011 were estimated to be:

Scenario 7ac

35

Retained catch: 17.804 million lbs, or 8,075.8 t,

Total catch: 19.390 million lbs, or 8,795.1 t,

MMB on 2/15/2012: 65.6036 million lbs, or 29,757.3 t,

Total catch includes retained catch and all other bycatch.

5. Based on the slope (0.817) of regression of 2011 model estimates of MMB against the terminal estimates of MMB during 2006-2010 (Figure 31b), ABC = 0.817*OFL, or 15.842 million lbs, or 7,185.6 t.

6. Alternative time periods of recruitment used to estimate $B_{35\%}$ for scenario 7ac:

Periods	$B_{35\%}$ (t)	MMB in 2011 Value(t)	MMB in 2011 $\%B_{35\%}$	F	OFL (t)	Stock Status
1969-1983	121,201.7	35,882.6	29.6%	0.07	2,267.2	Overfished, directed fishery closed
1969-2011	60,025.5	33,446.6	55.7%	0.16	4,939.0	No overfished
1984-2011	27,252.6	29,757.3	109.2%	0.32	8,795.1	No overfished
1995-2011	28,326.8	29,757.3	105.1%	0.32	8,795.1	No overfished

The retained catch for 1969-1984 option is below the TAC threshold.

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 1995-2011. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2011. The 2011 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 2011 (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 the $F_{40\%}$ scenario and similar to $B_{35\%}$ for the $F_{35\%}$ scenario (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 will continue to recruit to the legal population next year (Figure 34). However, no strong cohorts have been observed in the survey data after this cohort until this year (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011. Because this is one tow only, it is difficult to assume its strength until the next two or three years. 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.

	Retained Catch				Pot Bycatch		Trawl	Total
Year	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	959.7		18730.6	19690.4				19690.4
1966	1077.6		19212.4	20290.0				20290.0
1967	2174.6		15257.0	17431.6				17431.6
1968	3199.7		12459.7	15659.4				15659.4
1969	4572.1		6524.0	11096.1				11096.1
1970	3416.4		5889.4	9305.8				9305.8
1971	6497.8		2782.3	9280.2				9280.2
1972	10240.5		2141.0	12381.4				12381.4
1973	10858.6		103.4	10962.0				10962.0
1974	19171.7		215.9	19387.6				19387.6
1975	23281.2		0.0	23281.2				23281.2
1976	28993.6		0.0	28993.6			646.9	29640.5
1977	31736.9		0.0	31736.9			1217.9	32954.8
1978	39743.0		0.0	39743.0			1250.5	40993.5
1979	48910.0		0.0	48910.0			1262.4	50172.4
1980	58943.6		0.0	58943.6			968.3	59911.9
1981	15236.8		0.0	15236.8			203.0	15439.8
1982	1361.3		0.0	1361.3			544.7	1906.1
1983	0.0		0.0	0.0			401.5	401.5
1984	1897.1		0.0	1897.1			1050.4	2947.5
1985	1893.8		0.0	1893.8			375.9	2269.6
1986	5168.2		0.0	5168.2			195.8	5363.9
1987	5574.2		0.0	5574.2			140.9	5715.1
1988	3351.1		0.0	3351.1			532.3	3883.4
1989	4656.0		0.0	4656.0			169.4	4825.5
1990	9236.2	36.6	0.0	9272.8	516.5	523.4	227.2	10540.0
1991	7791.8	93.4	0.0	7885.1	399.7	64.2	261.2	9856.3
1992	3648.2	33.6	0.0	3681.8	540.4	353.6	258.9	5232.0
1993	6635.4	24.1	0.0	6659.6	747.8	514.1	379.0	8467.4
1994	0.0	42.3	0.0	42.3	0.0	0.0	81.9	124.2
1995	0.0	36.4	0.0	36.4	0.0	0.0	96.8	133.1
1996	3812.7	49.0	0.0	3861.7	161.3	0.9	107.9	4131.9
1997	3971.9	70.2	0.0	4042.1	239.7	15.5	76.1	4373.3
1998	6693.8	85.4	0.0	6779.2	940.7	701.9	161.1	8582.9
1999	5293.5	84.3	0.0	5377.9	308.1	6.7	184.9	5877.6
2000	3698.8	39.1	0.0	3737.9	353.5	35.2	104.5	4231.2
2001	3811.5	54.6	0.0	3866.2	409.3	140.0	149.9	4565.3
2002	4340.9	43.6	0.0	4384.5	433.8	6.1	111.1	4935.6
2003	7120.0	15.3	0.0	7135.3	882.3	321.4	135.0	8474.1
2004	6915.2	91.4	0.0	7006.7	338.3	153.3	125.4	7623.7
2005	8305.0	94.7	0.0	8399.7	1325.9	398.5	182.7	10306.8
2006	7005.3	137.9	0.0	7143.2	543.7	30.6	93.2	7810.7
2007	9237.9	66.1	0.0	9303.9	975.4	149.9	105.5	10534.7
2008	9216.1	0.0	0.0	9216.1	1142.1	119.8	151.4	10629.4
2009	7226.9	45.5	0.0	7272.5	866.4	67.6	104.2	8310.7
2010	6728.5	33.0	0.0	6761.5	776.9	97.1	73.9	7709.4

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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	29,383	3,594	217	168
2007	1,219	2,499	22,387	58,097	12,411	1,981	2,880
2008	1,221	3,352	14,567	49,315	8,488	1,013	673
2009	830	1,857	16,708	50,017	6,024	1,110	827
2010	705	1,633	20,137	35,367	6,839	898	863
2011	525	994					

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					3.131	28	
2008					3.064	22	
2009					2.553	21	
2010					2.410	18	

Table 4. Summary of statistics for the model (Scenario 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	6
Total number of fixed parameters	28
Free growth parameters	8
Initial abundance (1968)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	44
Female recruitment deviations	44
Natural and fishing mortality parameters	4
Survey catchability parameters	2
Pot male fishing mortality deviations	45
Bycatch mortality from the Tanner crab fishery	6
Pot female bycatch fishing mortality deviations	23
Trawl bycatch fishing mortality deviations	37
Initial (1968) length composition deviations	36
Free selectivity parameters	28
Effective sample size parameters	10
Total number of free parameters	291
Total number of fixed and free parameters	319
Negative log likelihood components	
Length compositions---retained catch	-1071.330
Length compositions---pot male discard	-826.629
Length compositions---pot female discard	-2066.440
Length compositions---survey	-53797.600
Length compositions---trawl discard	-1770.160
Length compositions---Tanner crab discards	-229.628
Pot discard male biomass	187.616
Retained catch biomass	49.034
Pot discard female biomass	0.377
Trawl discard	6.297
Survey biomass	76.208
Recruitment variation	116.773
Sex ratio of recruitment	0.030
Total	-59325.000

Table 5. Summary of model parameter estimates (scenario 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	16.309	0.020	16.309	0.020	-2.019	0.045	0.014	0.001	-4.654	0.067
1968					2.089	0.154				
1969	-0.034	0.117	0.620	0.079	2.099	0.006				
1970	-0.028	0.109	0.912	0.091	1.879	0.093				
1971	-0.034	0.081	1.617	0.060	1.493	0.110				
1972	-0.311	0.175	0.684	0.096	1.600	0.157				
1973	-0.364	0.099	1.368	0.052	1.379	0.238				
1974	0.055	0.084	1.536	0.049	1.543	0.200				
1975	0.345	0.064	2.101	0.041	1.351	0.149				
1976	-0.412	0.188	0.920	0.085	1.405	0.122			-0.211	0.094
1977	0.539	0.136	0.528	0.099	1.448	0.101			0.329	0.087
1978	0.357	0.109	0.879	0.080	1.531	0.071			0.237	0.080
1979	0.037	0.108	1.094	0.076	1.595	0.050			0.177	0.077
1980	0.003	0.101	1.377	0.078	2.099	0.004			0.112	0.078
1981	0.158	0.108	0.750	0.085	2.099	0.007			-0.359	0.076
1982	-0.167	0.046	2.152	0.041	0.302	0.044			1.381	0.078
1983	-0.095	0.072	1.186	0.049	-9.753	0.508			1.345	0.078
1984	0.262	0.060	1.003	0.043	1.089	0.058			2.200	0.003
1985	0.129	0.150	-0.897	0.098	1.266	0.067			1.457	0.079
1986	0.374	0.054	0.369	0.041	1.607	0.062			0.342	0.078
1987	-0.153	0.123	-0.497	0.064	1.136	0.057			-0.260	0.077
1988	0.232	0.152	-1.215	0.095	0.190	0.052			0.854	0.075
1989	0.093	0.137	-1.087	0.082	0.295	0.050			-0.498	0.075
1990	-0.012	0.064	-0.012	0.043	0.908	0.047	1.795	0.080	-0.292	0.075
1991	-0.161	0.099	-0.525	0.055	0.833	0.047	-0.240	0.079	-0.091	0.076
1992	-0.380	0.329	-2.211	0.166	0.305	0.046	1.999	0.011	-0.003	0.076
1993	-0.291	0.093	-0.664	0.053	1.003	0.048	1.837	0.081	0.475	0.076
1994	-0.072	0.305	-2.327	0.174	-10.768	0.501	1.999	0.063	-0.897	0.077
1995	0.032	0.037	0.908	0.032	-10.916	0.498	1.999	0.063	-0.833	0.076
1996	-0.383	0.212	-1.028	0.115	0.148	0.046	-3.852	0.145	-0.886	0.076
1997	-0.494	0.339	-1.924	0.172	0.239	0.046	-1.301	0.085	-1.270	0.076
1998	-0.224	0.109	-0.508	0.061	0.987	0.046	1.754	0.078	-0.509	0.074
1999	0.039	0.058	0.279	0.040	0.509	0.046	-2.407	0.088	-0.395	0.074
2000	0.131	0.126	-0.761	0.081	0.219	0.046	-0.545	0.079	-0.963	0.075
2001	0.743	0.155	-1.190	0.120	0.177	0.045	0.814	0.077	-0.696	0.075
2002	0.193	0.051	0.809	0.038	0.340	0.045	-2.557	0.088	-0.988	0.075
2003	0.012	0.195	-0.788	0.123	0.823	0.045	0.860	0.079	-0.882	0.075
2004	0.027	0.133	-0.205	0.085	0.644	0.046	0.130	0.080	-1.184	0.075
2005	0.374	0.061	0.693	0.053	1.040	0.047	0.608	0.078	-0.849	0.075
2006	-0.593	0.146	0.103	0.073	0.711	0.048	-1.734	0.080	-1.324	0.076
2007	-0.038	0.159	-0.693	0.103	0.984	0.050	-0.479	0.079	-1.180	0.077
2008	0.265	0.174	-1.165	0.123	1.139	0.054	-0.849	0.080	-0.856	0.078
2009	0.152	0.175	-1.141	0.119	0.921	0.060	-1.171	0.083	-1.196	0.080
2010	-0.213	0.175	-0.778	0.106	0.830	0.066	-0.659	0.086	-1.536	0.083
2011	0.206	0.189	-0.793	0.138						

Table 5 (continued). Summary of model parameter estimates for Bristol Bay red king crab. 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.	Parameter	Value	St.dev.	Dev. From 1968 Obs. Length comp. Length	Dev.	St.dev.
Mm80-84	0.544	0.014	log_srv_L50, m, 70-72	4.608	0.061	68	-0.008	0.004
Mf80-84	0.813	0.019	srv_slope, f, 70-72	0.125	0.012	73	-0.005	0.004
Mf76-79,85-93	0.063	0.006	log_srv_L50, f, 70-72	4.375	0.018	78	0.000	0.005
log_betal, females	0.187	0.053	log_srv_L50, m, 73-81	4.419	0.028	83	0.002	0.005
log_betal, males	0.478	0.080	srv_slope, f, 73-81	0.068	0.003	88	0.003	0.005
log_betar, females	-0.641	0.059	log_srv_L50, f, 73-81	4.444	0.017	93	0.002	0.005
log_betar, males	-0.575	0.043	log_srv_L50, m, 82-11	4.510	0.011	98	0.003	0.005
Q, females, 70-72	0.216	0.023	srv_slope, f, 82-10	0.052	0.002	103	0.002	0.005
Q, males, 70-72	0.549	0.119	log_srv_L50, f, 82-11	4.546	0.012	108	-0.003	0.005
Q, 68-69, 73-11	NA	NA	log_srv_L50, m, 68-69	4.500	0.020	113	-0.003	0.005
moltp_slope, 68-79	0.161	0.022	srv_slope, f, 68-69	0.058	0.008	118	0.000	0.005
moltp_slope, level 1	0.082	0.004	log_srv_L50, f, 68-69	4.592	0.043	123	-0.001	0.005
moltp_slope, level 2	0.089	0.004	TC_slope, females	0.311	0.093	128	-0.001	0.005
log_moltp_L50, 68-79	4.984	0.017	log_TC_L50, females	4.543	0.012	133	-0.003	0.005
log_moltp_L50, level 1	4.876	0.004	TC_slope, males	0.083	0.007	138	-0.003	0.006
log_moltp_L50, level 2	4.952	0.003	log_TC_L50, males	4.750	0.000	143	-0.001	0.007
log_N68	18.772	0.041	log_TC_F, males, 91	-4.123	0.081	148	0.001	0.007
log_avg_L50, 73-11	4.923	0.001	log_TC_F, males, 92	-5.223	0.081	153	0.003	0.006
log_avg_L50, 68-72	4.863	0.010	log_TC_F, males, 93	-6.429	0.084	158	0.001	0.006
ret_fish_slope, 73-11	0.501	0.024	log_TC_F, females, 91	-2.983	0.084	163	0.010	0.001
ret_fish_slope, 68-72	0.466	0.198	log_TC_F, females, 92	-4.158	0.083	68	-0.008	0.003
pot disc.males, φ	-0.245	0.011	log_TC_F, females, 93	-4.743	0.083	73	-0.010	0.001
pot disc.males, κ	0.003	0.000				78	-0.009	0.003
pot disc.males, γ	-0.013	0.000				83	-0.005	0.004
sel_62.5mm, 68-72	1.357	0.848				88	-0.002	0.004
post disc.fema., slope	0.188	0.099				93	0.002	0.005
log_pot disc.fema., L50	4.433	0.027				98	-0.002	0.005
trawl disc slope	0.054	0.003				103	-0.004	0.005
log_trawl disc L50	5.068	0.048				108	0.000	0.005
						113	0.001	0.005
						118	0.004	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 6. 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 7ac) from 1968-2011. 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	13.070	8.408	13.472	2.558	49.570		80.070	73.724
1969	12.204	5.820	12.416	2.872	52.181	44.256	87.140	72.809
1970	15.343	6.323	17.052	3.923	56.053	59.386	43.040	35.827
1971	16.966	8.483	22.066	4.759	61.576	119.853		42.840
1972	21.184	10.571	26.899	5.354	73.658	41.553	50.267	53.563
1973	27.477	12.920	37.469	6.251	89.634	80.556	159.504	156.394
1974	40.775	18.367	53.046	6.680	94.914	115.582	192.378	186.346
1975	46.124	25.603	63.959	6.487	102.493	238.563	207.459	225.648
1976	49.857	29.055	68.432	5.631	131.853	50.455	283.020	261.731
1977	58.428	30.894	78.488	4.526	161.766	55.701	362.280	281.059
1978	74.429	36.704	97.122	3.519	154.951	70.826	322.282	286.337
1979	74.755	45.329	95.455	2.951	139.936	73.646	243.490	275.901
1980	57.628	41.655	37.661	1.558	129.965	96.090	228.253	251.286
1981	20.142	11.276	14.095	0.690	56.919	55.608	111.748	107.154
1982	10.452	4.358	11.251	0.506	26.972	192.124	131.972	62.138
1983	8.322	3.543	9.880	0.416	18.232	75.610	47.189	51.399
1984	7.399	3.095	6.995	0.358	18.385	75.833	130.308	46.547
1985	8.298	2.390	11.063	0.496	14.664	10.543	33.005	34.949
1986	13.801	5.238	17.412	0.741	20.411	42.951	46.290	46.751
1987	17.078	7.806	24.290	0.927	24.522	13.684	66.139	53.350
1988	17.808	10.269	30.285	1.040	29.943	8.120	50.570	57.791
1989	19.720	12.132	34.625	1.104	28.114	8.559	58.735	61.551
1990	20.243	13.425	33.028	1.134	24.674	23.769	52.674	62.425
1991	16.753	12.343	28.416	1.116	22.894	13.254	82.835	57.190
1992	13.527	10.258	26.204	1.062	22.913	2.234	34.732	51.594
1993	13.462	8.795	21.921	0.989	20.539	10.886	47.159	48.290
1994	12.707	7.472	25.847	0.973	17.170	2.280	29.789	41.906
1995	13.068	8.737	27.596	0.926	16.591	60.934	35.927	47.287
1996	13.399	10.033	26.565	0.892	22.324	7.279	40.886	54.734
1997	12.707	9.366	25.198	0.874	32.336	2.846	78.993	58.948
1998	16.573	8.582	26.215	0.913	30.289	13.108	76.289	60.617
1999	18.661	10.385	31.734	1.023	26.688	32.632	59.684	61.128
2000	16.359	10.815	29.925	0.988	28.916	12.096	62.140	61.125
2001	15.516	11.180	29.783	0.982	32.987	11.422	47.621	64.164
2002	16.621	10.267	30.112	0.975	32.990	60.082	64.534	67.540
2003	17.546	11.362	29.614	1.004	39.407	11.073	87.428	72.845
2004	15.871	10.962	28.194	1.017	48.084	19.993	88.288	75.551
2005	19.040	10.611	29.888	1.110	46.766	59.362	96.177	81.976
2006	19.904	11.694	33.263	1.252	52.033	20.823	86.605	85.897
2007	19.615	12.727	31.507	1.372	60.488	11.875	94.460	91.272
2008	20.741	11.106	31.042	1.542	56.940	8.691	111.803	89.172
2009	21.648	11.069	33.465	1.830	51.522	8.367	80.545	84.590
2010	20.447	11.781	32.643	2.020	46.462	10.053	71.725	79.574
2011	17.943	12.750	29.757	1.705	42.000	12.199	58.064	75.739

Table 7. 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 2011-2020. Parameter estimates with scenario 0 are used for the projection.

Year	MMB	95% limits of MMB		Catch	95% limits of catch	
No directed fishery						
2011	37.832	35.178	40.329	0.000	0.000	0.000
2012	38.964	36.230	41.536	0.000	0.000	0.000
2013	39.493	36.722	42.101	0.000	0.000	0.000
2014	40.165	37.228	42.993	0.000	0.000	0.000
2015	42.195	37.296	50.678	0.000	0.000	0.000
2016	45.690	36.587	62.635	0.000	0.000	0.000
2017	49.590	36.080	71.971	0.000	0.000	0.000
2018	53.294	35.148	79.929	0.000	0.000	0.000
2019	56.728	34.894	87.748	0.000	0.000	0.000
2020	59.864	35.557	91.977	0.000	0.000	0.000
$F_{40\%}$						
2011	31.317	29.119	33.384	6.603	6.140	7.040
2012	27.201	25.609	28.739	5.922	5.182	6.577
2013	24.368	23.122	25.551	4.655	4.150	5.158
2014	22.913	21.719	24.211	3.908	3.508	4.311
2015	23.310	20.240	29.694	3.719	3.064	4.854
2016	25.149	18.819	38.824	3.926	2.629	5.739
2017	27.127	18.146	43.403	4.376	2.397	7.358
2018	28.669	17.548	47.763	4.843	2.188	8.330
2019	29.842	17.314	49.254	5.207	2.069	9.194
2020	30.745	17.883	50.128	5.474	2.177	9.550
$F_{35\%}$						
2011	29.751	27.794	31.705	8.186	7.480	8.736
2012	25.210	23.857	26.524	6.472	5.717	7.248
2013	22.316	21.271	23.310	4.901	4.414	5.385
2014	20.924	19.905	22.094	4.056	3.669	4.460
2015	21.364	18.449	27.364	3.882	3.180	5.290
2016	23.105	17.206	35.811	4.205	2.711	6.550
2017	24.866	16.555	39.412	4.763	2.481	8.392
2018	26.146	16.108	42.993	5.281	2.269	9.384
2019	27.057	15.898	44.179	5.661	2.178	10.295
2020	27.715	16.557	45.158	5.932	2.293	10.535

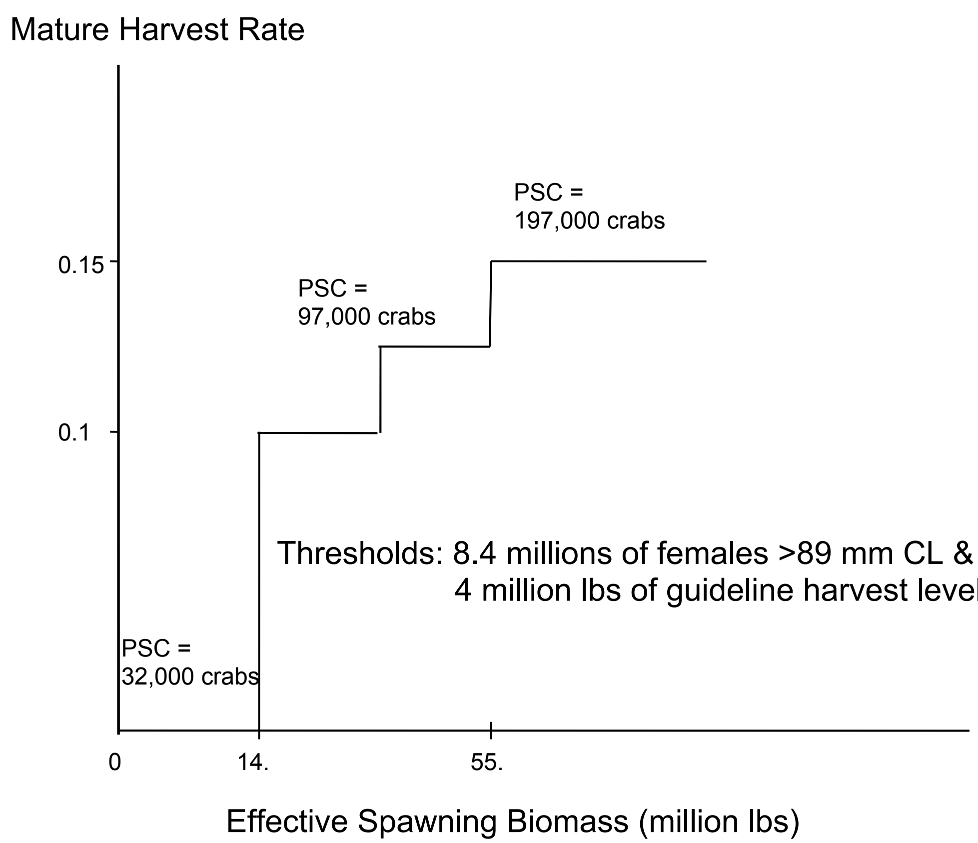

Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crabs) of Bristol Bay red king crabs in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates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

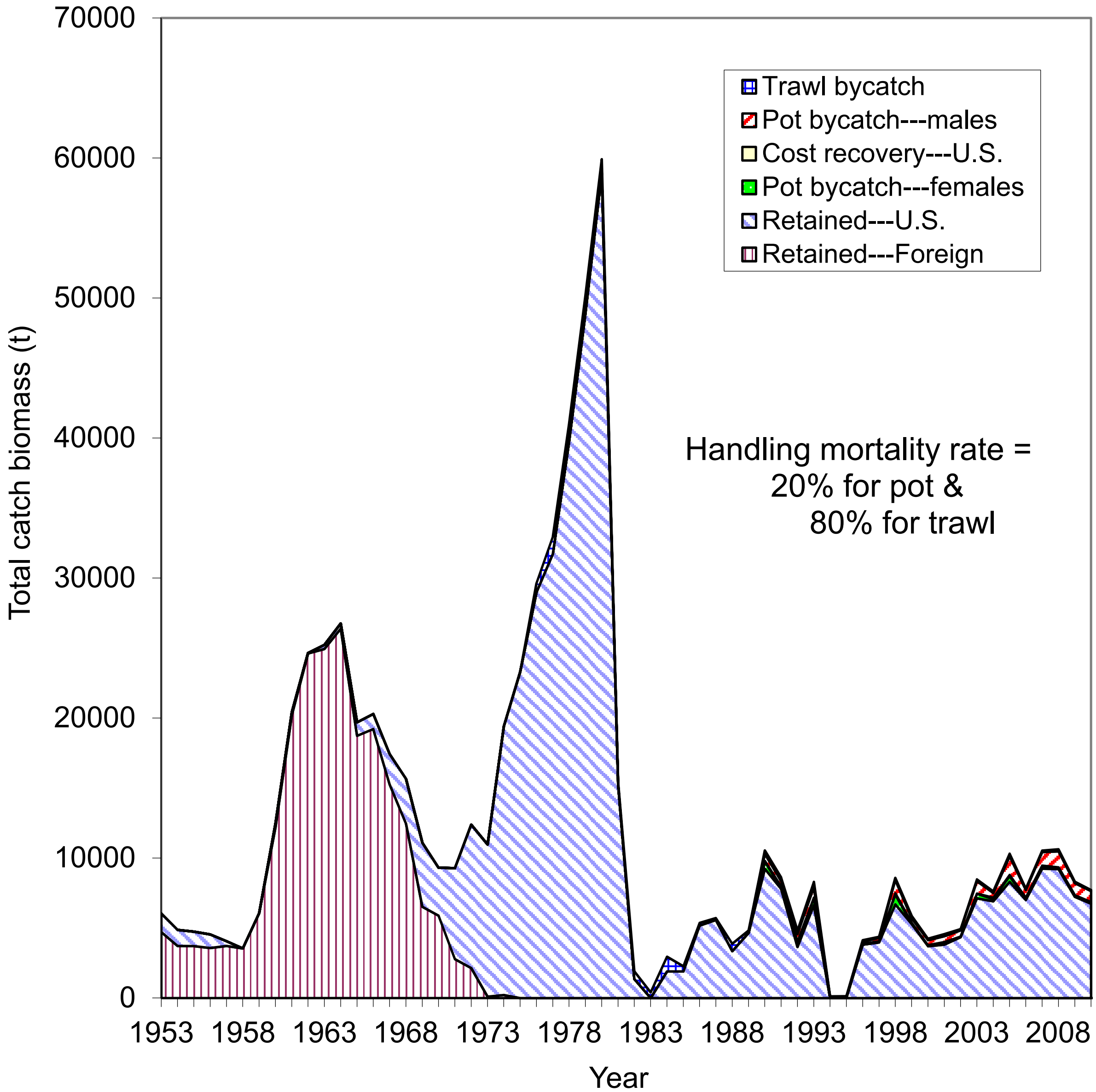

Figure 2. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1960 to 2010. Handling mortality rates were assumed to be 0.2 for the directed pot fishery and 0.8 for the trawl fisheries.

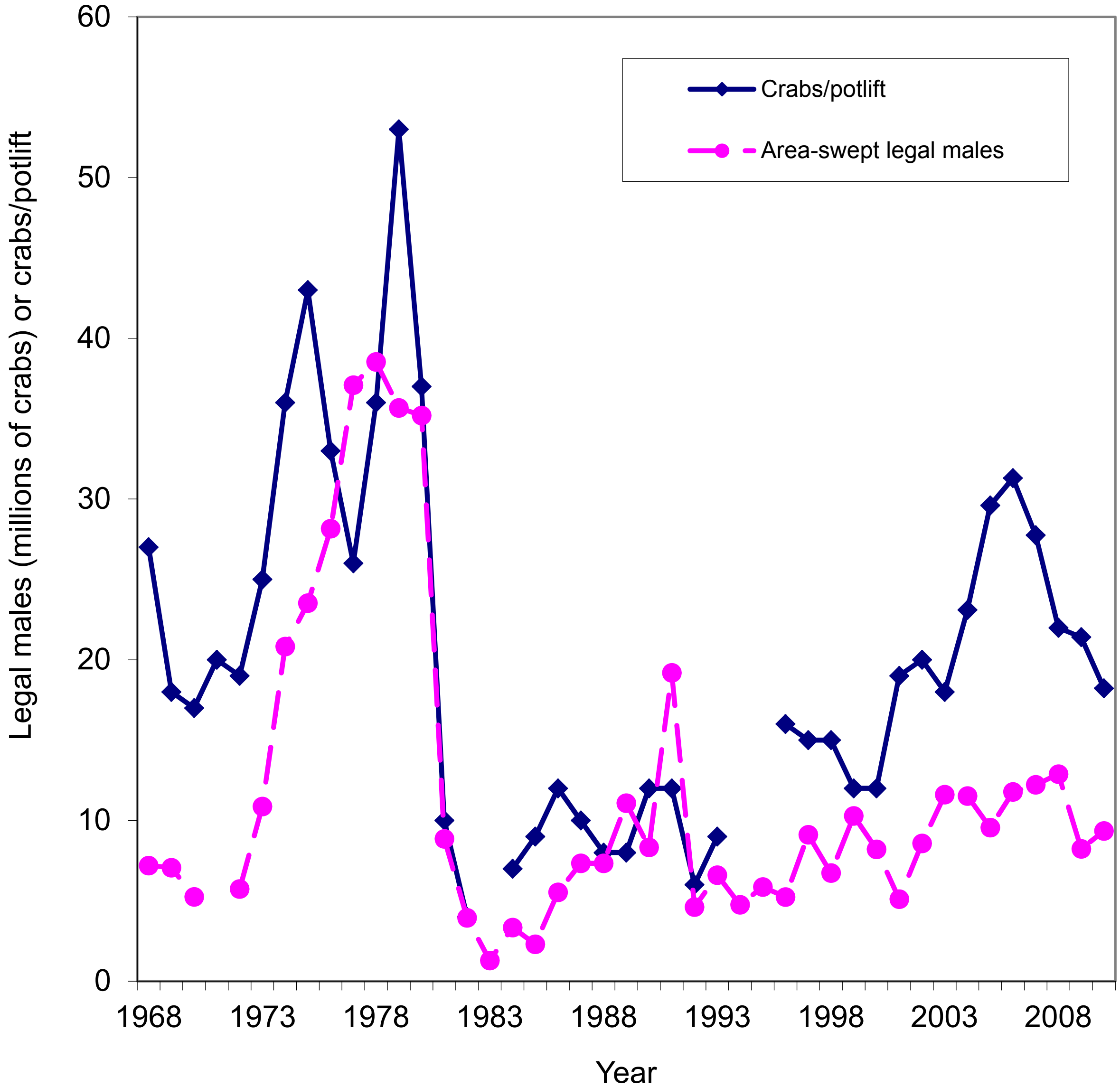

Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2010.

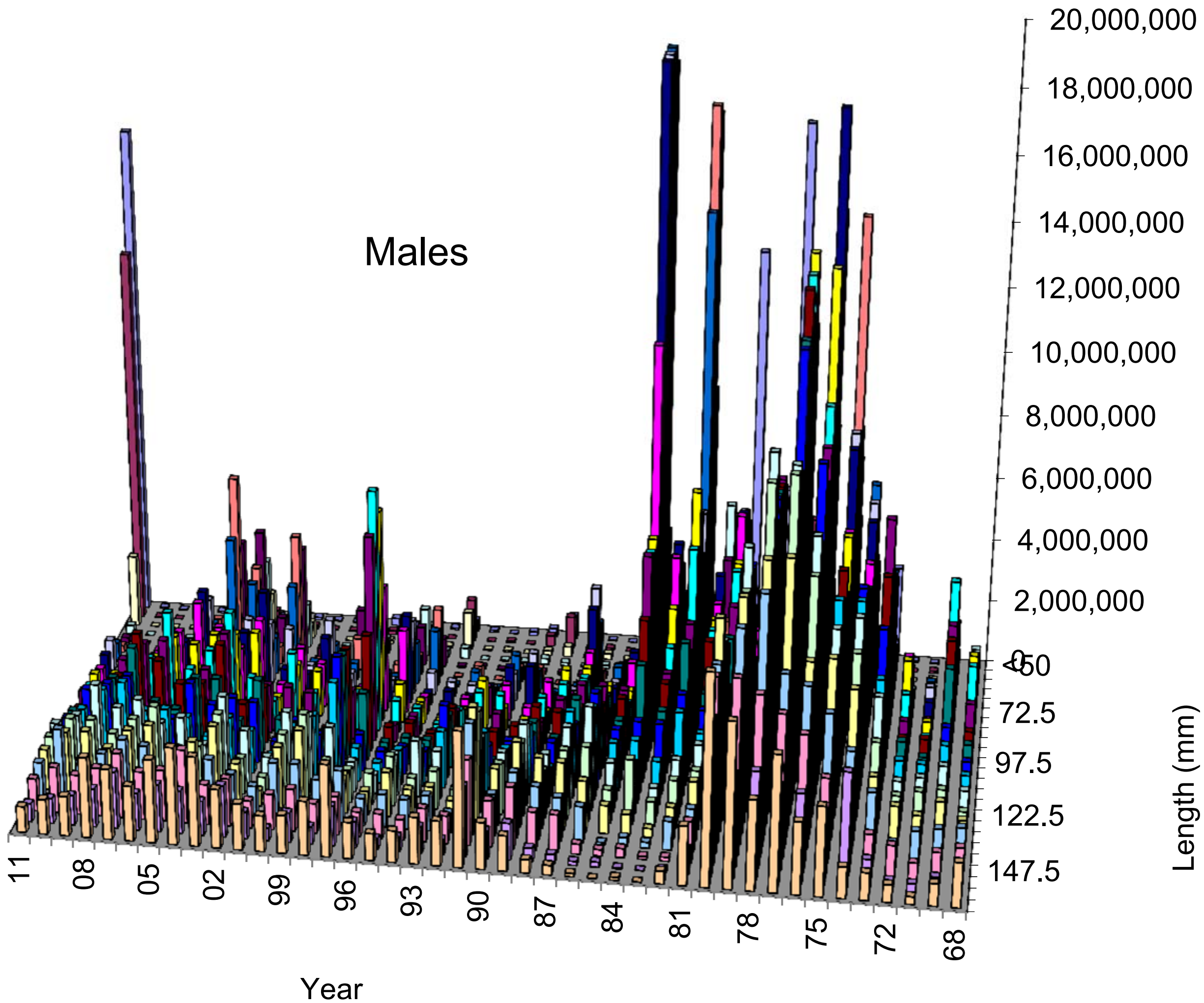

Figure 4. Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2011.

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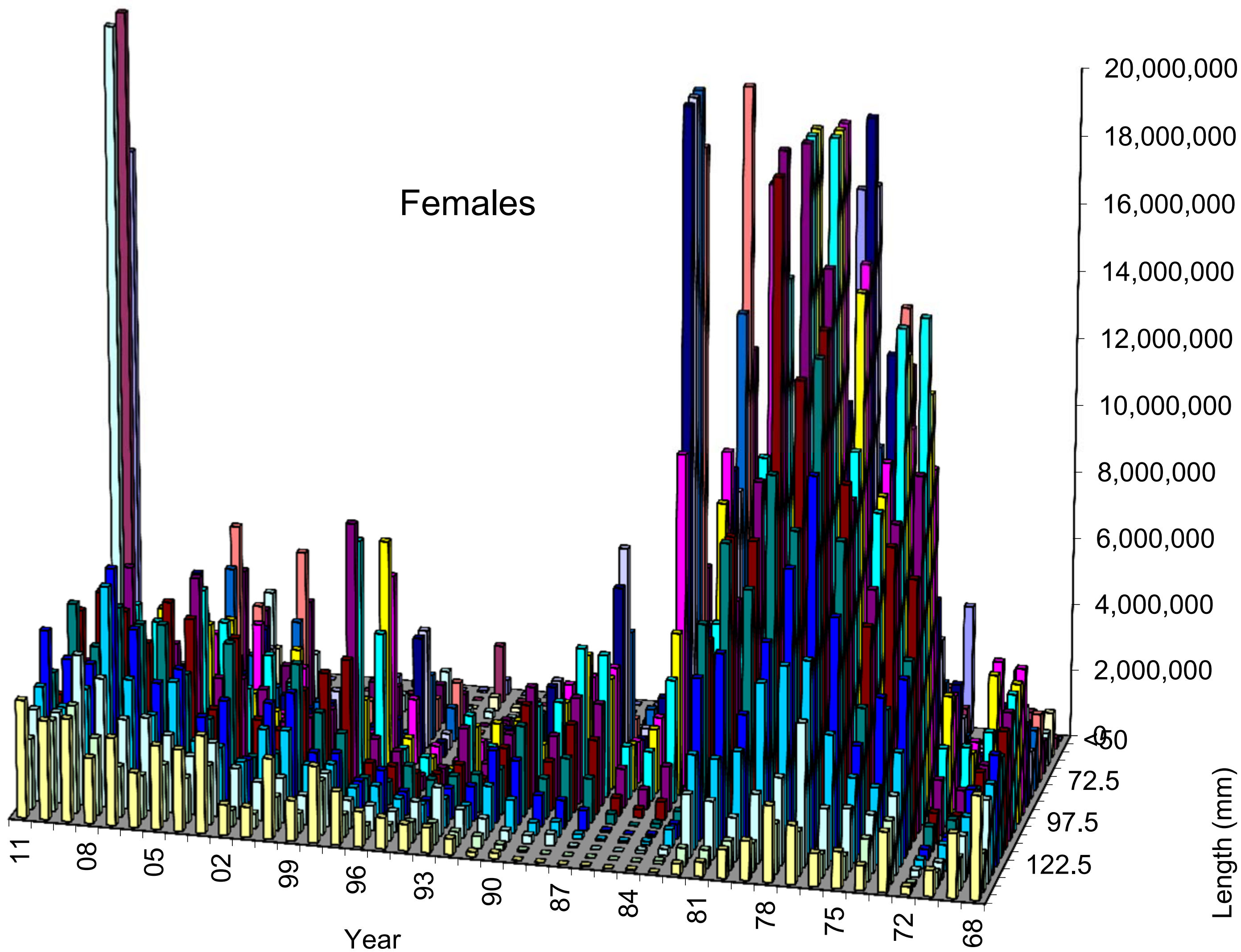

Figure 5. Survey abundances by length for female Bristol Bay red king crabs from 1968 to 2011.

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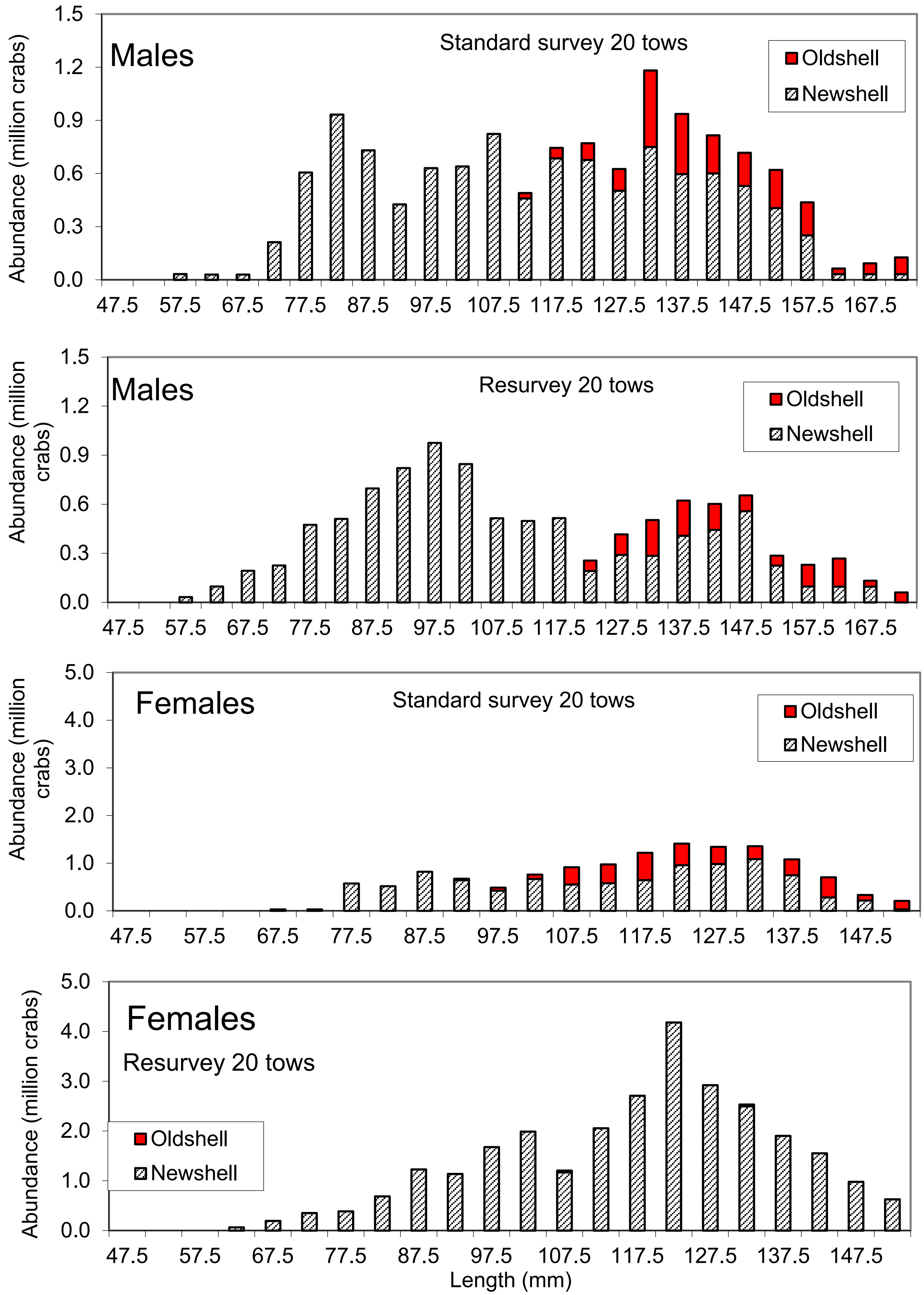

Figure 6. Comparison of area-swept estimates of abundance in 20 stations from the standard trawl survey and resurvey in 2011.

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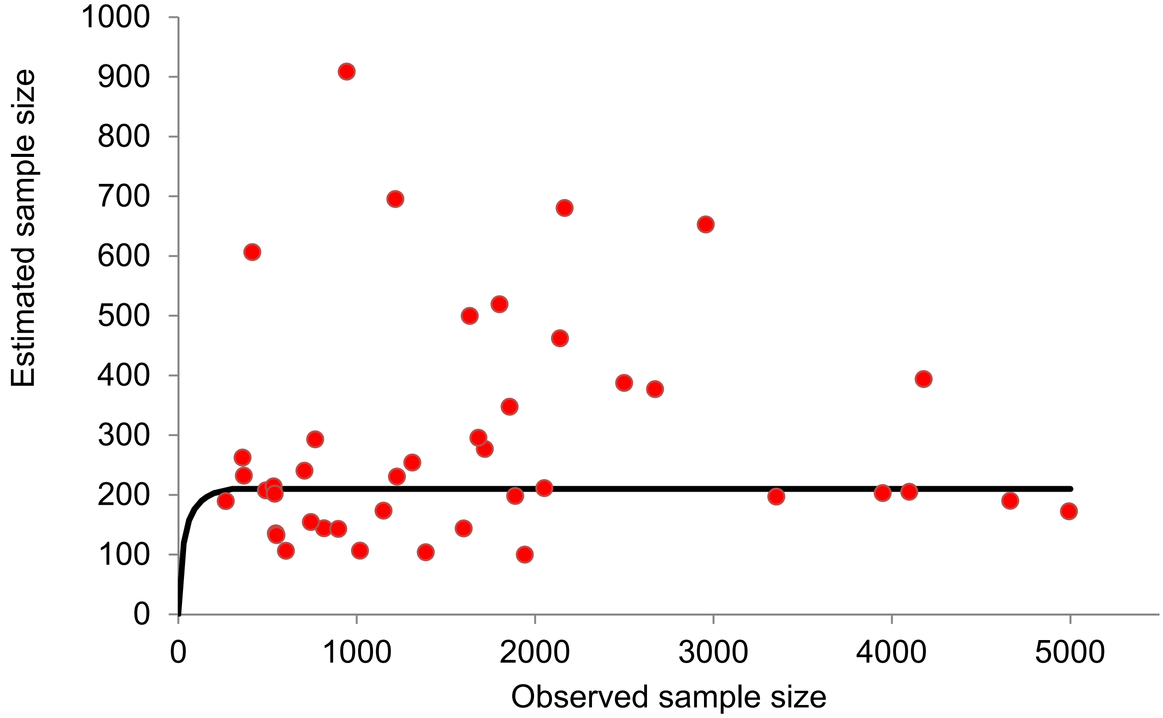


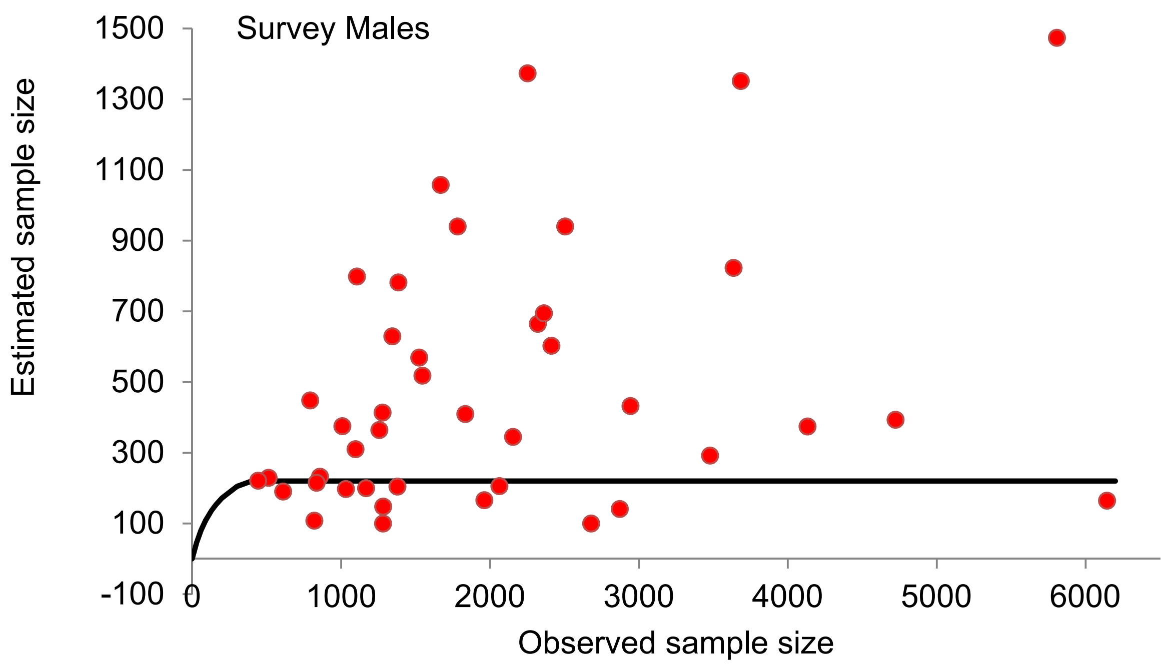


Figure 7a. Relationship between observed and estimated effective sample sizes for length/sex composition data with scenario 7ac: trawl survey data.

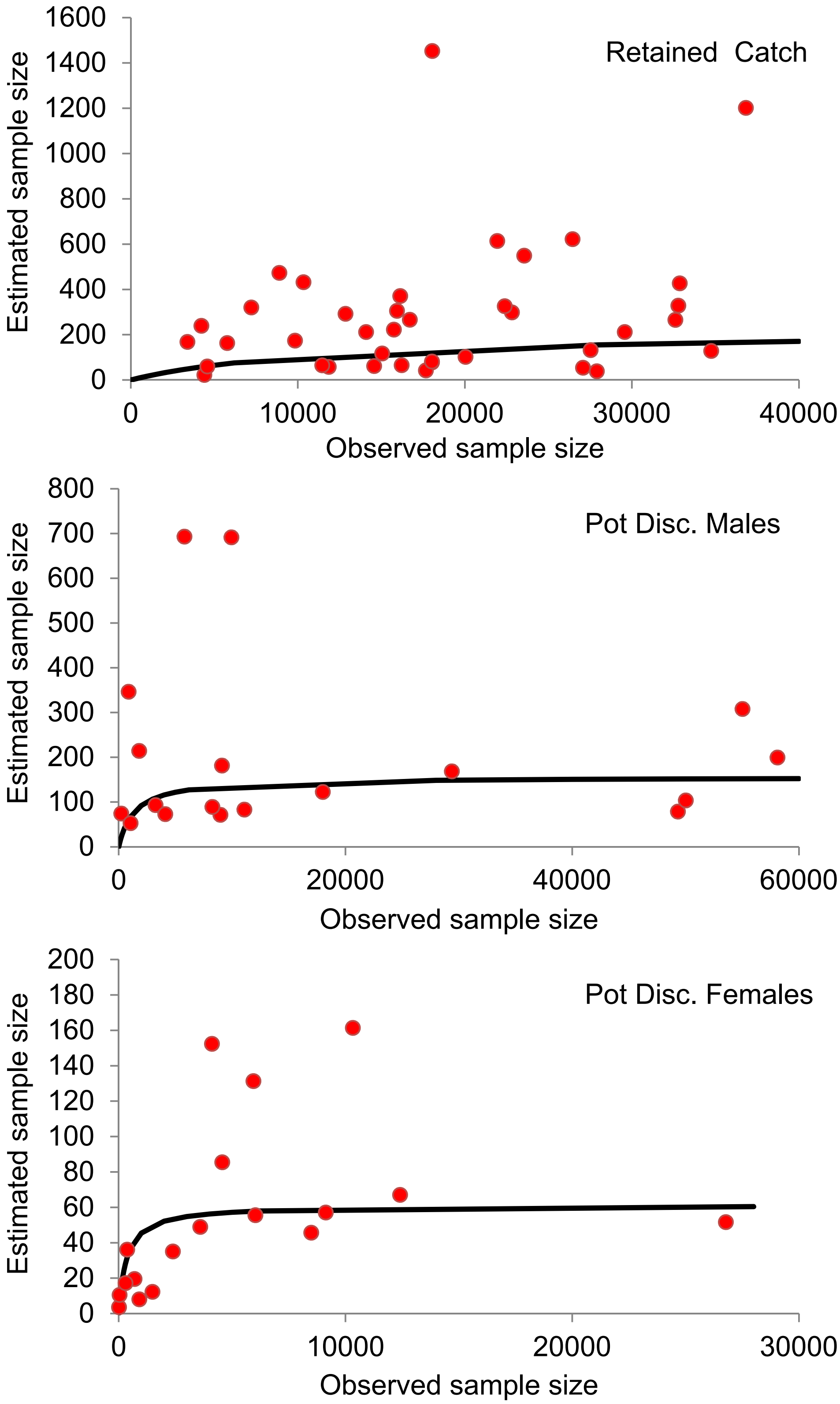


Figure 7b. Relationship between observed and estimated effective sample sizes for length/sex composition data with scenario 7ac: directed pot fishery data.

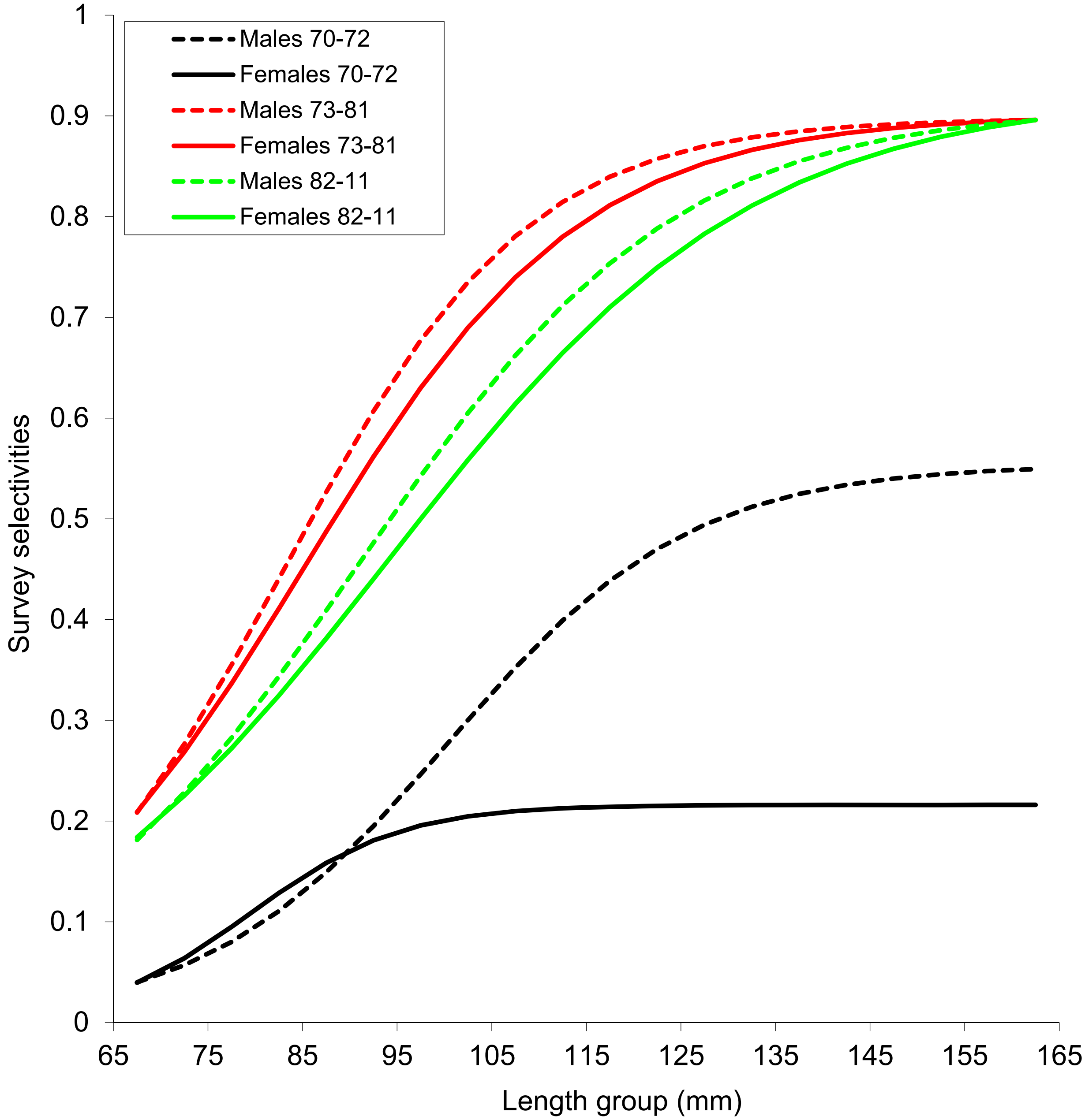
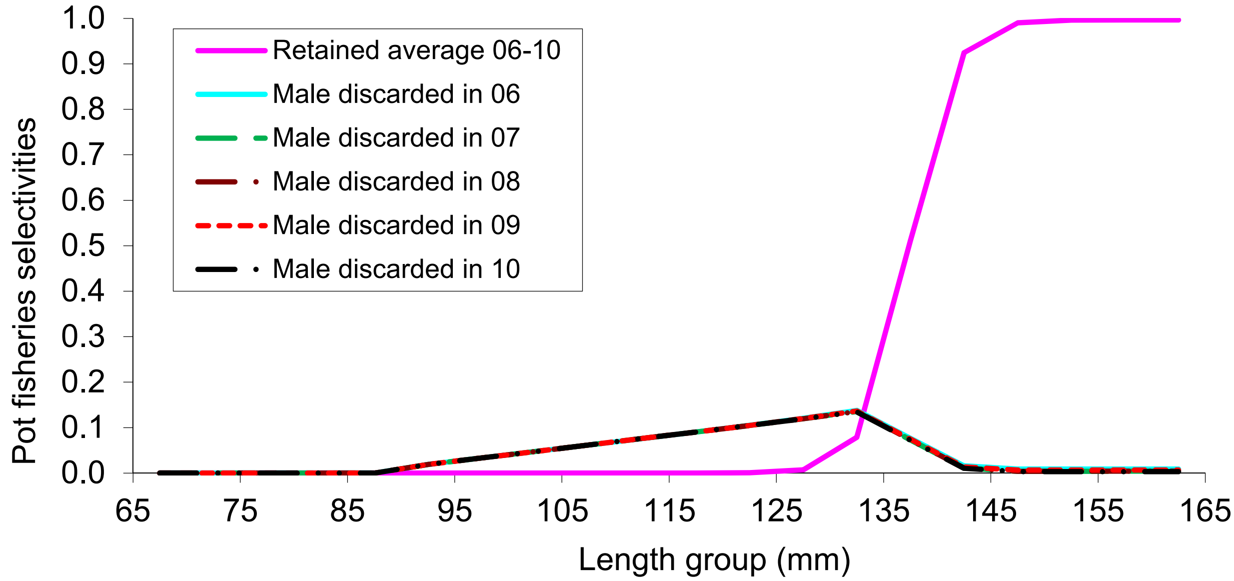


Figure 8a. Estimated trawl survey selectivities under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



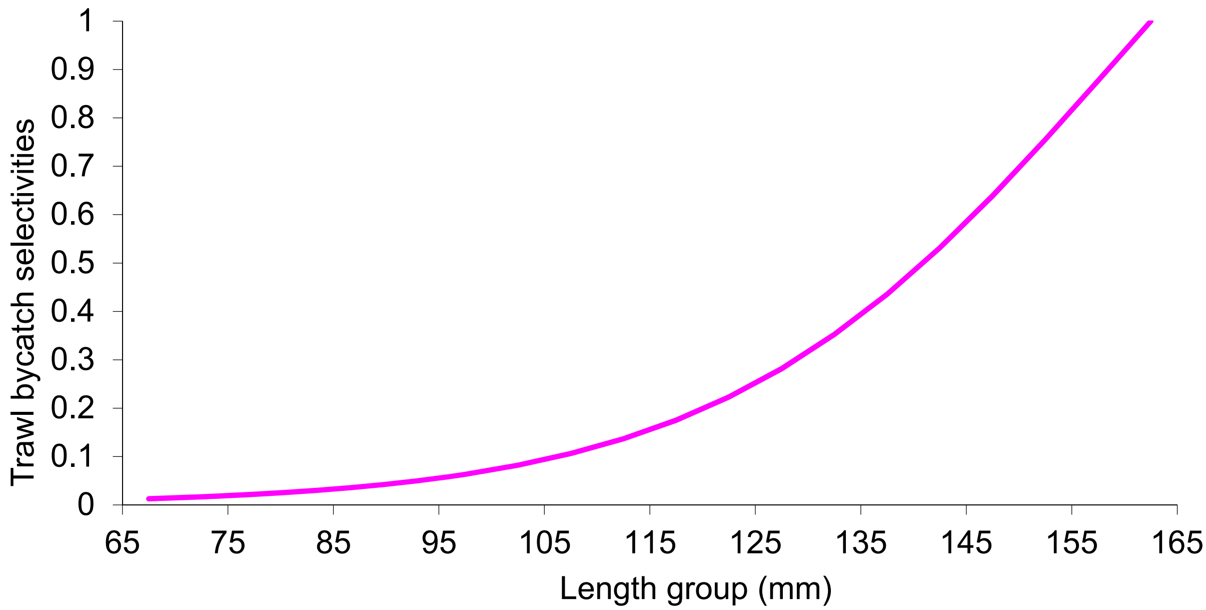


Figure 8b. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

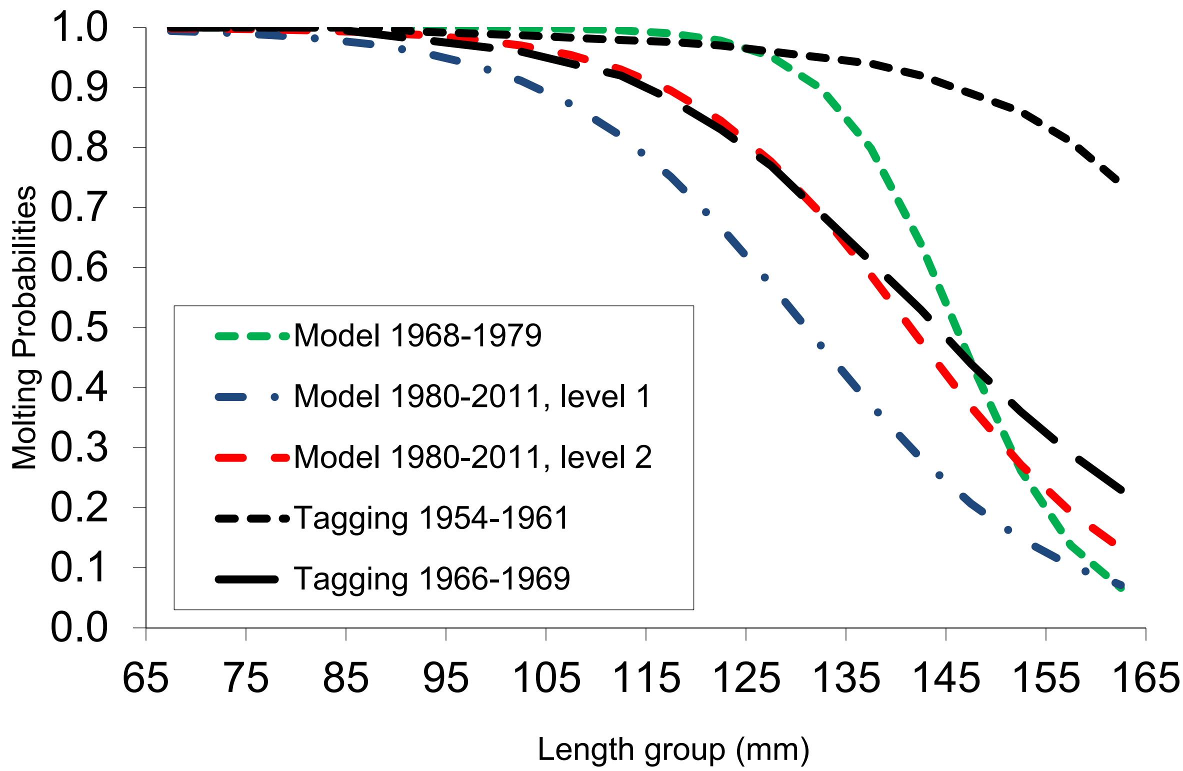


Figure 9. Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1968-2011 were estimated with a length-based model with pot handling mortality rate to be 0.2 under scenario 7ac.

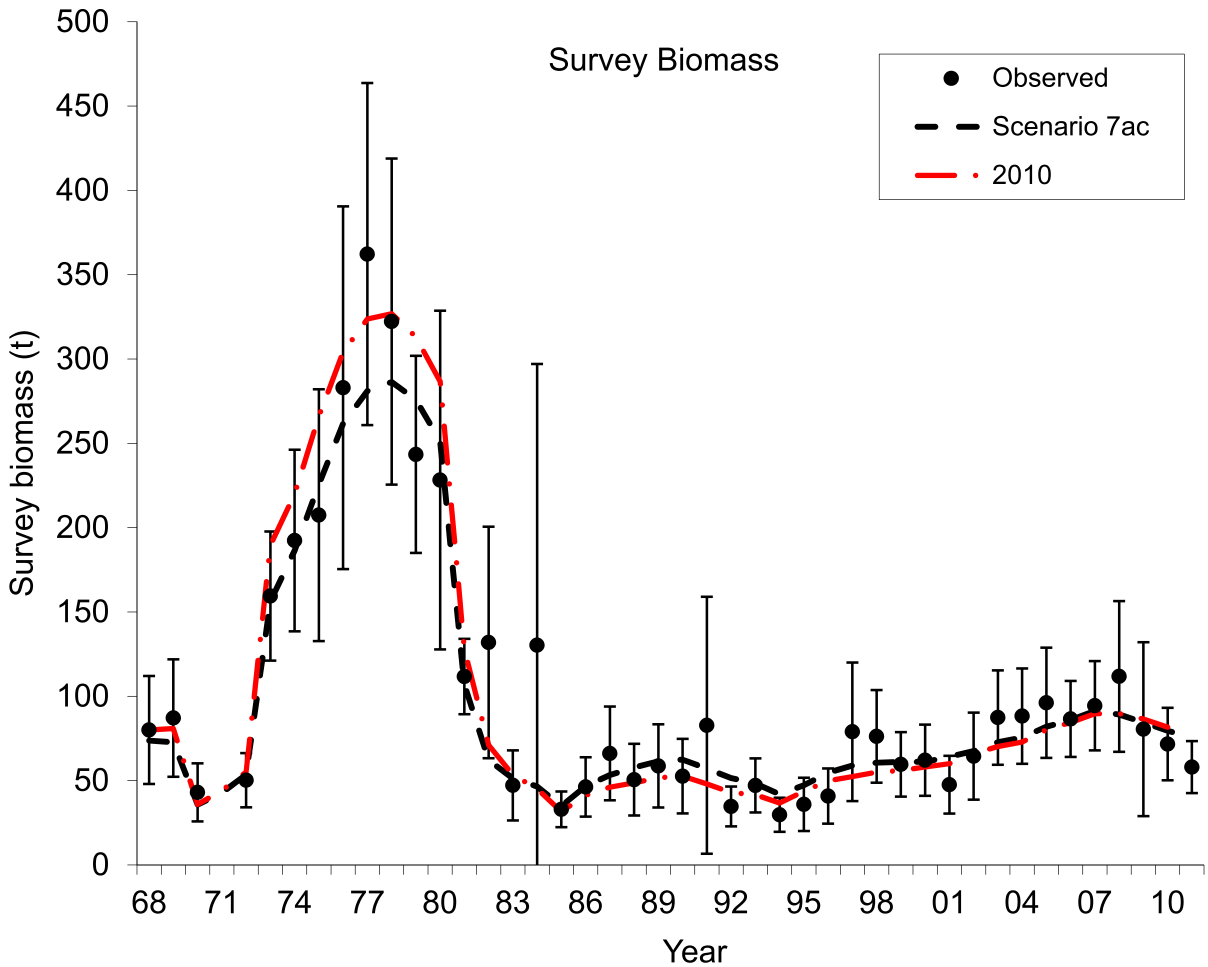


Figure 10a. Comparisons of area-swept estimates of total survey biomass and model prediction for scenario 0 (2010) & scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

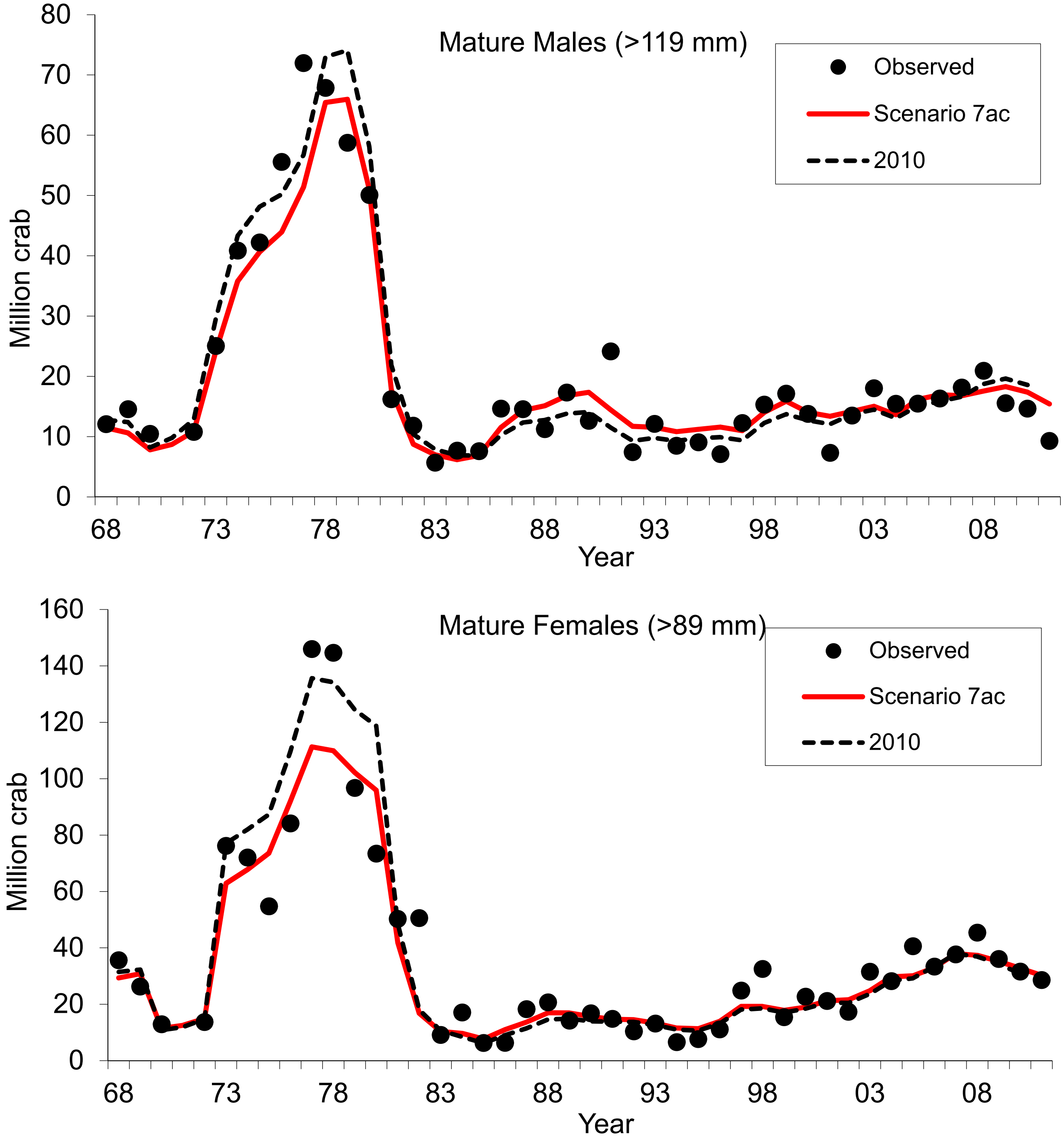


Figure 10b. Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for scenarios 0 (2010) & 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

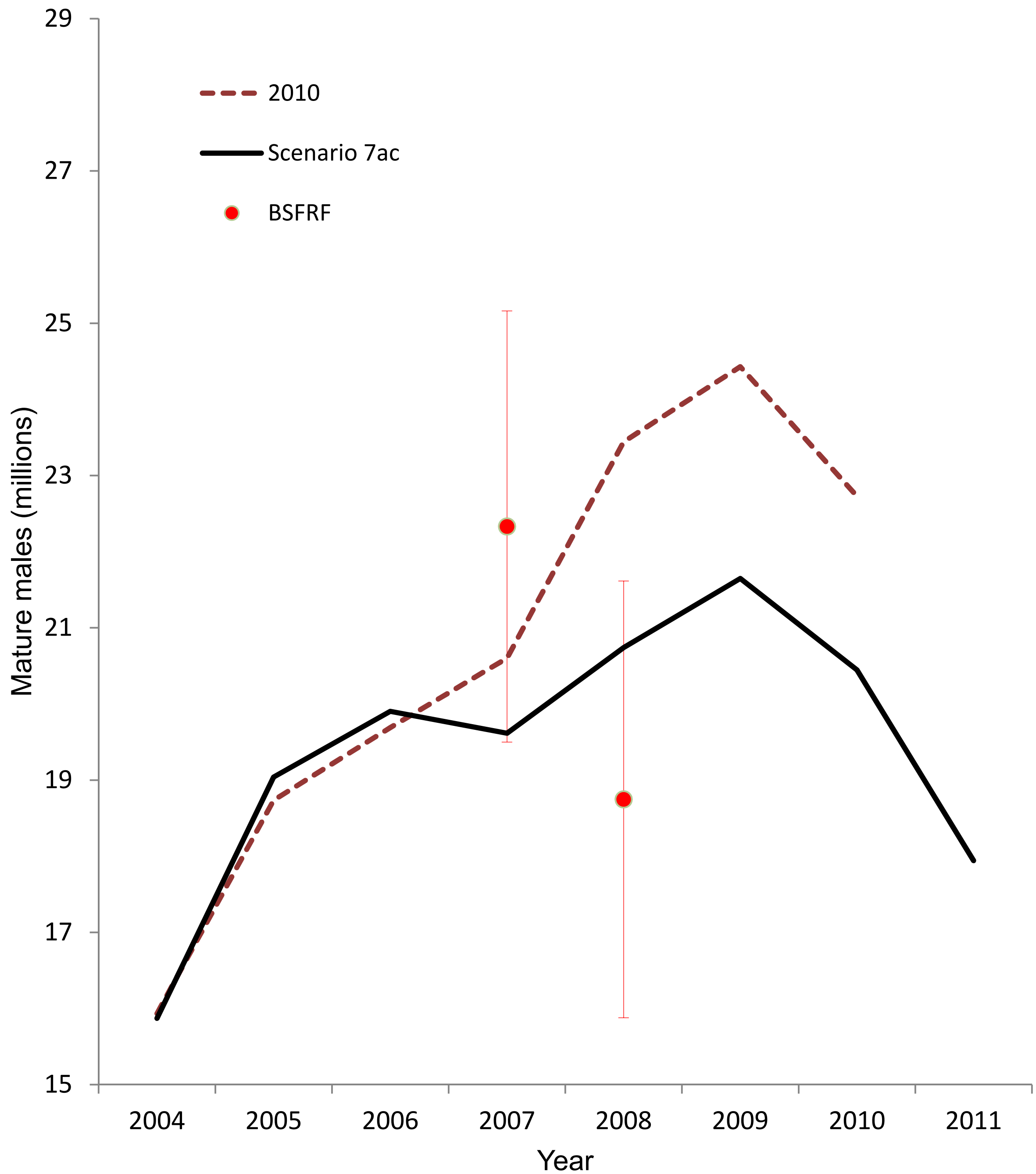


Figure 10c. Comparisons of total mature male abundance estimates by the BSFRF survey and the model for scenarios 0 (2010) & 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

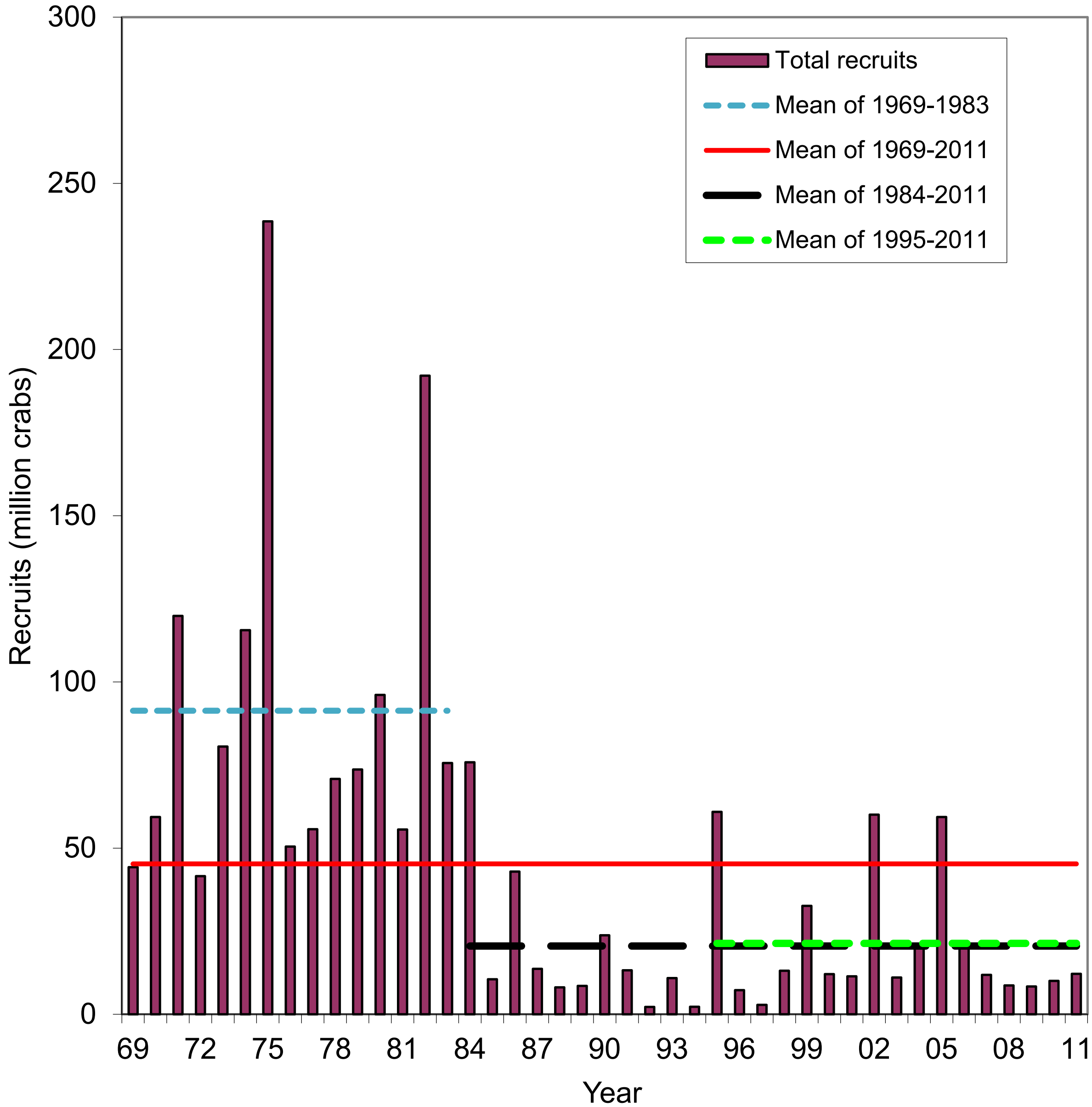


Figure 11. Estimated recruitment time series during 1969-2011 (occurred year) with scenario 7ac. Mean male recruits during 1984-2011 was used to estimate $B_{35\%}$.

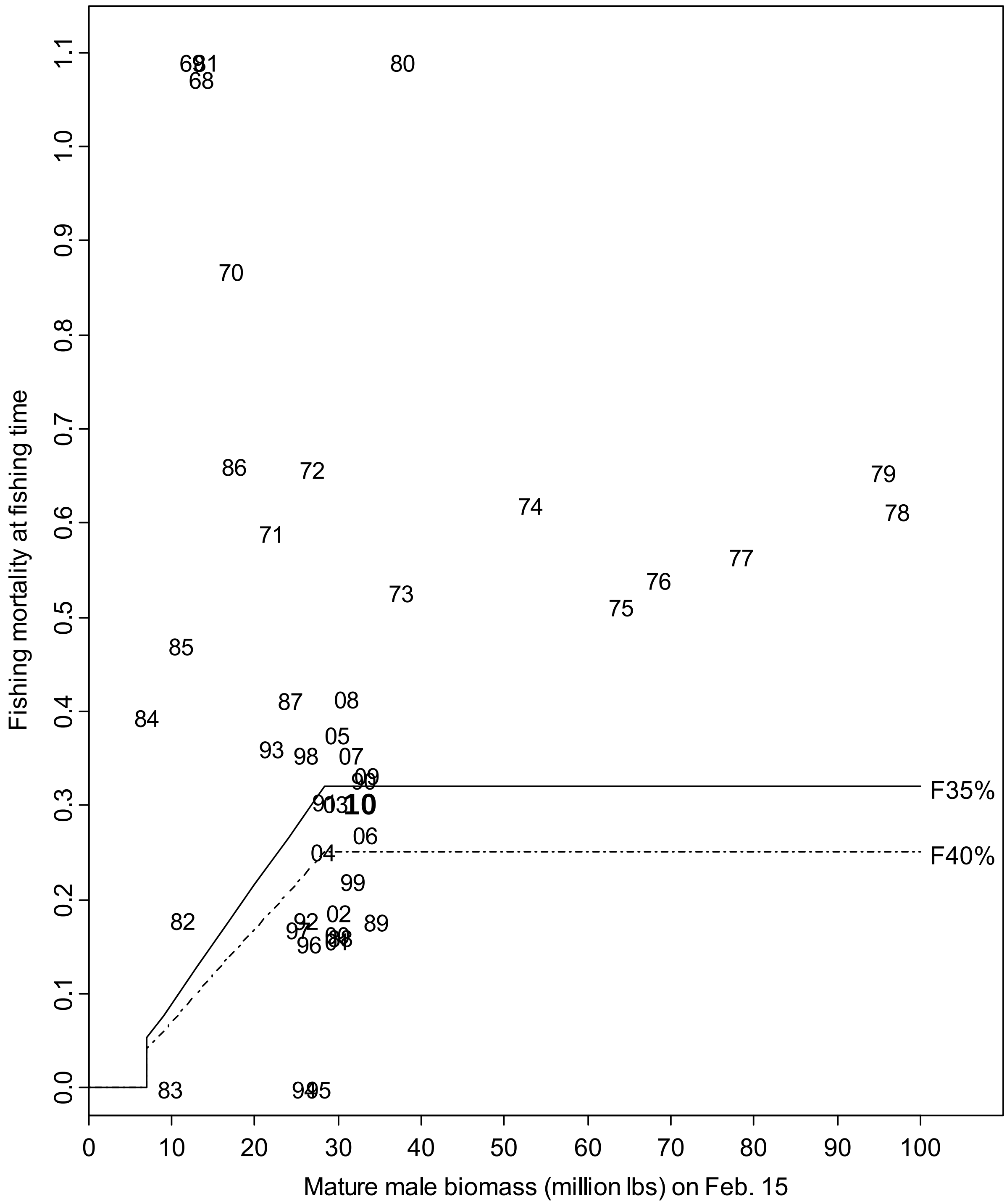


Figure 12. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1968-2010 under scenario 7ac. Average of recruitment from 1984 to 2011 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

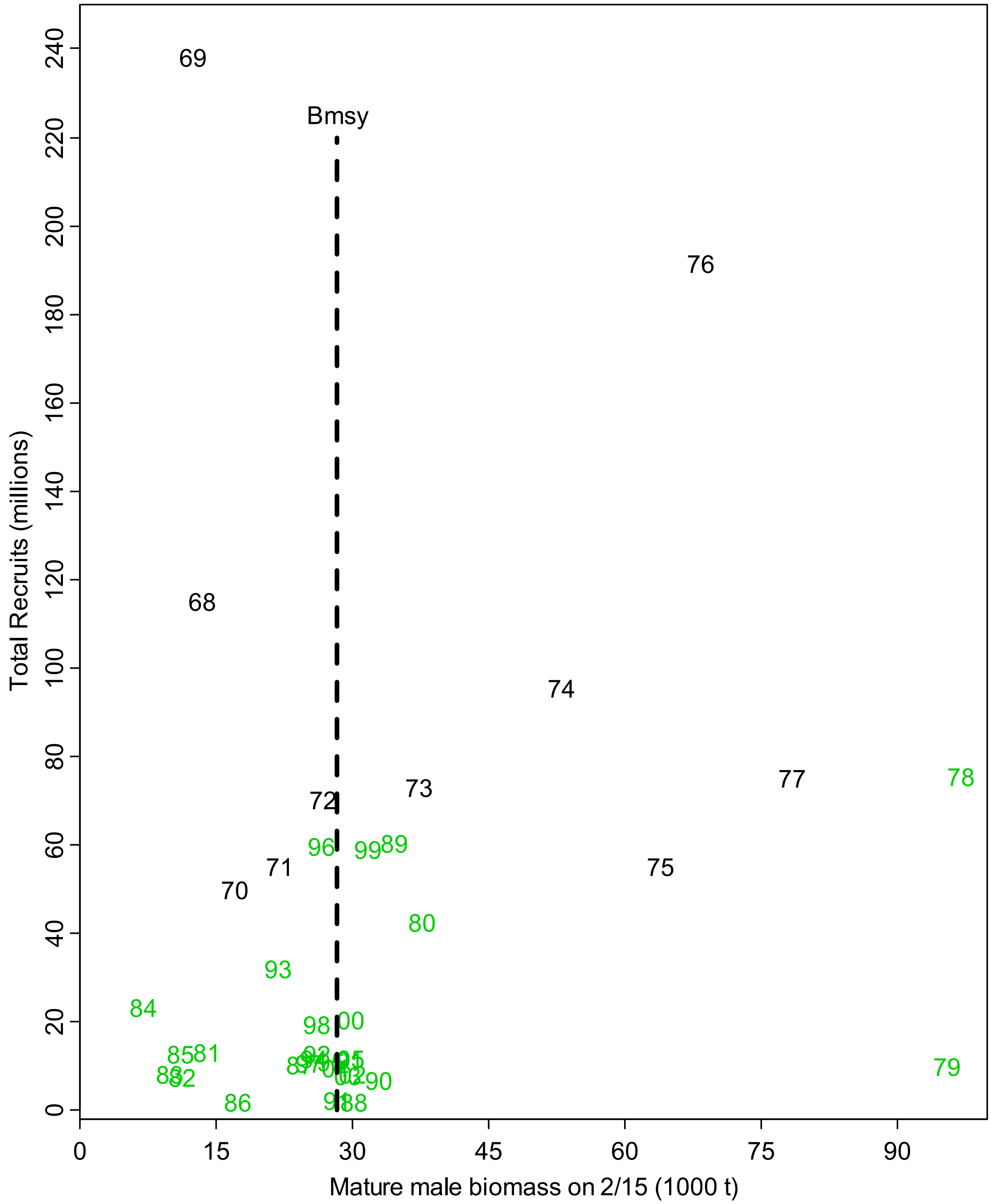


Figure 13a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 7ac. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2011.

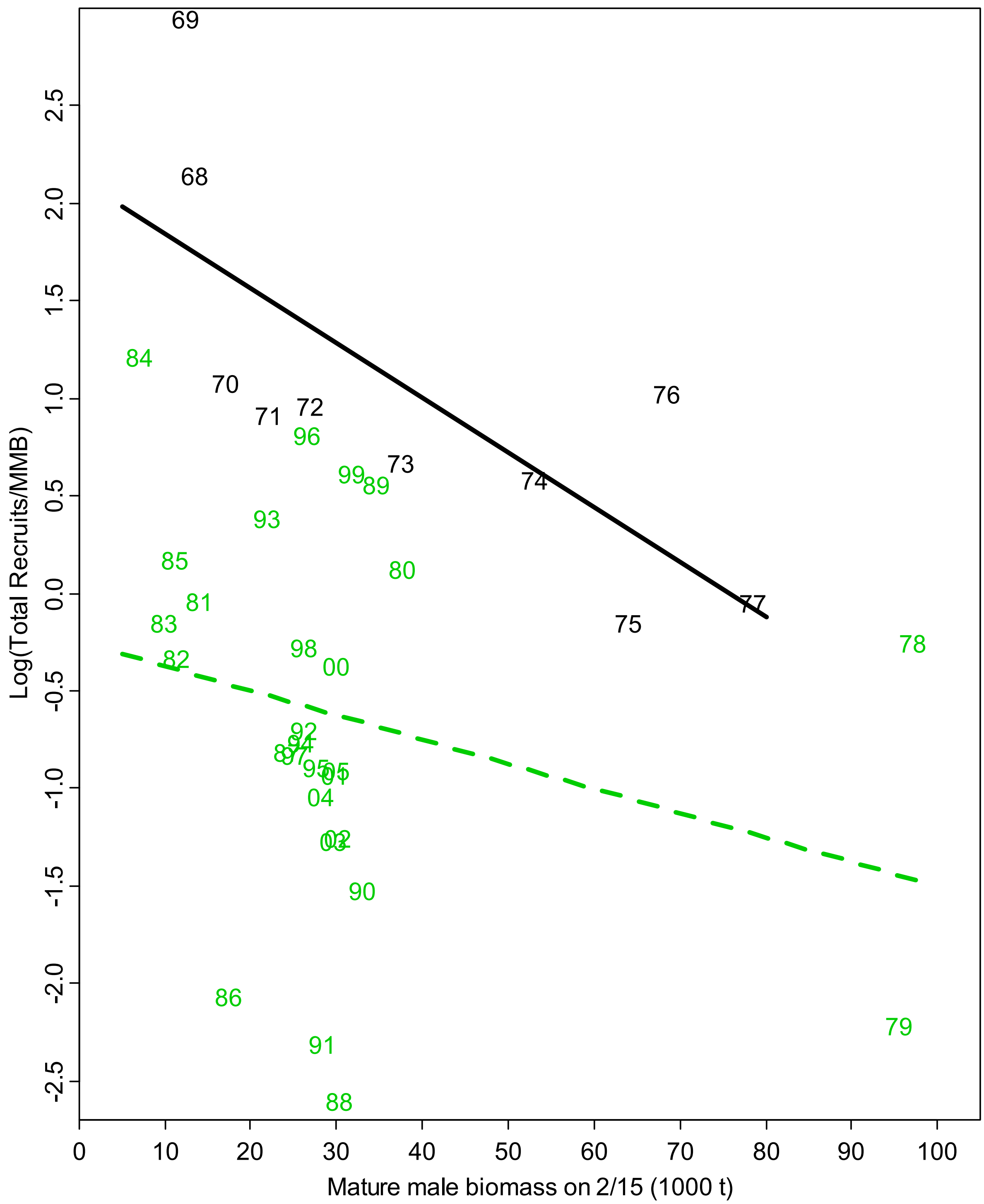


Figure 13b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 7ac. Numerical labels are years of mating, the solid line is the regression line for data of 1968-1977, and the dotted line is the regression line for data of 1978-2005.

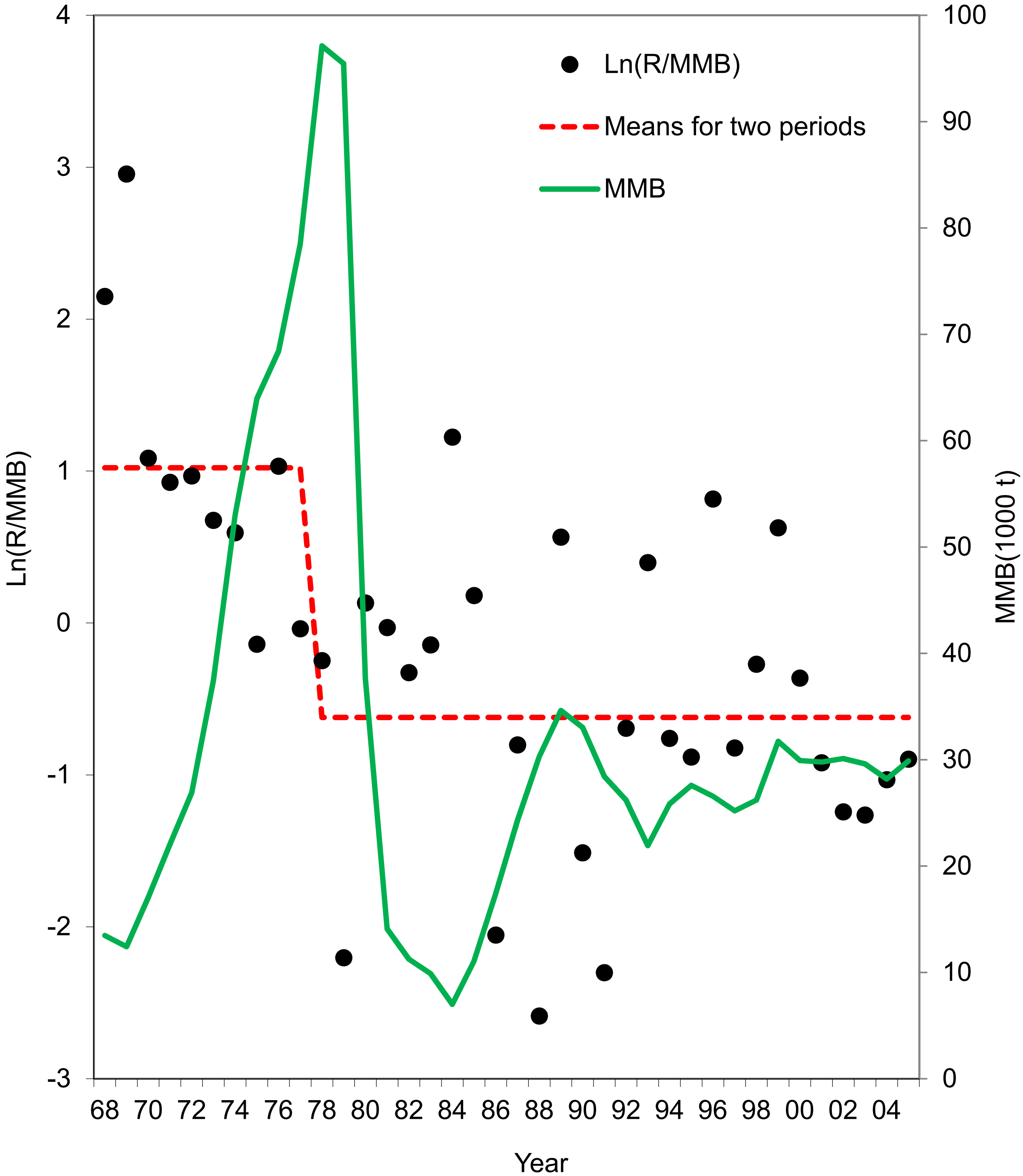


Figure 13c. Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2 under scenario 7ac. The dashed line is for the means of two periods: 1968-1977 and 1978-2005.

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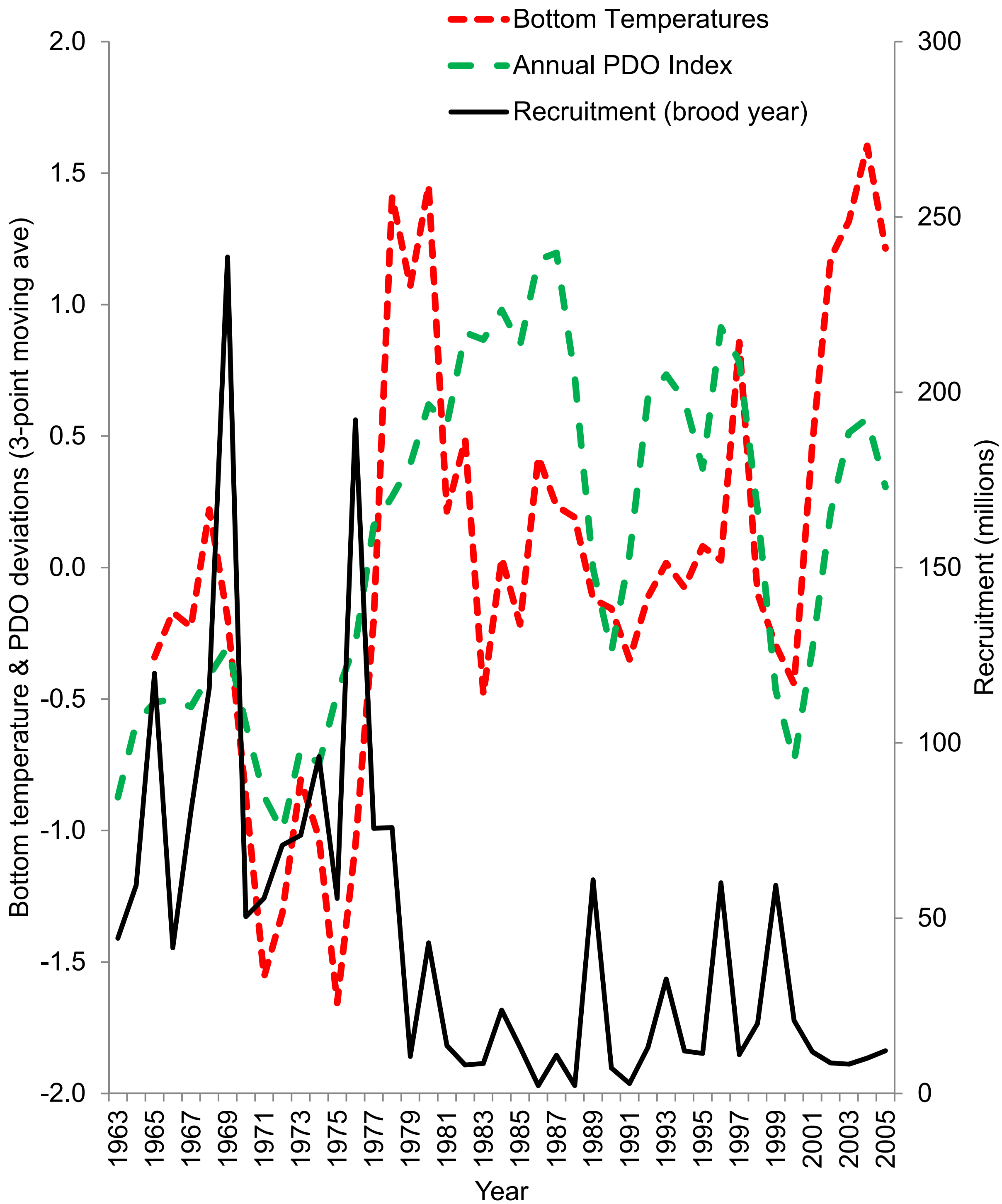

Figure 13d. Time series of recruitment in brood year, summer bottom temperatures in Bristol Bay and annual PDO index under scenario 7ac.

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Temperature Affects Crab Distribution

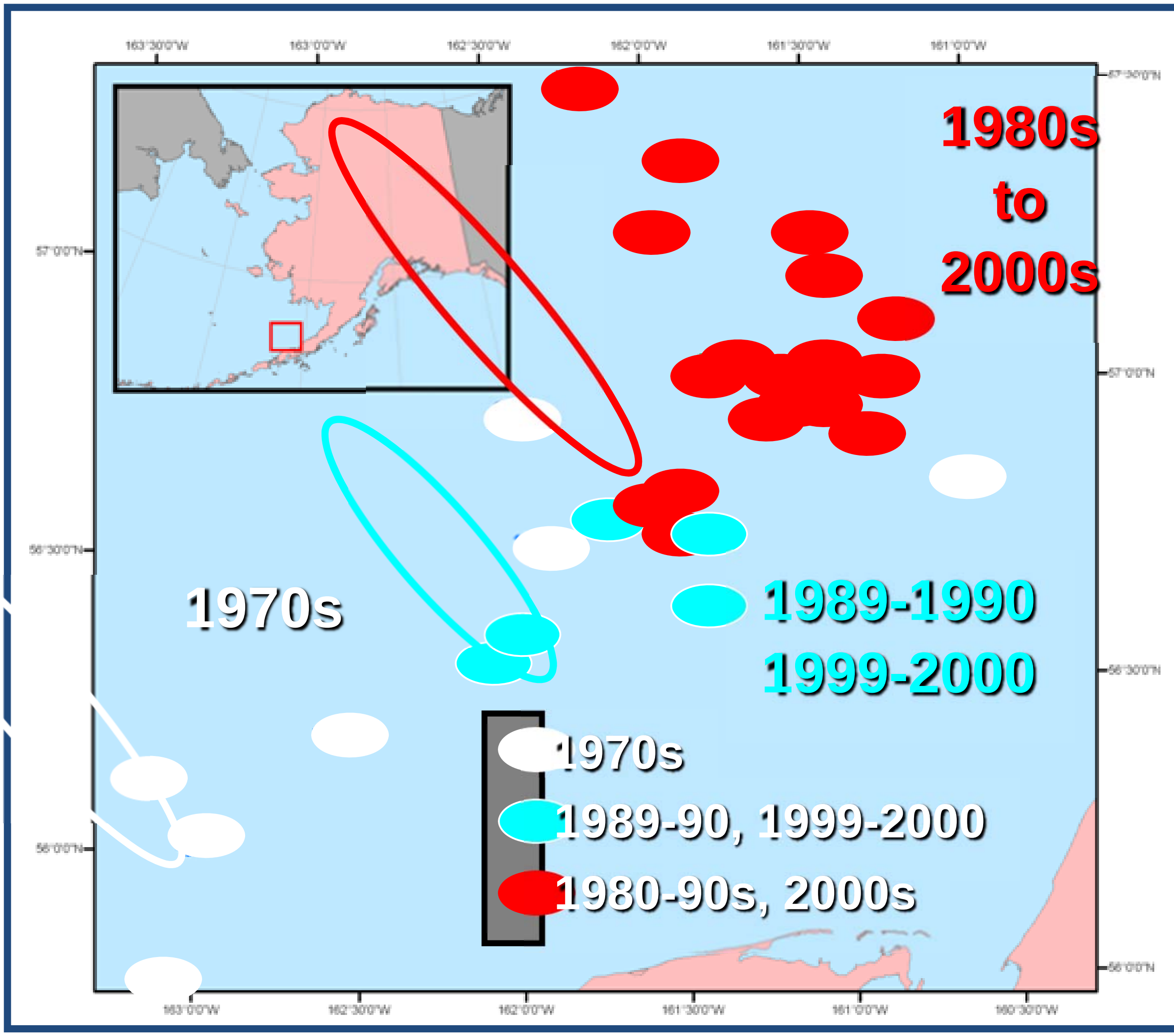

Figure 13e. Centers of Distribution of mature female red king crab in Bristol Bay (after Zheng & Kruse 2006). After the 1976/77 regime shift, the centers of distribution move from southern Bristol Bay to central Bristol Bay.

70

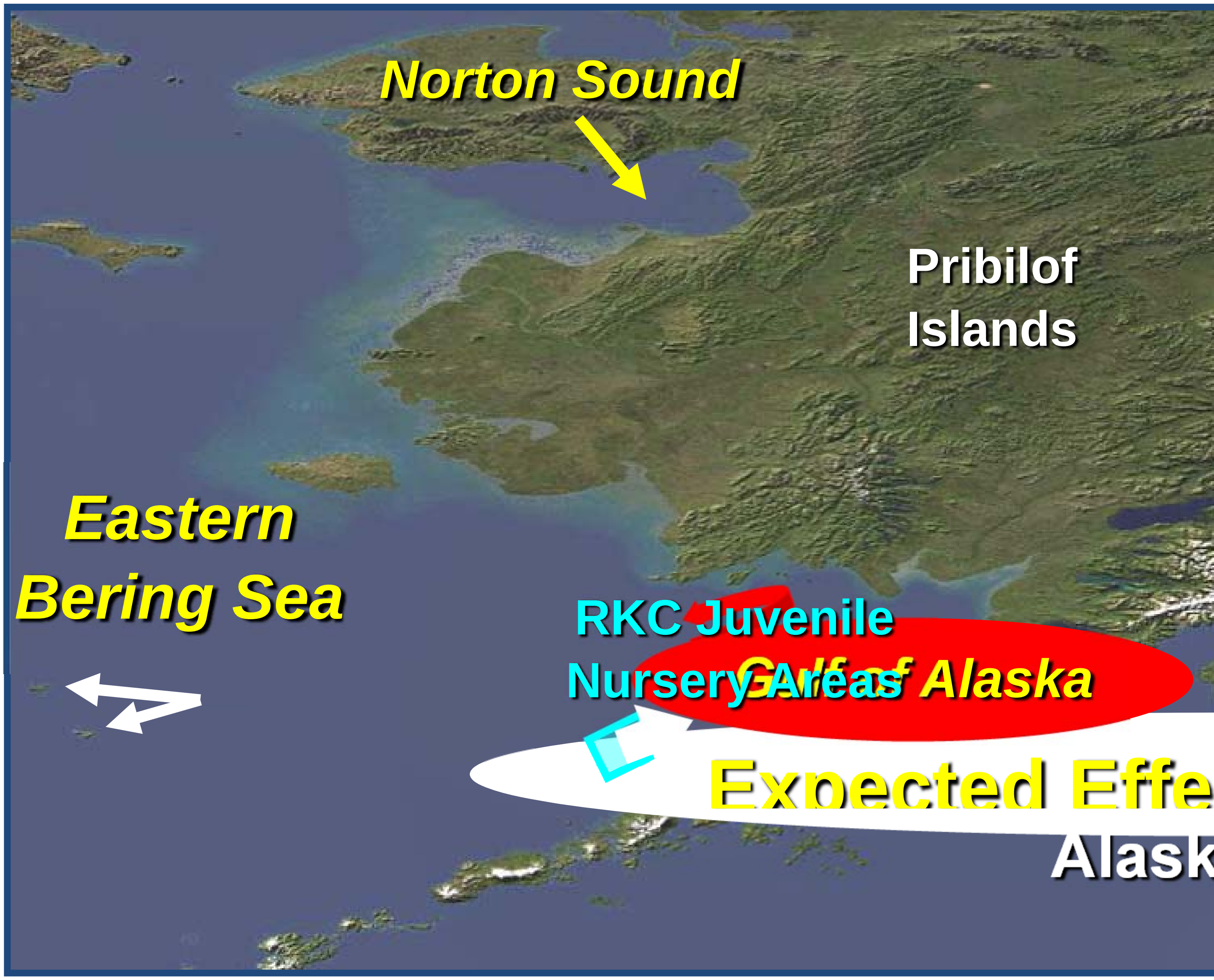

Figure 13f. During cool years, when crab hatching larvae in southern Bristol Bay, the larvae likely settle in the red king crab juvenile nursery areas. During warm years, when crab hatching larvae in central Bristol Bay, some larvae may settle in outside of the red king crab juvenile nursery areas.

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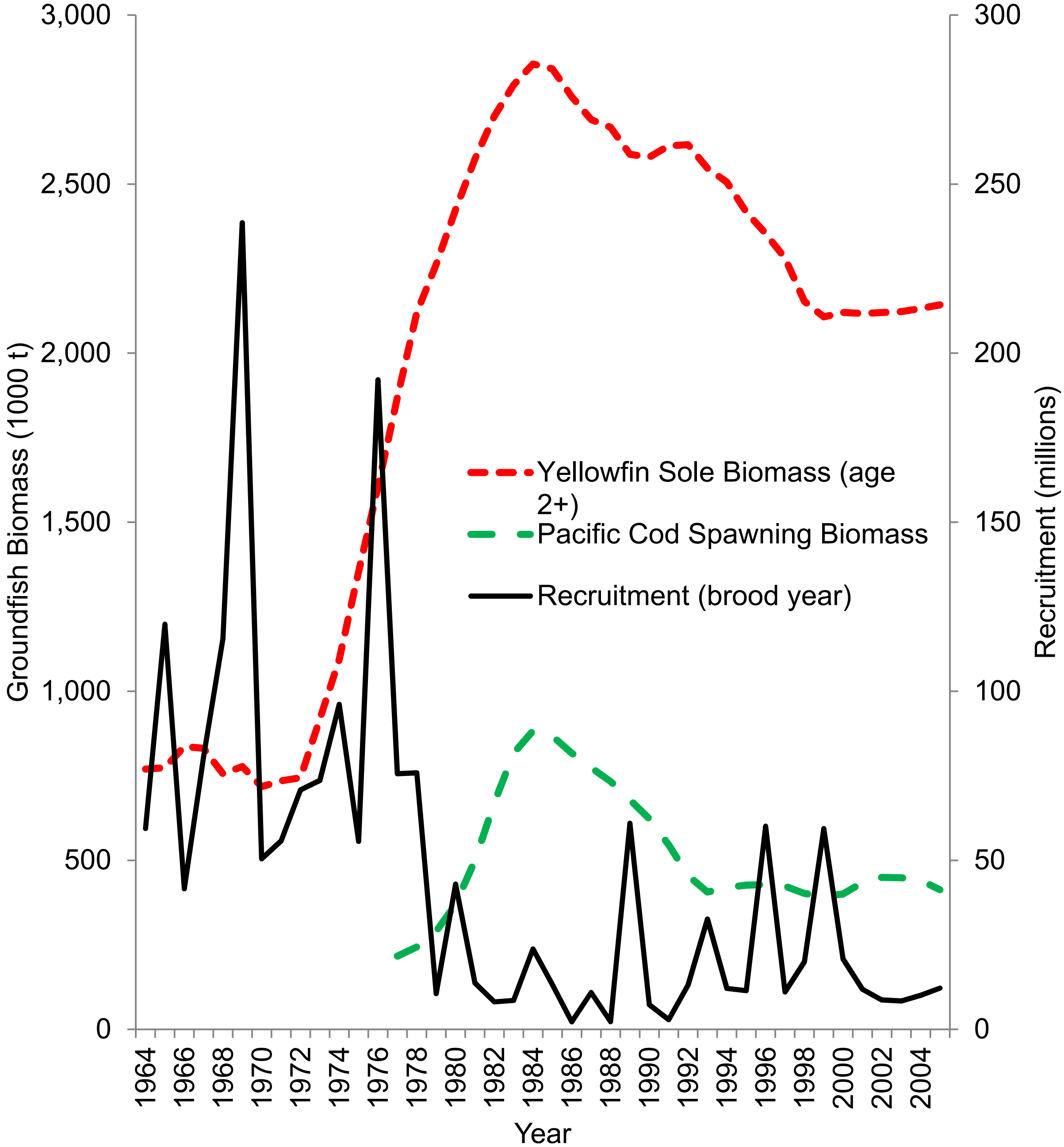
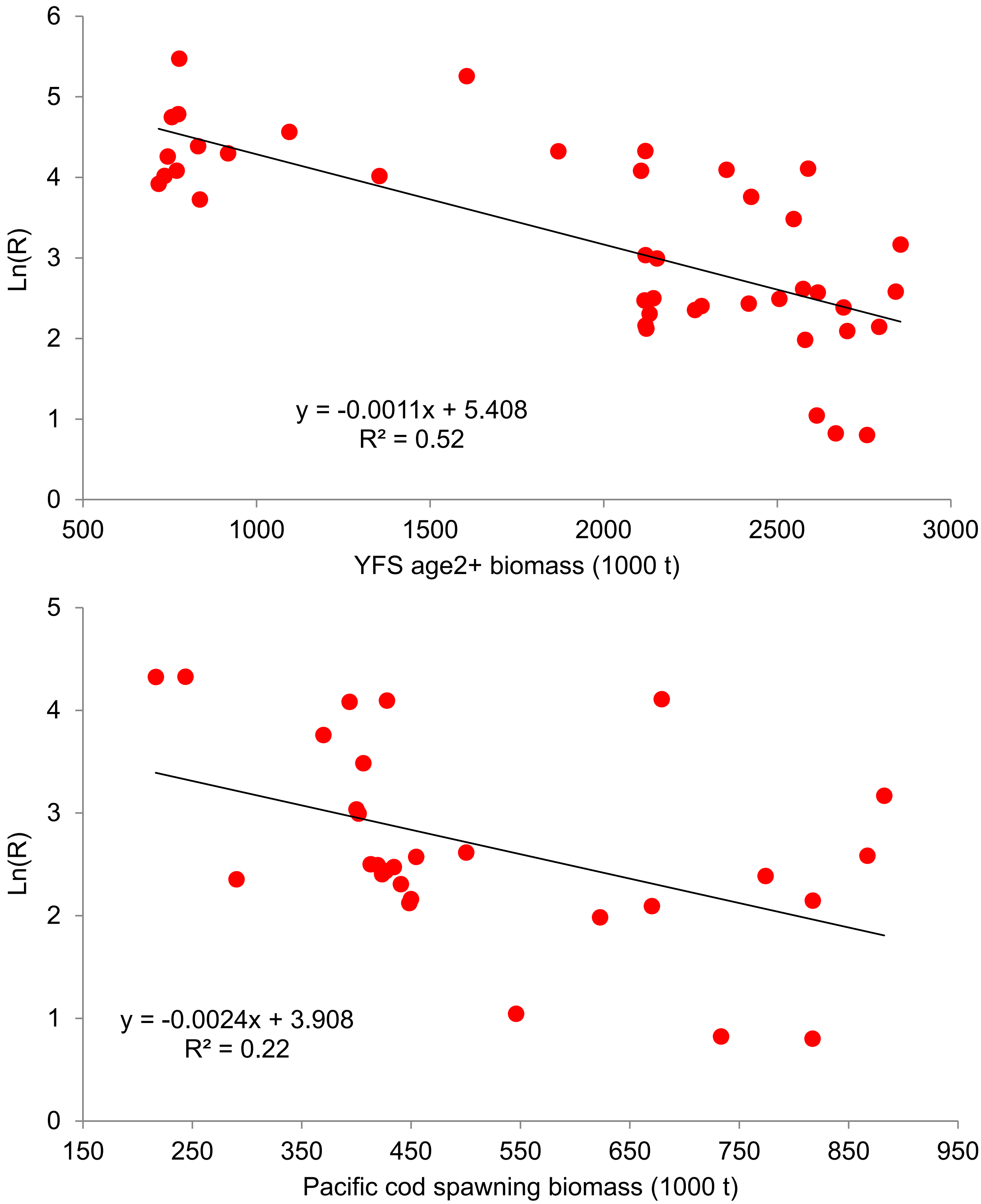


Figure 13g. Time series of recruitment in brood year, yellowfin sole biomass (age 2+) and Pacific cod spawning biomass under scenario 7ac. The groundfish biomass is from the Groundfish SAFE report. The Pacific cod biomass before 1977 was not available and should be less than the value in 1977.


6
5
4
3
2
1
0
Ln(R)
500
1000
1500
2000
2500
3000
YFS age2+ biomass (1000 t)
y = -0.0011x + 5.408
R² = 0.52
5
4
3
2
1
0
Ln(R)
150
250
350
450
550
650
750
850
950
Pacific cod spawning biomass (1000 t)
y = -0.0024x + 3.908
R² = 0.22

73

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

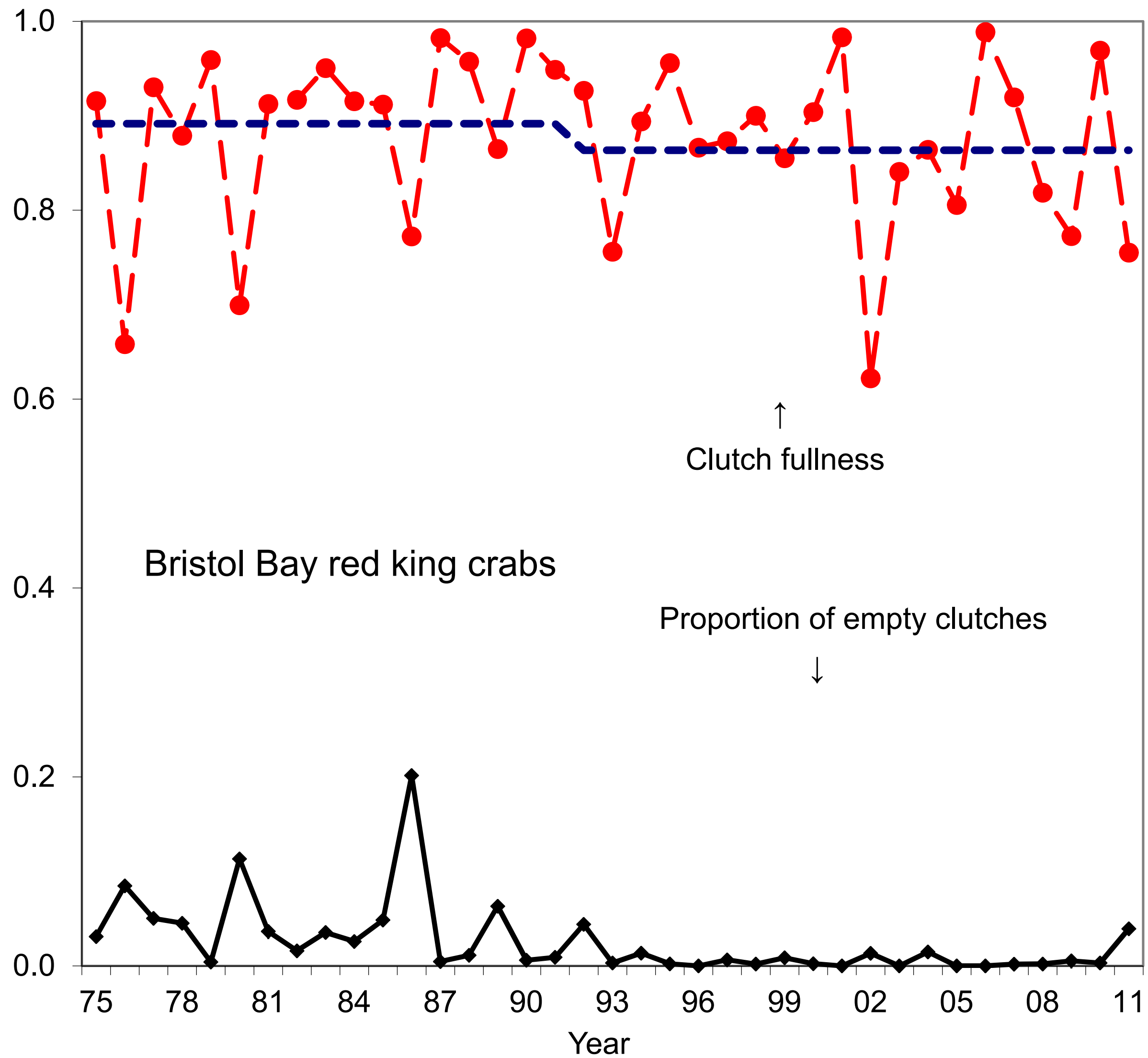
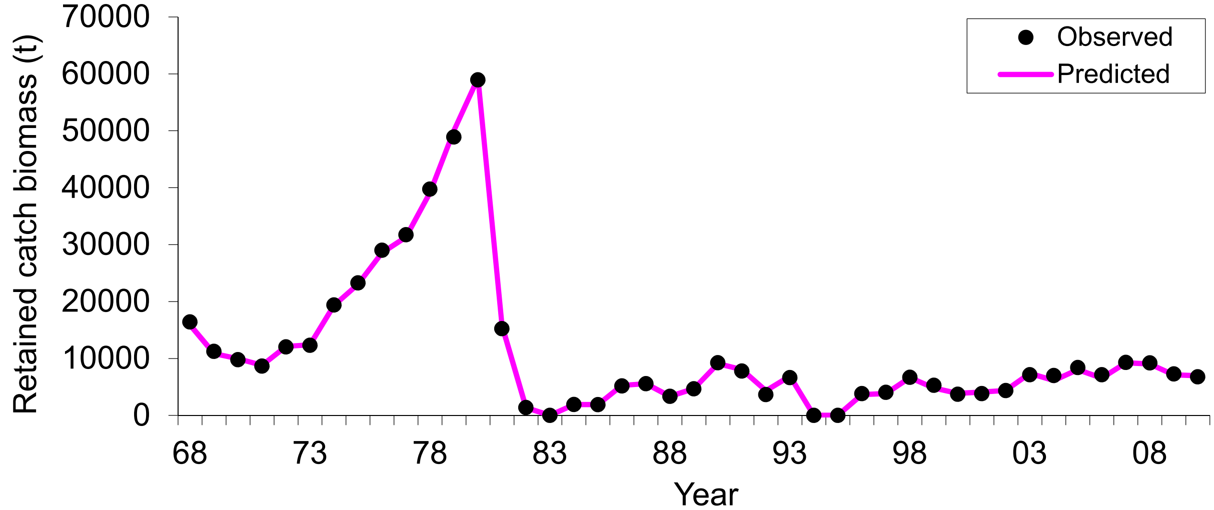
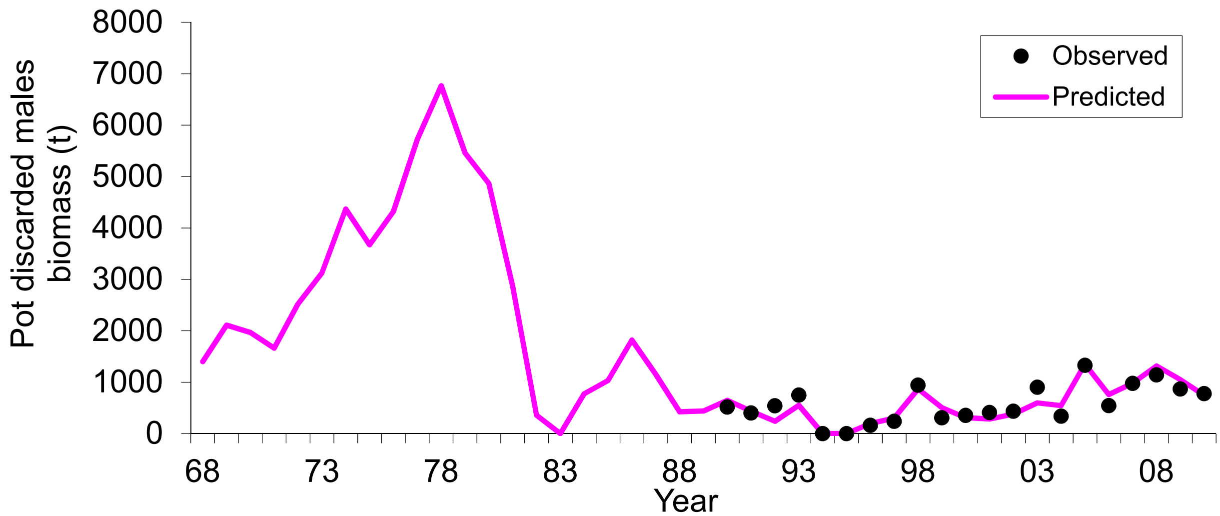


Figure 14. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crabs >89 mm CL from 1975 to 2011 from survey data. Oldshell females were excluded.


Retained catch biomass (t)
70000
60000
50000
40000
30000
20000
10000
0
68
73
78
83
88
93
98
03
08
Year
Observed
Predicted


Pot discarded males biomass (t)
8000
7000
6000
5000
4000
3000
2000
1000
0
68
73
78
83
88
93
98
03
08
Year
Observed
Predicted

75

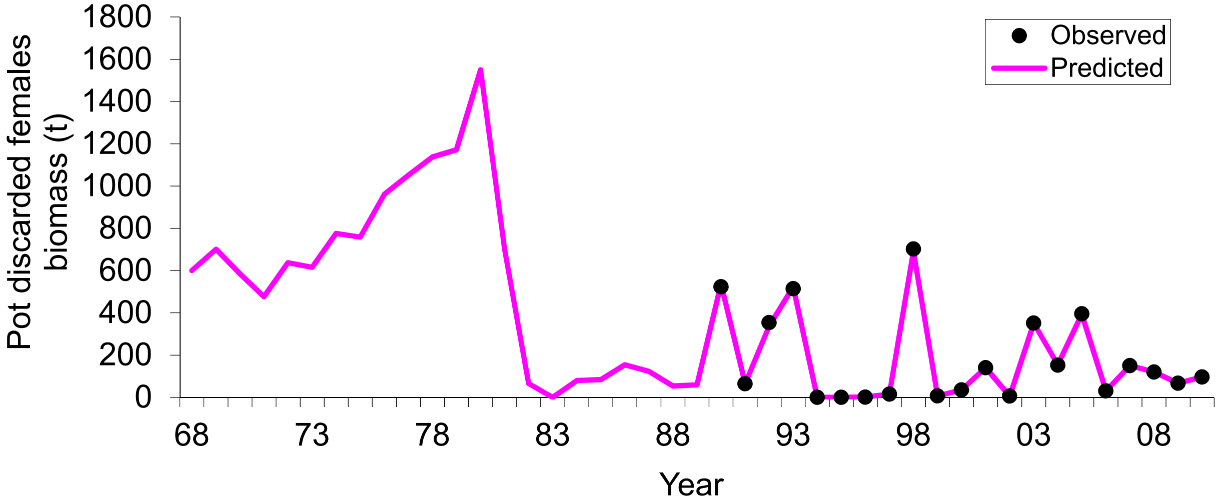
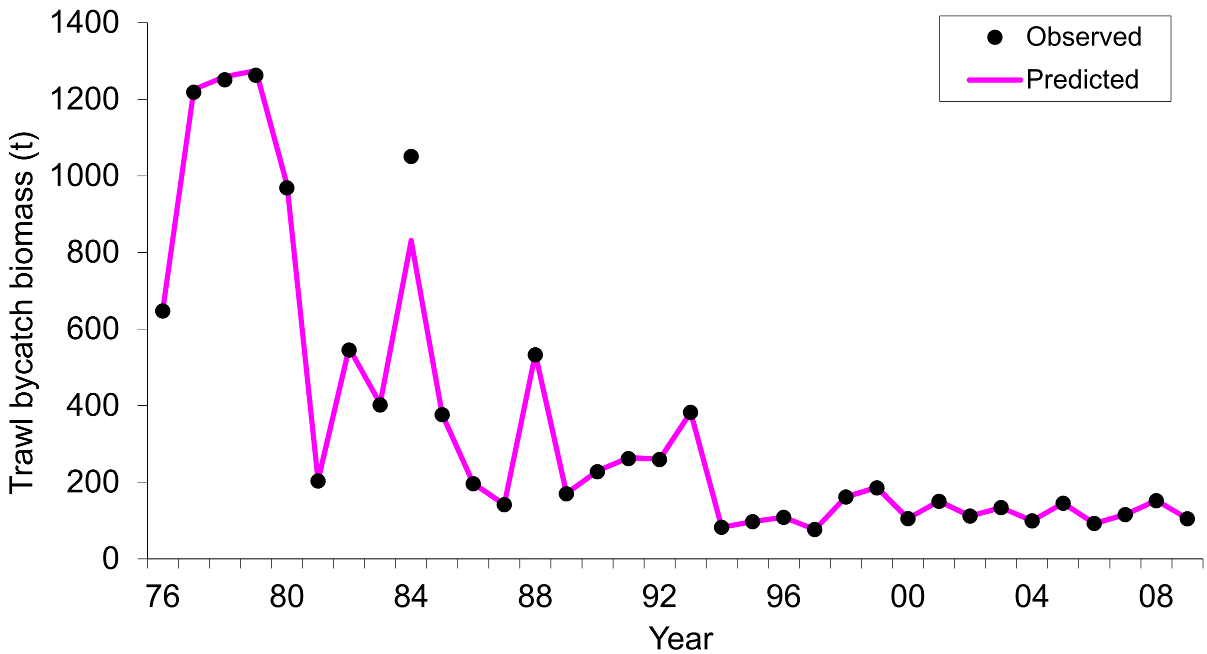


Figure 15a. Observed and predicted catch mortality biomass under scenario 7ac. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.



76

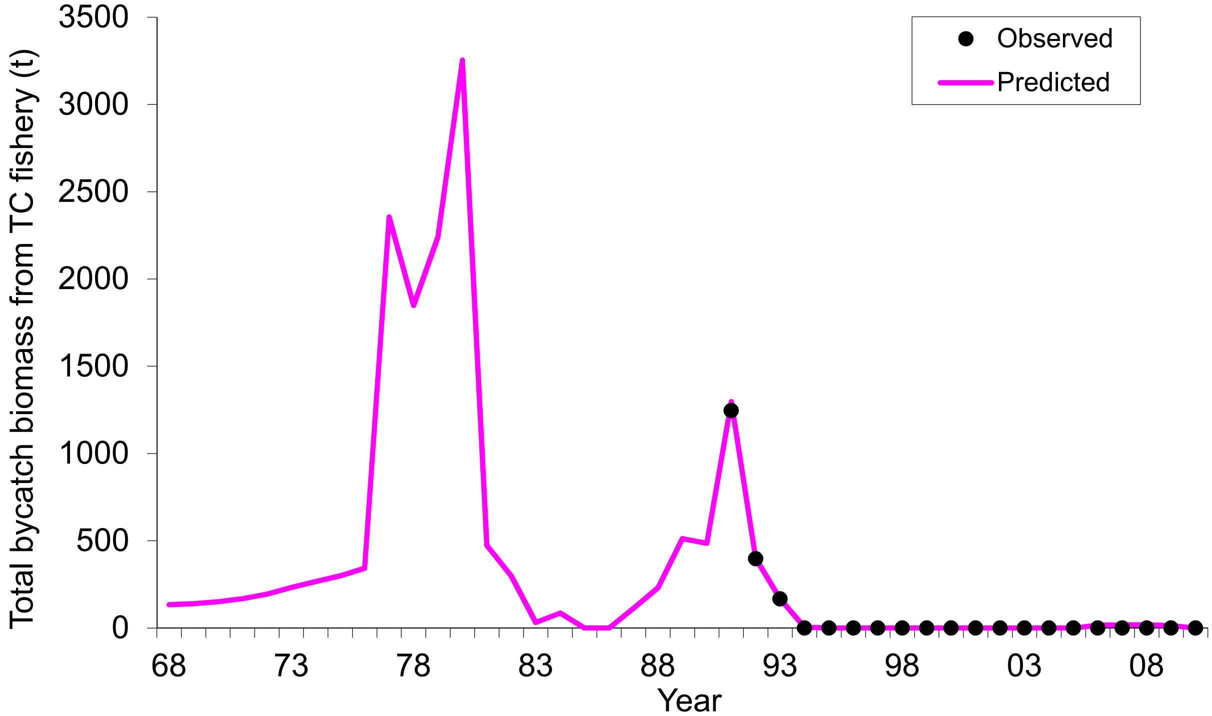


Figure 15b. Observed and predicted bycatch mortality biomass from trawl fisheries and Tanner crab fishery under scenario 7ac. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl bycatch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

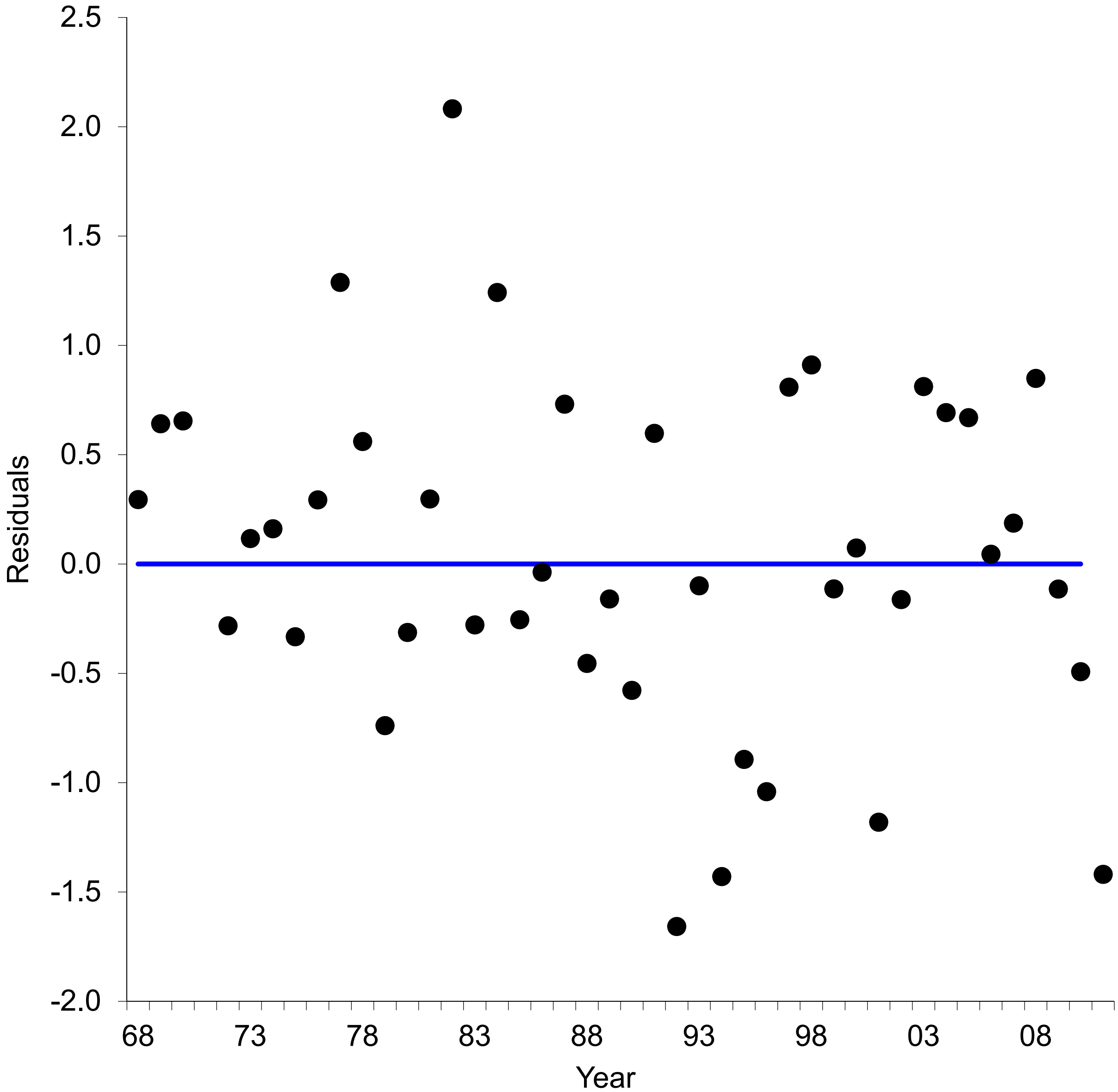


Figure 16. Standardized residuals of total survey biomass under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

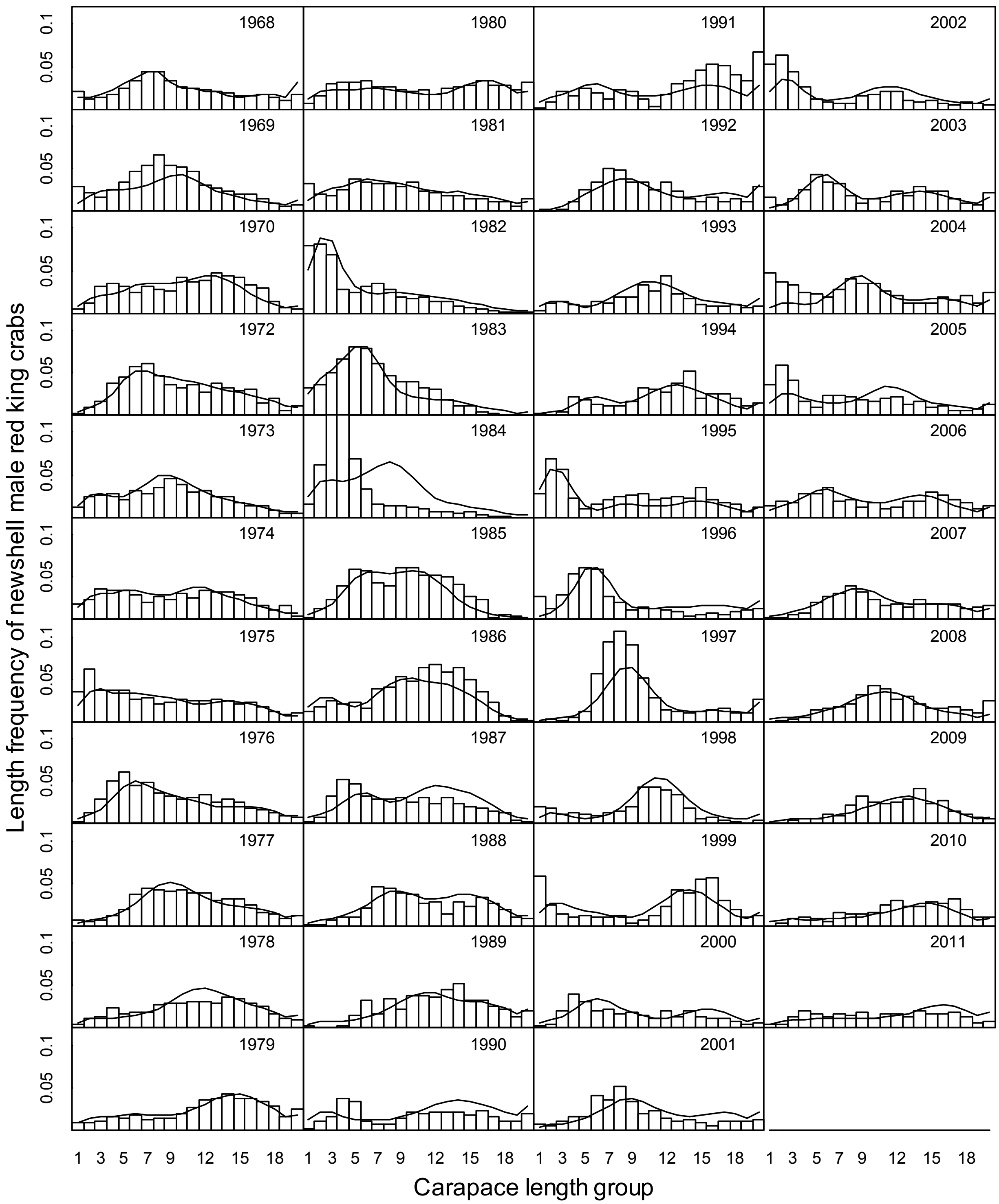


Figure 17. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay all-shell (before 1986) and newshell (1986-2011) male red king crabs by year under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, and the first length group is 67.5 mm.

79

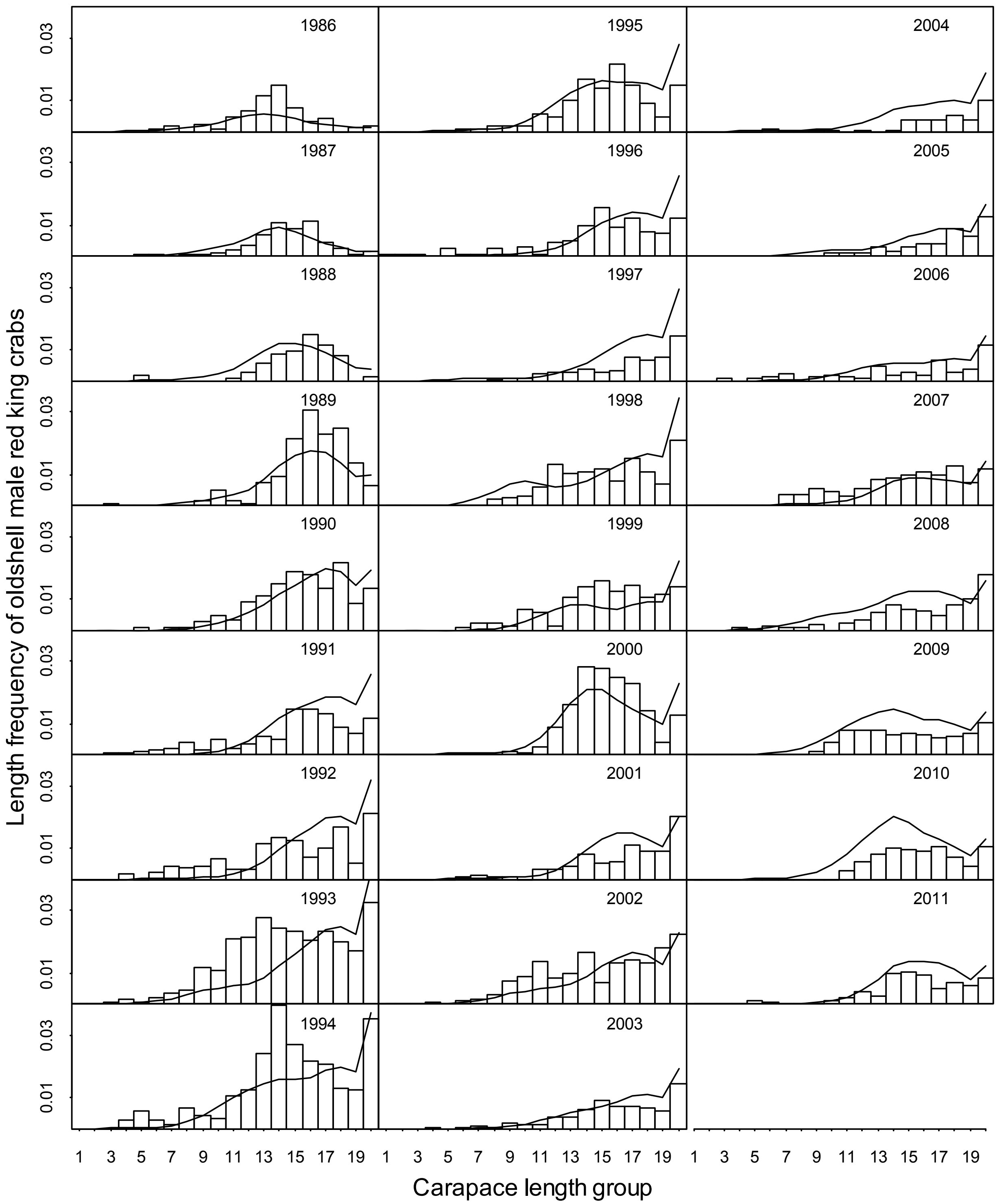


Figure 18. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay oldshell male red king crabs by year under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

80

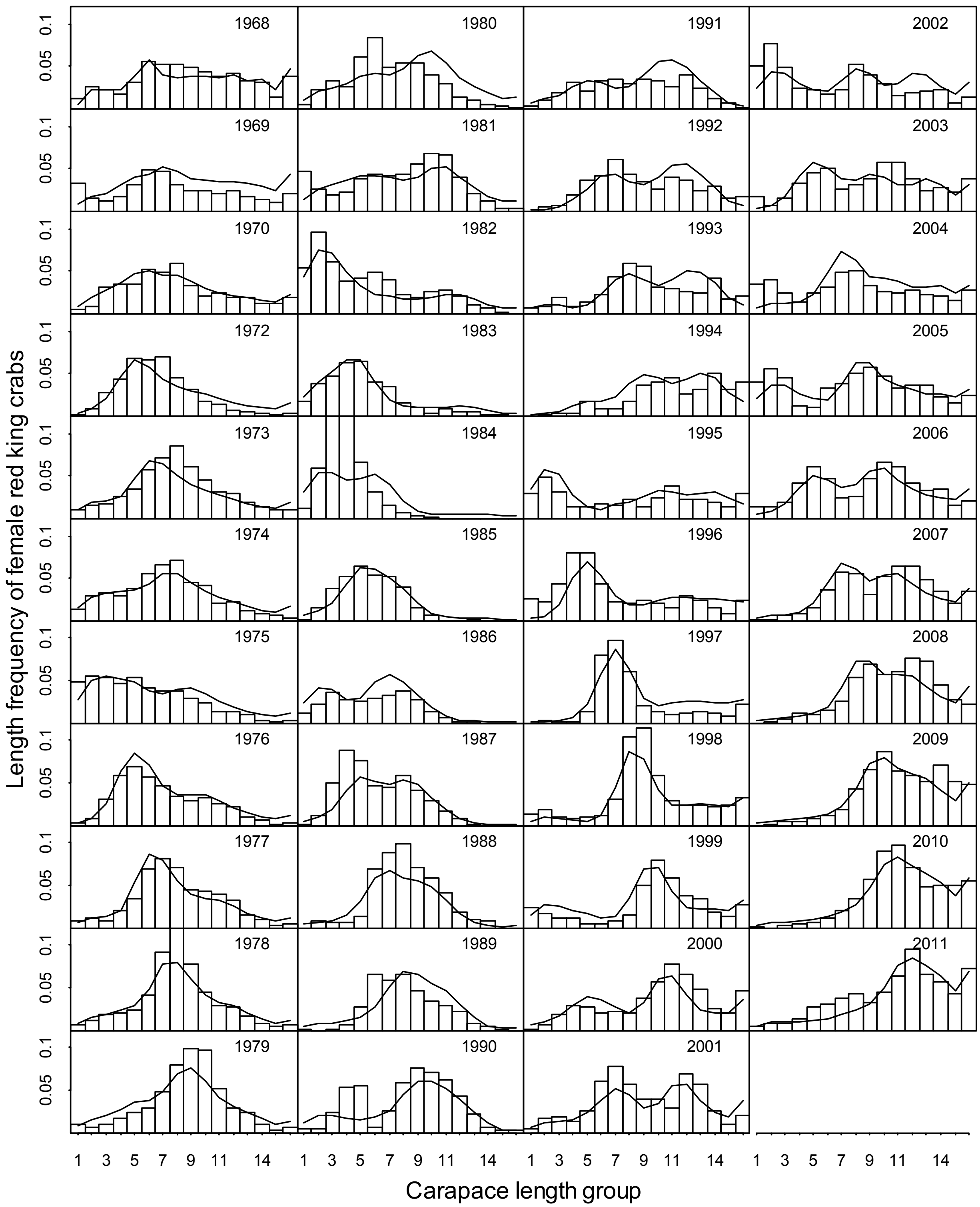


Figure 19. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

81

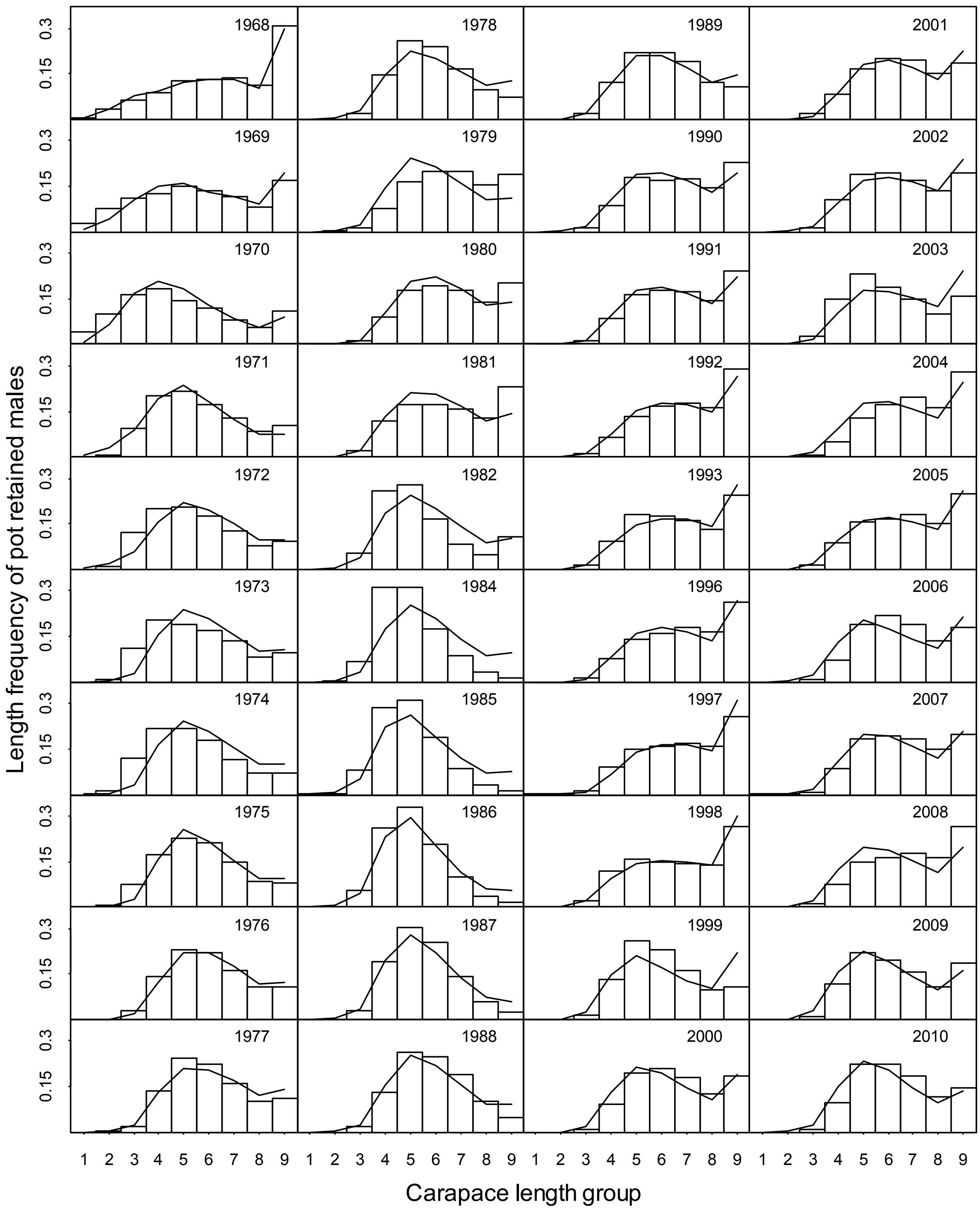


Figure 20. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 122.5 mm.

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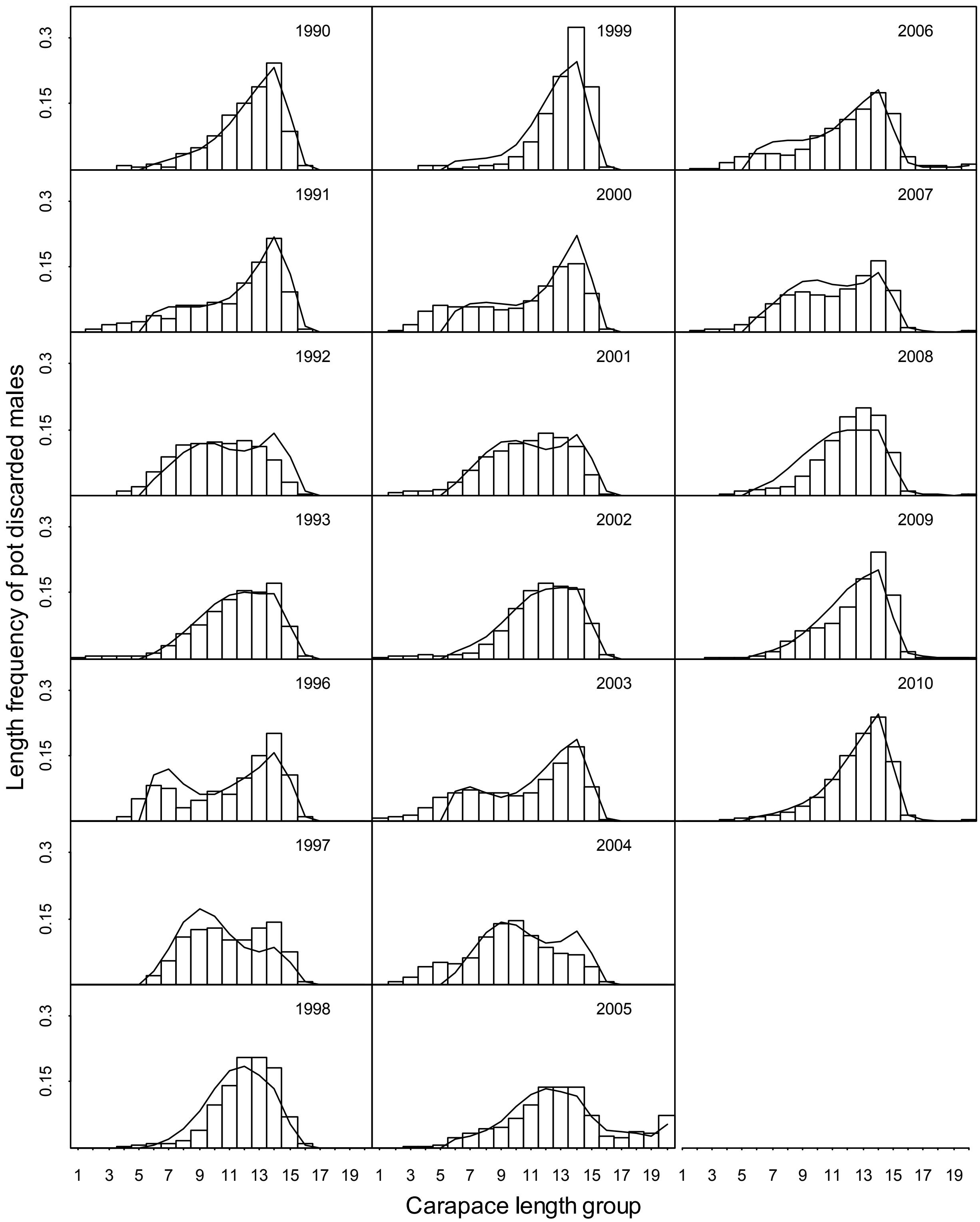

Figure 21. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

83

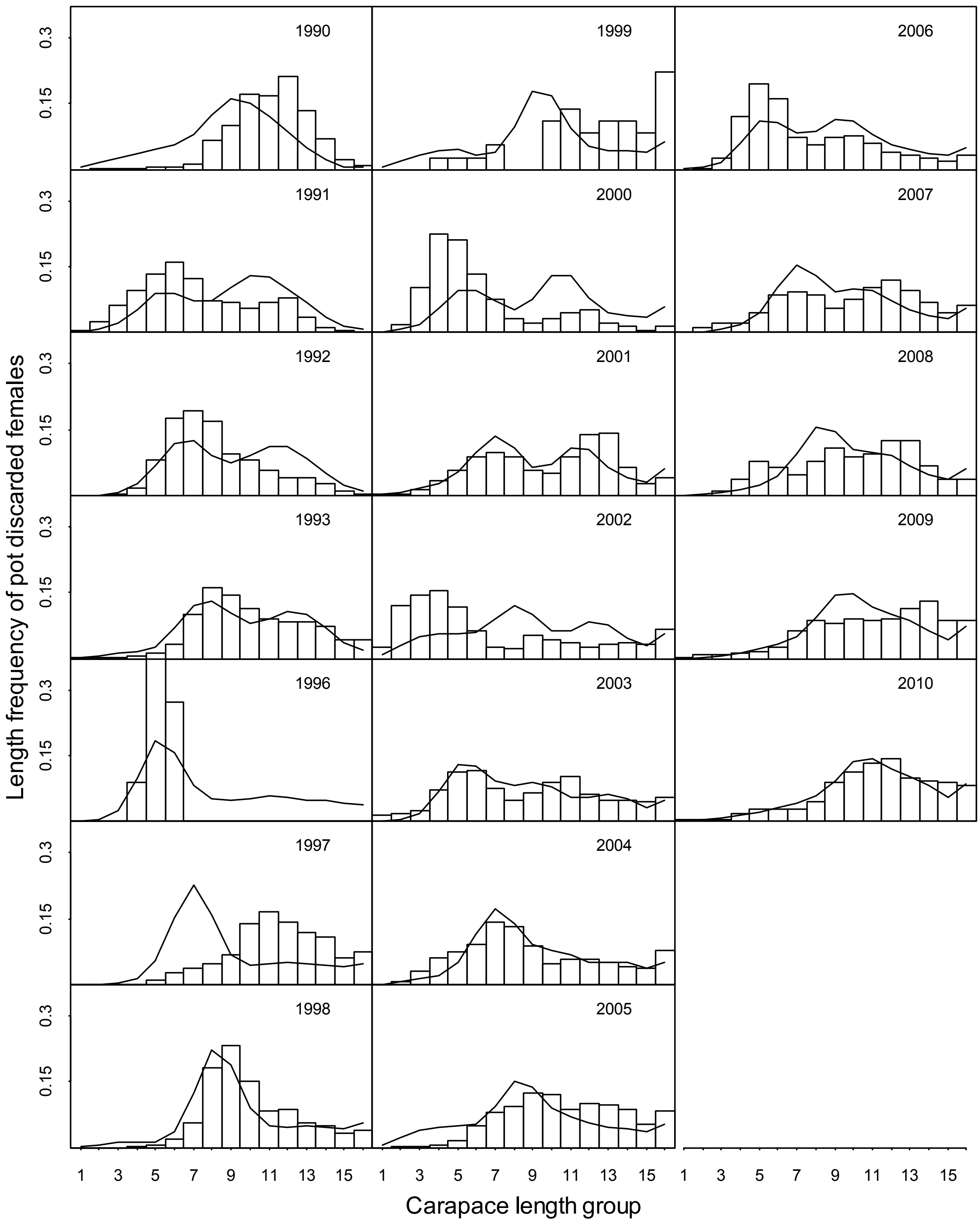

Figure 22. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery under scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

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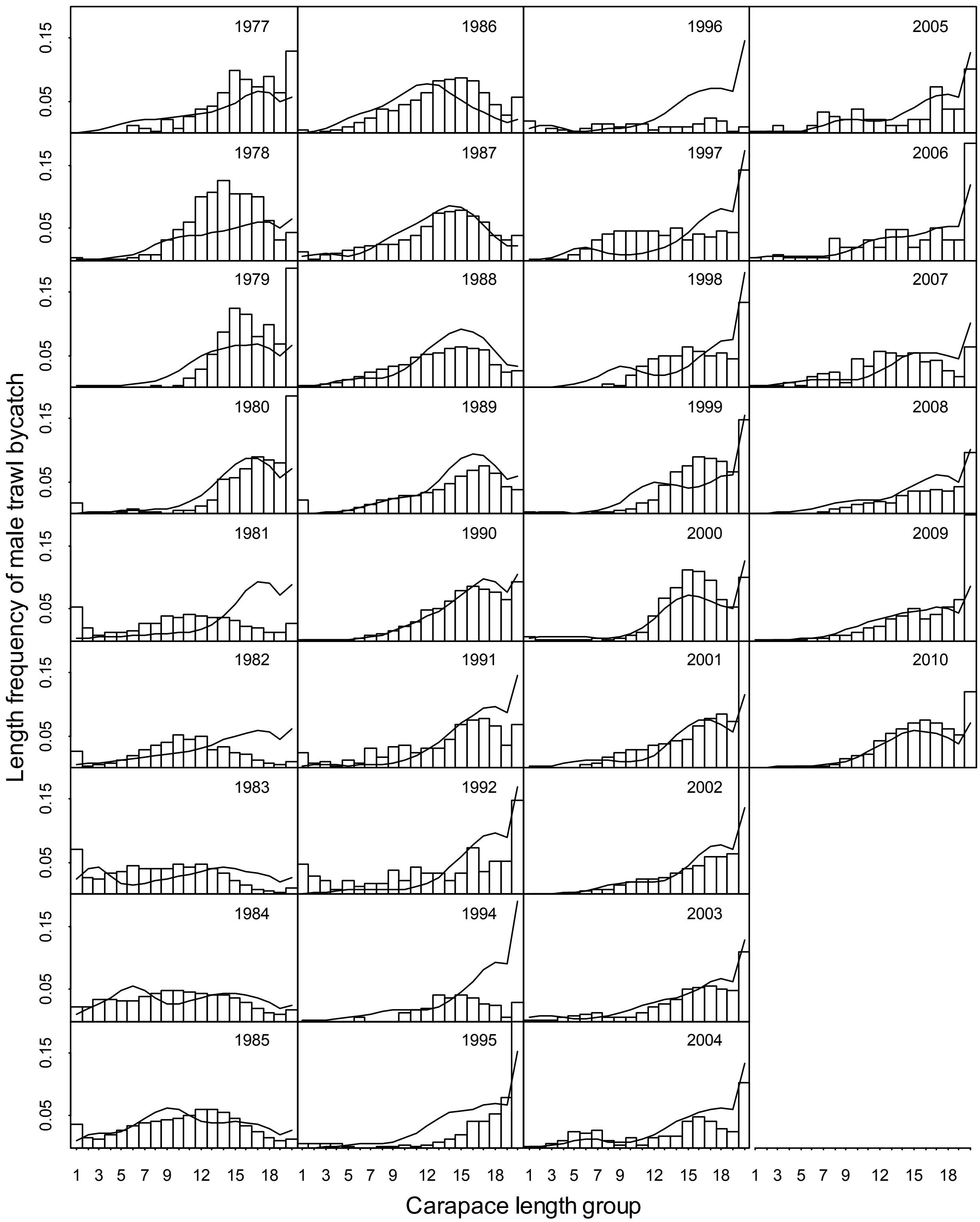

Figure 23. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries under scenario 7ac. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

85

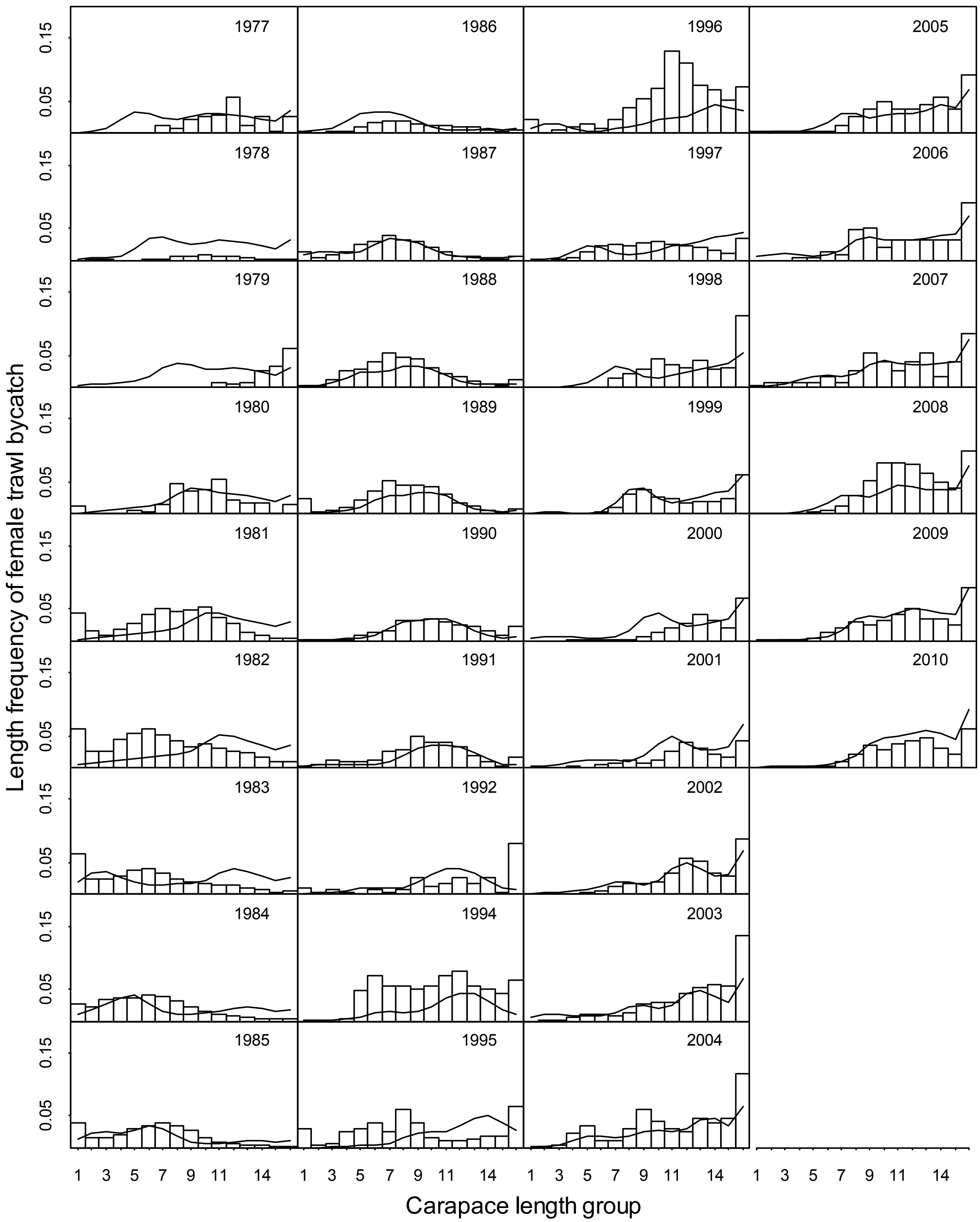

Figure 24. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries under scenario 7ac. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

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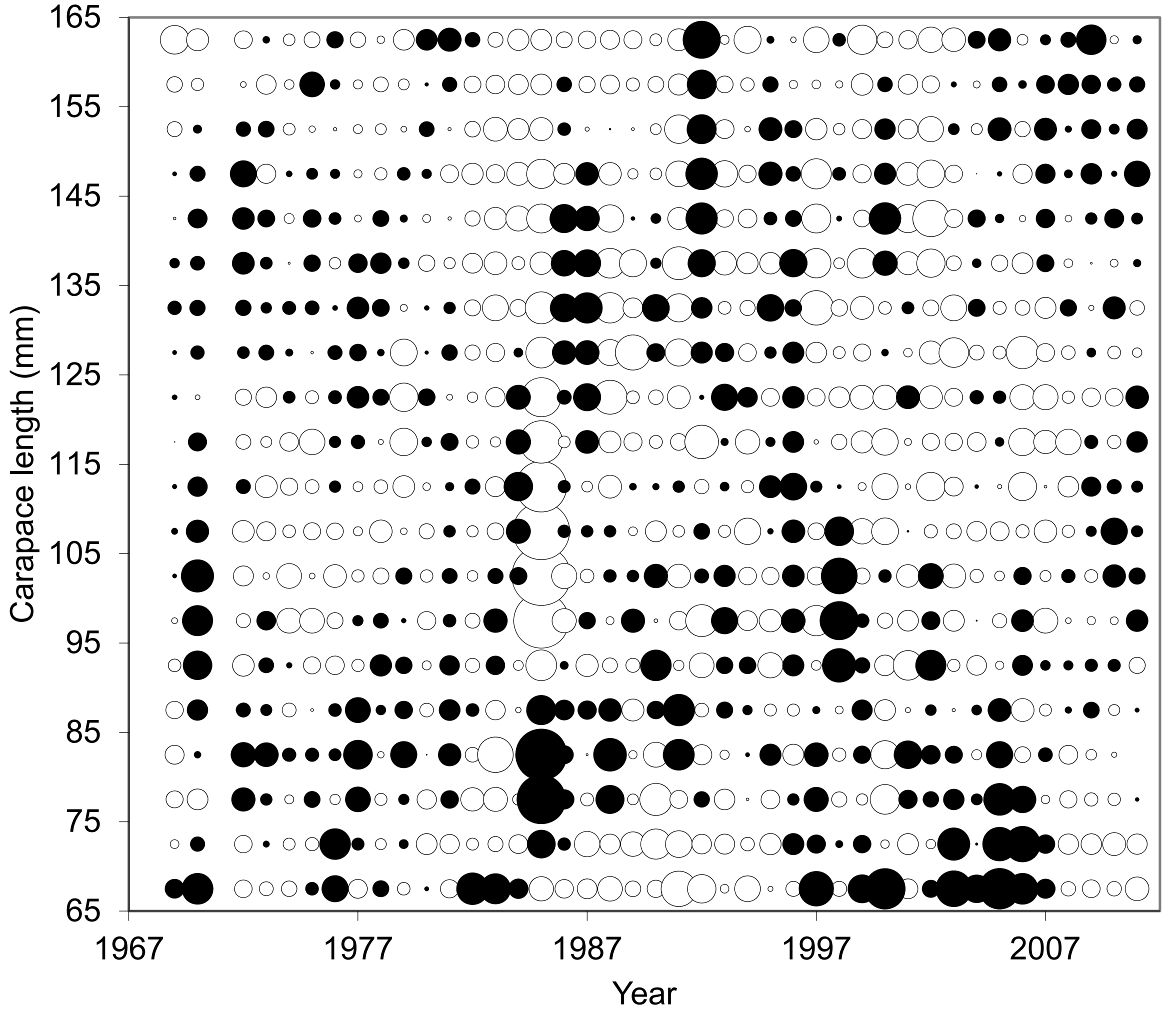


Figure 25. Standardized residuals of proportions of survey all-shell (1968-1985) and newshell (1986-2011) male red king crabs under scenario 7ac. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

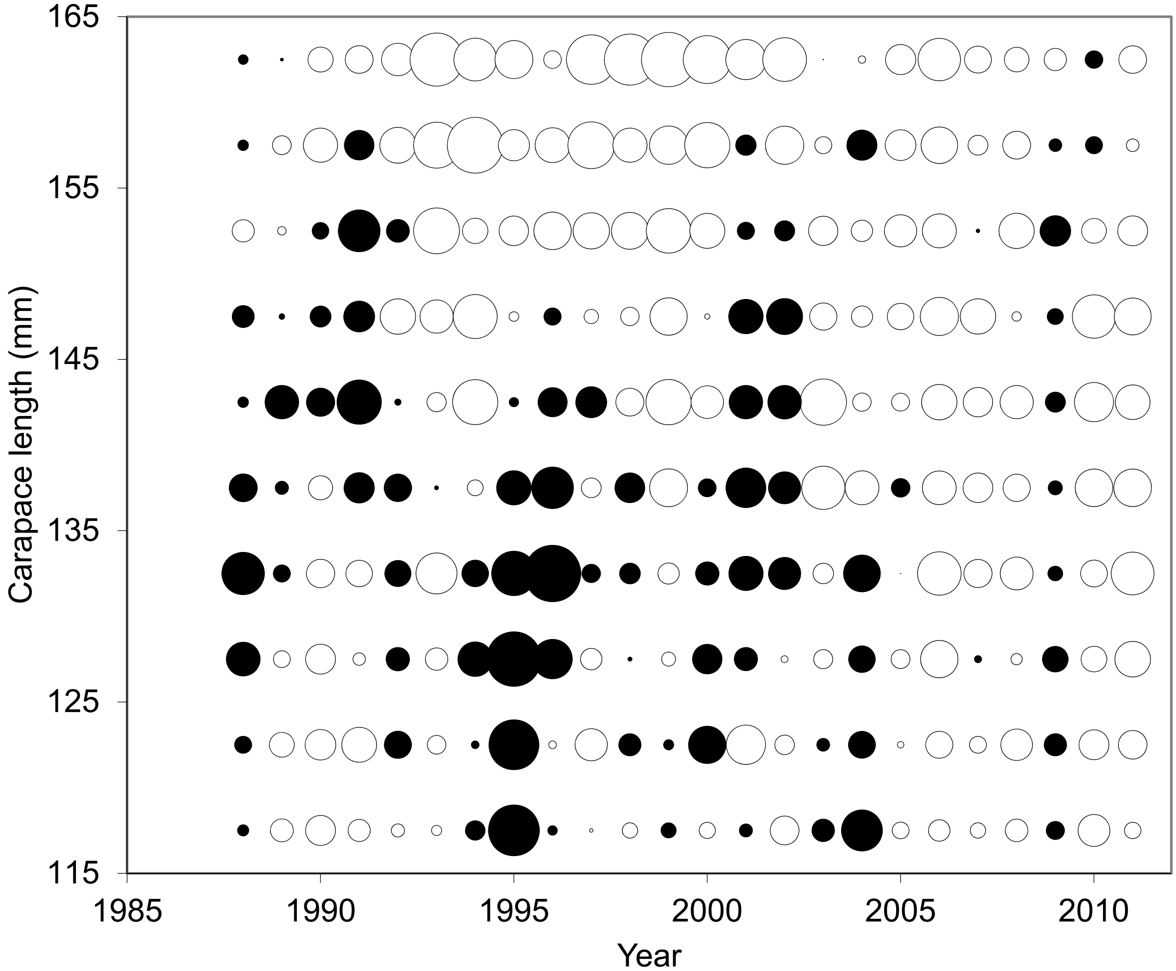


Figure 26. Standardized residuals of proportions of survey oldshell male red king crabs (1986-2011) under scenario 7ac. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

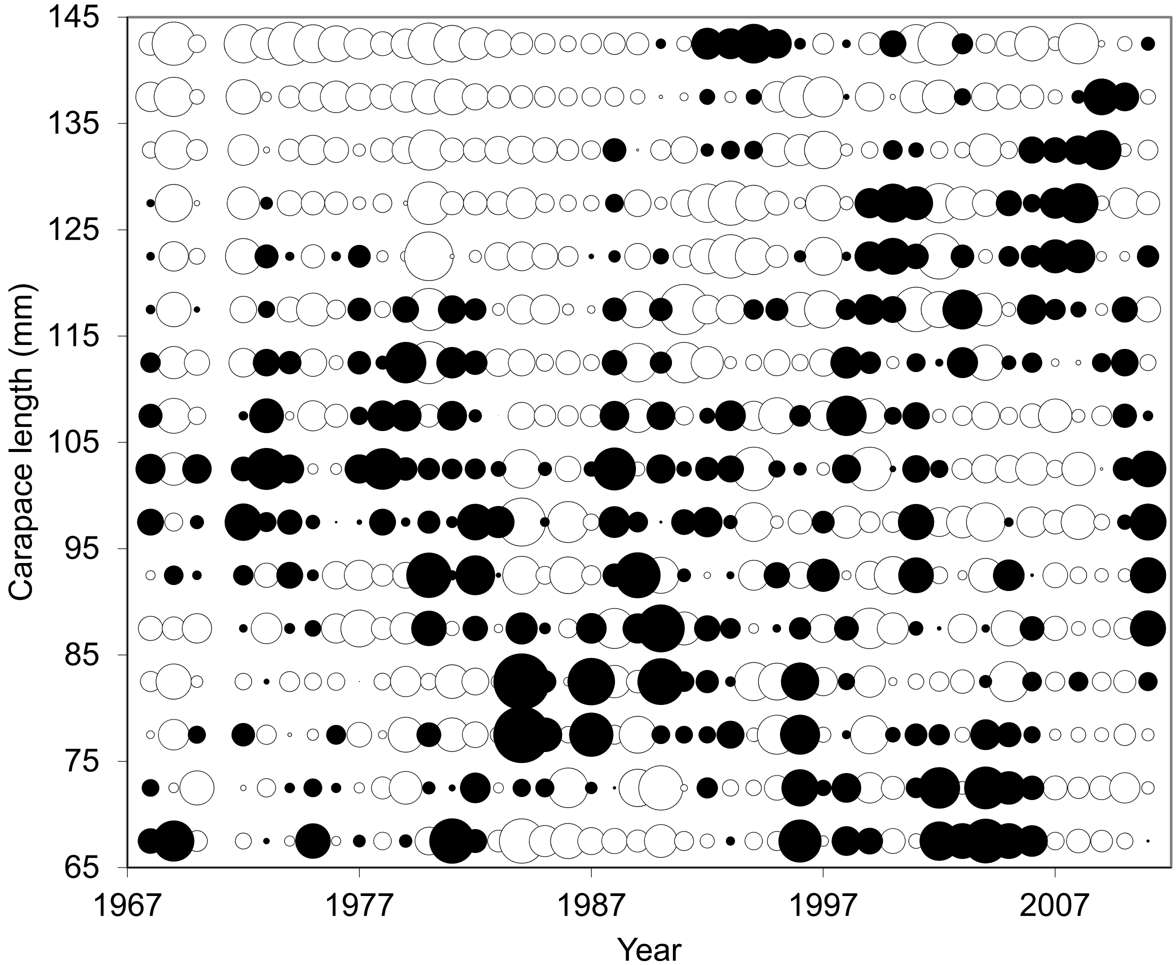
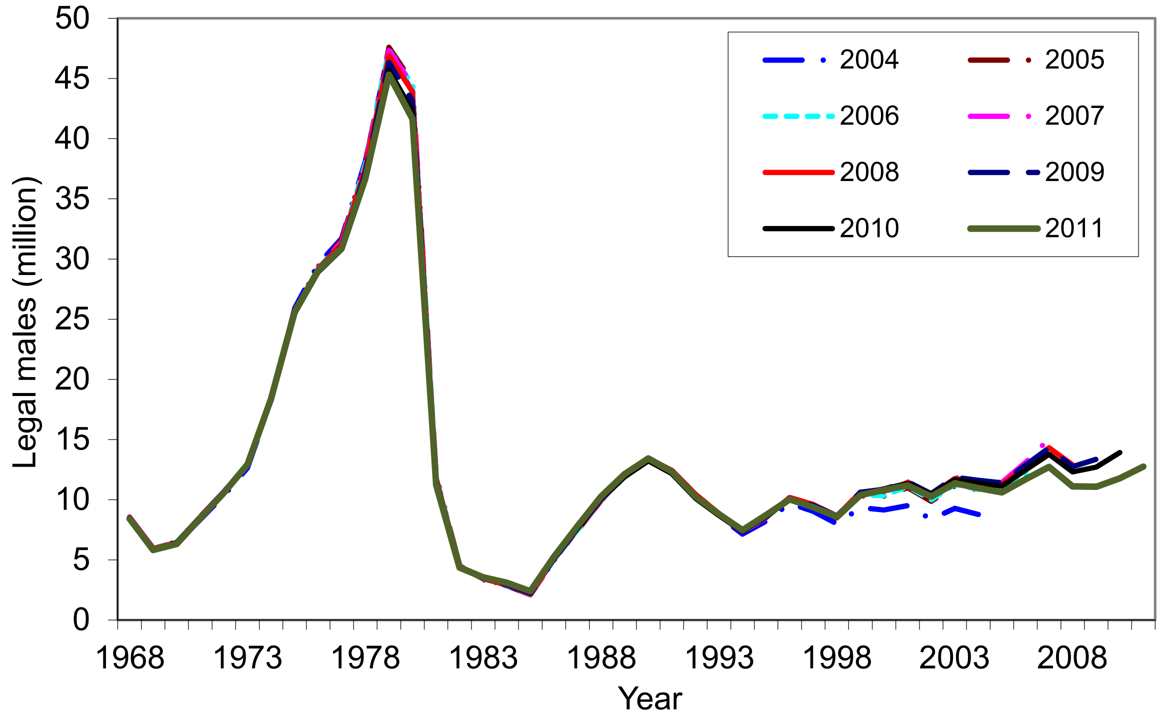


Figure 27. Standardized residuals of proportions of survey female red king crabs (1968-2011) under scenario 7ac. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



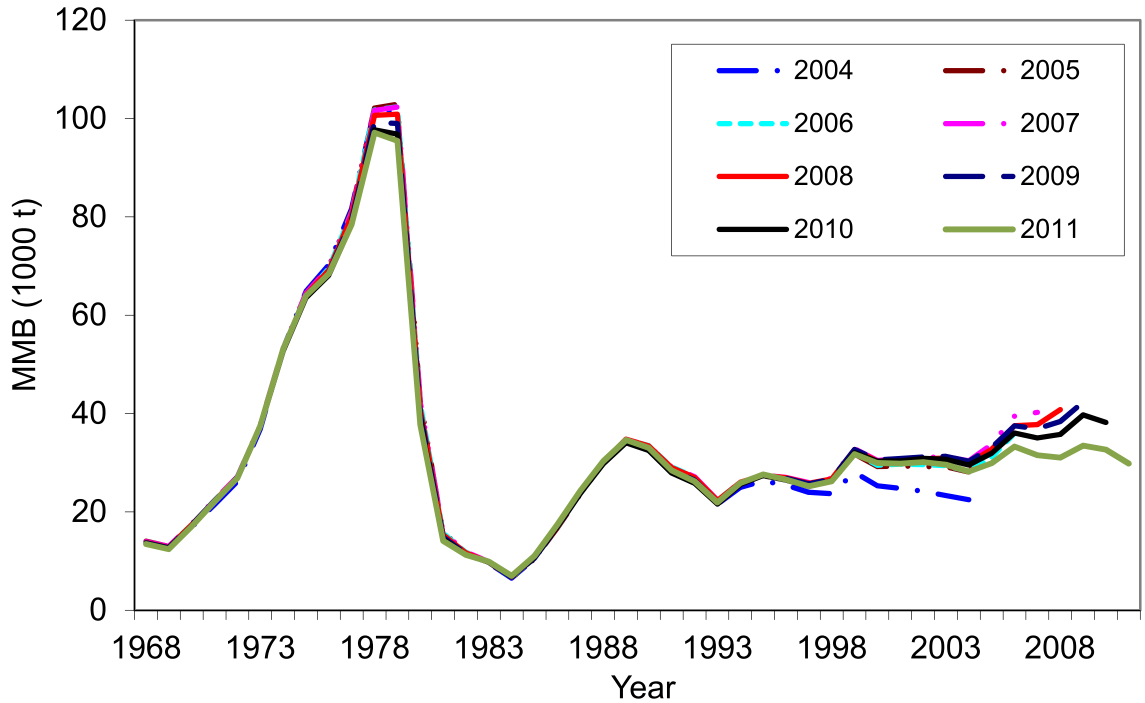


Figure 28. Comparison of estimates of legal male abundance (top) and mature male biomass (bottom) on Feb. 15 of Bristol Bay red king crab from 1968 to 2011 made with terminal years 2004-2011 with scenario 7ac. These are results of the 2011 model. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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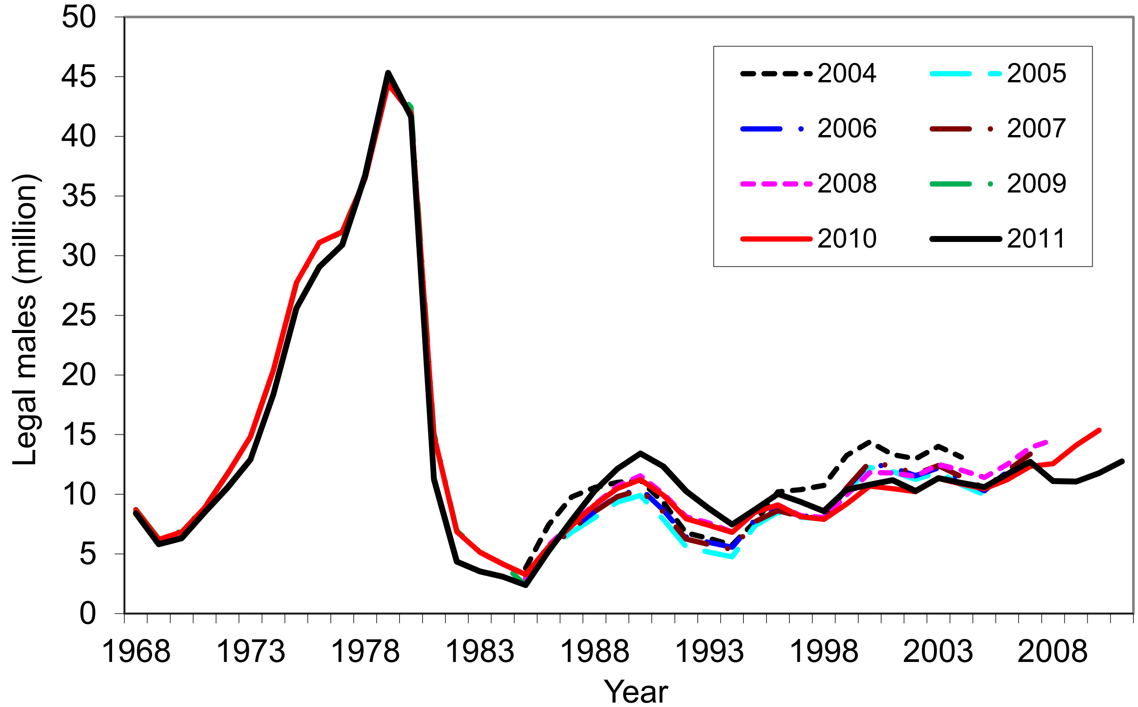

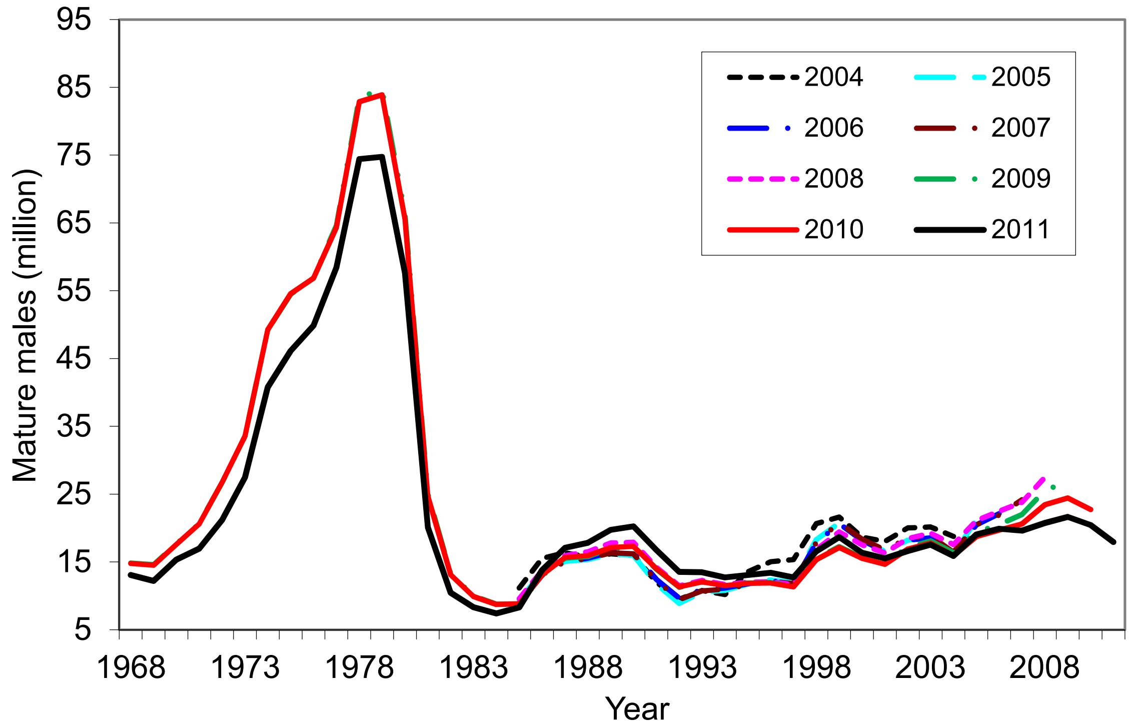

Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2011 made with terminal years 2004-2011. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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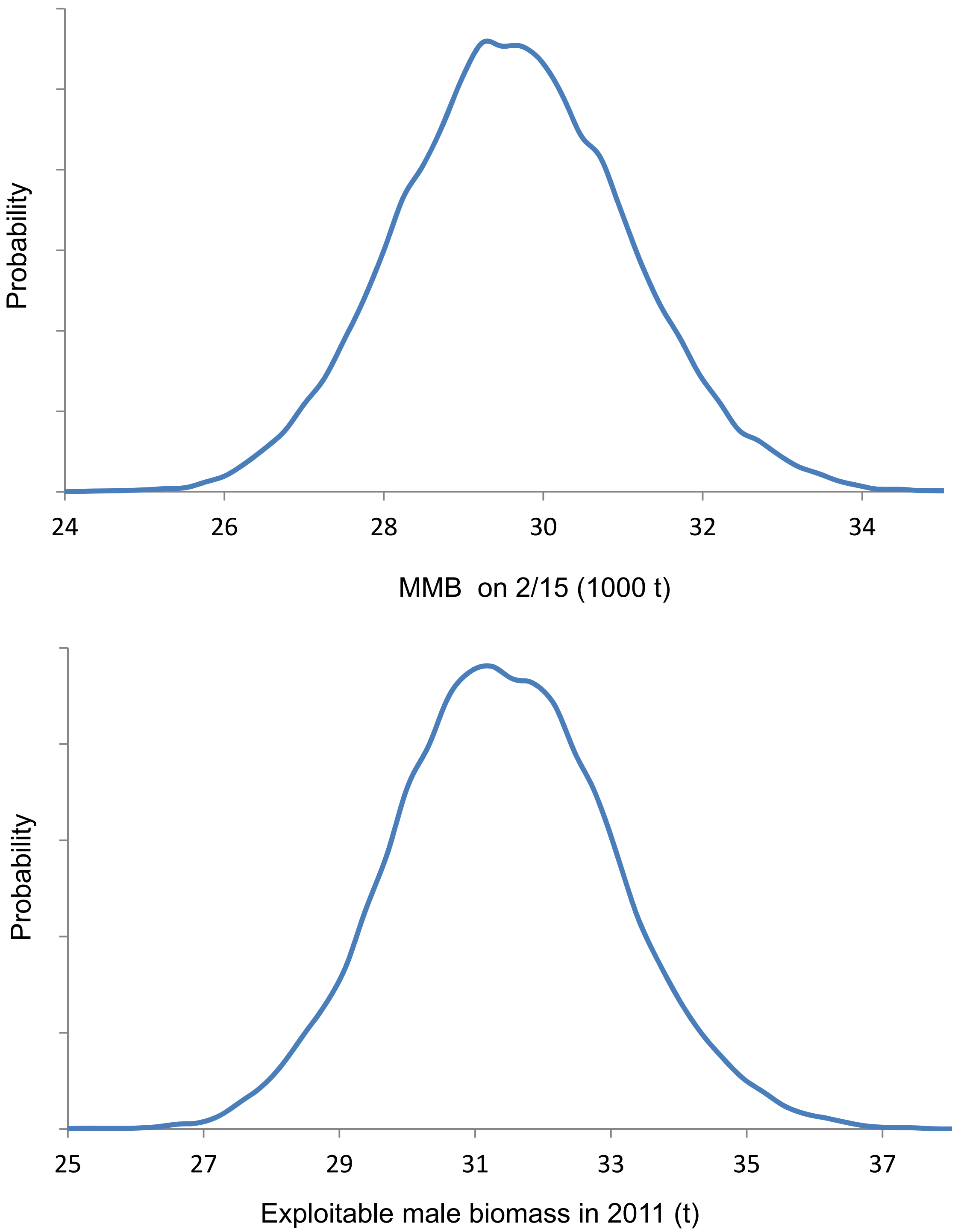

Figure 30. Probabilities for estimated mature male biomass on Feb. 15 and exploitable male biomass at the fishing time for the 2011 season with $F_{35\%}$ under scenario 7ac based on the mcmc method with 1000000 replicates. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

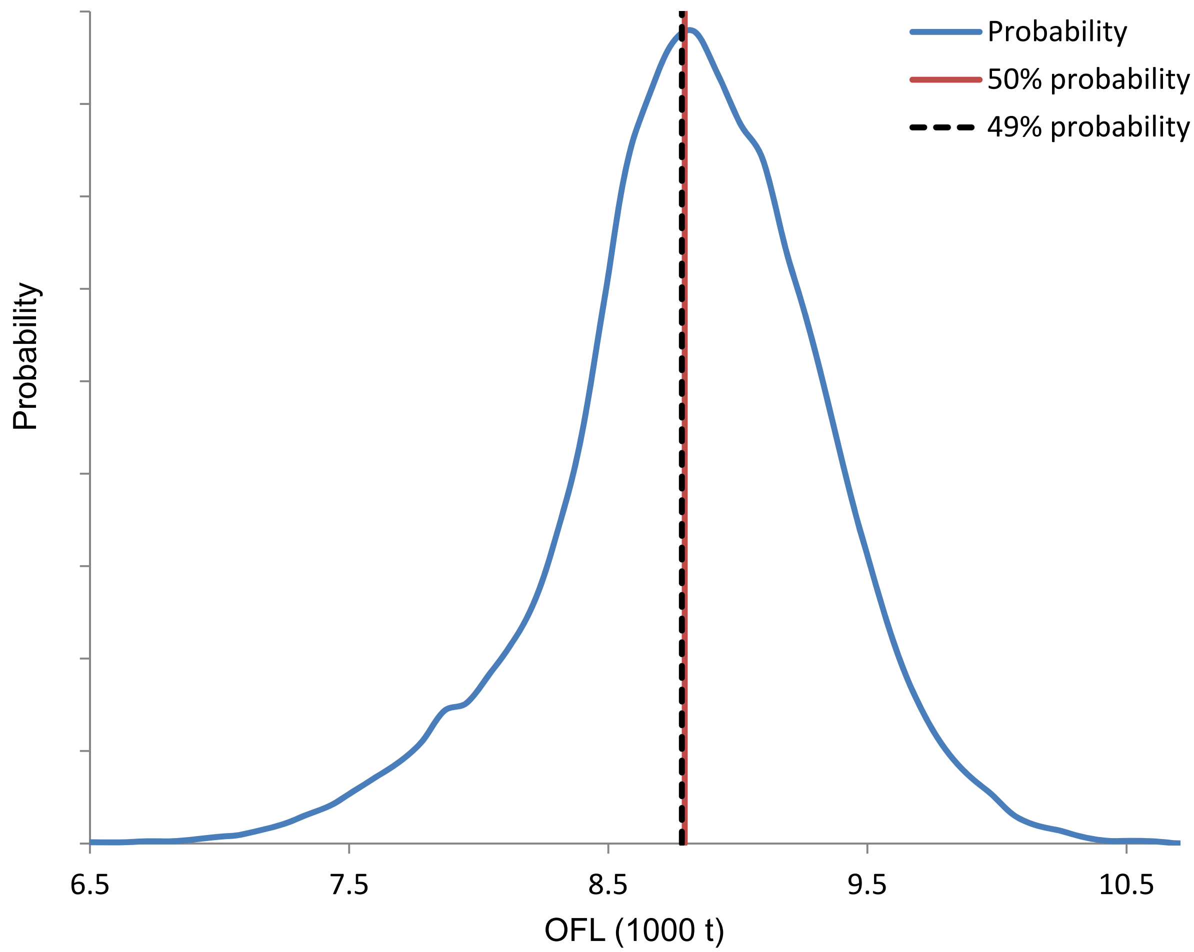

Figure 31a. The 2011 OFL distributions with scenario 7ac based on the mcmc method with 1000000 replicates. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

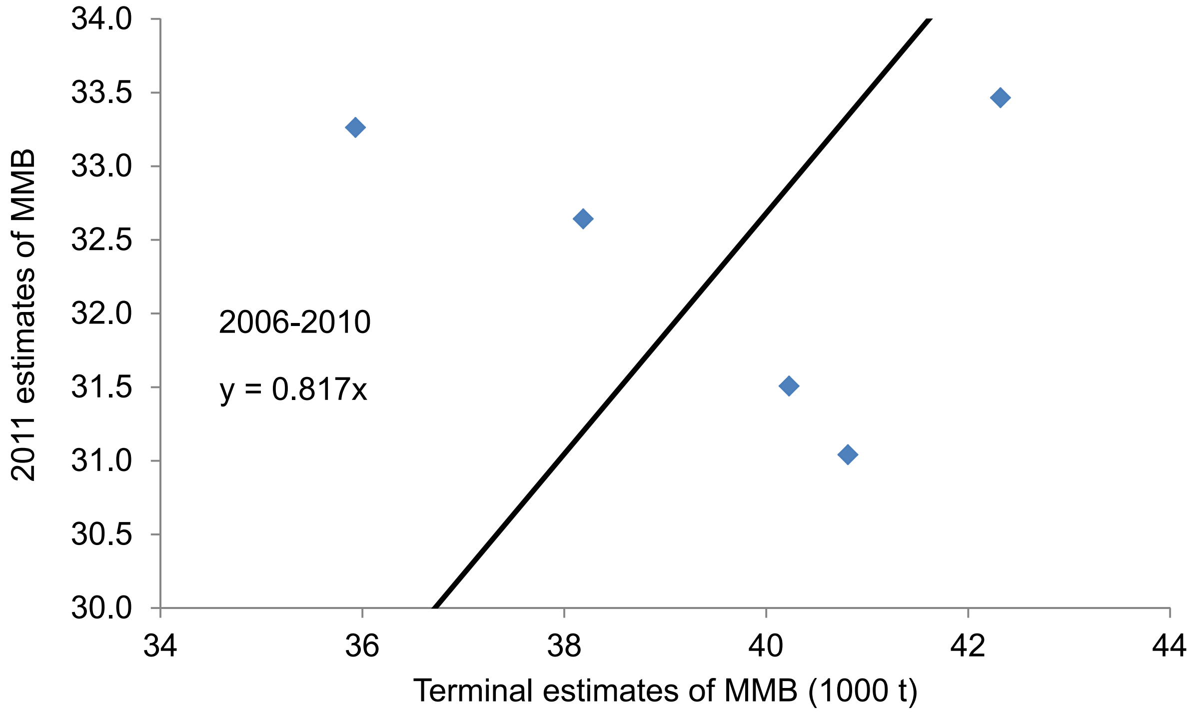

Figure 31b. Regression of 2011 model estimates of MMB (1000 t) against terminal year estimates of MMB during 2006-2010. The slope of 0.817 is used to adjust ABC for the retrospective bias of the 2011 model.

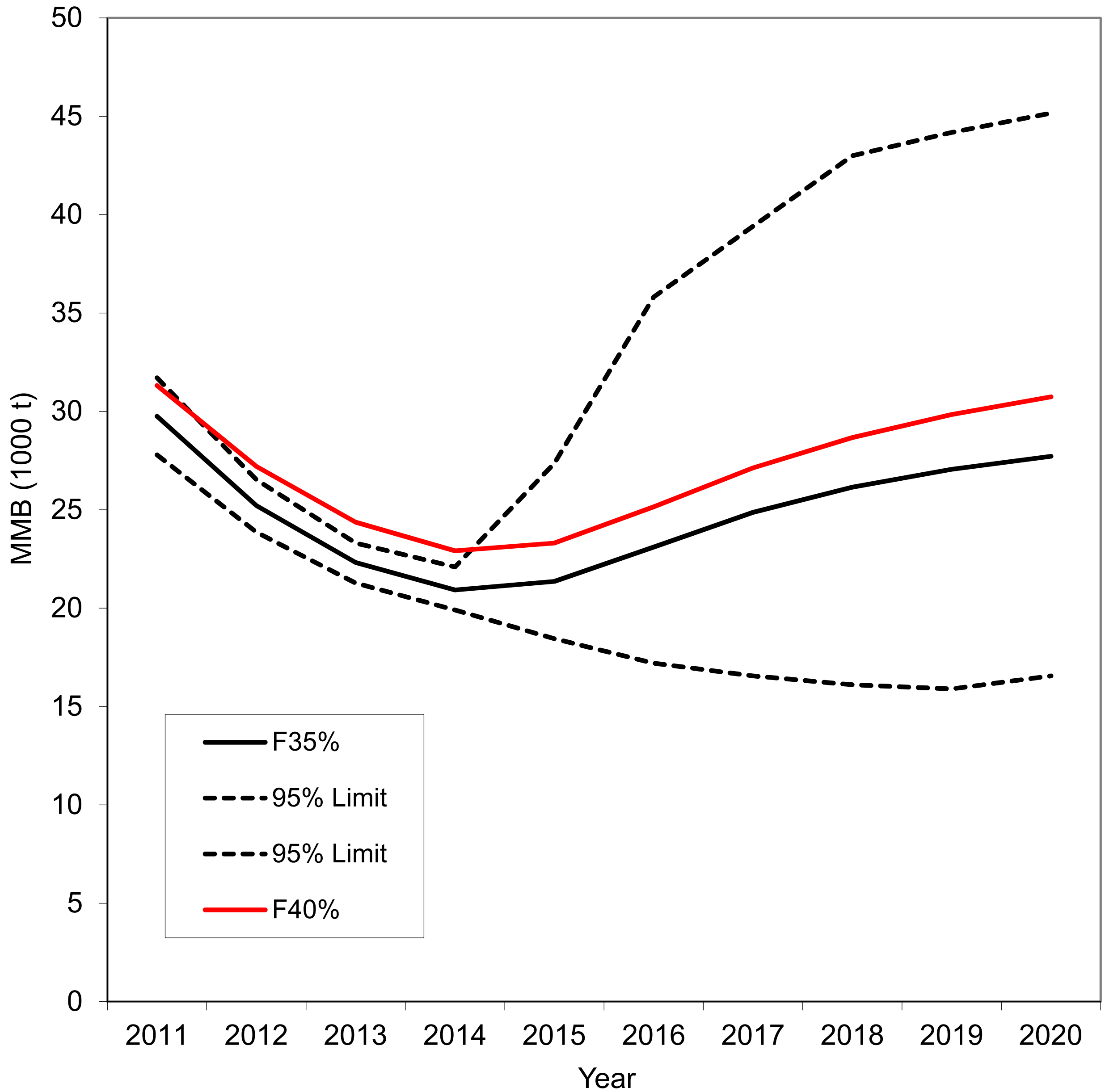

Figure 32. Projected mature male biomass on Feb. 15 with $F_{40\%}$, and $F_{35\%}$ harvest strategy during 2011-2120. Input parameter estimates are based on scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

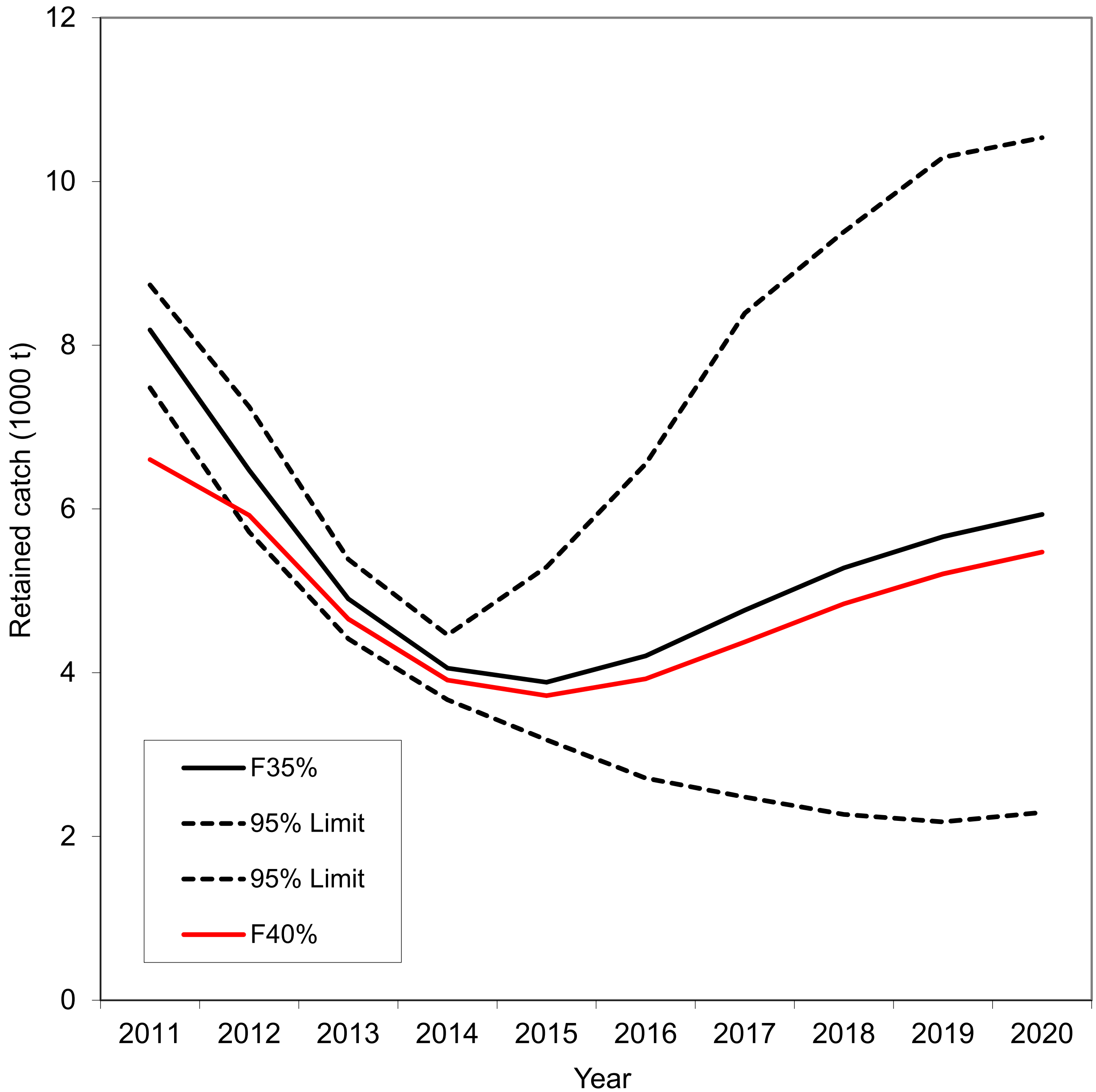

Figure 33. Projected retained catch biomass with $F_{40\%}$, and $F_{35\%}$ harvest strategy during 2011-2120. Input parameter estimates are based on scenario 7ac. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

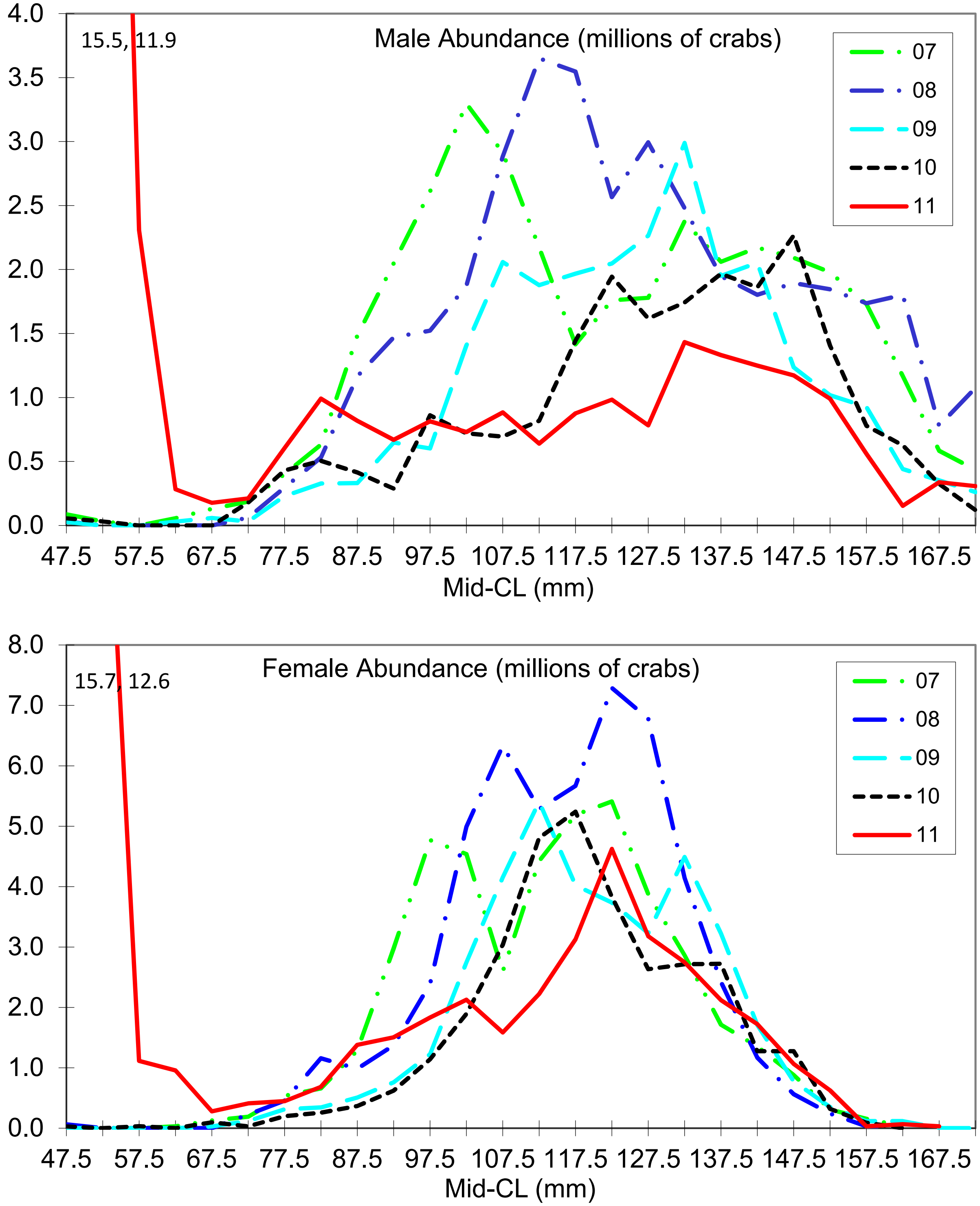

Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crabs in Bristol Bay from NMFS trawl surveys during 2007-2011. For purposes of these graphs, abundance estimates are based on area-swept methods.

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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:

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

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:

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

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:

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

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

$$R_{l,t} = R_t U_l, \quad (6)$$

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° 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:

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

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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 assumed to be 400 for retained males, 200 for trawl survey, 100 for pot male and Tanner crab fisheries bycatch, and 50 for trawl and pot female bycatch length composition data.

The weighted negative log-likelihood functions are:

$$
\begin{aligned}
&Length\ compositions: \quad -\sum \ln(Rf_i)\,, \\
&Biomasses\ other\ than\ survey: \quad \lambda_j \sum \left[\ln(C_t / \hat{C}_t)^2\right], \\
&NMFS\ survey\ biomass: \quad \sum \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))\right], \\
&BSFRF\ mature\ males: \quad \sum [\ln(N_t / \hat{N}_t)^2 / (2\ln(CV_t^2 + 1))], \qquad (12) \\
&R\ variation: \quad \lambda_R \sum [\ln(R_t / \overline{R})^2]\,, \\
&R\ sex\ ratio: \quad \lambda_s [\ln(\overline{R}_M / \overline{R}_F)^2]\,,
\end{aligned}
$$

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.

Weights λ_j 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. 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.

To increase the efficiency of the parameter-estimation algorithm, we assumed that the smoothed relative frequencies of length and shell classes from survey year 1968 approximate the true relative frequencies within sexes. Thus, only total abundances of males and females for the first year were estimated; 3n unknown parameters for the abundances in the first year, where n is the number of length-classes, were reduced to one under this assumption.

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: $W = 0.010271\, L^{2.388}$,

Ovigerous Females: $W = 0.02286\, L^{2.234}$, (13)

Males: $W = 0.000361\, L^{3.16}$,

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^{o} W during 1968 to 2005 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

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

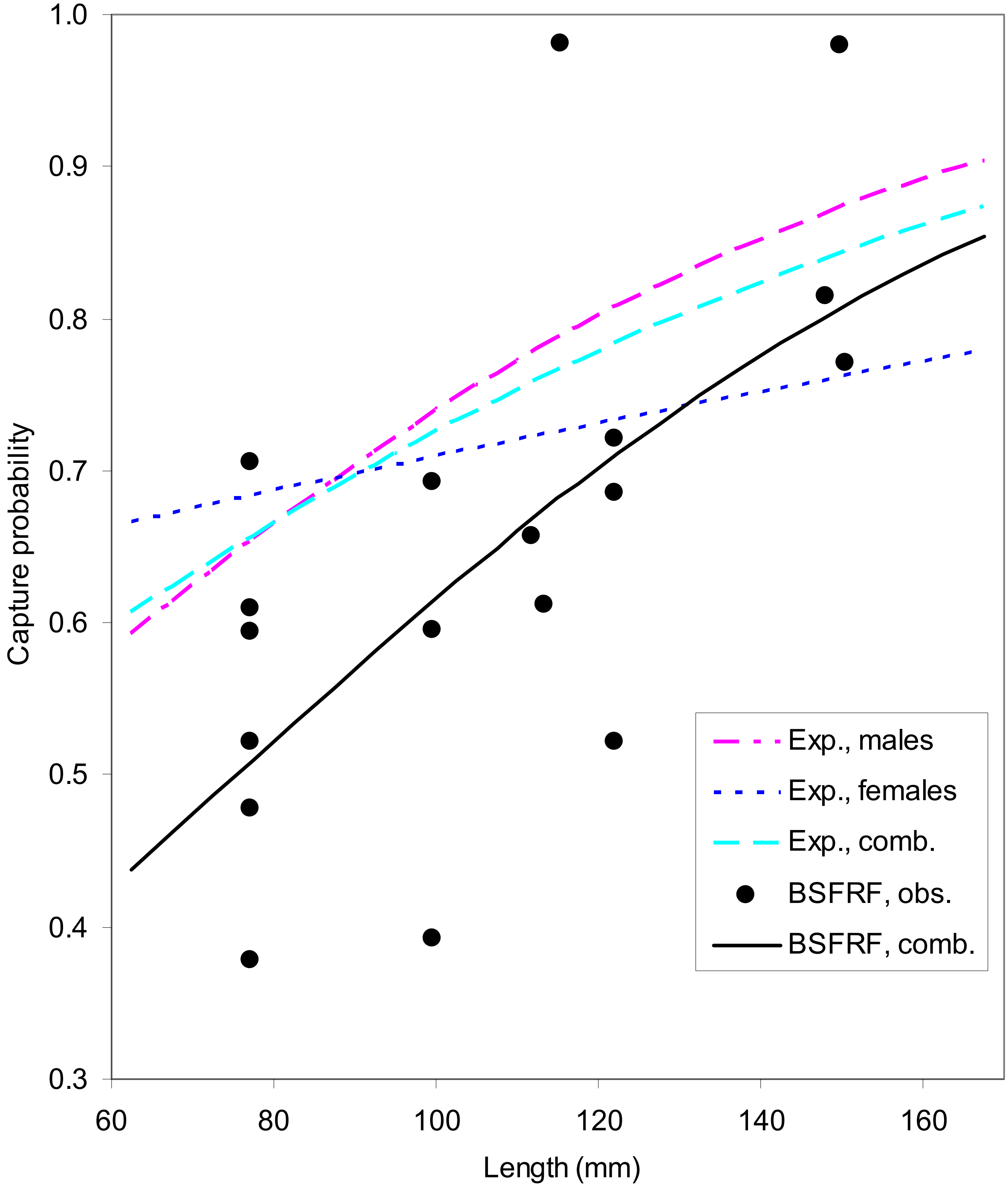

Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.

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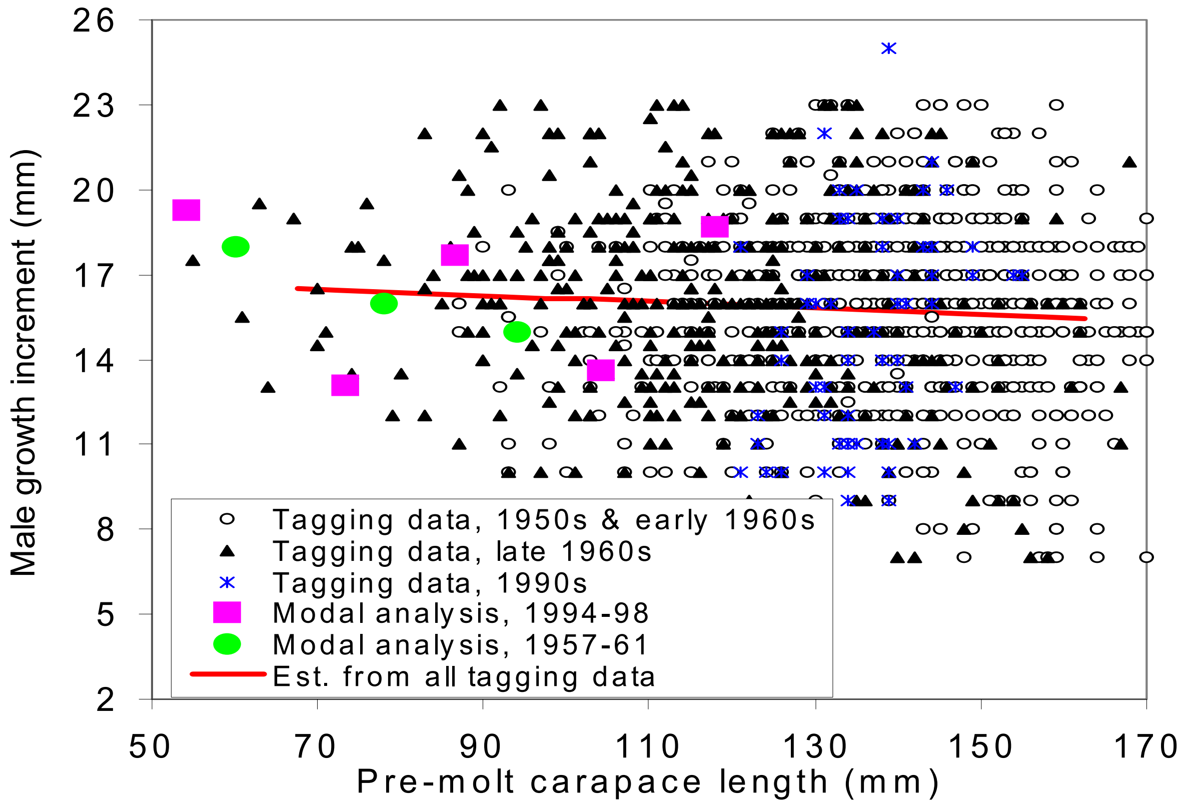

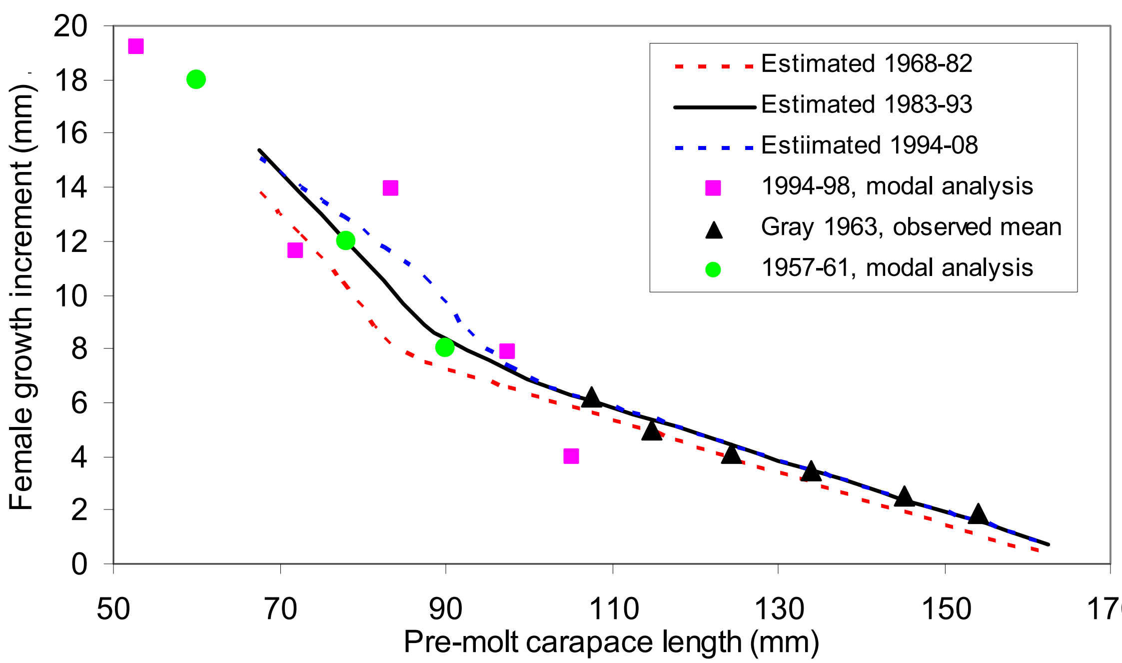

Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis.

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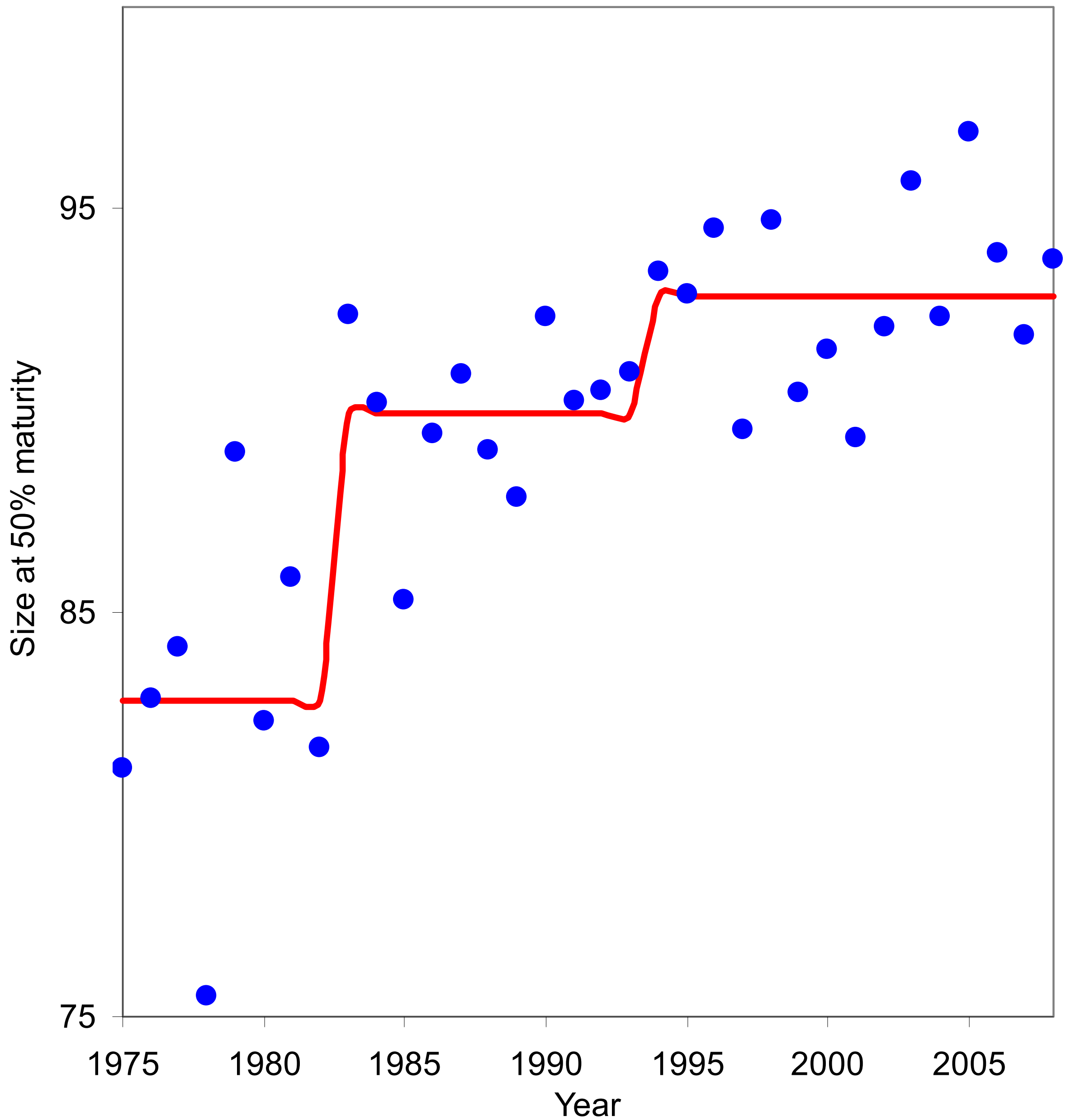

Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

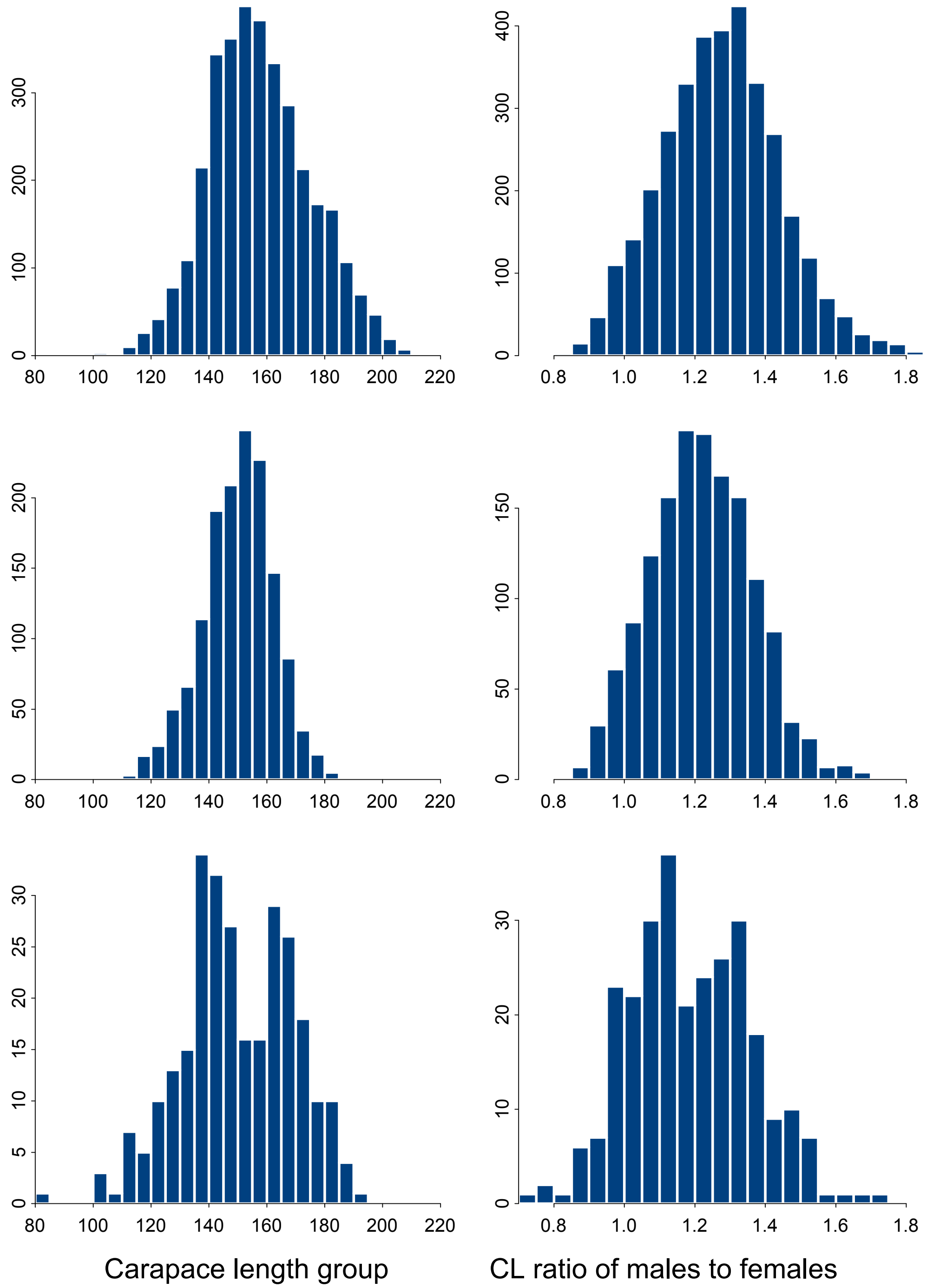

Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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

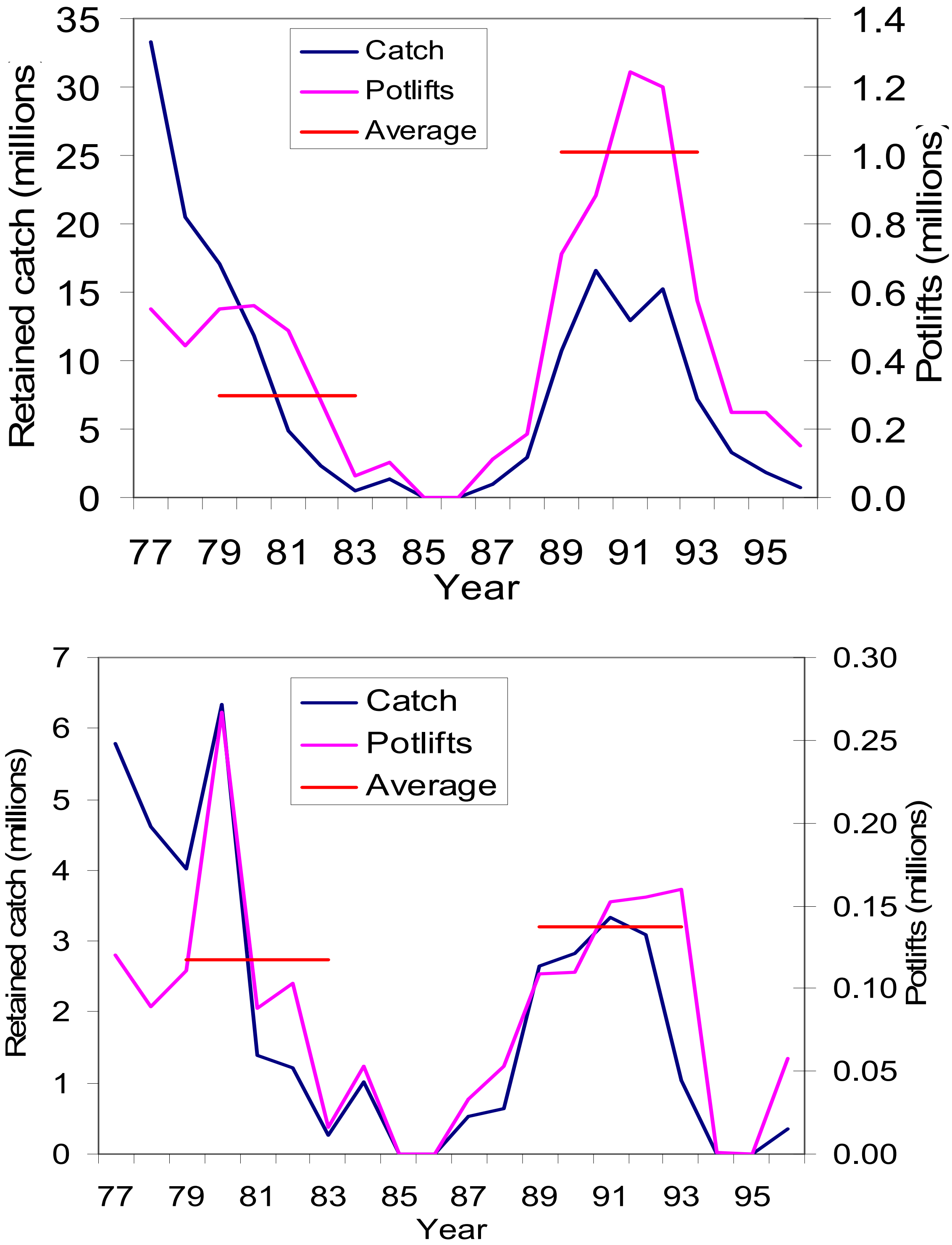

Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

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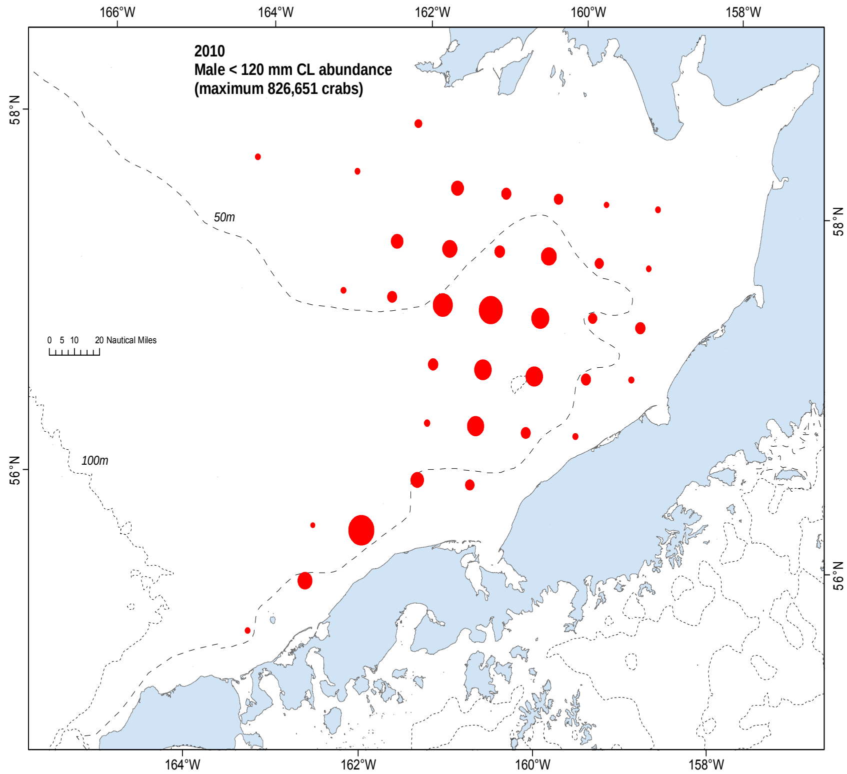
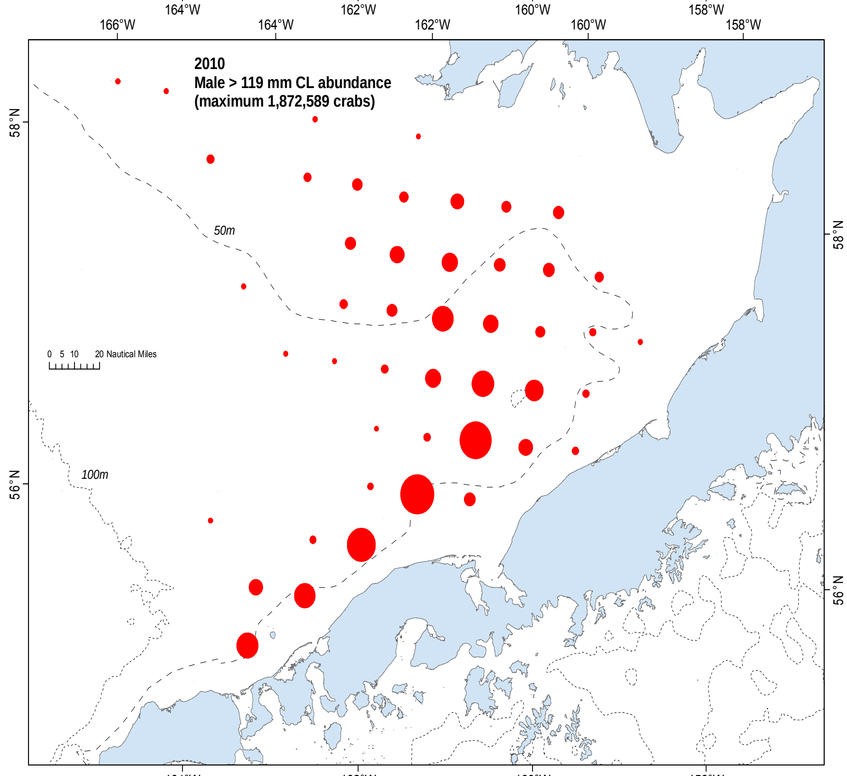
Appendix B. Spatial distributions of mature and juvenile male and female red king crabs in Bristol Bay from the 2010 and 2011 summer trawl surveys.





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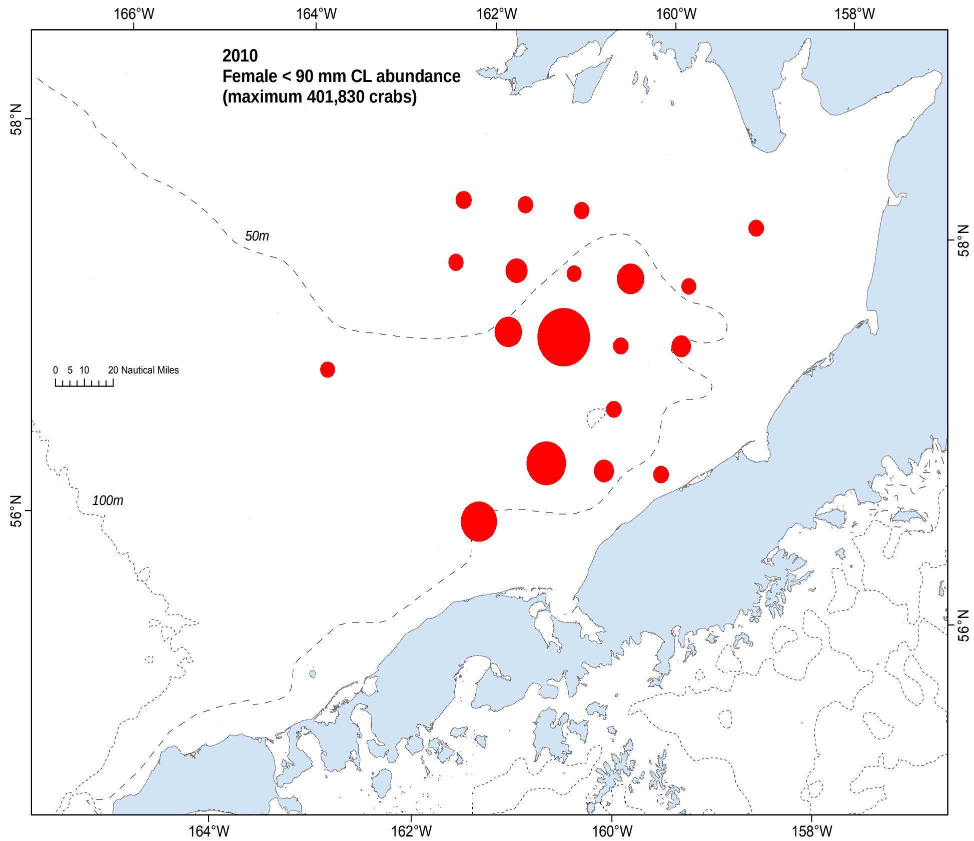
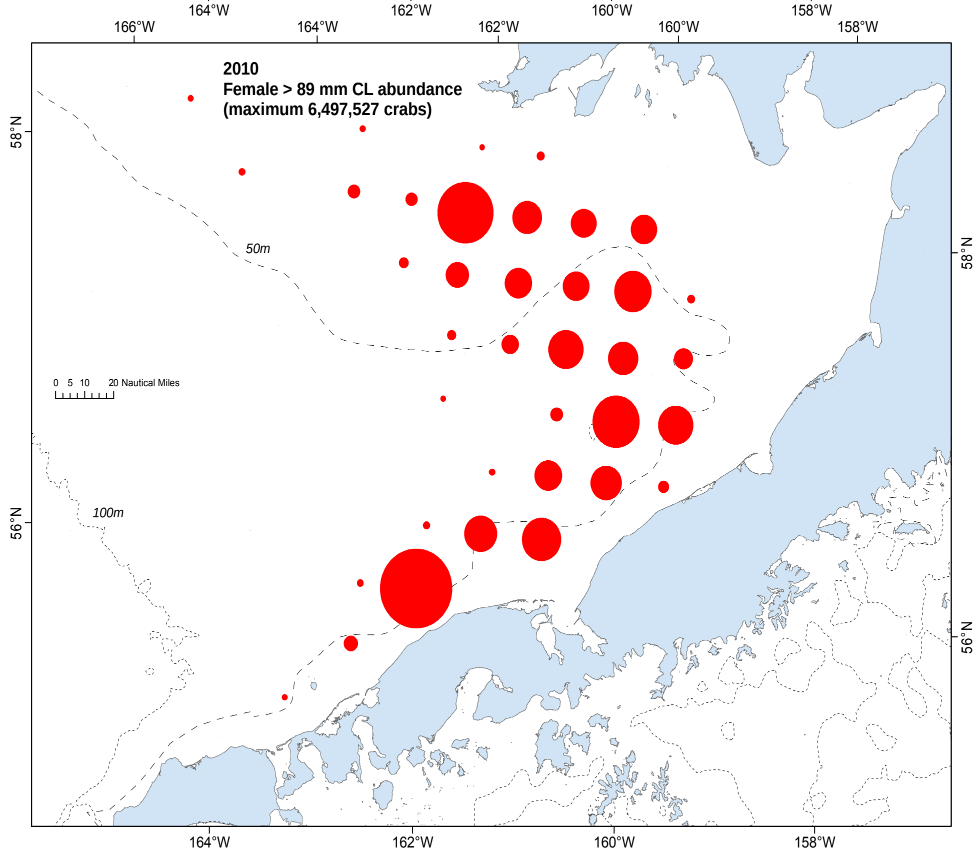
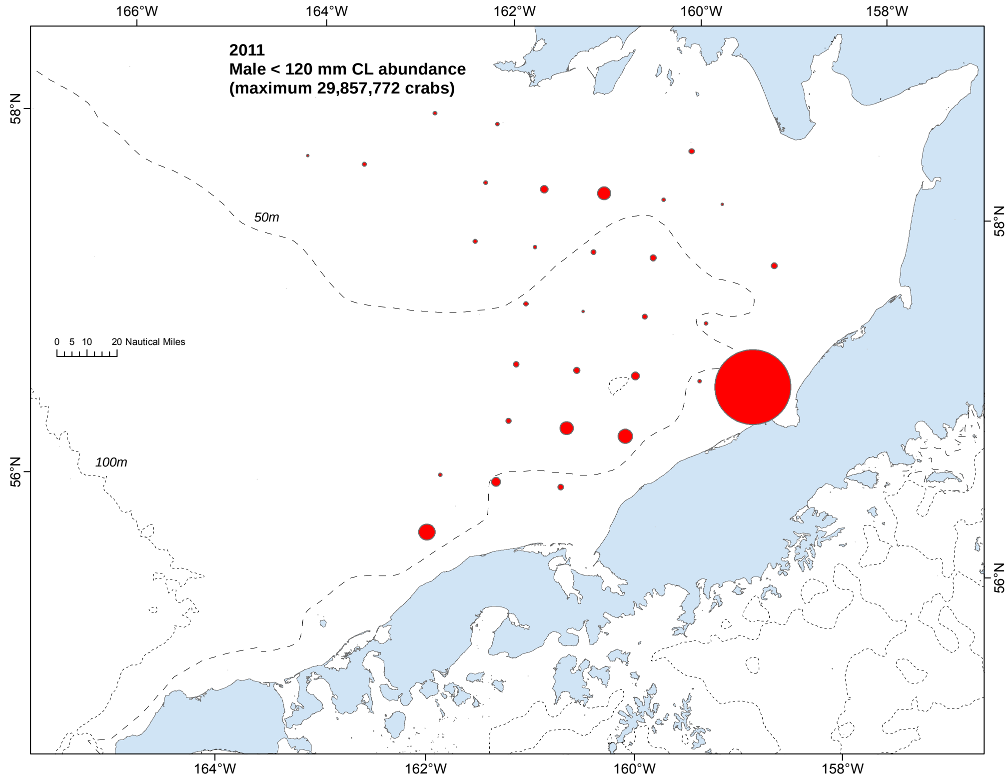
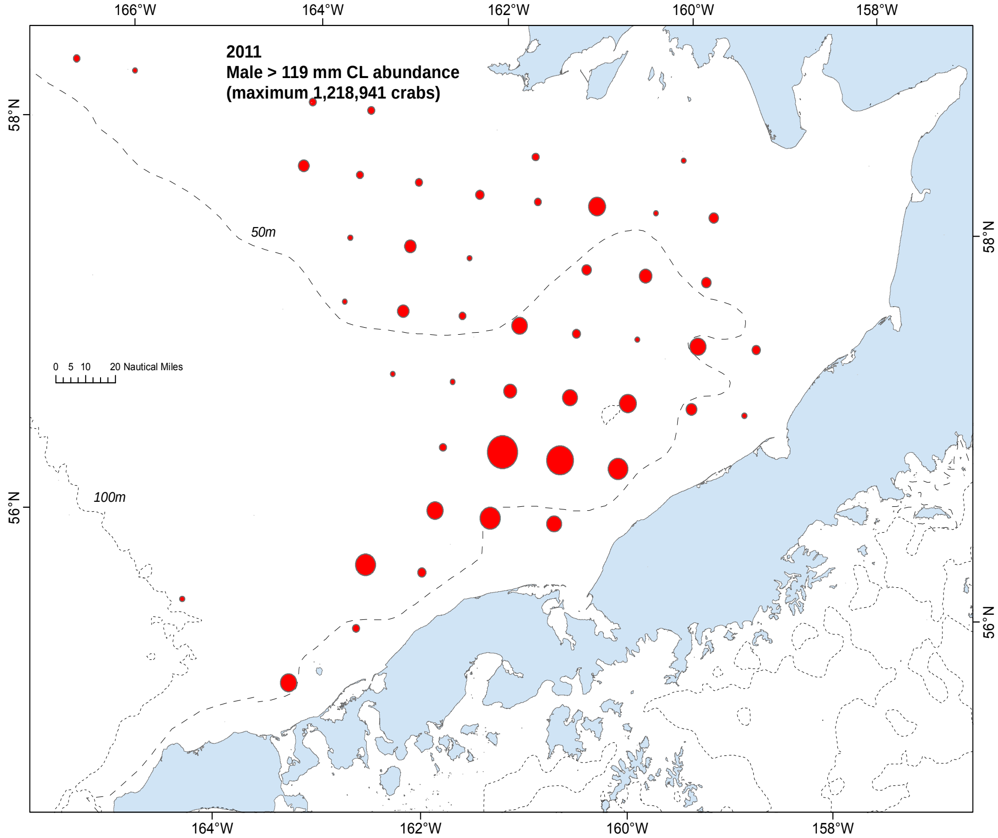

2010
Female < 90 mm CL abundance
(maximum 401,830 crabs)
166°W
164°W
162°W
160°W
158°W
58°N
56°N
50m
100m
0 5 10 20 Nautical Miles

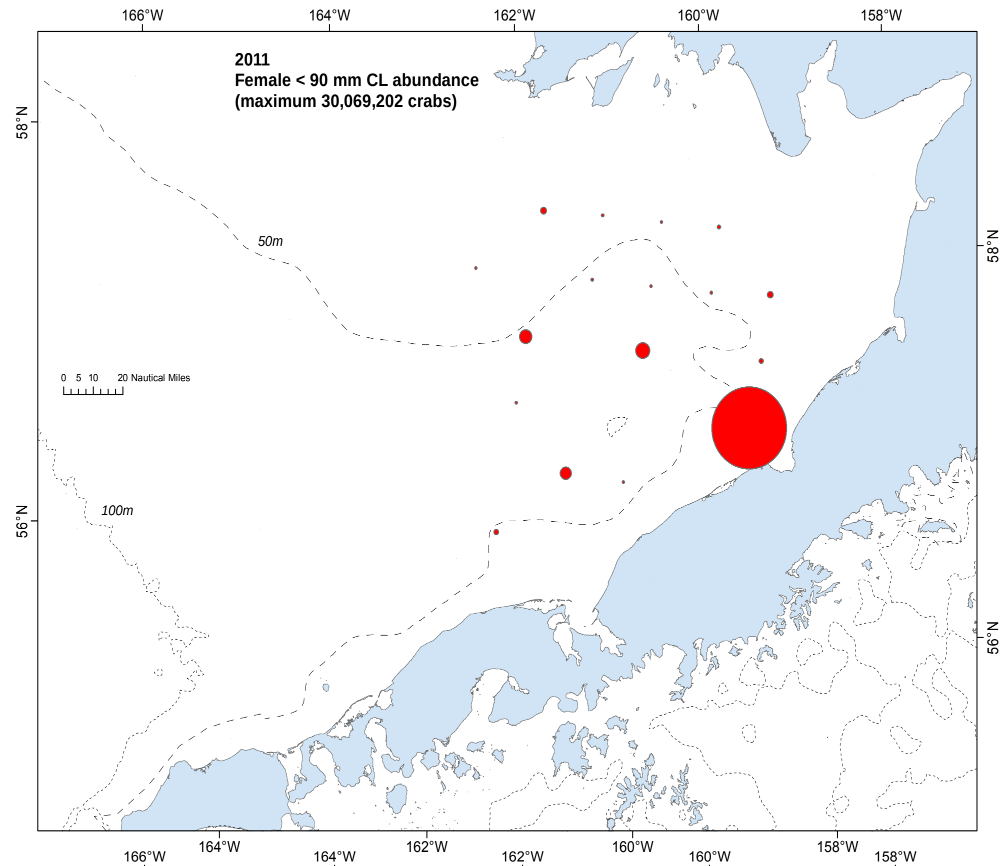

2010
Female > 89 mm CL abundance
(maximum 6,497,527 crabs)
166°W
164°W
162°W
160°W
158°W
58°N
56°N
50m
100m
0 5 10 20 Nautical Miles

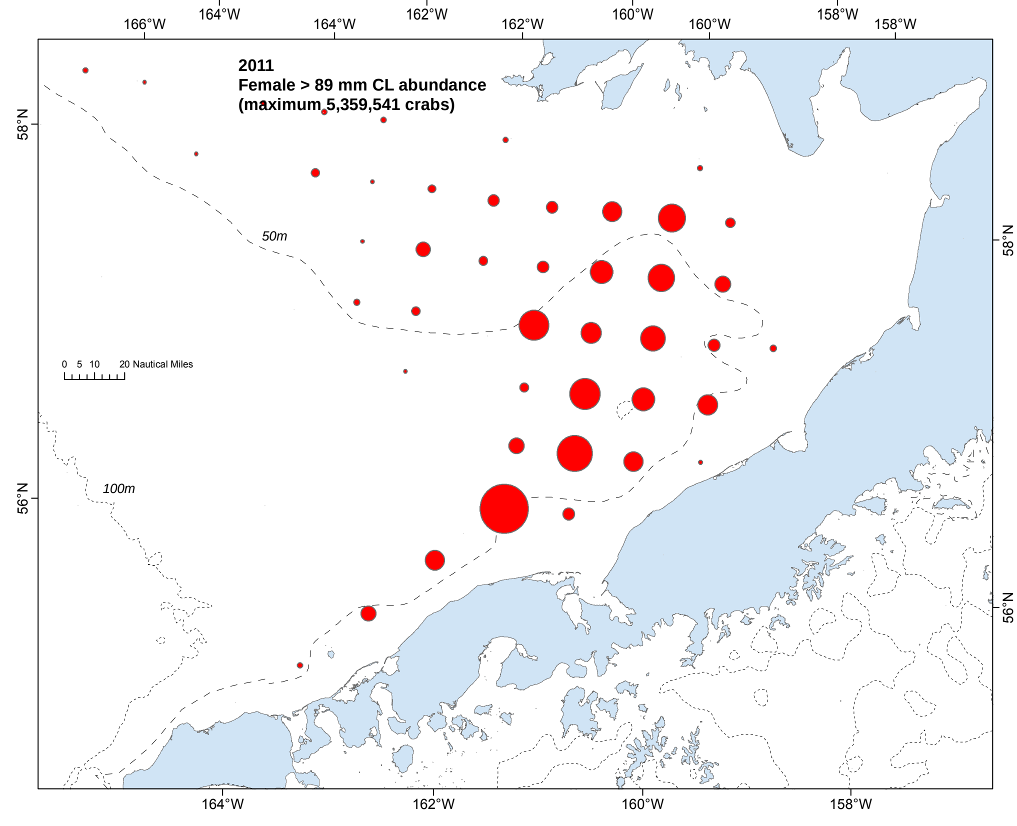
113


2011
Male < 120 mm CL abundance
(maximum 29,857,772 crabs)
50m
100m
0 5 10 20 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N


2011
Male > 119 mm CL abundance
(maximum 1,218,941 crabs)
50m
100m
0 5 10 20 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

114


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

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2011 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

Louis J. Rugolo and Benjamin J. Turnock
Alaska Fisheries Science Center
30 September 2011

Status of the 2010/11 Stock

Tanner crab MMB in 2009/10 declined substantially from previous years and fell below the minimum stock size threshold at survey time (MSST=0.5 $B_{MSY\ Proxy}$) (Rugolo and Turnock 2010). MMB at the time of the 2010 survey declined further by 8.3% relative to the 2009 survey. Under the plan, MMB estimated at the time of mating (mid-February) is gauged against the MSST to determine its status relative to the overfished criterion. This accounts for losses due to natural morality (M) from the survey to mating and losses due to directed and non-directed fishing. For the status determination, $B_{MSY\ Proxy}$=83.80 thousand metric tonnes (t) and the overfished status criterion, MSST, is 41.90 thousand t. After accounting for stock losses from M and those in the 2009/10 fisheries, the 2010 MMB at the time of mating was 28.44 thousand t. This represented a ratio of 0.34 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010).

For 2010/11, the State of Alaska closed directed commercial fishing for Tanner crab east and west of 166^0 W longitude (Pengilly 2010). The SOA's harvest strategy level of opening the Bering Sea District to fishing is 21 million pounds (9.5 thousand t) of mature female biomass in the Eastern Subdistrict at the time of the survey. Mature female biomass relative to this threshold is defined as the estimated biomass of females greater than 79 mm carapace width (cw). The 2010 survey estimate of total mature female Tanner crab biomass was 15.1 million pounds (6.8 thousand t).

For the current 2010/11 stock status determination, losses from the time of the 2010 survey to mating in 2011, plus losses from non-directed fishing are considered. There stock losses to directed fishing in 2010/11 due to the closure. After accounting for losses from M and the 2010/11 non-directed pot and groundfish fisheries, the 2011 MMB at the time of mating was 26.73 thousand t (-6.4% relative to 2010). This represents a ratio of 0.32 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. There is no change in the 2010/11 stock relative to the overfished determination made in 2010.

The management plan stock data table requested by the CPT is shown in Table A-1 of Appendix A.

Executive Summary

In 2011, Tanner crab MMB at the time of the survey was estimated at 41.8 thousand t representing a 23.2% increase relative to 2010. Mature male abundance rose 34.2% relative to 2010 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. The total abundance index for legal males increased 41.5% to 13.7 million crabs between 2010 and 2011owing largely to a high-density station in the area of the Pribilof Islands and the elimination of the 'hot-spot' re-sampling protocol in 2011. As a result, the 2011 survey male abundance and biomass estimates may be biased high relative to previous years that employed this re-sampling protocol. Legal males were distributed 37.1% (5.1 million crabs) east and 62.9% (8.6 million crabs) west of 166^0 W longitude compared to 56.1% (east) and 43.9% (west) in 2010 (Rugolo and Turnock 2010). The 2011 abundance index for pre-recruit male crabs (110-137 mm cw) was relatively unchanged (+0.1%) relative to 2010, and that for small males (<110 mm cw) increased 49.6% relative to 2010. Total male abundance increased 44.3% between 2010 and 2011 influenced by the increase in small and in legal-sized males. MMB in 2011 increased 23.2% relative to 2010. Compared to that estimated at the time of the 2010 survey, male recruit biomass (<110 mm cw) increased 47.8%, pre-recruit biomass (110-137 mm cw) decreased 0.9%, legal male biomass increased 44.2% and total male biomass increased 30.1%. Total male biomass in 2011 was comprised of 76.6% immature, 9.8% new shell mature and 13.5% old shell mature males.

Comparison of the male size frequency distributions between 2006 and 2011 revealed a decline in male abundance above 70 mm cw between 2006 and 2010, and relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-f). The male size frequency distribution in 2011 (Figure 10 f) reveals an apparent increase in pre-recruit abundance between 25-70 mm cw. The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e) and to 55-65 mm cw in 2011 (Figure 10 f). The increase in male abundance in 2011 if real and not biased high due to the change in sampling design, particularly for recruit-sized crab (<110 mm cw), is an encouraging sign. The relatively high percentage of old and very old shell males in the mature stock, however, may remain a concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab increased 8.7% in abundance in 2011 relative to 2010. Total female biomass in 2011 was comprised of 79.5% immature, 13.9% new shell mature and 6.6% old shell mature females. Among all female Tanner crab in 2011, 6.6% were collectively old shell and 91.1% new-hard shell. Small females (<85 mm cw) increased by 44.2% relative to 2010. Total 2011 female abundance increased 42.4% largely influenced by the increase in small females <85 mm cw. Total survey abundance of males and females combined increased 9.3% over that in 2010 driven by the increase in both small male and small female crabs. The survey length frequency distributions of female Tanner crab from 2006-2011 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11 a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance in 2007 through 2010. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw. A relatively strong recruit mode (35-50 mm cw) is apparent in the 2010 survey data (Figure 11 e) which grew to 55-70 mm cw in 2011 (Figure 11 f). The female size frequency distribution in 2011 (Figure 11 f) reveals an apparent strong pre-recruit abundance mode between 30-50 mm cw. The increase in pre-recruit sized female abundance in 2011 is an encouraging in terms of future reproductive potential.

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} for OFL-setting is the reference biomass ($B_{MSY\ Proxy}$)=83.33 thousand t of MMB at the time of mating estimated as the average survey male mature biomass at mating from 1974-1980 inclusive. The bias-corrected proxy B_{MSY} mean 1974-1980 MMB at mating is 93.24 thousand t. For Tier-4 stocks, the F_{OFL} is derived using an F_{OFL} Control Rule based on the relationship of current male mature biomass to the $B_{MSY\ Proxy}$ where, $F_{OFL}=\gamma M$. Amendment 24 and its associated EA defines a default value of gamma=1.0. Gamma is allowed to be less than or greater than unity resulting in overfishing limits more or less biologically conservative than fishing at M. Amendment 24 also cautions that γ should not be set to a value that would provide less biological conservation and more risk-prone overfishing definitions without defensible evidence that the stock could support fishing at levels in excess of M. The resultant overfishing limit (F_{OFL}) for Tier-4 stocks is specified in terms of a Total Catch OFL that includes all stock losses (retained catch, discard and bycatch mortalities) for males and females combined by the directed and all non-directed fisheries.

Using the bias-corrected 1974-1980 proxy B_{MSY}=93.24 thousand t, the estimated the 2011/12 Total Catch OFL=2,416.77 t for males and females combined. Total projected losses to MMB are 2,300.76 t. Conditioned on the 2011/12 snow crab retained catch=66.10 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 50.32 t and 2,156.09 t, respectively. The retained part of the catch OFL of legal-sized crabs is 94.35 t. At a 2011/12 snow crab retained catch= 70.92 thousand t, the 2011/12 retained Tanner crab catch is zero. At values of 2011/12 snow crab retained catch > 70.92 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch≤70.92 thousand t, the projected 2011/12 MMB at the time of mating is 33.54 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.36 and the 2011/12 F_{OFL}=0.07. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 116.0 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.06 and 0.03 respectively.

Using the non bias-corrected 1974-1980 proxy B_{MSY}=83.33 thousand t, the estimated the 2011/12 Total Catch OFL=2,752.85 t for males and females combined. Total projected losses to MMB are 2,631.76 t. Conditioned on the 2011/12 snow crab retained catch=66.10 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 165.45 t and 2,156.09 t, respectively. The retained part of the catch OFL of legal-sized crabs is 310.22 t. At a value of 2011/12 snow crab retained catch= 81.95thousand t, the 2011/12 retained Tanner crab catch is zero. At values of 2011/12 snow crab retained catch > 81.95 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch≤81.95 thousand t, the projected 2011/12 MMB at the time of mating is 33.20 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.40 and the 2011/12 F_{OFL}=0.08. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 121.08 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.07 and 0.05 respectively.

Status and catch specifications (1000 t) for EBS Tanner crab.

Year	MSST	Biomass (MMB)	OFL	TAC [E+W]	Retained Catch	Total Catch
2005/06[1/]		39.28		0.73	0.43	1.61
2006/07[1/]		59.18		1.35	0.96	3.15
2007/08[1/]		68.76		2.55	0.96	3.63
2008/09[1/]	43.04	53.63	7.04	1.95	0.88	2.25
2009/10	41.90	28.44	2.27	0.61	0.60	1.69
2010/11	41.67[2/]	26.73	1.45	0.0	0.0	0.87
2011/12	41.67	33.20[3/]	2.63[4/]			

Notes:
1/ Biomass and threshold definitions based on survey estimates derived using fixed 50 ft net width area-swept calculations.
2/ Non bias-corrected mean 1974-1980 MMB at mating using revised survey biomass estimates
3/ Projected 2011/12 MMB at mating after extraction of the estimated total catch OFL using non bias-corrected proxy B_{MSY}
4/ Total catch OFL for 2011/12 fishery based non bias-corrected proxy B_{MSY}

In 2010/11, Tanner crab MMB was below the MSST at the time of the 2010 survey, below MSST at the time of the 2010/11 fishery, and below MSST at the time of mating in mid-February 2011. Overfishing did not occur during the 2010/11 fishing year as total catch losses (0.87 thousand t) did not exceed the total catch OFL (1.45 thousand t). The 2010/11 MMB at the time of mating represented a ratio of 0.32

relative to $B_{MSY\ Proxy}$. The 2010/11 Tanner crab stock is determined to be overfished. In 2011 at the time of the survey, Tanner crab MMB increased 23.2% relative to 2010. Under a zero retained catch harvest strategy in 2011/12, there will be no change in the 2011/12 stock status relative to the overfished determination reached in September 2010.

A. Summary of Major Changes

1. Management of Fishery:

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab that will be in effect for the 2011/12 fishery. The previous minimum legal size limit was 5.5" (138 mm cw) throughout the Eastern Subdistrict. The new regulations established different minimum size limits east and west of 166^0 W longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of 166^0 W longitude, respectively.

2. *Input Data*:

This assessment examined area-swept biomass estimates from the NMFS bottom trawl survey for 1969-1975. Data for years 1969-1973 are not used in the OFL analysis. Previous survey data for 1969, 1970 and 1972-1975 for males and 1974-1975 for females were extracted form historical International Pacific Fisheries Commission (INPFC) documents.

3. Assessment Methodology:

There are no major changes to assessment methodology in this 2011 SAFE relative to the 2010 SAFE (Rugolo and Turnock 2010) in determining stock status or estimating the F_{OFL} and the catch components comprising the Total Catch OFL. Two additional approaches are added to this assessment to address management strategy changes and MSA requirements:

1. To address the new size limit strategies in effect for the 2011/12 fishery, we show an example of a method to derive guideline harvest levels that apportions the retained catch component of the OFL to the areas east and west of 166^0 W longitude (*see* Section F).
2. To address the requirement of the MSA to establish ACLs based on an ABC control rule that accounts for scientific uncertainty in the OFL, we develop a Tier-4 approach to derive an ACL=ABC for the 2011/12 fishery (*see* Section G).

B. Responses to SSC and CPT Comments

1. SSC Comments:

June 2011 Meeting:

In their review of the 2011 crab draft SAFE report, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *Authors Rugolo and Turnock developed a draft assessment in which they responded to changes suggested by the CPT and SSC in 2010, and to recommendations of the Crab Workshop (February 2011) and the SSC in April 2011. The CPT was encouraged by the changes and felt progress was being made, although the model is not yet ready for use in the stock assessment. The strategy is to continue improvements and evaluate it for assessment purposes in May 2012. Following a recommendation from the Crab Workshop, years 1969 through 1974 were not used for data quality reasons. The period 1974 through 1980 is now the period used for determining reference biomass; given the shortness of this period, the SSC recommends strongly that this time period be evaluated as intended by the authors.*
- *The main issues that have arisen in past reviews were discussed:*

- *Hybrids: previous reviews were concerned that misidentification of hybrids might have degraded data quality. However only 1 hybrid has been seen in the survey in the last 8 years of legal Tanner size. The authors did not think this is a big issue in recent years.*
- *Early bycatch data in groundfish fishery. Specifically, why is bycatch estimated to be so high in 1973/74 and 1974/75. Concerns were raised about mis-identification of snow crabs in previous SSC comments. The authors are examining this issue.*
- *Patterns in survey length frequency. See model scenarios below.*
- *Lack of fit to survey biomass between 1983 and 1987. See model scenarios below.*

- *The following model scenarios were decided at the CPT meeting:*
  - *Estimate survey catchability, Q, to see if this improves survey biomass fit in mid 1980s.*
  - *Include the underbag data.*
  - *Estimate growth and natural mortality with priors (especially important since growth data is borrowed from Kodiak).*
  - *Try different selectivity periods based on fishery changes.*
  - *Try dynamic initial biomass estimation.*
- *The SSC agrees with this plan of action.*
- *The CPT would wants to use the Tanner model for population projections despite its lack of approval for assessment. The SSC urges caution in proceeding in this direction. It's more appropriate that a model is accepted for assessment and then used for the projection. The CPT requested the authors to go ahead with the rebuilding model for evaluation in September 2011 if it can produce plausible results. Rebuilding scenarios would include no catch, bycatch only, different percentages of $F_{35\%}$, and the SOA harvest strategy. Recruitment scenarios could include random, a spawner-recruit relationship (SRR) model, a SRR with autocorrelation, an SRR with periodic behavior, and others. The SSC will review these scenarios and the performance of the model in September, 2011.*

These SSC comments and recommendations pertain to the Tanner crab stock assessment model (TCSAM) rather than to this Tier-4 assessment and 2011 SAFE report. The authors have addressed these comments in the separate TCSAM report that will be presented to the CPT and SSC in September 2011. The authors agree with and have addressed the SSC recommendations pertaining to the model.

The TCSAM has been extensively revised since the May 2011 CPT meeting. The authors formulated several model configurations to show the effects of principal changes to the model, and recommend a *Base Model* that attends to virtually all of the recommendations of the Crab Workshop, the SSC and plan team. The model is significantly improved over earlier intermediate versions seen by the Crab Workshop and SSC in April 2011. In the author's view, the *Base Model* represents the best available science and, while not perfect, a level of performance in modeling stock and fishery dynamics that may be acceptable to status of stock determination, OFL-setting and projection analysis. The authors will present the model to the CPT and SSC in September 2011 for review. Approval of the model for assessment will be made at the May 2012 CPT and June 2012 SSC meeting under the Council process. If it's approved, the model will apply to OFL-setting and stock status determination in the 2012/13 assessment cycle.

<u>October 2010 Meeting</u>:
In their review of the 2010 SAFE reports, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *The authors were responsive to SSC comments from June 2010. Lacking an assessment model, the authors continue to base stock status determination on results from the annual summer trawl survey. This year, the revised survey estimates were corrected based on survey net width for the first time and included the 2010 summer survey. The latest results confirm that* *estimated Tanner crab abundance has fallen below the MSST, which will require a rebuilding plan to be developed by October 1, 2012. The SSC noted a sharp one-year decline in the estimated abundance of mature females. Here, and in similar instances, the SSC would like the authors to report whether such declines are statistically significant.*

- *A stock assessment model is under development, but not yet ready for review. It's imperative that the model be completed for use as a projection model in the rebuilding analysis. A workshop on crab model development, held in February 2011 will be helpful in this regard. As noted in the June 2010 SSC report, the SSC would like the authors to develop a model capable of handling two different minimum size limits in the eastern and western areas, because the Alaska Board of Fisheries may take such an action at their next meeting on BSAI crabs. Also, the SSC looks forward to a model that considers recent results on gear selectivity.*
- *As indicated in the SSC's June 2010 report, the SSC concurs with the CPT that the years used for status determination should be investigated with respect to potential changes in productivity, and a rationale provided for the selected choice. In addition, the issue of Tanner/snow crab hybrids should be examined. Apparently, the hybrids are allocated to one species or the other based on eye color and mouth shape in the landings, but are identified as hybrids in the surveys and not counted toward the survey estimates for Tanner and snow crab. While in practice this could be a conservative approach, it would be useful to know how the current practice affects species-specific catches relative to the specified harvest strategy and whether some species-specific accounting needs to be better reconciled between stock assessments and catch reporting.*

The Tanner crab stock is currently managed under Tier-4 designation using trawl survey biomass estimates to gauge stock status. The Tanner crab stock was determined to be overfished based on the final 2010 stock assessment (Rugolo and Turnock 2010).

A stock assessment model for Tanner crab is in development. Results on the performance of the model were presented to the Crab Modeling Workshop in February 2011, to the SSC in March 2011 and to the CPT in May 2011. The Workshop reported that, "As currently formulated, the model is not sufficient for use in rebuilding analysis." The SSC reported in March 2011 that, while improvements to the model following the Workshop "…resulted in noted improvements in model fits, much work remains to be done and the current model is not yet ready for use in stock assessment or stock rebuilding analysis." We agree with those conclusions. The assessment model has been further developed since the May 2011 CPT meeting and will be presented to the CPT and SSC in September 2011 for review and acceptance for rebuilding analysis and for consideration of its use in stock assessment and OFL-setting. Approval of the model for assessment will be made at the May 2012 CPT and June 2012 SSC meeting under the Council process. If its approved, the model will apply to OFL-setting and stock status determination in the 2012/13 assessment cycle.

This assessment will propose an approach for review by the CPT and SSC to accommodate the new size limit strategy in the eastern and western areas under Tier-4. The years selected for determination of biomass reference points is an action item for the May CPT meeting (see response to September 2010 CPT recommendations). As indicated, Tanner-snow crab hybrids are enumerated in survey data although it's uncertain as to the level of accuracy in this designation or its consistency over the time series. The frequency of hybrids in the catch data is unknown and it's not apparent how the catch data can be retrospectively partitioned into non-hybrid and hybrid catch.

We expect the effect of Tanner-snow crab hybrids in the Tanner crab catch data to be negligible as somatic growth would need to approximated that of Tanner crab to result in hybrids retained by the directed Tanner fishery at legal size (138 mm cw). The largest size bin used in modeling snow crab is 130-135 mm cw plus group as snow crab larger than 135 mm cw are exceedingly uncommon. We examined the sizes of Tanner-snow crab hybrids observed in the survey data for 2004-2008 as an example. For these years, the largest and next largest size (mm cw) hybrid crab observed were: 2004 (126, 123), 2005 (133, 105), 2006 (138, 121), 2007 (133, 130), 2008 (149, 135). Only in 2008 was a single hybrid crab observed larger than 138 mm cw. We'll examine extant survey data to more completely understand the potential impact of the occurrence of hybrid crab in the Tanner retained catch. The authors recommend that improved species-specific accounting protocols be implemented to reconcile stock assessments and catch reporting.

June 2010 Meeting:
In their review of the crab SAFEs and OFLs, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *Tanner crab abundance has fallen below the MSST which will require a rebuilding plan to be developed. A stock assessment model is under development but not yet ready for review. The plan is to get CPT and SSC review in September / October 2010 for use in the rebuilding plan to be drafted by May 2011. The SSC would like the authors to develop a model capable of handling two different minimum size limits in the eastern and western areas as the BOF may take such action; this might be beneficial for optimal harvesting.*
- *Lacking a stock assessment model, stock status determination continues to be based on the trawl survey. This year the revised survey estimates corrected for survey net width were used for the first time. Final determination will be made after the summer survey.*
- *The SSC concurs with the CPT that the stock is in Tier 4, given the survey series and an estimate of M, and with the use of a default value for gamma of 1 to set OFL. The SSC requests that the authors and CPT reconsider the choice of years to be used in calculating B_{MSY}, currently 1969–1980. The issues of data quality and regime shift need to be more fully addressed. The SSC commented that it's possible that the generally warmer Bering Sea is in a new regime, with more groundfish predators (e.g., cod) and competitors (e.g., flatfish), which has caused a change in Tanner crab productivity. Two options might be to extend the time period to the current time or start the time period later, depending on identification of the shift.*
- *The CPT recommended that the text for OFL calculation should be revised to represent what was actually done. It might be helpful for the CPT to elaborate on what was incorrect in the SAFE, so that the authors can make the appropriate changes*.

As shown in this assessment, the 2009/10 Tanner crab stock is below the MSST and determined to be overfished. A length-based stock assessment model is in development. The current goal is to complete model development and have it approved by the CPT in May 2012 and by the SSC in June 2012 for application in 2012/13 OFL-setting. The model will be presented to the CPT in September 2011 for consideration of its use in developing the rebuilding plan. The timing of the start of the two year time frame for implementing the rebuilding plan by the Council is uncertain. Neither has it been specified when the draft the rebuilding plan will be required, nor the dates of the plan amendment process regarding review, comment and finalization of the rebuilding plan by the Council. The CPT discussed the requirements of for draft completion in May 2011 and will revisit this issue at the September 2011 meeting. The authors will have a better understanding of the requirements of rebuilding analysis once the elements of the rebuilding plan are identified and the required benchmark dates identified.

At the May 2010 meeting, the CPT considered genetic evidence presented in support of partitioning the EBS Tanner crab population into two stocks east and west of 166^0 W longitude. The CPT found this evidence lacking. The authors have found no evidence to support the argument that the eastern Bering

Sea shelf is member to two distinct, non-intermixing, non-interbreeding stocks of Tanner crab in which the linked population and fisheries dynamics are bifurcated east and west of 166^0 W longitude. The authors will consider approaches to handle different minimum size limits for the eastern and western areas consistent with the total catch OFL that may underlie optimum harvest strategies.

The authors agree that the stock status determination is based on trawl survey biomass and that these estimates are based on revised bottom trawl survey data using measured net widths beginning in 2010/11.

The authors agree that Tanner crab is a Tier-4 stock in which the OFL is based on M using a gamma of 1.0. As a general observation, we agree that over the time period 1960s to present, there has been an apparent shift in the eastern Bering Sea from a more decapod-dominated ecosystem to a more teleost-dominated ecosystem. We examined and could find no evidence of a change in Tanner crab productivity over this period, nor of changes in reproductive dynamics or life-history characteristics which would reveal temporal changes in recruitment success resulting from the "*generally warmer Bering Sea*". The authors have shown (Rugolo and Turnock 2010) that the historical patterns of fishery exploitation on MMB from the late 1960s to the present exceeded rates that we would deem biologically reasonable for this stock. Exploitation rates on MMB rose in the late 1970s and peaked at 0.69, then declined with the collapse in stock biomass through the mid-1980s, then rose again to 0.45 following the build up in the stock in the late1980s to early-1990s. At these rates, the Tanner crab stock would not be expected to persist at sustainable levels in the short-term, nor modulate around B_{MSY} in the long-term.

If there have been effects of "*generally warmer*" ambient temperatures on Tanner crab productivity or from increased competition and predation on survival, empirical data don't exist to demonstrate these effects nor would the magnitude of such effects, if any, be readily separable from the effects of excessive fishing mortality on the stock. The former range of years (1969-1980) used for estimating $B_{MSY\ Proxy}$ included a five year period (1976-1980) of sharply declining and low male mature biomass. Inclusion of these years was required by the SSC in 2009. The authors do not believe that these that these five years represent levels of male mature biomass that, if fished at F_{MSY}, would yield MSY to the fishery. The revised range of years (1974-1980) for estimating $B_{MSY\ Proxy}$ also includes this five years of declining and low male mature biomass. Extending the time period to the current time would include time periods where the stock had collapsed and the fishery closed due to conservation concerns. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of proxy B_{MSY} would be inconsistent with the tenet of selection of a range of years that represent the stock living dynamically at B_{MSY} while being fished at rates approximating F_{MSY}, and thereby yielding MSY to the fisheries.

The OFL calculation in this and previous assessments represents what is done. In this assessment, the authors revised Section E.2 (Model Description) to clarify the computational logic used in OFL-setting.

2. CPT Comments:

<u>May 2011 Meeting</u>:

In their review of the draft 2011 SAFE, the CPT made the following comments and recommendations:

- *The team had no recommendations on the proposed approach for estimating retained catch OFLs for the areas east and west of 166^0 W longitude.*
- *The team recommends the assessment include an author's recommended ABC and a rationale for the recommended ABC. How the OFL is calculated should not change but rather be reflected*

in the rationale for the lower ABC which accounts for a source of uncertainty not reflected in the standard calculation process.

- *On the stock assessment model, the team encourages development and an update on the model in September 2011 focusing on model fits and to move forward as quickly as possible. Suggestions on the model by the team:*
  - *free up Q to address the residual pattern*
  - *include underbag data as it pertains to this assessment*
  - *free up as many parameters (e.g., growth, M) as possible perhaps – e.g., growth data are not from the Bering Sea*
  - *examine length compositions and other data sources to evaluate model fit to the survey data, particularly in the early years.*
  - *consider a large number of selectivity time-blocks to see what the data want, then explore if reasons to justify choices of selectivity time-blocks. (Doug noted Bristol Bay was closed in mid-1990s for RKC so no bycatch occurred in BBRKC fishery, thus entire catch in west*
  - *examine dynamic B_0, i.e. what would have happened has the fishery never occurred*
- *The team discussed base years for estimating B_{MSY} proxy for this stock. The team noted that it's now a very limited number of years, and questioned why this stock has such a different year-set than all others. There should be some common productivity periods for all stocks. The stock with the most similar catch history is BBRKC. The assessment document needs to justify the assumed change in production change. In particular, there needs to be more information on recruitment and trends in recruitment over time.*
- *Possibilities for the years used to estimate the B_{MSY} proxy include: (a) 1974-1980; (b) early 1990's when stock higher (than now); (c) years in which F was at a reasonable level; and (d) the entire time-period. The team recommended that the author consider all four options and that the assessment document argue why each option is and is not appropriate. The authors should also consider the status of the fishery historically.*
- *The team discussed how to develop and analyze rebuilding plan alternatives in absence of a model. Without an approved assessment model, it's not possible to estimate the required pieces of a rebuilding plan: minimum time to rebuild, target time to rebuild, and harvest rate that would achieve rebuilding in the target time period. Or to evaluate different rebuilding options. The team will develop rebuilding plan alternatives in September 2011 as the structure of the alternatives will be driven by whether the assessment model can be used. The model could be used for initial projection of the time frame to rebuild and which can be updated as the model improves. The team recommended going forward with projection model focusing on recruitment; it should be possible to use the model to develop a rebuilding plan if the model is sufficiently close to acceptance in September.*

The approach presented in the document to apportion the retained catch OFL into TACs east and west of 166^0 W. longitude is for illustration. The illustrated TACs are not area-specific retained catch OFLs. The sum of all stock losses in the eastern and western areas is gauged against the Total Catch OFL to assess if overfishing occurred.

The authors will recommend an ABC and the rationale for the additional uncertainty in the calculation.

The authors have addressed the team's recommendations on the Tanner crab stock assessment model, in the separate TCSAM report that will be presented to the CPT and SSC in September 2011.

The authors considered the team's comments on the base years for estimating the B_{MSY} proxy for this stock. The team's observation that there should be a common productivity period for all stocks is unfounded, presumes that the principal driver of crab reproductive potential is the environment, and that the latter has changed magnitude and direction sufficient to explain observed crab stock history. Each crab stock has experienced its own exploitation history, expresses its own unique reproductive dynamics, and its own compensatory mechanisms and responses to external forces. There should be no *a priori* expectation that all crab stocks in the eastern Bering Sea should have the same reproductive history or change in productivity, if any, as a result of forces operating against equilibrium such as exploitation or elements embodied in natural mortality. The authors have not assumed a "*change in production*" in the assessment. The authors have noted that they find no evidence of a change in Tanner crab productivity, nor of changes in reproductive dynamics or life-history characteristics which would reveal temporal changes in recruitment success consistent with the so-called '*regime shift*' paradigm.

The authors have considered the suggested possibilities for the years to estimate the B_{MSY} proxy. This assessment presents results of Total Catch OFL based on the status quo period 1974-1980 (SSC 2009) and the entire time period for comparison. We considered and found no intermediate period (e.g., 1990s when the stock was higher than now, or years in which F was at a reasonable level) that represents, or resulted in biomass that is consistent with B_{MSY}. The secondary mode of mature male biomass in the late-1980s and early-1990s was affected by contemporaneous and antecedent high exploitation rates. A B_{MSY} proxy estimated using these years would underestimate the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries. While exploitation rates were low in the early-to-mid-1980s, the duration is insufficient given the 'k' reproductive strategy of Tanner crab to have resulted in the stock reaching equilibrium in the early-1990s which, coupled with the rise in exploitation in the 1990s that eroded stock biomass. The period 1980 to 2010 is characterized by exceedingly low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to 2010) of collapsed stock. During this period, the stock experienced exploitation rates in excess of current F_{MSY} estimates – at approximately 3M in the late-1970s, and 2M in the late-1980s preceding the collapses. During 1980-2009, the stock has not maintained itself at a level that could be reasonably construed as in dynamic equilibrium or at a level indicative of B_{MSY} capable of providing maximum sustainable yield to the fisheries by definition. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of a proxy B_{MSY} is inconsistent with the tenet of selection of a range of years that represent the stock living at B_{MSY}, being fished at rates approximating F_{MSY}, and thereby yielding MSY to the fisheries.

The TCSAM has been extensively revised since the May 2011 CPT meeting, and significantly improved over earlier intermediate versions seen by the Crab Workshop, SSC in April 2011 and CPT in May 2011. The CPT will review the model for the purpose of use in stock assessment and the rebuilding analysis. In the author's view, the recommended *Base Model* represents the best available science and a level of performance in modeling stock and fishery dynamics that may be acceptable to assessment and projection analysis. The authors will present the CPT results of a stock projection model run using the *Base Model* configuration as a case example of the utility of the model for rebuilding plan analysis.

September 2010 Meeting:

In their review of the 2010 stock assessment, the CPT made the following recommendations related to Tanner crab rebuilding plan and stock assessment:

- *The rebuilding plan will need to consider and address possible effects of groundfish fisheries and may need to recommend controls on the mortality to EBS Tanner crab due to bycatch in the groundfish fisheries.*
- *The time period for computing B_{REF} should be reviewed and evaluated in the rebuilding plan; options for that time period should be considered and evaluated for review by the SSC. The CPT*

received public testimony recommending a reconsideration of the validity of the period used to compute B_{REF} in the September 2010 assessment (i.e., 1969-1980).

The authors agree that the Tanner crab rebuilding plan must address the effects of bycatch from the groundfish fisheries. To the extent that non-directed stock losses may affect stock recovery, the plan may need to recommend controls on the mortality of Tanner crab resulting from these fisheries.

The time period of years selected for determining the biomass reference point is an action item for the May CPT meeting. Based on the outcome of the Crab Modeling Workshop (February 2011) and recommendations of the SSC (March 2011), the 1969-1973 survey biomass estimates will be excluded from the analysis. By this change, the revised time period for computing $B_{MSY\ Proxy}$ from 1974-1980 resulting in $B_{MSY\ Proxy}$=83.30 thousand t. The authors recommend this result.

The authors listened to the public testimony at the September 2010 CPT meeting that questioned the validity of the 1969-1980 period for computing $B_{MSY\ Proxy}$. Although the CPT minutes don't elaborate, the stated criticism was that the current environmental regime the eastern Bering Sea has resulted in a different production potential for the Tanner crab stock and that there should be no expectation that the stock could recover to levels observed during this period. This hypothesis is speculative and we suggest that it's incumbent on its advocates to provide the CPT results of an analysis that gives clear and convincing evidence for its support. Otherwise, we consider it capricious to employ inference from presumptive argument to lower the threshold biomass considered to represent a rebuilt stock particularly given the importance of this decision to the health of the ecosystem and the fisheries.

The testimony that the Tanner crab stock should not be expected to recover to levels observed prior to 1980 is inconsistent with the data. If we consider stock performance measured as MMB at the time of the fishery (i.e., prior to catch extraction), that mean quantity over the revised time period (1974-1980) for computing B_{REF} is 123.2 thousand t (se=24.8). Even after experiencing excessive rates of exploitation prior to 1980 and the presumptive effects of the so-called '*1976 environmental regime change'*, the stock recovered to an average 1989-1992 MMB at fishery = 94.0 thousand t (se=0.9), or 76.3% of 123.2 thousand t. Extending this average one year on either side of the mode to 1988-1993, the mean MMB at fishery was 81.1 thousand t (se=8.2), or 65.8% of B^*_{REF}. Recruits which gave rise to this mode of MMB in the late-1980s to early-1990s were from cohorts produced in the early-1980s – thus, after the so-called '*1976 environmental regime change'* and any presumed change in reproductive potential. The Tanner crab stock demonstrated the ability to recover to greater than 75% of this reference biomass despite the collective effects of excessive exploitation and the theorized environmental regime change.

We observe that the current measure of $B_{MSY\ Proxy}$ employed for EBS crab stocks (i.e., MMB at mating) exempts excessive fishery exploitation in the measure of reproductive biomass since MMB at mating is tabulated after the extraction of the catch. The authors propose an alternative $B_{MSY\ Proxy}$ measure which adjusts for exploitation in excess of F_{MSY}. Using the 1974-1980 mean MMB at the time of the fishery (B^*_{REF}= 123.2 thousand t) as a proxy for B_{MSY}, if exploited at F_{MSY}=M=0.23 would yield a mean MSY catch of 28.3 thousand t. Extracting this catch from B^*_{REF} gives an alternative proxy estimate of B_{MSY}=94.9 thousand t over 1974-1980 compared to 83.3 thousand t based on MMB at mating. The current $B_{MSY\ Proxy}$ based on MMB at mating is a biased low measure of reproductive potential in instances where fishery removals exceed those estimated using F_{MSY}. If recruitment was maintained despite excessive removals, the extent of this bias is proportional to the magnitude of the catch in excess of MSY.

As a general observation, we agree that from the 1960s to present, there has been an apparent shift in the eastern Bering Sea from a more decapod-dominated ecosystem to a more teleost-dominated ecosystem currently. We've not found evidence of a change in Tanner crab productivity over this period, nor of changes in reproductive dynamics or life-history characteristics which reveal temporal changes in recruitment resulting from the purported '1*976 environmental regime change*'. The authors have shown (Rugolo and Turnock 2010) that the historical patterns of fishery exploitation on MMB from the late 1960s to the present exceeded rates that we would now deem biologically reasonable for this stock. Exploitation rates on MMB rose in the late 1970s and peaked at 0.69 in 1978, then declined with the collapse in stock biomass through the mid-1980s, then rose again to 0.45 and followed the build up in the stock in the late-1980s to early-1990s. The exploitation rate on legal male biomass in 1978 was estimated in this assessment was 0.94. At these rates, the Tanner crab stock would not be expected to persist at sustainable levels in the short-term, nor modulate around B_{MSY} in the long-term.

If there have been effects of a change in environmental regime on Tanner crab productivity or from increased competition and predation on survival, empirical data have not shown those effects. Neither would the magnitude of those effects, if any, be easily separable from those of excessive fishing mortality on the stock. The revised range of years (1974-1980) used to estimate $B_{MSY\ Proxy}$ includes a five year period (1976-1980) of sharply declining and low male mature biomass. Inclusion of these five years was required by the SSC in 2009. The authors do not believe that these that these five years represent levels of mature male biomass that, if fished at F_{MSY}, would yield MSY to the fishery. Extending the time period to present would include time periods where the stock had collapsed and the fishery closed due to conservation concerns. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of $B_{MSY\ Proxy}$ would be inconsistent with the tenet of selection of a range of years that represent the stock living at B_{MSY}, being fished at rates approximating F_{MSY}, and thereby yielding MSY to the fisheries.

May 2010 Meeting:
In their stock assessment review, the CPT made the following comments concerning the Tanner crab Tier-4 stock assessment:

- *The current assessment estimates a likely upper limit on MMB at time of mating. Final results depend on fishery performance. It is estimated from the 2009 survey that the stock was below the MSST at that time, and the catches during the 2009/10 fishery will have led to the MMB at mating in 2010 being lower. A formal determination of the stock being overfished will occur with the Fall 2010 assessment.*

The CPT had the following recommendations for the authors:

- *Include CV's with point estimates in the tables.*
- *Determine whether groundfish discards are based on all groundfish fisheries or only trawl fisheries.*
- *Revise the text for OFL calculation (Eq. 3 and 4) to represent what was actually done.*
- *Remove Appendix A as it came from a prior assessment.*
- *Provide the September meeting with a summary of progress with the new model. The CPT may recommend that additional planning meeting may be necessary depending on progress given the necessity of this model for the rebuilding plan.*

In this document, the authors provide a final assessment of the status of the 2009/10 Tanner crab stock based on estimated MMB at mating in mid-February 2010. The 2009/10 stock is below the status determination criterion indicative of an overfished stock. The authors made best attempts to address the recommendations of the CPT in this assessment. Developing the time-series of CVs for metrics tabled in this document has proven more involved than anticipated given the change in survey data based on measured net widths used in this assessment. We'll continue to make best efforts to develop these data and work with the Shellfish Assessment Program who is lead concerning data verification and re-estimation of the historical time series. As we previously reported to the CPT, groundfish discards are based on all groundfish fisheries. The OFL calculation in this and previous assessments represents what is done. The authors revised Section E.2 (Model Description) to clarify the computational logic used in OFL-setting. Appendix A is removed in this assessment. The authors will discuss progress on the new model at the September 2010 meeting.

C. Introduction

1. Scientific Name and General Distribution

Tanner crab *Chionoecetes bairdi* originally described by Rathbun (1924) is one of five species in the genus *Chionoecetes*. The taxonomic classification attributable to Garth (1958) has been revised (see McLaughlin et al. 2005) to include name changes for a number of hierarchical categories:

Class	Malacostraca
Order	Decapoda
Infraorder	Brachyra
Superfamily	Majoidea
Family	Oregoniidae
Genus	Chionoecetes

The common name for *C. bairdi* of "Tanner crab" (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" has 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".

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). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break where water temperatures are generally warmer. The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo 2010). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 58°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

2. 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). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit. Somerton (1981a) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. Somerton's conclusions are limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor consider stock movement with ontogeny. Thus, biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time are confounded by these omissions.

Despite the custom of setting management controls for this stock east and west of 166^0 W longitude, the unit stock of Tanner crab in the EBS comprises crab throughout the geographic range of the NMFS trawl survey. No evidence supports partitioning the unit stock into discrete, non-interbreeding, non-mixing sub-populations which can be assessed and managed separately. Given requisite understanding of the geographic fidelity of the stock over its range and its availability to the fisheries, partitioning the total catch OFL may be possible to allow setting TACs or issuing of IFQs for the Eastern and Western District fisheries consistent with the total catch OFL.

D. Data

1. The Survey

The NMFS conducts an annual trawl survey in the EBS to determine the distribution and abundance of commercially-important crab and groundfish fishery resources (Chilton et al. 2011). The survey has been conducted since 1968 by the Resource Conservation and Engineering (RACE) Division of the Alaska Fisheries Science Center. It's been conducted annually since 1975 when it also expanded into Bristol Bay and the majority of the Bering Sea continental shelf. Since 1988, 376 standard stations have been included in the survey covering a 150,776 nm^2 area of the EBS with station depths ranging from 20 to 150 meters depth. The annual collection of data on the distribution and abundance of crab and groundfish resources provides fishery-independent estimates of population metrics and biological data used for the management of target fishery resources. Crustacean resources targeted by this survey are red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), hair crab (*Erimacrus isenbeckii*), Tanner crab (*Chionoecetes bairdi*) and snow crab *(C. opilio*). The sampling methodology specifies the majority of tows made at the centers of squares defined by a 20 x 20 nmi (37 x 37 km) grid (Figures 1 and 2). Near St. Matthew Island and the Pribilof Islands, additional tows were made at the corners of squares that define high density sampling strata for blue king crab and red king crab.

The eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope has been the standard gear since 1982. Each tow was approximately 0.5 h in duration towed at 3 knots, and conducted in strict compliance with established NMFS groundfish bottom trawl protocols (Stauffer 2004). Crabs are sorted by species and sex, and then a sample of the catch measured to the nearest millimeter to provide a size-frequency distribution. Derived population metrics are indices of relative abundance and biomass and do not necessarily represent absolute abundance or biomass. They are most precise for large crabs, and are least precise for small crabs due to gear selectivity, and for females of some stocks due to differential crab behavior.

Estimates of Tanner crab stock biomass, population metrics and length frequencies from the trawl survey used in this assessment were based on area-swept calculations using measured net widths spreads for 1969-2010. Survey for 1969-1973 are not used in the OFL analysis. Previous survey data for 1969, 1970 and 1972-1975 for males and 1974-1975 for females were extracted form historical International Pacific Fisheries Commission (INPFC) documents. Figures 1 and 2 present the distribution catch-per-unit effort by tow for legal males, sublegal males, ovigerous females, barren mature females and immature females from the 2011 survey. The highest abundance of males and females occurs from 163 to 170 degrees W longitude with the distinction that males also reveal moderate levels of abundance in the area of the Pribilof Islands. Areas of highest abundance of male and female Tanner crab in 2011 occurred from southwestern Bristol Bay northeastward to the Pribilof Islands. Figures 13 and 14 show the 5 mm size frequency abundance estimated in the survey for male and female Tanner crab from 1969-2011.

Stock Biomass

Tanner crab male mature biomass (MMB) and legal male biomass (LMB) exhibited periods of peak biomass in the early to mid-1970s and the early to mid-1990s (Table 5, Figure 4b). LMB and MMB estimates in this analysis date to 1974. The components of MMB and LMB at the time the survey, at the time of the fishery and at the time of mating are shown in Table 5 and Figure 6. The historical bimodal distribution in male biomass (Figure 4) is also reflected in the pattern of the directed fisheries with peak modes in the mid-1960s through mid-1970s and in the late-1980s to early-1990s (Table 5, Figure 5), and collapsed stock status following those modes. MMB at the survey revealed an all-time high of 257.0

thousand t in 1975, and a second peak of 108.3 thousand t in 1991 (Figure 4). From the late-1990s through 2008, MMB rose at a moderate rate from a low of 10.4 thousand t in 1997 to 73.6 thousand t in 2007 before falling to 32.1 thousand t in 2010. Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the B_{MSY} level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt. Tanner crab MMB at the time of mating in mid-February 2010 fell below the MSST resulting Tanner crab being declared overfished in September 2010.

In 2011, Tanner crab MMB at the time of the survey was estimated at 41.8 thousand t representing a 23.2% increase relative to 2010. Mature male abundance rose 34.2% relative to 2010 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. Legal males were sparsely and patchily distributed throughout the survey range with an area of moderate abundance in southern Bristol Bay and an area of high density near the Pribilof Islands (Figure 1). The total abundance index for legal males increased 41.5% to 13.7 million crabs between 2010 and 2011owing largely to a high-density station in the area of the Pribilof Islands and the elimination of the 'hot-spot' re-sampling protocol in 2011. As a result, the 2011 survey male abundance and biomass estimates are biased high relative to all previous years that employed this re-sampling protocol. Legal-sized males represent only a small portion (3.6%) of total male abundance in 2011. Legal males were distributed 37.1% (5.1 million crabs) east and 62.9% (8.6 million crabs) west of 166^0 W longitude compared to 56.1% (east) and 43.9% (west) in 2010 (Rugolo and Turnock 2010). The 2011 abundance index for pre-recruit male crabs (110-137 mm cw) was relatively unchanged (+0.1%) relative to 2010, and that for small males (<110 mm cw) increased 49.6% relative to 2010 for all areas combined (Figure 9). Pre-recruit crab in 2011 were widely distributed across the range of the survey from southern Bristol Bay northwest to St. Matthew Island (Figure 1). Regions of highest abundance of pre-recruit males in 2010 were seen in southwestern Bristol Bay and the surrounding area of the Pribilof Islands (Figure 1). Total male abundance increased 44.3% between 2010 and 2011 influenced by the increase in small and in legal-sized males (Figure 9). MMB in 2011 increased 23.2% relative to 2010. Compared to that estimated at the time of the 2010 survey, male recruit biomass (<110 mm cw) increased 47.8%, pre-recruit biomass (110-137 mm cw) decreased 0.9%, legal male biomass increased 44.2% and total male biomass increased 30.1%. Total male biomass in 2011 was comprised of 76.6% immature, 9.8% new shell mature and 13.5% old shell mature males.

Comparison of the male size frequency distributions between 2006 and 2011 revealed a decline in male abundance above 70 mm cw between 2006 and 2010, and relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-f). The male size frequency distribution in 2011 (Figure 10 f) reveals an apparent increase in pre-recruit abundance between 25-70 mm cw. The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e) and to 55-65 mm cw in 2011 (Figure 10 f). Among all male Tanner crab in 2011, 13.5% were old shell in all categories combined, and 86.5% were comprised of molting, new-soft and new-hard shell (85.1%) categories combined. Among legal-sized males, 52.7% were old shell all categories combined relative to 42.2% in 2010, and 47.1% were new-hard shells. The increase in male abundance in 2011 if not biased high due to the change in sampling design, particularly for recruit-sized crab (<110 mm cw), is an encouraging sign. The relatively high percentage of old and very old shell males in the mature stock, however, may remain a concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab increased 8.7% in abundance in 2011 relative to 2010. Total female biomass in 2011 was comprised of 79.5% immature, 13.9% new shell mature and 6.6% old shell mature females. Among all female Tanner crab in 2011, 6.6% were collectively old shell and 91.1% new-hard shell. Small females (<85 mm cw) increased by 44.2% to 269.5 million crabs relative to 2010 and comprise 94.7% of total female abundance. Total 2011 female abundance increased 42.4% to 284.6 million crabs largely influenced by the increase in small females <85 mm cw (Figure 9). Total survey abundance of males and females combined increased 9.3% over that in 2010 driven by the increase in both small male and small female crabs. Ovigerous females were distributed from southern Bristol Bay at relatively highest abundance northwestward to south of St. Matthew Island with an area of moderate density near the Pribilof Islands (Figure 2). Immature female Tanner crab displayed a similar distribution to mature females although they were slightly more densely distributed relative to matures along the southeast-northwest cline from southwestern Bristol Bay, north of the Pribilof Islands to west and south of St. Matthew Island (Figure 2). The survey length frequency distributions of female Tanner crab from 2006-2011 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11 a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance in 2007 through 2010. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw. A relatively strong recruit mode (35-50 mm cw) is apparent in the 2010 survey data (Figure 11 e) which grew to 55-70 mm cw in 2011 (Figure 11 f). The female size frequency distribution in 2011 (Figure 11 f) reveals an apparent strong pre-recruit abundance mode between 30-50 mm cw. The increase in pre-recruit sized female abundance in 2011 is an encouraging in terms of future reproductive potential.

2. The Fishery

Management Unit

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 fisheries management plan (NPFMC 1998). The plan defers certain management controls for Tanner crab to the SOA with federal oversight (Bowers et al. 2008). The state manages Tanner crab based on registration areas divided into districts. Under the plan, 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 3) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36’ N lat. 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 longitude. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168° W longitude 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 that will be in effect for the 2011/12 fishery. The previously minimum legal size limit was 5.5” (138 mm cw) throughout the Eastern Subdistrict. The new regulations established different minimum size limits east and west of 166^0 W longitude. That for the fishery to the east will be 4.8” (122 mm cw), and that to the west will be 4.4” (112 mm cw). The industry may self-impose retention of crab above 5.5” (138 mm cw) and 5” (127 mm cw) east and west of 166^0 W longitude, respectively.

The domestic Tanner crab (*C. bairdi*) pot fishery rapidly developed in the mid-1970s (Table 2, Figures 5). For stock biomass and fishery data tabled in this document, we adopted the convention that ‘year’ refers to the survey year, and fishery data are those subsequent to the survey, through prior to the survey in the following year. Other notation is explicit – e.g., 2008/09 is the 2008 summer survey and the winter 2009 fishery. United States landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery (Table 2). Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early-1970s, reaching a high of 30.21 thousand t in 1977 (Table 2, Figure 5). Landings fell precipitously after the peak in 1977 through the early 1980s, and domestic fishing was closed in 1985 and 1986 as a result of depressed stock status. In 1987, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990 at 18.19 thousand t, and then fell sharply through the mid-1990s (Figure 5). The domestic Tanner crab fishery closed between 1997 and 2004 as a result of severely depressed stock condition. The domestic Tanner crab fishery re-opened in 2005 and has averaged 0.77 thousand t retained catch between 2005-2009/10 (Table 2). Landings of Tanner crab in the foreign Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 19.95 thousand t in 1969 (Table 2, Figure 5). The Russian tangle net fishery was prosecuted between 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.

For the 2010/11 fishery, the SOA closed directed commercial fishing for Tanner crab. The SOA's harvest strategy for opening the fishing is 21 million pounds (9.5 thousand t) of mature female biomass in the Eastern Subdistrict at the time of the survey. The 2010 survey estimate of total mature female Tanner crab biomass was 15.1 million pounds (6.8 thousand t).

Discard and bycatch losses of Tanner crab originate from the directed pot fishery, non-directed pot fisheries (notably, for snow crab and red king crab), and the groundfish fisheries (Table 3). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). Total Tanner crab discard and bycatch losses by sex are shown in Table 3 for 1965-2011. The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 2). These losses were persistently high during the late-1960s through the late-1970s; male losses peaked in 1970 at 20.17 thousand t (Table 3). A subsequent peak mode of discard/bycatch losses occurred in the late-1980s through the early-1990s which, although briefer in duration, revealed higher losses for males than the earlier mode, peaking at 22.82 thousand t in 1990. From 1965-1975, 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 (Table 3). Total Tanner crab retained catch plus non-directed losses of males and females (Table 4, Figure 4a) reflect the performance patterns in the directed and non-directed fisheries. Total male catch rose sharply with fishery development in the early-1960s and reveals a bimodal distribution between 1965 and 1980 with peaks of 47.48 thousand t in 1969 and 52.30 thousand t in 1977 (Table 4, Figure 4a). Total male catch rose sharply after the directed domestic fishery reopened in 1987 and reached a peak of 41.01 thousand t in 1990. Total male and female catch fell sharply thereafter with the collapse of the stock and the fishery closure in 1997.

Since re-opening of the domestic fishery in 2005, the relationship of total male discard/bycatch losses by non-directed crab pot and groundfish fisheries to retained catch shifted relative to that between 1980-1996 (Tables 2 and 3). For 2005-2009, the ratio of total male discard losses to retained catch was 2.2, 1.8, 2.5,1.3, and 1.6 respectively, and averaged 1.9 (ser=0.2). The majority of these male losses are sub-legal sized crab, and the principal contributor to these non-retained losses is the non-directed snow crab fishery (Table 7a). This contrasts the pre-closure performance of the domestic fishery (1980-1996) which averaged 1.3 (se=0.1) pounds of non-retained male losses to each pound of retained catch. Corresponding ratios in terms of numbers of non-retained male losses to retained legal crab are more striking due to the contribution of sub-legal sized crab to total male discards. Discard and bycatch losses of male and female Tanner crab (Table 3) during the closures of the directed domestic fishery (1985-1986 and 1997-2004) reflect losses due to non-directed EBS pot fisheries and the domestic groundfish fisheries.

Exploitation Rates

The historical patterns of fishery exploitation on LMB and MMB were derived (Table 6, Figures 7a and 7b). The exploitation rate on LMB was estimated as the proportion of retained catch to LMB at the time of the fishery, while that on MMB as the proportion of total male catch to MMB at the time of the fishery. During 1974-2009, exploitation rate (μ) on LMB was highest in 1979 at 0.94 and second highest in 1981 at 0.54; thereafter, it fell with stock condition through the mid-1980s. LMB exploitation rates revealed a second prominent mode during 1989-1993, peaking at 0.46 in 1991 and averaging 0.44 during those five years (Table 6, Figure 7b). At these rates of exploitation on LMB, the Tanner crab was not expected to persist at maximum sustainable levels even in the short-term, nor modulate around B_{MSY} in the long-term. The pattern of μ on MMB from 1974-2009 reveals two analogous high periods: one associated with the high total catches in the mid-1970s to 1980; the other coincident with the mode of high catches in the late-1980s through early-1990s. Exploitation rates on MMB peaked at 0.69 in 1979 and at 0.44 in 1990, averaged 0.23 over 1986-1997 and followed the build up in stock biomass during that period.

3. Life-History

Reproduction

In most majid crabs, the molt to maturity is the final or terminal molt. For *C. bairdi*, it’s now accepted that both males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo terminal molt at maturity. Females terminally molt from their last juvenile, or pubescent, instar usually 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 their 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 stored sperm from 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), however, 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 reach the legal harvest size (NPFMC 2007).

Although observations are lacking for the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous Tanner crab 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).

Fecundity

A variety of factors affect female Tanner crab fecundity including female size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004a). Of these factors, female size is the most important, with estimates of 89 to 424 thousand eggs for EBS females 75 to 124 mm carapace width (cw) respectively (Haynes et al. 1976). Maturity status is another significant 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., barren) suggesting that female Tanner crab reproductive output is a declining function of age (NMFS 2004a).

The fraction of barren mature females by shell condition (Figure 15) and the fraction of mature females with clutches one-half full or less by shell condition (Figure 16) are shown. After 1991, 20-40% of new shell females brooded clutches less than or equal to 50% full, and in 2009 this number was approximately 23%. We developed a Tanner crab Egg Production Index (EPI) by female shell condition that incorporates observed clutch size measurements taken on the survey and fecundity by carapace width for 1976-2009 (Figure 17). Figure 17 also presents estimates of male and female mature biomass relative to the shell condition class EPIs in these years. Although male and female mature biomass increased after 2005, egg production does not increase proportionally to mature biomass (Figure 17).

Size at Maturity

Maturity at length (cw) schedules were estimated for male and female Tanner crab from extant NMFS trawl survey data. For females, we used egg and maturity code information collected on the survey from 1976-2009 to estimate the maturity curves for new shell females, and for the aggregate class of females all shell conditions combined. SM50%, for females all shell classes combined was estimated to be 68.8 mm cw, and that for new shell females was 74.6 mm cw. For males, data from the special collection of morphometric measurements taken to the 0.1 mm in 2008 on the NMFS survey was used to derive the classification rules between immature and mature crab based on chela allometry using the mixture-of-two-regressions analysis. We estimated classification lines between chela height and carapace width defining morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of 166^0 W longitude. We then applied these rules to historical survey data from 1990-2007 to apportion male crab to the immature and mature populations. We examined and found no significant differences between the classification lines of the sub-stock components (E and W of 166^0 W longitude), or between the sub-stock components and that of the unit stock classification line. SM50%, for males all shell condition classes combined was estimated to be 91.9 mm cw, and that for new shell males was 104.4 mm cw. By comparison, Zheng (1999) in development of the current SOA harvest strategy used knife-edge maturity of >79 mm cw for females and >112 mm cw for males. For harvest strategy purposes, mature females are defined as females >=80 mm cw (Bowers et al. 2008).

Somerton (1981b) noted differences in the size of Tanner crab female maturity across the range of the unit stock. As previously noted, Somerton's interpretations were limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor did he consider the pattern of ontogenous stock movement. Thus, maturity estimated based on comparisons of the proportions of mature individuals at length in any area, or on changes in the proportion of mature individuals at length over time are confounded by these omissions. Nonetheless, we report that for the 5 survey years from 1975 to 1979, east of 167° 15' W longitude, Somerton (1981a) estimated that the mean size of mature females ranged from 92.0 to 93.6 mm cw. West of that longitude, the size of 50% female maturity ranged from 78.0 to 82.0 mm cw. For male Tanner crab during the same survey years, he estimated size at 50% maturity was 117.0 mm cw and 108.9 mm cw east and west of 167° 15' W longitude, respectively.

Mortality

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

We examined empirical evidence for estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, estimates of longevity of Tanner crab are lacking. We reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab (Turnock and Rugolo

2010) given the analogues in population dynamic and life-history characteristics between these species, where longevity would be at least 20 years. Using 20 years as a proxy for longevity and assuming that this age represents the upper 98.5th percentile of the distribution of ages in an unexploited population, M is estimated to be 0.23 (Hoenig 1983). If 20 years is assumed to represent the 95% percentile of the distribution of ages in an unexploited stock, M is estimated to be 0.15. The natural mortality rate (M) of EBS Tanner crab is set at 0.23 for assessing stock status and OFL-setting based on the current expectation of longevity of at least 15 y. This rate of M=0.23 is consistent with that used in Amendment 24 and its associated EA that established new overfishing definitions for crab stocks under the plan.

Growth and Age

Rugolo and Turnock (2010) derived the growth relationships for male and female Tanner crab using data collected in the Gulf of Alaska near Kodiak (Munk pers. comm., Donaldson et al. 1981), and examined growth relationships developed by Zheng and Kruse (1999). Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of survey data assuming no terminal molt at maturity. Somerton's approach did not directly measure molt increments and his findings were confounded by not recognizing that inter-annual modal length progression was biased sicne male and female crab ceased growing after their maturity molt. We compared our 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. Initial results suggest that gpm is expressed by two distinct rates of growth for both males and females – a higher rate of growth to an intermediate size in the area 90-100 mm cw, coupled with a decrease in growth rate from that intermediate size thereafter. Such 'dog-leg' shaped growth curves are corroborated in work of Stone et al. (2003), Somerton (1981), Donaldson et al. (1981) and in the data of Munk. Work on the growth relationships is ongoing and we intend to examine curvilinear functions to fit the observed pattern of growth.

Somerton (1981a) studied growth of Tanner crab in the EBS and used modal length analysis to estimate growth per molt. Because of a lack data on smaller instars and no estimates of molt frequency, he combined size at age estimates from Kodiak crab (Donaldson et al. 1981) to construct a growth and age schedule for EBS Tanner crabs (Table 1). Radiometric ageing has suggested that age after the terminal molt to maturity may be 6-7 years (Nevisi et al. 1996). If mean age at maturity is 8-10 y, these results suggest that maximum age of an exploited stock is 14-17 y.

Weight at Length

We derived weight at length relationships for male, immature female and mature female Tanner crab based on special collections of length and weight data on the NMFS trawl survey in 2006, 2007 and 2009 (Figure 15). The fitted weight (kg)-length (mm cw) relationship for males of shell condition classes 2 (SC2) through class 5 (SC5) inclusive is: $W=0.00016(cw)^{3.136}$. Those for immature (SC2) and mature (SC2-SC4) females are, respectively, $W=0.00064(cw)^{2.794}$ and $W=0.00034(cw)^{2.956}$.

E. The Analytic Approach
1. History of Modeling Approaches

Tier-4 OFL Control Rule

Old Survey Data:

Tanner crab is managed as a Tier-4 stock. Through the 2009 assessment, the proxy B_{MSY} for management is the reference biomass ($B_{MSY\ Proxy}$)=86.80 thousand t MMB at the time of mating estimated as the average observed MMB_{mating} from the time period of 1969-80. As reported in Rugolo and Turnock (2009), Tanner crab MMB in 2009 declined to 39.74 thousand t and even at the time of the survey it was below the minimum stock size threshold MSST=0.5 $B_{MSY\ Proxy}$=43.04 thousand t. After accounting for all losses to the stock from the 2009/10 fisheries and natural mortality, the 2009/10 MMB at mating was 32.52 thousand t. This represented a ratio of 0.38 relative to $B_{MSY\ Proxy}$ which was below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was deemed approaching an overfished condition as determined using stock relative to $B_{MSY\ Proxy}$ and MSST computed using survey MMB estimates based on the fixed 50 ft net width area-swept calculations.

New Survey Data:

Beginning with the 2010 assessment, all stock metrics, as well as overfishing definitions were based on survey estimates derived using the measured net width area-swept calculations. This resulted in changes in the historical time series data. Using the revised survey data, the equivalent proxy B_{MSY}=83.80 thousand t and MSST=41.90 thousand t. After accounting for all losses to the stock from natural mortality and the 2009/10 fisheries, the 2009/10 MMB at the time of mating was 28.44 thousand t. This represented a ratio of 0.34 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010). For the 2011 assessment, $B_{MSY\ Proxy}$ estimated over the revised period (1974-1980) is 83.33 thousand t and MSST=41.67 thousand t. The bias-corrected $B_{MSY\ Proxy}$ estimated over 1974-1980 is 93.24 thousand t and MSST=46.62 thousand t.

MMB at the time of the 2010 survey declined 8.3% relative to that in 2009. Under the plan, MMB estimated at the time of mating (mid-February) is gauged against the MSST to determine its status relative to the overfished criterion after accounting for all stock losses due to M and directed and non-directed fishing. After accounting for stock losses from M and those in the 2009/10 fisheries, the 2010 MMB at the time of mating was 28.44 thousand t. This represented a ratio of 0.34 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010).

For the 2010/11 stock status determination, losses from the time of the 2010 survey to mating in 2011 and those from non-directed fishing are considered. The directed fishery was closed in 2010/11. Considering stock losses from M and the 2010/11 non-directed pot and groundfish fisheries, the 2011 MMB at the time of mating was 26.73 thousand t (-6.4% relative to 2010). This represents a ratio of 0.32 relative to $B_{MSY\ Proxy}$ and a ratio of 0.29 relative to the bias-corrected $B_{MSY\ Proxy}$ which are both below the limit that defines an overfished stock. Thus, there is no change in the 2010/11 stock relative to the overfished determination made in 2010.

In the Environmental Assessment associated with Amendment 24 to the BSAI King and Tanner Crab fishery management plan (NPFMC 2008), Tier-4 stocks are characterized as those where essential life-history information and understanding are incomplete. Although a full assessment model cannot be specified for Tier-4 stocks or stock-recruitment relationship defined, sufficient information may be available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Such modeling approaches can serve the basis for estimating the annual status determination criteria to assess stock status and to establish harvest control rules.

In Tier-4, a default value of M and a scaler Gamma (**γ**) are used in OFL setting. The proxy for B_{MSY} represents the level of equilibrium stock biomass indicative of maximum sustainable yield (MSY) to fisheries whose mean performance exploits the stock at F_{MSY}. For Tier-4 stocks, the $B_{MSY\ Proxy}$ is estimated as the average biomass over a specified period that satisfies the expectation of equilibrium biomass yielding MSY at F_{MSY}. It can also be estimated as a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock where data exist. In Tier-4, the F_{OFL} is calculated as the product of **γ** and M, where M is the instantaneous rate of natural mortality. The Amendment 24 and its EA defines a default value of gamma=1.0. Gamma is allowed to be less than or greater than unity resulting in overfishing limits more or less biologically conservative than fishing at M. The specification of the scaler **γ** in the EA was intended to allow adjustments in the overfishing definitions to account for differences in the biomass measures used in EA simulation analyses. However, since Tier-4 stocks are information-poor by definition, the EA associated with Amendment 24 states that **γ** should not be set to a value that would provide less biological conservation and more risk-prone overfishing definitions without defensible evidence that the stock could support fishing at levels in excess of M. The resultant overfishing limit for Tier-4 stocks is the total catch OFL that includes expected retained plus discard and bycatch losses. For Tier-4 stocks, a minimum stock size threshold (MSST) is specified; if current MMB is below MSST, the stock is overfished.

For Tier-4 stocks, the F_{OFL} is derived using and F_{OFL} Control Rule (Figure 8) according to whether current mature stock biomass metric (B) belongs to stock status levels a, b or c in the algorithm below. The stock biomass level beta (β) represents a minimum threshold below which directed fishing mortality is set to zero. The F_{OFL} Control Rule sets β=0.25. The parameter alpha moderates the slope of the non-constant portion of the control rule. For biomass levels where $\beta < B \leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B/B_{MSY}. The value of M is 0.23 for eastern Bering Sea Tanner crab. In the analysis of Tier-3 for snow crab, *C. opilio,* and red king crab, *P. camtschaticus*, a B_{MSY} proxy reference value ($B_{MSY\ Proxy}$) equal to 35% of the maximum spawning potential of the unfished stock was specified (Annon 2008, EA associated with Amendment 24). For Tier-4 stocks, a reference biomass value ($B_{MSY\ Proxy}$) must is specified consistent with the expectation of a measure of equilibrium stock biomass (B_{MSY}) capable of yielding MSY to the fisheries operating at F_{MSY}.

Stock Status Level:		F_{OFL}:
a.	$B/ B_{MSY\ Proxy} > 1.0$	$F_{OFL} = \gamma M$
b.	$\beta < B/ B_{MSY\ Proxy} \leq 1.0$	$F_{OFL} = \gamma M\ [(B/ B_{MSY\ Proxy} - \alpha)/(1 - \alpha)]$
c.	$B/ B_{MSY\ Proxy} \leq \beta$	Directed Fishery F=0
		$F_{OFL} \leq F_{MSY}$

2. Model Description

In the Tier-4 OFL-setting approach EBS Tanner crab, various measures of stock biomass and catch components are integrated in the overfishing level determination. Here, we define each component and illustrate the approach used for OFL-setting based on these metrics.

A. Definition of Terms:

The following terms will be used in the illustration of our Tier-4 OFL-setting approach.

Let:

B_1	=	male mature biomass at the time of the survey
B_2	=	male mature biomass at the time of the fishery
B_3	=	male mature biomass at the time of mating
L_1	=	legal male biomass at the time of the survey
L_2	=	legal male biomass at the time of the fishery
L_3	=	legal male biomass at the time of mating
S_1	=	survival rate after 6 months of M = $e^{-M/2}$ from survey time to the nominal start of the fishery. (Not used in OFL-setting calculations).
S_2	=	survival rate from the time of the survey to mating (Δ=8 months) = $e^{-2M/3}$
M	=	instantaneous rate of natural mortality = 0.23
γ	=	scaler on M = 1.0
α	=	location parameter that determines intersection of sloping part of OFL control rule and the x-axis
β	=	minimum stock biomass threshold below which directed fishing is set to zero
$B_{MSY\ Proxy}$	=	reference biomass value proxy for B_{MSY}
B_{MSY}	=	equilibrium biomass that yields maximum sustainable yield to the fisheries under an applied F_{OFL}
F_{OFL}	=	fishing mortality rate proxy for F_{MSY} that yields the Total Catch OFL (TC_{OFL}) using the F_{OFL} control rule
U_{OFL}	=	exploitation rate at the applied F_{OFL} = $(1-e^{-FOFL})$
TC_{OFL}	=	total catch overfishing limit corresponding to the F_{OFL} applied to male mature biomass at mating = $B_3S_2U_{OFL}$
C_1	=	total catch losses to MMB from retained + non-retained mortalities. Will equal TC_{OFL} if all projected catch losses are realized.
C_2	=	total catch losses to LMB from retained + non-retained mortalities
C_{RET}	=	retained catch of male mature biomass in the directed fishery in 2010/11
C_{3RET}	=	3-year average (2007-09) retained catch of male mature biomass in the directed fishery
CO_{RET}	=	projected 2010/11 snow crab retained catch OFL
D_1	=	discard mortality of MMB by the directed fishery
D_2	=	discard mortality of MMB by the non-directed snow crab fishery
D_3	=	discard mortality of MMB by the EBS groundfish fisheries
R_1	=	3-year average (2007-09) ratio of discarded mature male biomass per retained catch biomass in the directed fishery
R_2	=	3-year average (2007-09) rate of discarded mature male biomass per retained snow crab catch in the non-directed snow crab fishery
R_3	=	3-year average (2007-09) groundfish fishery discards of mature male biomass
HM_1	=	post-release mortality rate for pot discarded crab (0.50)
HM_1	=	post-release mortality rate for groundfish discarded crab (0.80)
TC_{PART}	=	residual part of the TC_{OFL} available to the directed fishery

B. OFL-Setting:

Determination of the total catch OFL (TC_{OFL}), F_{OFL}, resultant measures of stock biomass and the various catch components is a straightforward process given the F_{OFL} control rule and an estimate of MMB at the time of mating. The following prescription illustrates the logic of the computational approach, the arithmetic employed and formulae used in the estimation of all stock metrics an catch components:

1. Finding F_{OFL}:

Given $B_{MSY\ Proxy}$ and the estimate of mature male biomass at the time of mating, B_3, the overfishing limit F_{OFL} is found using the FOFL control rule algorithm:

$$F_{OFL} = \gamma M\ [(B_3/\ B_{MSY\ Proxy} - \alpha)/(1 - \alpha)] \quad (1)$$

2. Finding the TC_{OFL}:

Given the F_{OFL}, we can estimate the total catch OFL (TC_{OFL}) that results from applied fishing at the F_{OFL} on B_3 by:

$$TC_{OFL} = (B_1S_2U_{OFL}) \quad (2)$$

$$= (B_1S_2(1\text{-}e^{-\ FOFL})) \quad (3)$$

3. Finding B_3:

In the current directed fishery, catches occur mainly in January and February, and in March to a lesser extent. Retained catches coincide with the nominal time of mating (mid-February) eight months from the mid-point survey (mid-June), and span the nominal time of mating. We treat survival from survey to mating as a Type I process in which the stock is depreciated by M through mid-February then the catch is extracted instantaneously.

Thus, the estimate of male mature biomass at the time of mating (B_3) results from the combined survival of crab from the time of the survey to mating after natural morality, less the extraction of the total catch OFL (TC_{OFL}).

$$B_3 = (B_1S_2) - TC_{OFL} \quad (4)$$

$$= (B_1S_2) – (B_1S_2U_{OFL}) \quad (5)$$

$$= (B_1S_2) – B_1S_2(1\text{-}e^{-\ FOFL}) \quad (6)$$

Replacing B_3 in (1) with equations (3) and (6) gives:

$$F_{OFL} = \gamma M\ [[[(B_1S_2) – B_1S_2(1\text{-}e^{-\ FOFL})]/\ B_{MSY\ Proxy}] – \alpha]/(1 - \alpha)] \quad (7)$$

Since there are unknowns on either side of the equality in equation (7), there is no analytical solution and it must be solved iteratively. This is because the F_{OFL} rate depends on the level of mature male biomass at mating (B_3) which, in turn, depends on the extracted $TC_{OFL.}$ Thus, we can't know the F_{OFL} until we extract the total catch OFL using the F_{OFL} control rule, and we can't estimate the TC_{OFL} until we have know the F_{OFL}. An iterative flow to solve for the F_{OFL} and TC_{OFL} is shown:

i. Initial guess at the F_{OFL-1} using B_1 in the F_{OFL} control rule. If B_1 is on the sloping part of the control rule, F_{OFL-1} will be too large by definition since $B_1>B_3$.
ii. Estimate TC_{OFL} using this F_{OFL-1}.
iii. Estimate B_3 using equation (4).
iv. Re-estimate the F_{OFL-2} using B_3 in the F_{OFL} control rule.
v. Test if F_{OFL-1}-F_{OFL-2} =0. If yes, set the final F_{OFL}=F_{OFL-2}. If no, depreciate F_{OFL-2} by a small increment resulting in F_{OFL-3}.
vi. Repeat using F_{OFL-3} in step ii to estimate the TC_{OFL} using F_{OFL-3} and end the iteration when the test in step v. is yes.

At the termination of the iteration, the final F_{OFL} for the OFL-setting will be known. Given that F_{OFL}, estimate the TC_{OFL} using equation (3) and the B_3 using equation (4).

4. Find Discard Catches in Non-Directed Fisheries:
Discard losses of male mature biomass are attributed to losses from the non-directed EBS crab pot fisheries and the groundfish fisheries. In practice, the discard catch components are estimated from past performance in the respective fisheries considered to be most representative of current conditions.

a. Non-Directed Pot Fishery Discard Mortalities:
Non-directed pot fishery discard losses to male mature biomass are principally attributed to the snow crab fishery and to the Bristol Bay red king crab fishery to a lesser extent. For example, the 2010/11 Tanner crab discards by the snow crab fishery comprised 98.3% of all pot discards from the snow crab and red king crab fisheries combined. In this analysis, we used data from the previous three fishing seasons (2008, 2009 and 2010) to estimate of the 3-year average ratio of Tanner crab mature male biomass discards in the snow crab fishery to snow crab retained catch (R_2) (Table 7b). Discard mortality of MMB by the non-directed snow crab fishery (D_2) in the 2010/11 TC_{OFL} is derived as the product of R_2 and the projected 2010/11 snow crab retained catch OFL (CO_{RET}) (Turnock and Rugolo 2011) given by:

$$D_2 = R_2\, CO_{RET}\, HM_1 \tag{8}$$

b. Groundfish Fisheries Discard Mortalities:
Discard losses to male mature biomass resulting from bycatch in the groundfish fisheries (D_3) was estimated using the average groundfish bycatch of Tanner crab over 2008-10 (R_3) (Table 7c) supplied by the Alaska Regional Office, 08/11. We assumed that this average bycatch of Tanner crab would occur in the 2011/12 fishery. Reported bycatch are for males and females combined. The sex distribution of this bycatch is unavailable for this analysis. The proportion of males in the groundfish fisheries bycatch (P_M) was estimated assuming a sex ratio of 1:1 in the bycatch and apportioning the catch based on the ratio of mean weights of 120 mm cw male crab to 87.5 mm cw female crab resulting in a 60.2% v. 39.8% male to female split.

For all groundfish fishery discards, a post-release handling mortality rate of 0.80 was used (HM_2). Discard mortality of MMB by the groundfish fisheries (D_3) in the 2010/11 TC_{OFL} is given by:

$$D_3 = R_3\, P_M\, HM_2 \tag{9}$$

5. Partial TC_{OFL} Available to Directed Tanner Crab Fishery:
Through this stage in the analysis, we've computed the total catch OFL (TC_{OFL}) for the 2011/12 fisheries which represents the threshold level of MMB catch beyond which constitutes overfishing. We have also computed the expected discard mortalities of MMB in the TC_{OFL} from the non-directed crab pot fisheries and the groundfish fisheries. These latter losses to male mature biomass can be considered fixed costs to MMB. They would occur whether or not a directed fishery is allowed, and are independent to an extent of the status of the Tanner crab stock (B_3) in 2011/12. They depend on the expected performance of the respective non-directed fisheries whose mean performance in terms of discards is not expected to change markedly in the 2011/12 fishing season. Projected discard mortalities depend on the relationship between Tanner male mature biomass and average discards being representative of current conditions – that, neither Tanner MMB nor the operations of the non-directed fisheries will change substantially so as make the relationships between recent 3-year performance and discards invalid.

6. Find Directed Tanner Crab Fishery Discard Mortalities:
The residual part (TC_{PART}) of the TC_{OFL} available to the directed fishery is estimated by extraction of the projected discard mortalities in the non-directed pot (D_2) and groundfish (D_3) fisheries by:

$$TC_{PART} = TC_{OFL} - (D_2 + D_3) \qquad (10)$$

However, since the directed Tanner fishery also contributes to discard mortalities of male mature biomass, the residual part (TC_{PART}) of the TC_{OFL} available to the directed fishery must be partitioned to allow for retained catch biomass (C_{RET}) and discard mortalities of male mature biomass (D_1). After accounting for discard losses by the directed fishery, the retained catch component of the OFL is by:

$$C_{RET} = TC_{PART} - D_1 \qquad (11)$$

Discard losses of mature male biomass by the directed 2011/12 fishery (D_1) was estimated using data from the most recent three Tanner crab fisheries, for which there were fisheries, supplied by D. Pengilly, ADF&G (08/24/09) and B.Gaeuman (ADF&G, 07/02/10) (Table 7a). (The directed fishery was closed in 2010/11.) The average ratios of legal and sublegal male and female discards to the average retained catch in the 2007/08, 2008/09 and 2009/10 fisheries are used to project discard losses in the 2011/12 fishery. Here, R_1 is the 3-year average rate of discarded mature male biomass per retained catch biomass in the 2007-09 directed Tanner fisheries. For all pot discards, a post-release mortality rate of 0.50 was used (HM_1=0.50). Directed fishery discard losses (D_1) to male mature biomass is given by:

$$D_1 = C_{RET} R_1 HM_1 \qquad (12)$$

Substituting for D_1 in equation (11) with equation (12), gives:

$$C_{RET} = TC_{PART} - C_{RET} R_1 HM_1 \qquad (13)$$

At this stage in the analysis, TC_{PART} is known from equation (10). Also, known are R_1 and HM_1. However, C_{RET} is unknown and D_1 depends on C_{RET}. As with equation (7), there are unknowns on either side of the equality; there's no analytical solution and equation (13) which must be solved iteratively. This is readily accomplished by substitution of C_{RET} in equation (12) to estimate D_1 until the sum of $C_{RET} + D_1 = TC_{PART}$ which is known.

C. Exploitation Rates:

Exploitation rates on legal male biomass (μ_L) and mature male biomass (μ_M) at the time of the fishery are calculated as the ratio of total directed plus non-directed losses to legal male biomass (M_L) and mature male biomass (M_M) to the respective legal and mature male biomass at the time of the fishery (L_2 and M_2, respectively).

$$\mu_L = M_L/L_2 \quad (14)$$

$$\mu_M = M_M/M_2 \quad (15)$$

3. Model Selection

In May 2008, the CPT requested that the authors examine the feasibility of estimating $F_{35\%}$ for the Tanner crab stock using fishery selectivity. The SSC had recommended using fishery selectivity and maturity to estimate $F_{35\%}$ as the proxy F_{OFL}, and to estimate gamma as the ratio of $F_{35\%}$ to M. Results of that study are presented in Rugolo and Turnock (2009). In summary, fishery selectivity for Tanner crab used in the EA analysis were estimated on historical fishery performance data prior to the 1997 closure. We estimated selectivity for the contemporary fishery following its reopening in 2005 and found that the current selectivity for the directed and non-directed pot fisheries differed from those used in the EA. While it's desirable for Tier-4 stocks to employ the $F_{35\%}$ proxy for F_{MSY} where reliable data on fishery performance exist, the authors and SSC considered it premature to employ this approach for the Tier-4 Tanner assessment given these changes in performance observed in 2005-2007 versus those of the pre-1997 closure. Since the EA selectivity patterns no longer applied, their use in estimating $F_{35\%}$ and a factor in estimating gamma, may provide misleading and incorrect results in terms of management controls. The SSC concurred with the author's findings and recommended the $F_{35\%}$ not be used in OFL-setting since it could provide misleading results, and to set gamma=1.0.

In this assessment, gamma is set to 1.0, and discard mortalities from the directed and non-directed pot fisheries and the groundfish fisheries are included in OFL-setting. Even if pot fishery selectivities did not change after the reopening in 2005 relative to pre-1997, the EA simulations which suggest that $F_{35\%}$ may be a suitable F_{MSY} proxy for snow crab and Bristol Bay red king crab did not account for non-retained stock losses. Thus, it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. A further consideration in the estimation of gamma as the ratio of the EA $F_{35\%}$ to M is the fact that the MMB metric used in this assessment employs a maturity schedule, whereas the EA simulations employed knife-edge maturity at size. Thus, currency differences in the measure of reproductive biomass are potentially confounding.

The EA guidance prescribes that gamma should not be set to a level that would provide for more risk-prone overfishing definitions without defensible evidence that the stock could support levels in excess of M. Examination of the historical performance of the fishery (Figure 4a) and stock biomass (Figure 6) reveals that the Tanner crab stock has not been maintained in dynamic equilibrium over any sustained period, nor persisted in the face of exploitation rates (Table 6, Figures 7and 7b) that exceed levels we would consider biologically meaningful for this stock. The difference between fishery selectivity and maturity in EBS crab stocks has been suggested as a reason to allow gamma to exceed unity. Notwithstanding the technical challenges noted in estimating current fishery selectivity, this relies on theoretical population dynamic considerations in mature male biomass which are violated given the unique reproductive dynamic features of this stock (e.g., male-female size dependencies for successful copulation, male guarding and competition). Since a fundamental precept of precautionary fishery management is that the stock should not be exploited at a rate in excess of the F_{OFL}, we find no evidence that would justify a gamma in excess of 1.0 or fishing at an F_{OFL} rate greater than M on this stock.

4. Results

This assessment uses the proxy B_{MSY} ($B_{MSY\ Proxy}$) calculated as the average MMB at the time of mating over 1974-1980 inclusive. Formerly, $B_{MSY\ Proxy}$ was estimated as the average over 1969-1980 as requested by the SSC in 2009. As a result of recommendations of the Crab Workshop (Martel and Stam 2011) and the SSC in April 2011, 1969-1973 revised survey data are excluded from the analysis. The 1969-1973 survey did not consistently sample Tanner habitat which resulted in variable and biased low biomass estimates. The revised years (1974-1980) is a period of initially high then sharply declining male mature biomass resulting in a biased low proxy B_{MSY}. The production of stock biomass over 1974-1980 was affected by contemporaneous and antecedent high exploitation rates (Table 6, Figure 7a). This proxy B_{MSY} may underestimate the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries if fished at F_{MSY}.

The time period from 1980 to present is characterized by low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock and the imposition of a rebuilding plan by the NPFMC in 1999. During this period, the stock experienced exploitation rates in excess of current F_{MSY} estimates – at approximately 3M in the late-1970s, and 2M in the late-1980s preceding the collapses. During 1980-2009, the stock has not maintained itself at a level that could be reasonably construed as in dynamic equilibrium or at a level indicative of B_{MSY} capable of providing maximum sustainable yield to the fisheries. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of $B_{MSY\ Proxy}$ would be inconsistent with the tenet of selection of a range of years that represent the stock living at B_{MSY}, being fished at rates approximating F_{MSY}, and yielding MSY to the fisheries. The authors will revisit the choice of a proxy B_{MSY} with the development of the Tanner crab stock assessment model.

F. Calculation of the 2011/12 OFL

We estimated the Total Catch OFL and associated catch components for the 2011/12 Tanner crab fishery at three levels of proxy B_{MSY}: [1] bias-corrected 1974-1980 MMB at mating (93.24 thousand t); [2] non bias-corrected mean 19674-1980 MMB at mating (83.33 thousand t); and [3] mean 1974-2010 MMB at mating (37.01 thousand t) requested by the CPT (May 2011). Bias-correction of the indices of MMB at mating follows the method proposed by Rugolo and Turnock (2011), and reviewed by the CPT in May 2011. The non bias-corrected and bias-corrected estimates of MMB are shown in Table 8 columns 3 and 6, respectively, along with the respective mean values. For each proxy B_{MSY} values, we estimated 2011/12 catch components at three levels of projected 2011/12 snow crab retained catch. While the Total Catch OFL, F_{OFL} and $MMB_{2011/12}/B_{MSY\ Proxy}$ at each proxy B_{MSY} is unaffected by the level of 2011/12 snow crab retained catch, the Tanner retained catch changes as a result of expected discard losses in the 2011/12 snow crab fishery.

For the 2011/12 Tanner crab OFL-setting analysis, we used three levels of assumed 2011/12 snow crab retained catch: [1] Model-6 2011/12 snow crab retained catch=66.10 thousand t (145.72 million pounds); [2] projected ABC=90% of Model-6 retained catch, or 59.49 thousand t (131.15 million pounds); and [3] either 70.92 thousand t (156.35 million pounds) or 81.95 thousand t (180.66 million pounds) which result in discard losses of Tanner crab in the snow crab fishery at levels resulting in zero Tanner 2011/12 retained catch under the bias-corrected and non bias-corrected proxy B_{MSY} values, respectively.

The authors recommended the use of bias-corrected proxy B_{MSY}. A proxy B_{MSY} based on 1974-2010 is fundamentally inconsistent with a measure of stock biomass indicative of B_{MSY} that would provide maximum sustainable yield to the fisheries if fished at F_{MSY}. It's for illustration per CPT request.

Here, we discuss only the OFL-setting results for the bias-corrected (Table 9) and non bias-corrected (Table 10) proxy B_{MSY} for the input levels of 2011/12 snow crab retained catch OFL. Results assuming a proxy B_{MSY} based on 1974-2010 are shown in Table 11.

Using the bias-corrected 1974-1980 proxy B_{MSY}=93.24 thousand t, the estimated the 2011/12 Total Catch OFL=2,416.77 t for males and females combined (Table 9). Total projected losses to MMB are 2,300.76 t. Conditioned on the 2011/12 snow crab retained catch=66.10 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 50.32 t and 2,156.09 t, respectively. The retained part of the catch OFL of legal-sized crabs is 94.35 t. At a 2011/12 snow crab retained catch= 70.92 thousand t, the 2011/12 retained Tanner crab catch is zero. At values of 2011/12 snow crab retained catch > 70.92 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch≤70.92 thousand t, the projected 2011/12 MMB at the time of mating is 33.54 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.36 and the 2011/12 F_{OFL}=0.07. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 116.0 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.06 and 0.03 respectively.

Using the non bias-corrected 1974-1980 proxy B_{MSY}=83.33 thousand t, the estimated the 2011/12 Total Catch OFL=2,752.85 t for males and females combined (Table 10). Total projected losses to MMB are 2,631.76 t. Conditioned on the 2011/12 snow crab retained catch=66.10 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 165.45 t and 2,156.09 t, respectively. The retained part of the catch OFL of legal-sized crabs is 310.22 t. At a value of 2011/12 snow crab retained catch= 81.95thousand t, the 2011/12 retained Tanner crab catch is zero. At values of 2011/12 snow crab retained catch > 81.95 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch≤81.95 thousand t, the projected 2011/12 MMB at the time of mating is 33.20 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.40 and the 2011/12 F_{OFL}=0.08. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 121.08 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.07 and 0.05 respectively.

1. The 2011/12 OFL Apportioned E-W of 166^0 *W Longitude:*

In March 2011, the BOF approved a new minimum size limit strategy for Tanner crab effective for the 2011/12 fishery. The new regulations established different minimum size limits east and west of 166^0 W longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of 166^0 W longitude, respectively.

An approach to accommodate the new harvest regulations in the eastern and western areas under Tier-4 is proposed for illustration. For Tier-4 stocks, the F_{OFL} is specified using an F_{OFL} control rule according to whether projected mature male biomass at mating belongs to one of three stock status levels. If MMB is greater than the minimum stock size threshold beta (β), the Total Catch OFL is derived as the product of MMB and the F_{OFL}. Since fishery selectivity is not factored in the Tier-4 process, the biomass of all mature males is used in the calculation of the Total Catch OFL. Thus, mature male crab of all sizes are vulnerable to the F_{OFL} and no additional adjustment is required for a minimum legal size limit in an area – i.e., mature male fishery selectivity=1.0 for all sizes.

A basis to apportion the Total Catch OFL into guideline harvest levels (GHLs) in the areas east and west of 166^0 W longitude would be the relative proportion of MMB in those areas estimated at the time of the survey. An assumption of this approach is that movement of crab from the time of the survey to the fishery is negligible or, alternatively, movement does not occur predominately from one area to the other. If so, a GHL_E and a GHL_W can be established with the following provisos:

1. The GHL_E and a GHL_W are not area-specific total catch OFLs. They're guidelines for harvest to be taken under the size limit strategy implemented in each area.
2. The Total Catch OFL remains as the status determination criterion. The sum of all stock losses to the east and west of 166^0 W longitude will be gauged against the Total Catch OFL to assess overfishing.
3. In setting harvest policies for the new size limit strategy, the aim is not to exceed GHL_E and GHL_W. While there is no rule against setting GHL_E or GHL_W to the retained component of the Total Catch OFL, doing so would exploit MMB in that area at a rate that exceeds the F_{OFL} which could lead to unintended consequences on the reproductive potential of the stock as a whole.

Once the retained catch component (C_{RET}) of the total catch OFL is known from Eq. 13, the guideline harvest level for the area east of 166^0 W longitude (GHL_E) and for the area west of 166^0 W longitude (GHL_W) can be estimated as the product of C_{RET} and the proportion of MMB estimated in the respective areas ($P_{MMB\text{-}E}$, $P_{MMB\text{-}W}$) at the time of the survey by:

$$GHL_E = C_{RET}\,P_{MMB\text{-}E} \qquad (16)$$

$$GHL_W = C_{RET}\,P_{MMB\text{-}W} \qquad (17)$$

In the 2011 survey, MMB was distributed 35.8% to the east and 64.2% to the west of 166^0 W longitude.

G. *Calculation of the 2010/11 ACL=ABC*

Background

The Environmental Assessment for amendments 38 and 39 to the management for the BSAI KTC stocks (NPFMC 2010) established methods by which the Council will set Annual Catch Limits (ACLs) to meet the requirements of the Magnuson-Stevens Act. The 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 NPFMC's SSC.

Two methods for establishing the ABC control rule were considered: 1) a constant buffer approach where the ABC is set by applying a multiplier (M) to the OFL to meet a pre-specified buffer below the OFL; and 2) a variable buffer approach where the ABC is set based upon a pre-specified percentile (P*) of the distribution for the OFL that accounts for uncertainty in the OFL. P* is the probability that the ABC would exceed the OFL and overfishing occur. Two sources of uncertainty were used in setting the ABC for each stock: 1) σ_w, or within assessment uncertainty; and 2) σ_b, additional uncertainty, where total uncertainty $\sigma_{total}=\sigma_w+\sigma_b$. For all stocks, the EA recommended that some level of additional uncertainty be used in computing ABCs. An additional level of uncertainty equal to 0.30 is recommended for Tanner in this Tier-4 analysis.

Uncertainty in the Assessment

Additional uncertainty in this Tier-4 assessment is associated with estimates of stock biomass and the OFL which may be high relative to more well-studied BSAI crab stocks. Potential sources of additional uncertainty considered in formulating the ABC were: 1) pre-specified population dynamic parameters and life-history rates such as natural mortality, size-weight, maturity; 2) the assumption that $F_{msy}=F_{35\%}$ when applying the OFL control rule; and 3) the assumption that B_{msy} is represented by $B_{35\%}$ with an average biomass corresponding to MSY calculated over 1974-1980 using survey MMB at mating. The coefficient of variation (0.13) for the observed survey estimate of mature male biomass for 2011 is taken as the measure of within assessment uncertainty (σ_w).

Approach

The ABC=ACL for the 2011/12 fishery is estimated based on the Tier-4 control rule. Uncertainty was incorporated in the 2011/12 ABC in the estimation of survey biomass from the log-normal distribution incorporating σ_w=0.13 at two levels of additional uncertainty, σ_b=0 and σ_b=0.30 (σ_{total}=0.13 and σ_{total}=0.33, respectively) using the notation of the EA, and in the estimation of $B_{MSY\ Proxy}$ from the distribution based on non-parametric bootstrapping of the 1974-80 survey estimates of MMB at mating.

In 2010, the NPFMC prescribed that ABCs be established for all BSAI crab stocks at P*=0.49. Under this prescription, annual ACL=ABC levels are established such that the risk of ovefishing, P[ABC>OFL], equals 49%. We derived the relationship between the probability of overfishing and the OFL multiplier (M) via simulation and found the value of M corresponding to P*=0.49 at the specified levels of total scientific uncertainty, σ_{total}=0.13 and σ_{total}=0.33.

P[ABC > OFL] = 0.49	
σ_{TOTAL}	Multiplier (M)
0.13	M_1=1.0
0.33	M_2=0.82

Results

Given the retained catch component (C_{RET}) of the total catch OFL from Eq. 13, if M_1 is the OFL multiplier under σ_{total}=0.13 and M_2 is the multiplier under σ_{total}=0.33, the respective retained catch components at these levels of total scientific uncertainty ($C_{RET,0.13}$ and $C_{RET,0.33}$) are given by:

$$C_{RET,0.13} = C_{RET}\,M_1 \quad (18)$$

$$C_{RET,0.33} = C_{RET}\,M_2 \quad (19)$$

The revised guideline harvest levels for the areas east and west of 166^0 W longitude under σ_{total}=0.13 ($GHL_{E,0.13}$, $GHL_{W,0.13}$) are estimated as the product of $C_{RET,0.13}$ and the proportion of MMB estimated in the respective areas (P_{MMB-E}, P_{MMB-W}) at the time of the survey. The revised guideline harvest levels for the areas east and west of 166^0 W longitude under σ_{total}=0.33 ($GHL_{E,0.33}$, $GHL_{W,0.33}$) are estimated as the product of $C_{RET,0.33}$ and the proportion of MMB estimated in the respective areas (P_{MMB-E}, P_{MMB-W}) at the time of the survey.

$$GHL_{E,0.13} = C_{RET,0.13}\,P_{MMB-E} \quad (20)$$

$$GHL_{W,0.13} = C_{RET,0.13}\,P_{MMB-W} \quad (21)$$

$$GHL_{E,0.33} = C_{RET,0.33}\,P_{MMB-E} \quad (22)$$

$$GHL_{W,0.33} = C_{RET,0.33}\,P_{MMB-W} \quad (23)$$

We recommend the use of a total uncertainty of 0.33 in this Tier-4 assessment, resulting in a multiplier of 0.82. Based on the bias-corrected proxy B_{MSY} and conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, the retained part of the 2011/12 Tanner catch OFL=0.82·220.52 t=180.83 t. Based on the non bias-corrected proxy B_{MSY} and conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, the retained part of the 2011/12 Tanner catch OFL=0.82·355.80 t=291.76 t.

The ABC equivalent of any projected retained catch OFL is calculated as the product of the multiplier M_2=0.82 and the tabled retained catch OFL shown in Tables 9 through 11.

H. Data Gaps and Research Priorities

A length-based stock assessment model (TCSAM) for this stock is being developed. The TCSAM will incorporate population and survey performance metrics from time series survey data from 1974-2010. The goal is to promote the Tanner crab stock to a Tier-3 management status and to formulate OFLs based on the TCSAM. Antecedent analysis is being preformed to derive model inputs, parameters and schedules. For both males and females, these include the estimation of growth, maturity, survey selectivity, and fishing power. Also required is the reformulation of length-weight relationships, molting probability schedules and growth transition matrices.

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Table 1. Age (months), mean size (mm cw) and instar number for male Tanner crab in Kodiak and the eastern Bering Sea.

	Kodiak		EBS
Instar Number	Mean Size (mm cw)	Mean Age (months)	Mean Size (mm cw)
1	3.4	1.8	-
2	4.5	4.5	-
3	6.0	3.5	-
4	7.9	4.9	-
5	10.4	6.6	-
6	13.7	8.9	-
7	18.1	11.9	17.2
8	23.9	15.9	24.4
9	31.6	21.1	33.5
10	41.7	28.1	45.9
11	53.6	37.3	60.7
12	67.8	47.2	79.3
13	84.6	59.0	98.5
14	106.3	73.1	112.5
15	129.5	85.3	126.8
16	154.3	106.2	141.8
17	180.8	124.5	157.2

Table 2. Eastern Bering Sea *C. bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965/66-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T)				
	US Pot	Japan	Russia	Total
Year				
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			0
1986/87	0			0
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			0
1998/99	0			0
1999/00	0			0
2000/01	0			0
2001/02	0			0
2002/03	0			0
2003/04	0			0
2004/05	0			0
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			0

Table 3. Eastern Bering Sea *C. bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish fisheries, 1965/66-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Discard and Bycatch Losses (1000T)
[HMPot=0.50; HM_{GF}=0.80]

	All Pot		Groundfish		Total	
Year	Male	Female	Male	Female	Male	Female
1965/66	0.78	0.22	2.79	1.85	3.58	2.07
1966/67	1.00	0.28	5.06	3.35	6.06	3.63
1967/68	5.55	1.55	7.88	5.21	13.43	6.77
1968/69	7.35	2.05	5.98	3.96	13.32	6.01
1969/70	11.22	3.14	8.78	5.81	20.00	8.95
1970/71	10.40	2.91	9.76	6.46	20.17	9.37
1971/72	8.45	2.36	10.95	7.25	19.41	9.61
1972/73	6.90	1.93	6.29	4.16	13.19	6.09
1973/74	5.59	1.51	8.60	5.69	14.20	7.21
1974/75	6.62	1.78	11.91	7.88	18.53	9.66
1975/76	8.23	2.11	4.61	3.05	12.84	5.16
1976/77	12.92	3.49	2.00	1.32	14.92	4.81
1977/78	15.42	4.14	1.35	0.89	16.78	5.04
1978/79	10.42	2.58	1.55	1.03	11.98	3.61
1979/80	9.34	2.32	1.24	0.82	10.58	3.14
1980/81	8.29	1.80	1.02	0.67	9.31	2.47
1981/82	2.75	0.64	0.71	0.47	3.46	1.11
1982/83	1.51	0.32	0.22	0.14	1.73	0.47
1983/84	0.54	0.09	0.32	0.21	0.87	0.31
1984/85	1.25	0.23	0.31	0.21	1.57	0.43
1985/86	0.47	0.05	0.19	0.13	0.66	0.17
1986/87	0.61	0.06	0.31	0.21	0.93	0.27
1987/88	2.00	0.27	0.31	0.20	2.30	0.47
1988/89	5.56	0.77	0.22	0.15	5.79	0.92
1989/90	12.04	1.98	0.32	0.21	12.36	2.20
1990/91	22.36	3.50	0.45	0.30	22.82	3.80
1991/92	20.88	3.07	1.22	0.81	22.10	3.88
1992/93	12.36	1.09	1.33	0.88	13.69	1.97
1993/94	6.74	1.23	0.85	0.56	7.59	1.79
1994/95	3.51	1.06	1.01	0.67	4.52	1.73
1995/96	2.42	1.18	0.73	0.49	3.15	1.67
1996/97	0.55	0.16	0.77	0.51	1.32	0.67
1997/98	0.96	0.11	0.57	0.38	1.53	0.49
1998/99	1.05	0.09	0.45	0.30	1.50	0.39
1999/00	0.39	0.07	0.30	0.20	0.69	0.28
2000/01	0.11	0.01	0.36	0.24	0.46	0.25
2001/02	0.18	0.01	0.57	0.38	0.75	0.38
2002/03	0.31	0.02	0.35	0.23	0.66	0.25
2003/04	0.12	0.01	0.20	0.14	0.33	0.15
2004/05	0.06	0.01	0.32	0.22	0.39	0.22
2005/06	0.65	0.04	0.30	0.20	0.95	0.23
2006/07	1.37	0.25	0.35	0.23	1.71	0.48
2007/08	2.01	0.10	0.33	0.22	2.35	0.33
2008/09	0.91	0.03	0.26	0.17	1.17	0.20
2009/10	0.82	0.01	0.15	0.10	0.97	0.11
2010/11	0.69	0.01	0.10	0.07	0.79	0.08

Table 4. Eastern Bering Sea *C. bairdi* total catch in the directed (retained) and non-directed fisheries, 1965/66-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Total Catch (Retained + Non-Retained) (1000T)			
Year	Male	Female	Total
1965/66	5.44	2.03	7.46
1966/67	8.37	3.54	11.91
1967/68	26.82	6.63	33.45
1968/69	31.17	5.91	37.08
1969/70	47.25	8.79	56.04
1970/71	45.41	9.20	54.61
1971/72	39.90	9.47	49.38
1972/73	29.98	6.02	35.99
1973/74	27.22	7.21	34.43
1974/75	33.77	9.66	43.43
1975/76	30.49	5.16	35.65
1976/77	44.93	4.81	49.74
1977/78	52.30	5.04	57.34
1978/79	33.07	3.61	36.68
1979/80	29.59	3.14	32.73
1980/81	22.73	2.47	25.21
1981/82	8.45	1.11	9.56
1982/83	4.12	0.47	4.59
1983/84	1.42	0.31	1.72
1984/85	3.00	0.43	3.43
1985/86	0.66	0.17	0.84
1986/87	0.93	0.27	1.19
1987/88	3.30	0.47	3.77
1988/89	8.97	0.92	9.88
1989/90	23.47	2.20	25.67
1990/91	41.01	3.80	44.81
1991/92	36.53	3.88	40.41
1992/93	29.61	1.97	31.58
1993/94	15.25	1.79	17.04
1994/95	8.06	1.73	9.79
1995/96	5.07	1.67	6.74
1996/97	2.13	0.67	2.81
1997/98	1.53	0.49	2.02
1998/99	1.50	0.39	1.89
1999/00	0.69	0.28	0.96
2000/01	0.46	0.25	0.71
2001/02	0.75	0.38	1.14
2002/03	0.66	0.25	0.90
2003/04	0.33	0.15	0.48
2004/05	0.39	0.22	0.61
2005/06	1.38	0.23	1.61
2006/07	2.67	0.48	3.15
2007/08	3.30	0.33	3.63
2008/09	2.05	0.20	2.25
2009/10	1.58	0.11	1.69
2010/11	0.79	0.08	0.87

Table 5a. Observed eastern Bering Sea *C. bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1974/75-2011/12.

Eastern Bering Sea *Chionoecetes bairdi* Survey Biomass (1000T)

	Male Mature Biomass			Legal Male Biomass		
Year	Survey	Fishery	Mating	Survey	Fishery	Mating
1974/75	206.29	183.88	143.20	94.52	84.25	65.84
1975/76	257.02	229.10	189.99	168.79	150.46	127.14
1976/77	151.60	135.13	85.12	93.80	83.61	50.45
1977/78	129.63	115.54	58.90	77.66	69.22	31.09
1978/79	79.18	70.58	34.86	41.92	37.37	14.87
1979/80	48.14	42.91	11.71	22.69	20.22	0.46
1980/81	95.65	85.26	59.32	30.96	27.59	13.13
1981/82	55.51	49.48	39.17	10.40	9.27	3.93
1982/83	46.84	41.75	36.06	6.75	6.02	3.40
1983/84	27.22	24.27	21.94	4.40	3.92	3.22
1984/85	23.18	20.67	16.89	6.40	5.71	4.06
1985/86	11.01	9.81	8.78	3.81	3.40	3.27
1986/87	13.74	12.25	10.86	2.50	2.23	2.14
1987/88	26.76	23.85	19.66	5.79	5.16	3.97
1988/89	65.02	57.96	46.81	16.12	14.37	10.65
1989/90	105.65	94.18	67.16	32.41	28.89	16.69
1990/91	103.60	92.34	47.86	45.50	40.55	20.84
1991/92	108.34	96.57	56.41	35.15	31.33	15.73
1992/93	104.33	93.00	59.89	39.59	35.29	18.04
1993/94	58.76	52.38	35.16	18.80	16.76	8.46
1994/95	40.12	35.76	26.36	15.21	13.56	9.51
1995/96	29.62	26.40	20.34	9.47	8.44	6.20
1996/97	24.28	21.64	18.70	8.61	7.68	6.57
1997/98	10.43	9.30	7.42	3.32	2.96	2.85
1998/99	9.99	8.91	7.07	2.02	1.80	1.73
1999/00	12.80	11.41	10.29	2.14	1.91	1.84
2000/01	15.93	14.20	13.20	4.39	3.91	3.77
2001/02	17.79	15.86	14.51	5.90	5.26	5.06
2002/03	17.06	15.21	13.98	6.14	5.47	5.27
2003/04	23.19	20.67	19.56	6.61	5.89	5.67
2004/05	24.73	22.04	20.83	4.83	4.31	4.15
2005/06	42.40	37.80	34.99	10.28	9.16	8.39
2006/07	64.72	57.69	52.84	12.77	11.38	9.99
2007/08	73.56	65.57	59.80	10.48	9.34	8.03
2008/09	61.60	54.91	50.80	14.49	12.91	11.55
2009/10	34.99	31.19	28.44	7.03	6.26	5.43
2010/11	32.08	28.59	26.73	8.22	7.33	7.05
2011/12	41.78	37.24		14.73	13.13	

Table 5b. Observed eastern Bering Sea *C. bairdi* survey female, male and total spawning biomass (1000 t) and observed abundance of legal male crab ≥ 138mm (million crab), 1974-2011.

Observed Survey Mature Male and Female Biomass and Legal Male Abundance

Year	Mature Biomass (1000 t)			Male ≥ 138 mm
	Male	Female	Total	(10^6 crab)
1974	206.3	94.9	301.2	87.53
1975	257.0	66.0	323.0	151.45
1976	151.6	81.1	232.7	86.07
1977	129.6	80.8	210.4	68.49
1978	79.2	45.9	125.1	37.65
1979	48.1	34.2	82.3	21.33
1980	95.6	111.3	207.0	28.53
1981	55.5	67.3	122.8	10.14
1982	46.8	96.6	143.5	6.82
1983	27.2	32.9	60.1	4.70
1984	23.2	23.9	47.1	6.19
1985	11.0	9.7	20.7	3.54
1986	13.7	7.8	21.6	2.27
1987	26.8	28.1	54.9	5.73
1988	65.0	51.6	116.7	15.60
1989	105.7	49.0	154.6	32.73
1990	103.6	66.7	170.3	42.93
1991	108.3	79.4	187.8	33.89
1992	104.3	45.7	150.0	39.65
1993	58.8	19.4	78.2	18.22
1994	40.1	17.1	57.2	14.81
1995	29.6	22.4	52.0	9.45
1996	24.3	17.0	41.3	8.56
1997	10.4	6.3	16.7	3.24
1998	10.0	4.7	14.7	1.97
1999	12.8	8.3	21.1	2.07
2000	15.9	7.8	23.7	4.60
2001	17.8	9.7	27.5	5.97
2002	17.1	8.9	26.0	5.94
2003	23.2	14.1	37.3	6.31
2004	24.7	8.1	32.8	4.50
2005	42.4	22.1	64.5	10.41
2006	64.7	37.1	101.8	13.36
2007	73.6	25.2	98.8	10.90
2008	61.6	20.6	82.2	14.39
2009	35.0	14.2	49.2	6.91
2010	32.1	10.3	42.3	8.01
2011	41.8	15.7	57.5	13.7

Table 6. Eastern Bering Sea *C. bairdi* fishery exploitation rate on male mature biomass (MMB) and legal mature biomass (LMB), 1974/75-2010/11. Exploitation rates are based on biomass; μ on MMB uses total catch losses while μ on LMB uses total retained legal catch.

Eastern Bering Sea *Chionoecetes bairdi* Exploitation Rate @ Time Fishery		
Year	MMB	LMB
1974/75	0.18	0.18
1975/76	0.13	0.12
1976/77	0.33	0.36
1977/78	0.45	0.51
1978/79	0.47	0.56
1979/80	0.69	0.94
1980/81	0.27	0.49
1981/82	0.17	0.54
1982/83	0.10	0.40
1983/84	0.06	0.14
1984/85	0.14	0.25
1985/86	0.07	0.00
1986/87	0.08	0.00
1987/88	0.14	0.19
1988/89	0.15	0.22
1989/90	0.25	0.38
1990/91	0.44	0.45
1991/92	0.38	0.46
1992/93	0.32	0.45
1993/94	0.29	0.46
1994/95	0.23	0.26
1995/96	0.19	0.23
1996/97	0.10	0.11
1997/98	0.16	0
1998/99	0.17	0
1999/00	0.06	0
2000/01	0.03	0
2001/02	0.05	0
2002/03	0.04	0
2003/04	0.02	0
2004/05	0.02	0
2005/06	0.04	0.05
2006/07	0.05	0.08
2007/08	0.05	0.10
2008/09	0.04	0.07
2009/10	0.05	0.10
2010/11	0.03	0

Table 7. Data used to estimate discard and bycatch losses in the t 2011/12 fishery: (a) average directed fishery performance; (b) Tanner discards in non-directed EBS crab pot fisheries and snow crab retained catch, and (c) average Tanner crab bycatch in the EBS groundfish fisheries.

(a)

Average Observer Fishery Data EBS Tanner Crab Directed Fishery [2007/08, 2008/09, 2009/10]			
Discard:		1000T	Ratio:
	S.Legal ♂:	0.85	1.05
	Legal ♂:	0.02	0.02
	All ♀:	0.04	0.05
Retained:		0.81	1.0
	Total:	1.72	

(b)

Tanner Crab Non-Directed Pot Fishery Discards (1000T) (Combined Opilio + RKC Pot Fisheries)				
Year	Opilio Retained		Bairdi Discard	Ratio
2008/09	26.56		1.93	0.07
2009/10	21.78		1.39	0.05
2010/11	24.61		1.57	0.07
2011/12	24.61	1/	Average:	0.06
	42.77	2/		
	57.30	3/		
	Projected Bairdi Discards (1000T) 1/:			1.48
	Projected Bairdi Discards (1000T) 2/:			2.57
	Projected Bairdi Discards (1000T) 3/:			3.44

1/ 2010/11 retained catch.

2/ Value at which 2011/12 Tanner retained catch OFL=0.

3/ Projected 2011/12 retained catch OFL @0.75F35%.

(c)

Groundfish Fishery Tanner Crab Bycatch (1000 T) (Male + Female Combined)		
Year		Bycatch
2008		0.53
2009		0.32
2010		0.22
	Average:	0.36

Table 8. Bias-correction of B_{MSY} Proxy=mean 1974-1980 MMB at the time of mating. Correction of biased estimated B_{MSY} at mating resulting from total observed catch losses greater or less than F_{MSY} catch in fishing years 1974/75 through 1981/81. F_{MSY}=M=0.23.

Bias Correction in Proxy B_{MSY} Given Total Observed Catch ≠ F_{MSY} Catch					
	Observed MMB		Observed	Est. F_{MSY}	Adj. MMB
Year	@Fishery	@Mating	Total Catch	Total Catch	@Mating
			(1000 T)		
1974/75	183.88	143.33	33.63	37.78	139.17
1975/76	229.10	190.07	30.41	47.07	173.40
1976/77	135.13	84.85	45.20	27.76	102.27
1977/78	115.54	58.91	52.28	23.74	87.45
1978/79	70.58	35.51	32.42	14.50	53.42
1979/80	42.91	11.32	29.98	8.82	32.48
1980/81	85.26	59.32	22.73	17.52	64.53
	Mean	83.33		Mean	93.24

Table 9. Catch overfishing limits, stock and fishery metrics for the 2011/12 Eastern Bering Sea *C. bairdi* fishery. B_{MSY} Proxy is the bias-corrected mean 1974-1980 MMB at the time of mating at three levels of projected 2011/12 snow crab retained catch. µ on MMB is Total Catch OFL/MMB at the time of the fishery.

2011/12 Eastern Bering Sea *Chionoecetes bairdi*	2011/12 Opilio Retained Catch (1000 t)		
Catch OFL, Stock and Fishery Metrics	59.49 [1/]	66.10 [2/]	70.92 [3/]
Metrics (1000T):			
B_{REF}:	93.24	93.24	93.24
MMB @ Mating:	33.54	33.54	33.54
B/B_{REF}:	0.36	0.36	0.36
F_{OFL}:	0.07	0.07	0.07
Catch Components (1000T):			
Total ♂ Catch OFL:	2.30	2.30	2.30
Directed Discard Losses MMB:	0.12	0.05	0.00
Non-Directed Discard Losses MMB:	1.96	2.16	2.30
Retained Part of Total ♂ Catch OFL:	0.22	0.09	0.00
Discard + Bycatch Losses ♀:	0.12	0.12	0.11
Total ♂ Catch OFL + ♀ Losses:	2.42	2.42	2.41
Rates:			
µ on MMB @ Fishery:	0.062	0.062	0.062
BREF=bias-corrected mean 1974-1980 MMB@mating			

1/ ABC=90% of Model-6 2011/12 Estimated Retained Catch
2/ Model-6 2011/12 Estimated Retained Catch
3/ Value @which the 2011/12 Tanner Crab Retained Catch=0

Table 10. Catch overfishing limits, stock and fishery metrics for the 2011/12 Eastern Bering Sea *C. bairdi* fishery. B_{MSY} Proxy is the non bias-corrected mean 1974-1980 MMB at the time of mating at three levels of projected 2011/12 snow crab retained catch. μ on MMB is Total Catch OFL/MMB at the time of the fishery.

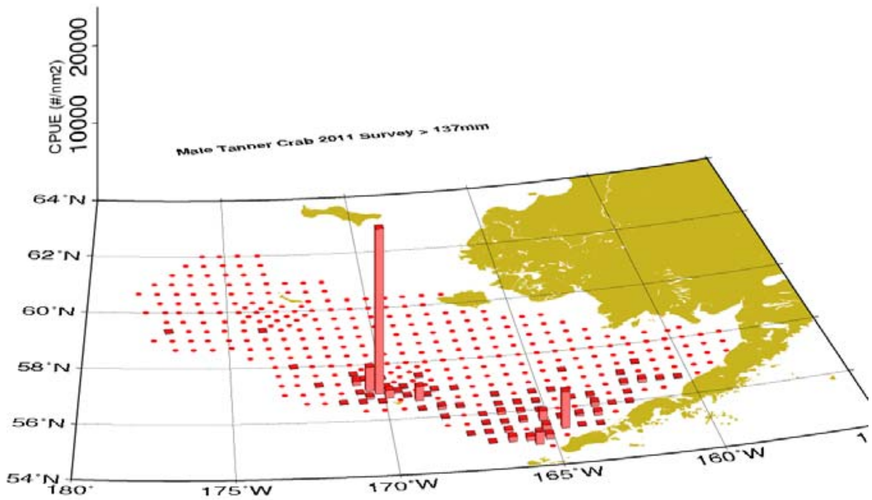
2011/12 Eastern Bering Sea *Chionoecetes bairdi* Catch OFL, Stock and Fishery Metrics	2011/12 Opilio Retained Catch (1000 t)		
	59.49[1/]	66.10[2/]	81.95[3/]
Metrics (1000T):			
B_{REF}:	83.33	83.33	83.33
MMB @ Mating:	33.20	33.20	33.20
B/B_{REF}:	0.40	0.40	0.40
F_{OFL}:	0.08	0.08	0.08
Catch Components (1000T):			
Total ♂ Catch OFL:	2.63	2.63	2.63
Directed Discard Losses MMB:	0.23	0.17	0.00
Non-Directed Discard Losses MMB:	1.96	2.16	2.63
Retained Part of Total ♂ Catch OFL:	0.44	0.31	0.00
Discard + Bycatch Losses ♀:	0.12	0.12	0.11
Total ♂ Catch OFL + ♀ Losses:	2.76	2.75	2.75
Rates:			
μ on MMB @ Fishery:	0.071	0.071	0.071
BREF=mean 1974-1980 MMB@mating			

1/ ABC=90% of Model-6 2011/12 Estimated Retained Catch
2/ Model-6 2011/12 Estimated Retained Catch
3/ Value @which the 2011/12 Tanner Crab Retained Catch=0

Table 11. Catch overfishing limits, stock and fishery metrics for the 2011/12 Eastern Bering Sea *C. bairdi* fishery. B_{MSY} Proxy is the mean 1974-2010 MMB at the time of mating at three levels of projected 2011/12 snow crab retained catch. µ on MMB is Total Catch OFL/MMB at the time of the fishery.

2011/12 Eastern Bering Sea *Chionoecetes bairdi* Catch OFL, Stock and Fishery Metrics	2011/12 Opilio Retained Catch (1000 t)		
	59.49[1/]	66.10[2/]	81.95[3/]
Metrics (1000T):			
B_{REF}:	37.01	37.01	37.01
MMB @ Mating:	29.91	29.91	29.91
B/B_{REF}:	0.81	0.81	0.81
F_{OFL}:	0.18	0.18	0.18
Catch Components (1000T):			
Total ♂ Catch OFL:	5.93	5.93	5.93
Directed Discard Losses MMB:	1.38	1.31	1.15
Non-Directed Discard Losses MMB:	1.96	2.16	2.63
Retained Part of Total ♂ Catch OFL:	2.59	2.46	2.15
Discard + Bycatch Losses ♀:	0.17	0.17	0.16
Total ♂ Catch OFL + ♀ Losses:	6.11	6.10	6.10
Rates:			
µ on MMB @ Fishery:	0.159	0.159	0.159
BREF=mean 1974-2010 MMB@mating			

1/ ABC=90% of Model-6 2011/12 Estimated Retained Catch
2/ Model-6 2011/12 Estimated Retained Catch
3/ Value @which the 2011/12 Tanner Crab Retained Catch=0 | BREF=mean 1974-1980 MMB at mating



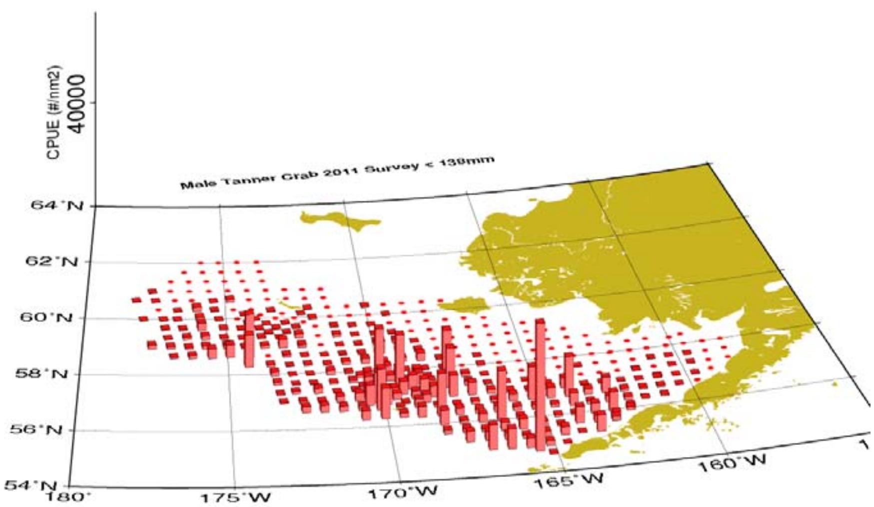


Figure 1. Distribution and abundance of legal (>= 138 mm cw) (top) and sublegal (< 138 mm cw) (bottom) male Tanner crab in the summer 2011 NMFS bottom trawl survey.

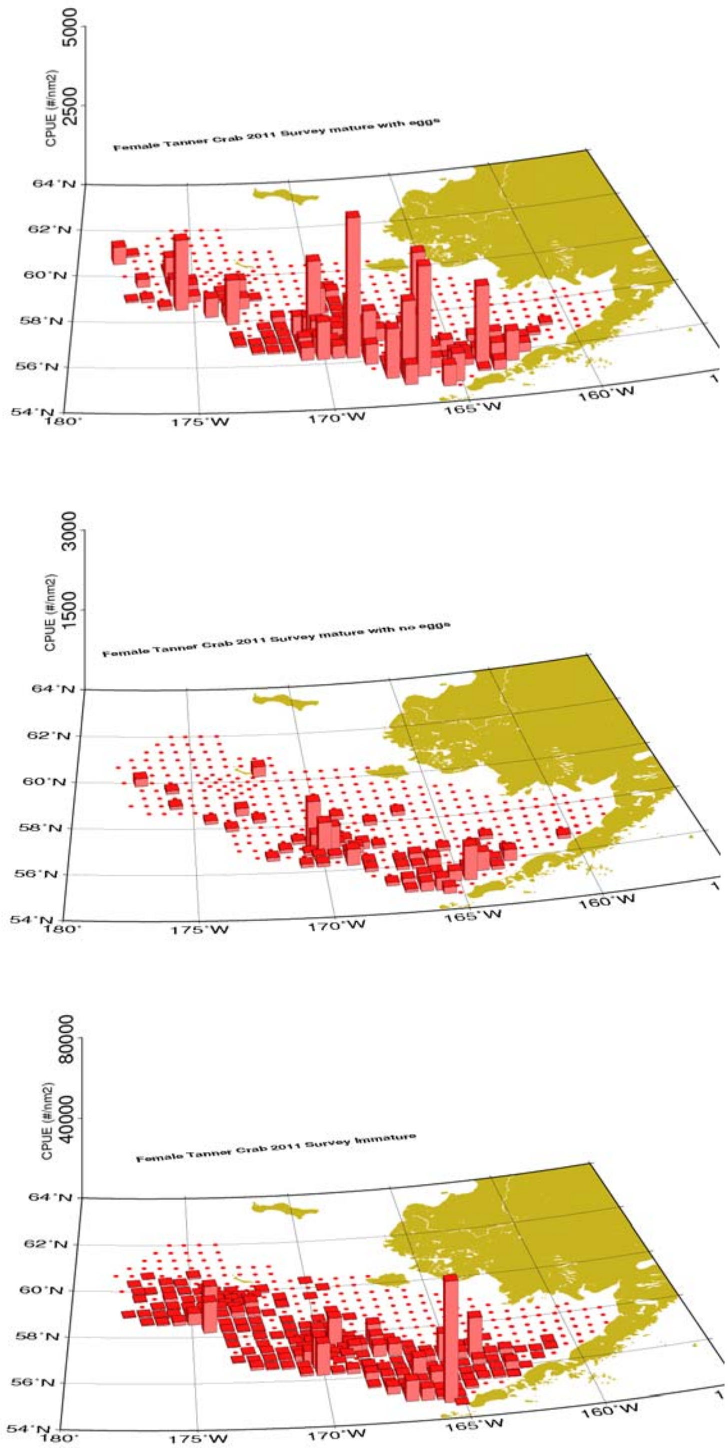


Figure 2. Distribution and abundance of ovigerous (top), barren mature (middle), and immature (bottom) female Tanner crab in the summer 2011 NMFS bottom trawl survey.

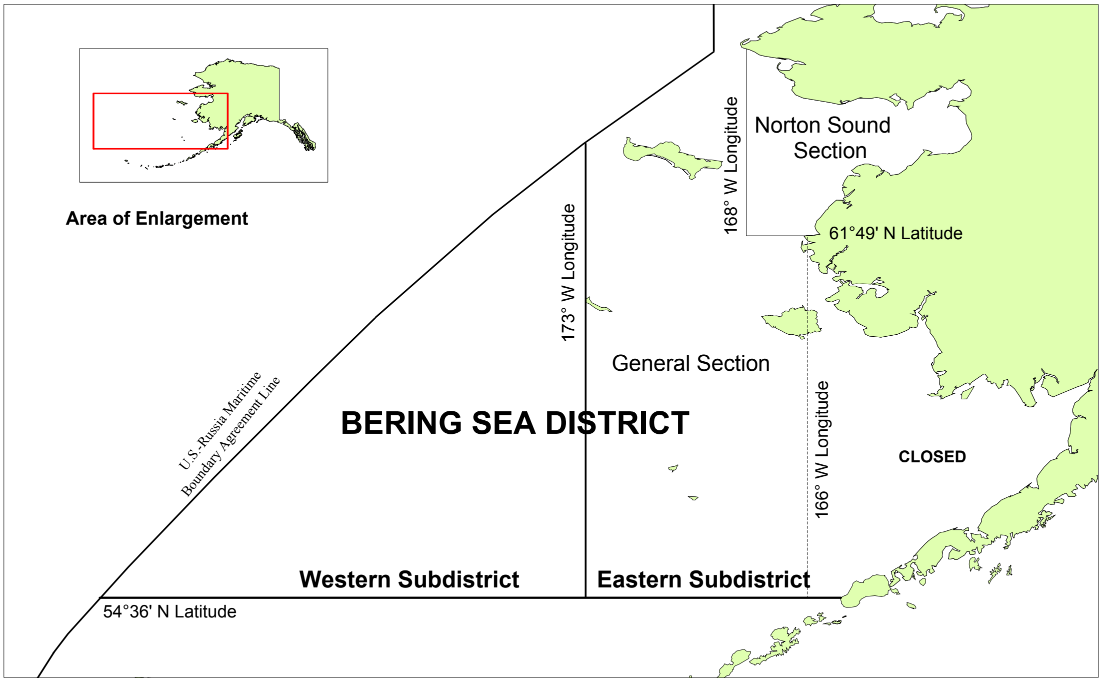
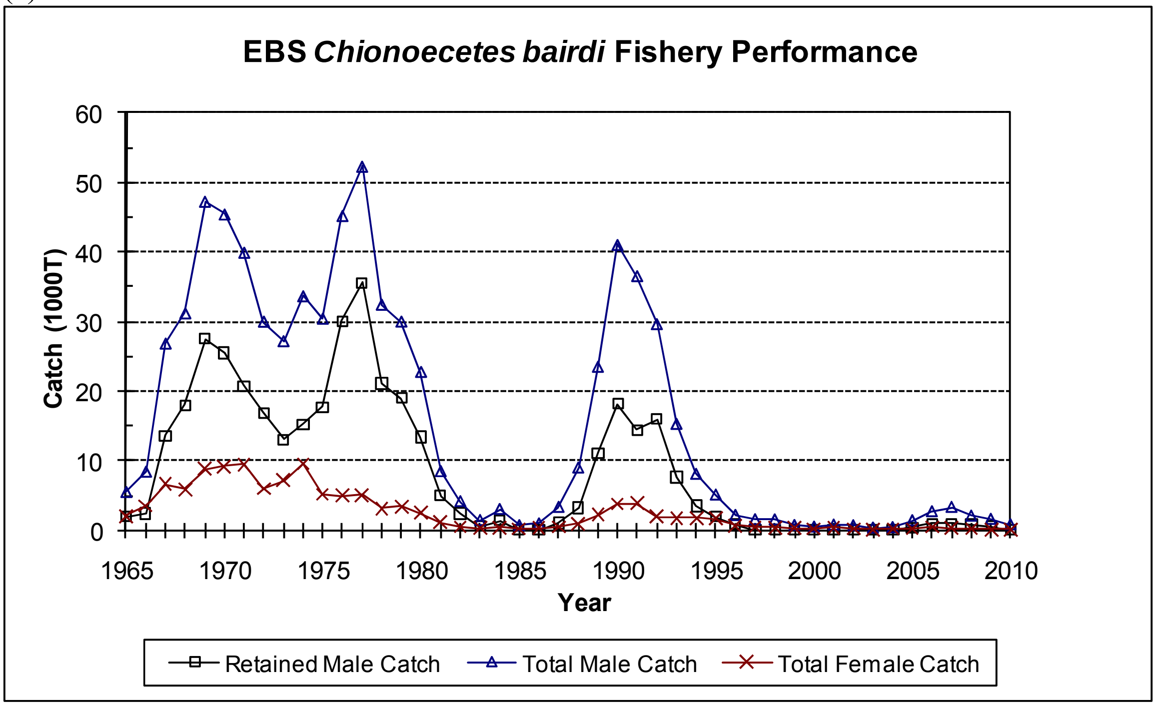


Figure 3. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)



(b)

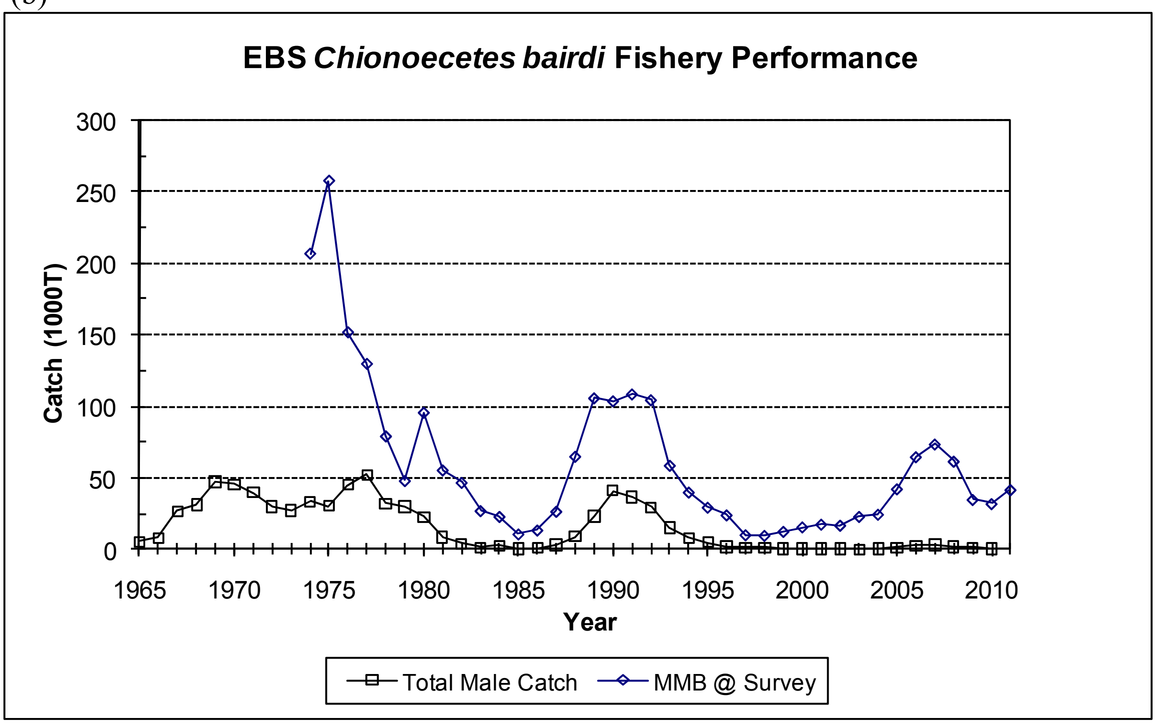


Figure 4. Eastern Bering Sea *C. bairdi* retained male catch, total (retained + bycatch) male catch and total female catch (a), and total male catch v. male mature biomass at the time of the survey (b) for years 1965/66 to 2010/11.

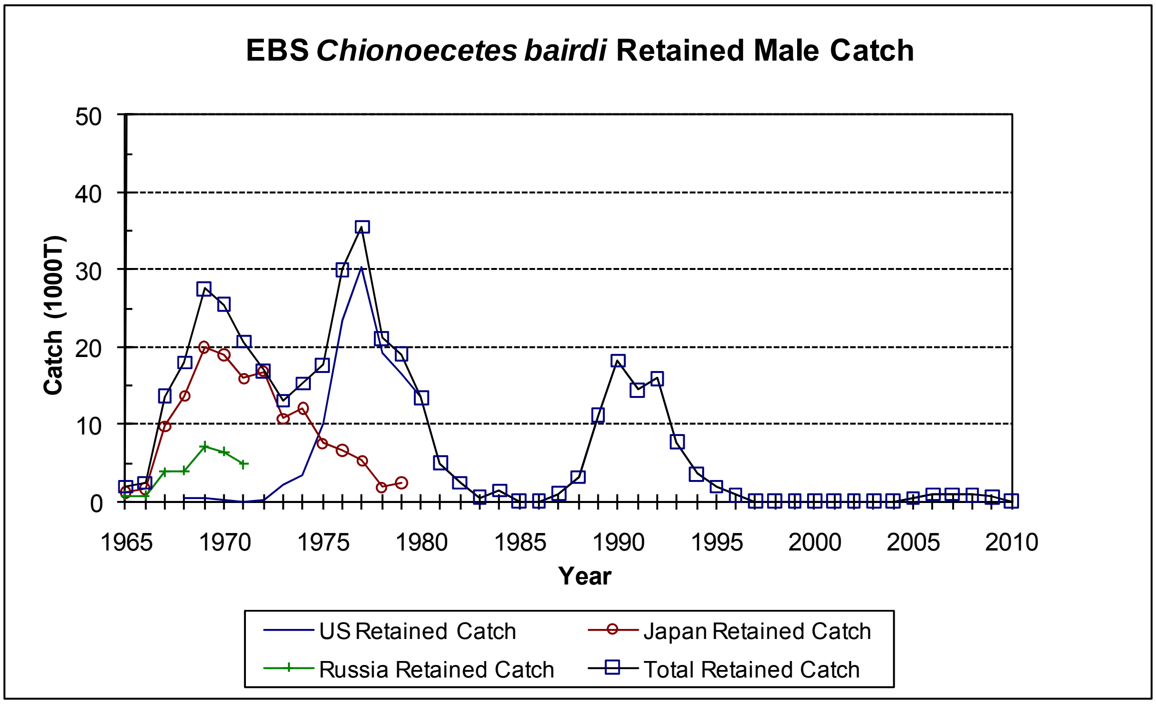


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965/66 to 2010/11.

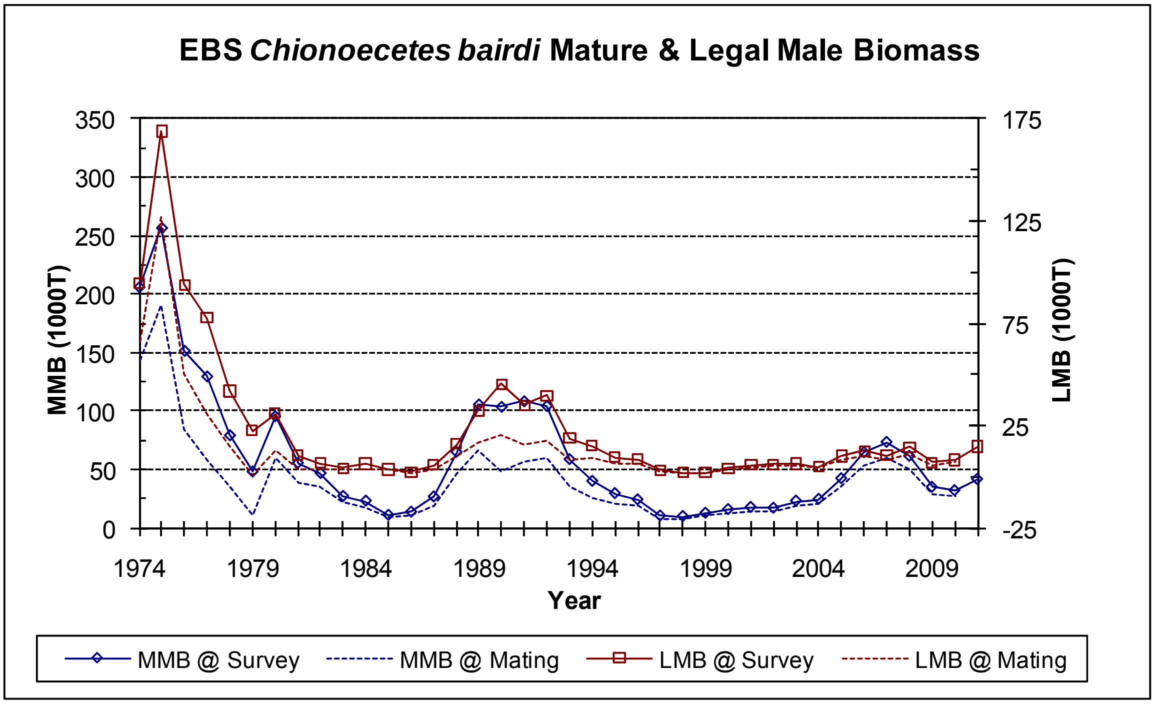
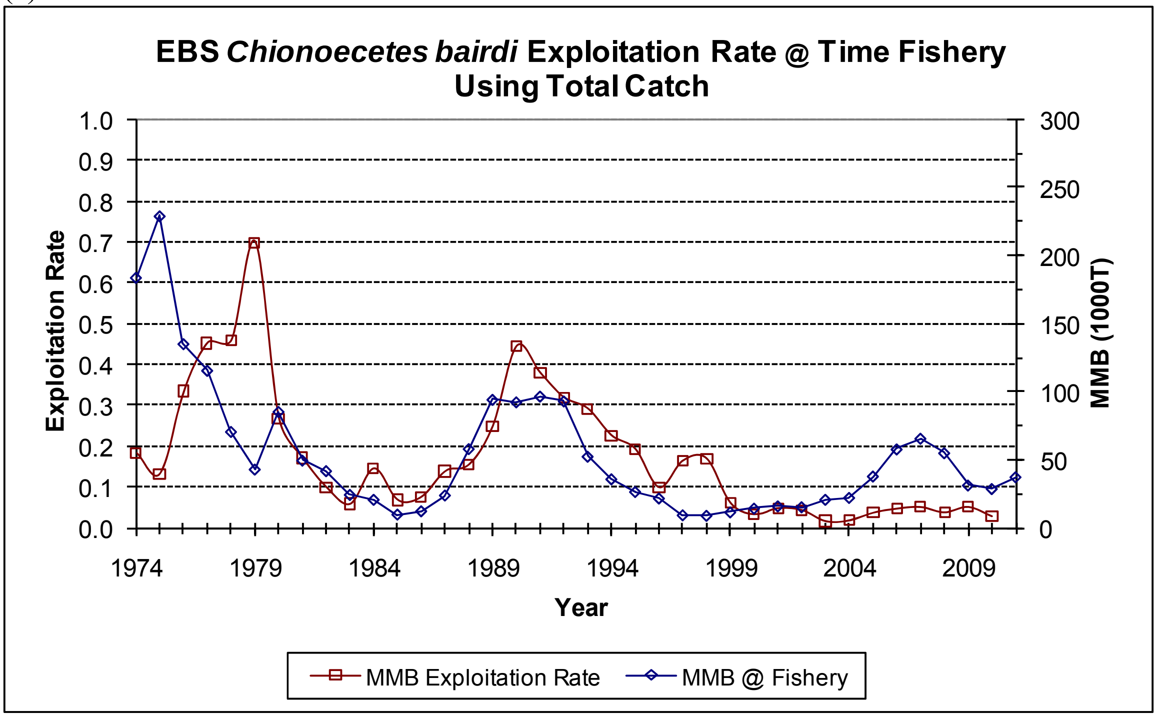


Figure 6. Eastern Bering Sea *C. bairdi* mature and legal male biomass at time of the survey and mating, 1974/75 to 2010/11.

(a)



(b)

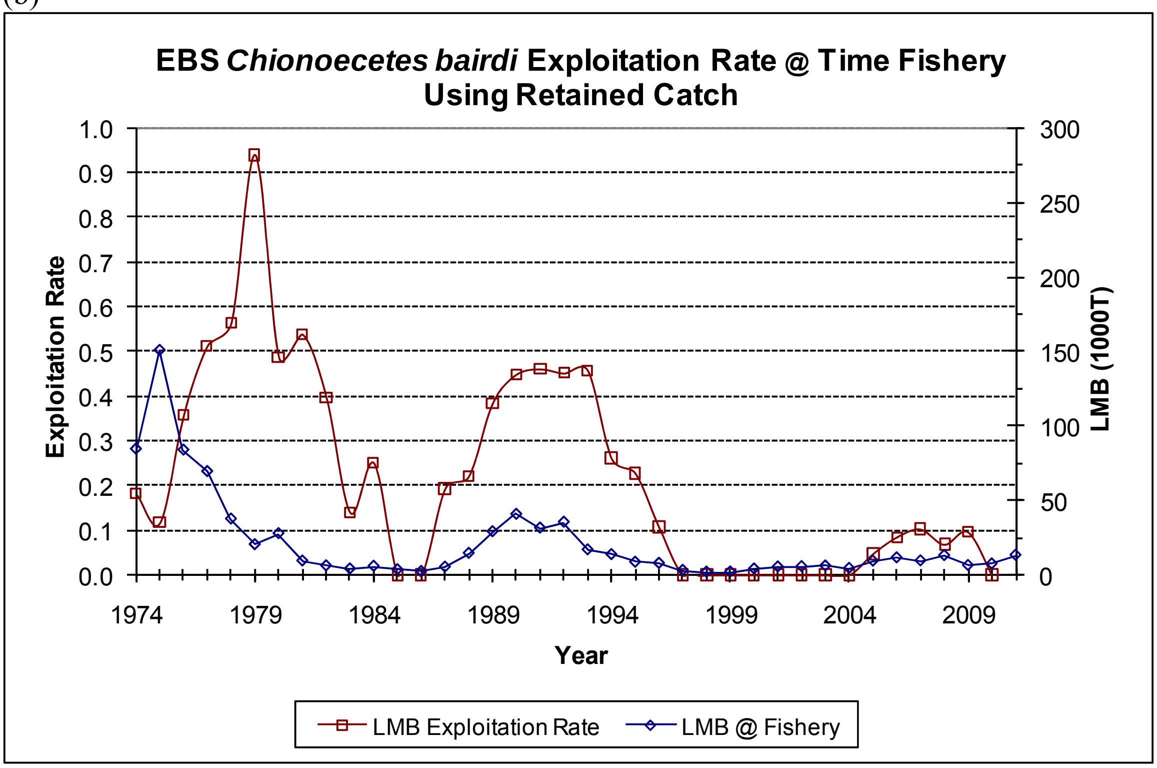


Figure 7. Eastern Bering Sea *C. bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1974/75 to 2010/11.

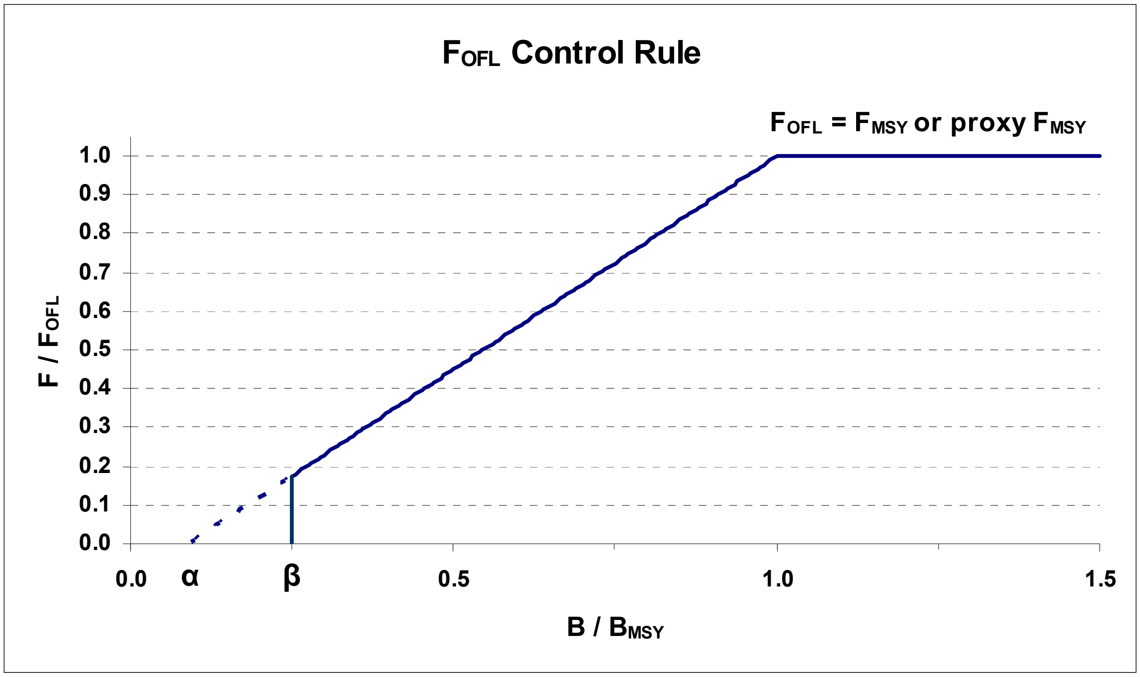


Figure 8. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

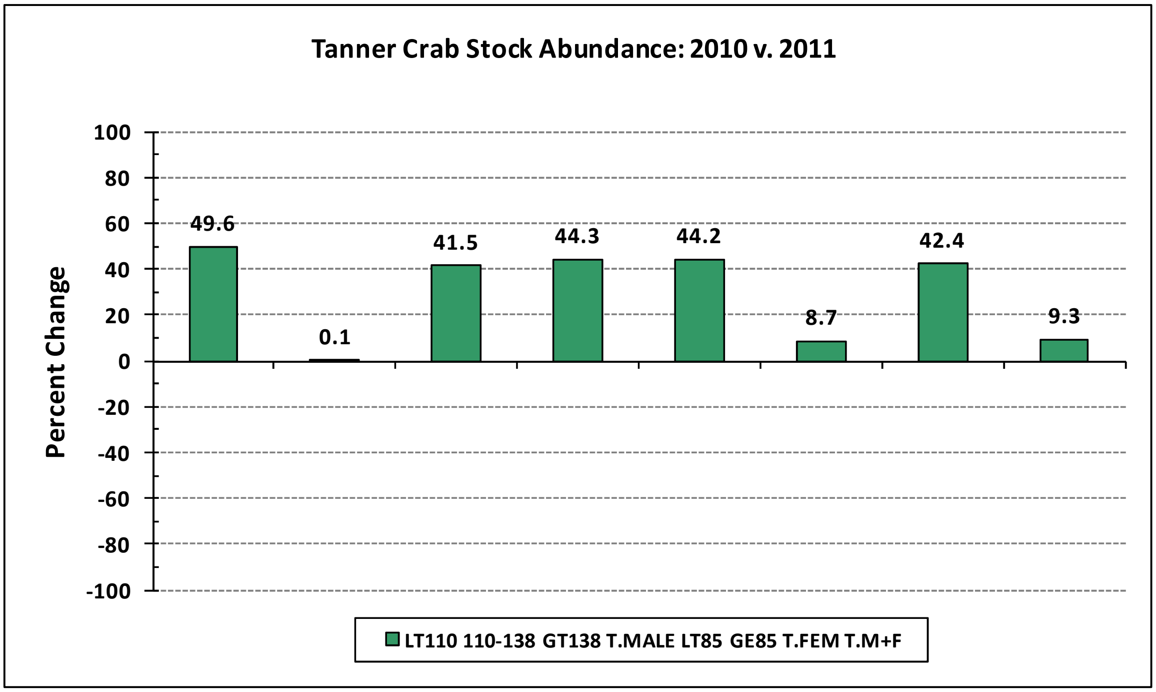
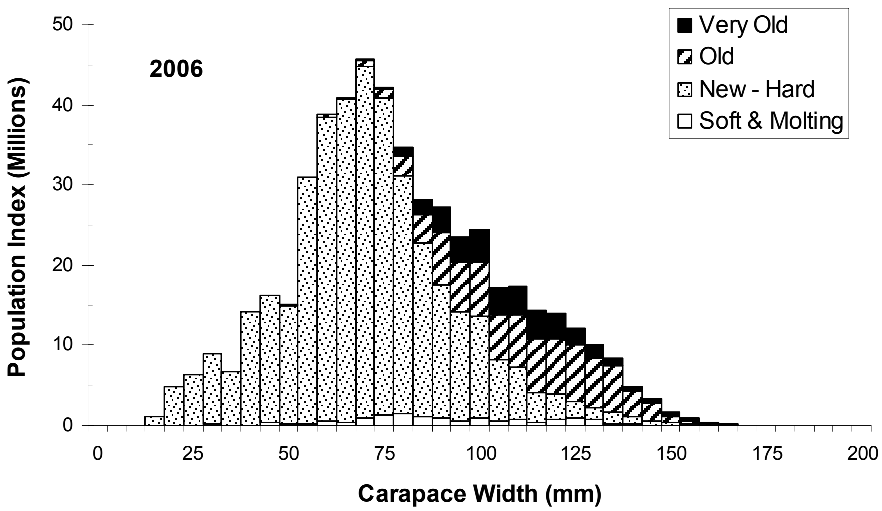


Figure 9. Percent change in Tanner crab stock abundance between the 2010 and 2011 summer trawl survey for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.

(a)



(b)

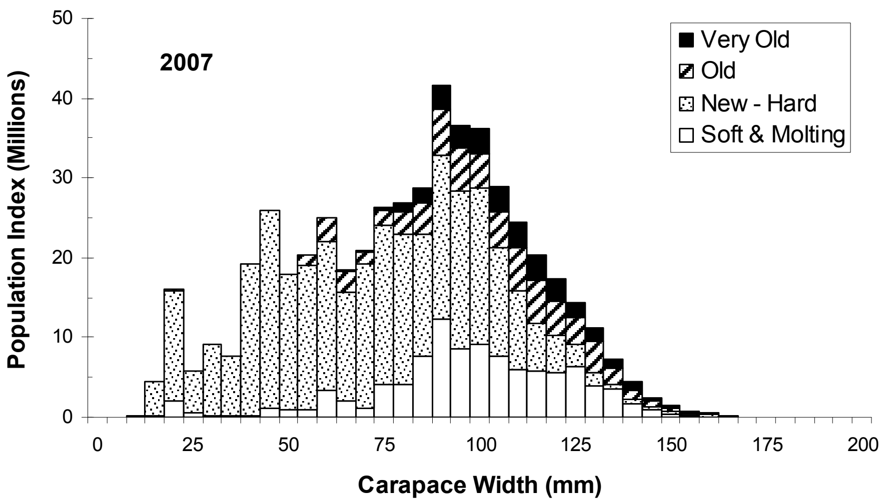
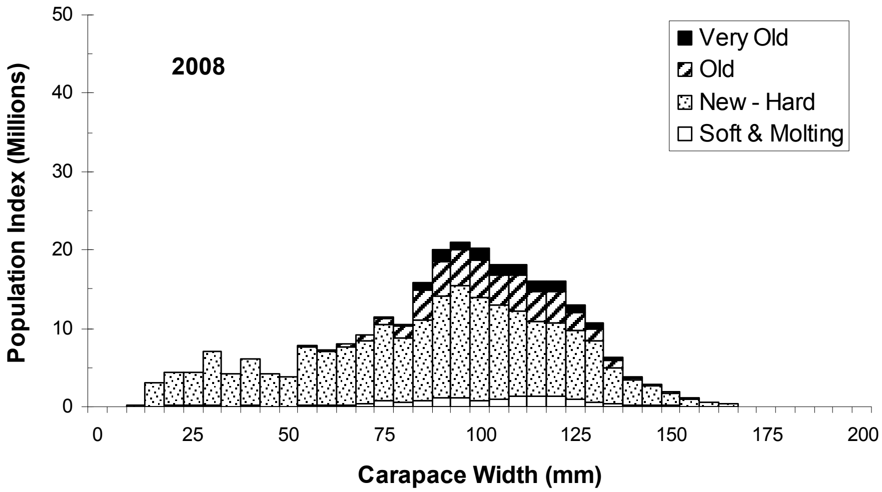


Figure 10 (a-b). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(c)



(d)

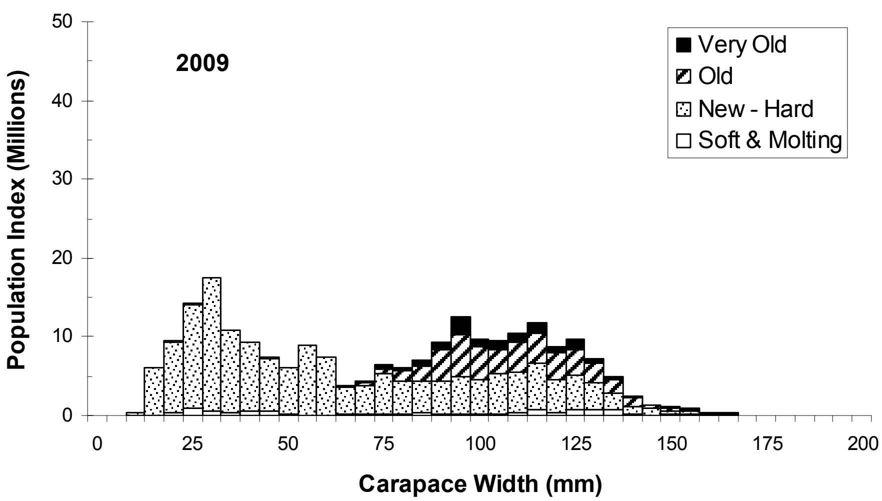
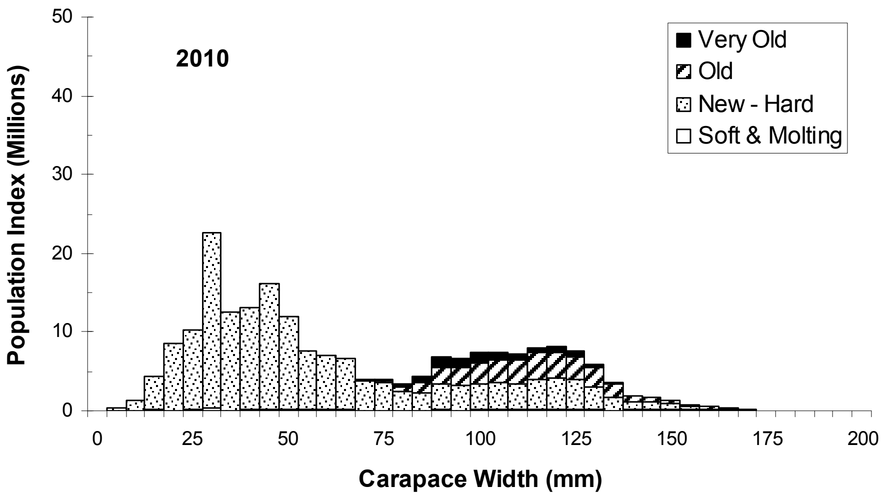


Figure 10 (c-d). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)



(f)

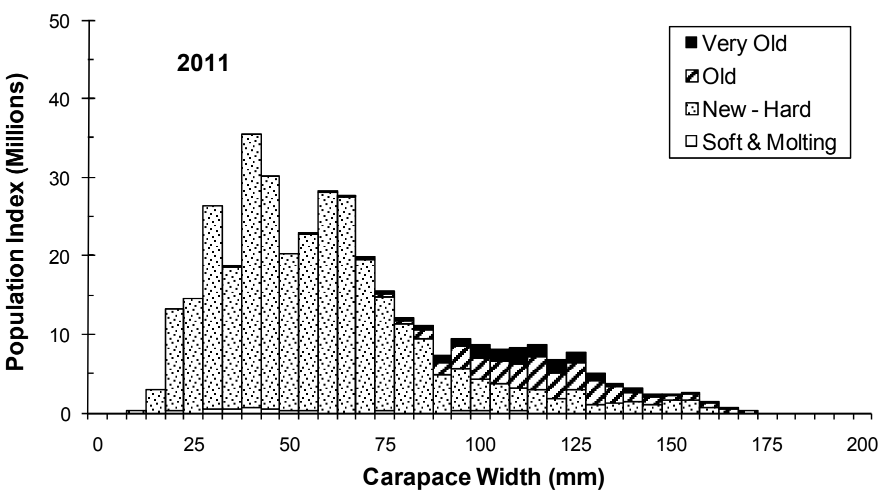
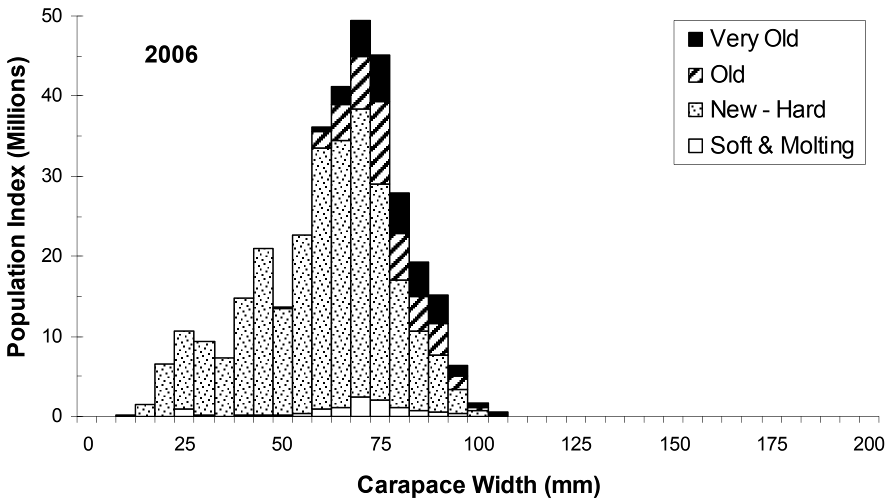


Figure 10 (e-f). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11 to 2011/12.

(a)



(b)

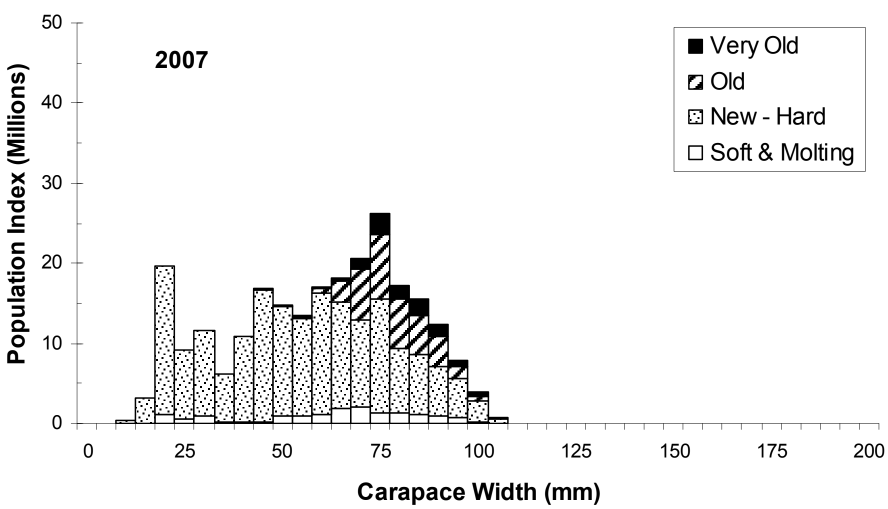
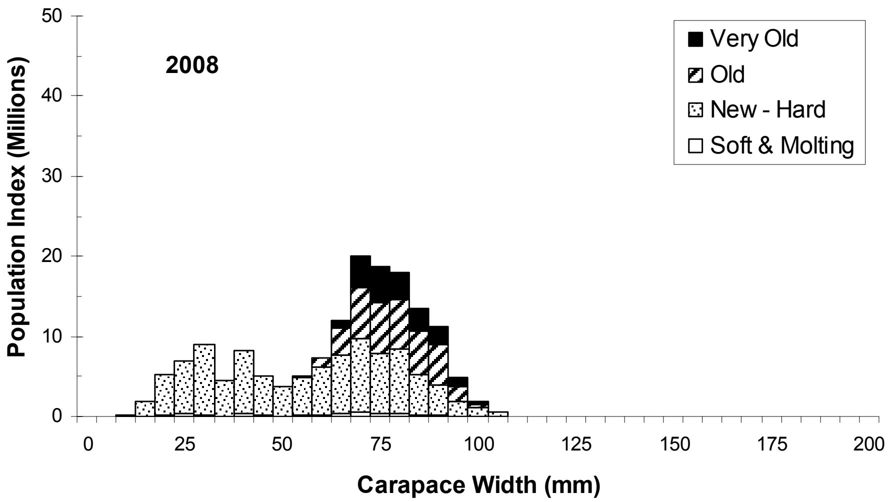


Figure 11 (a-b). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(c)



(d)

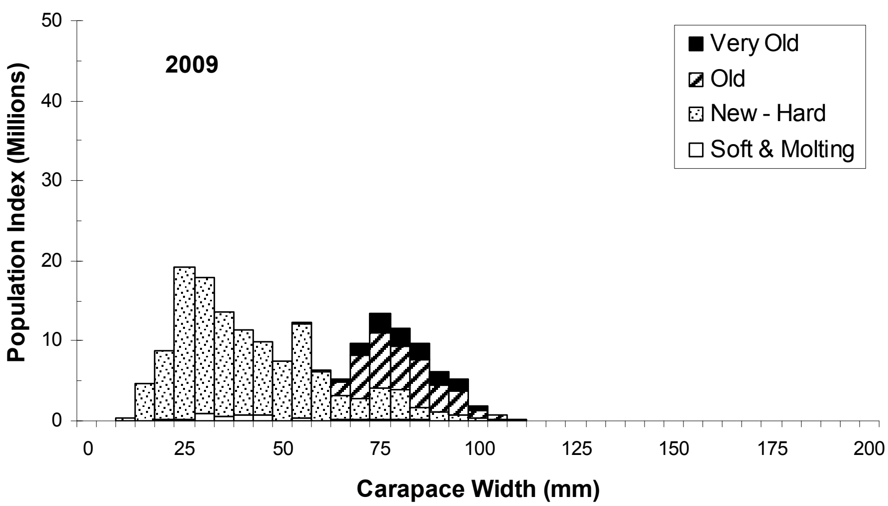
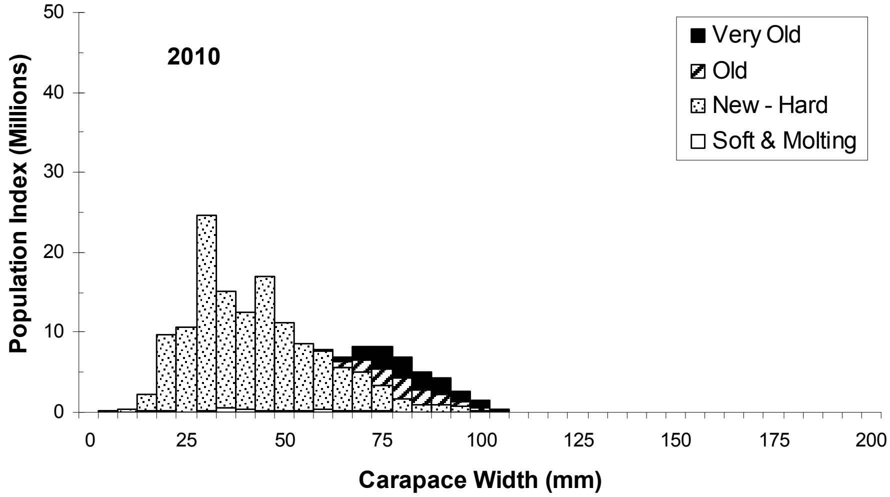


Figure 11 (c-d). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)



(f)

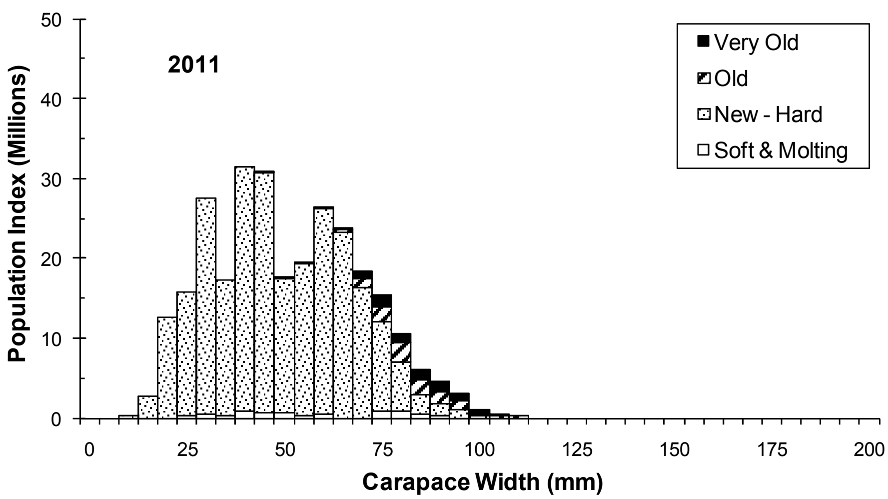


Figure 11 (e-f). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11 to 2011/12.

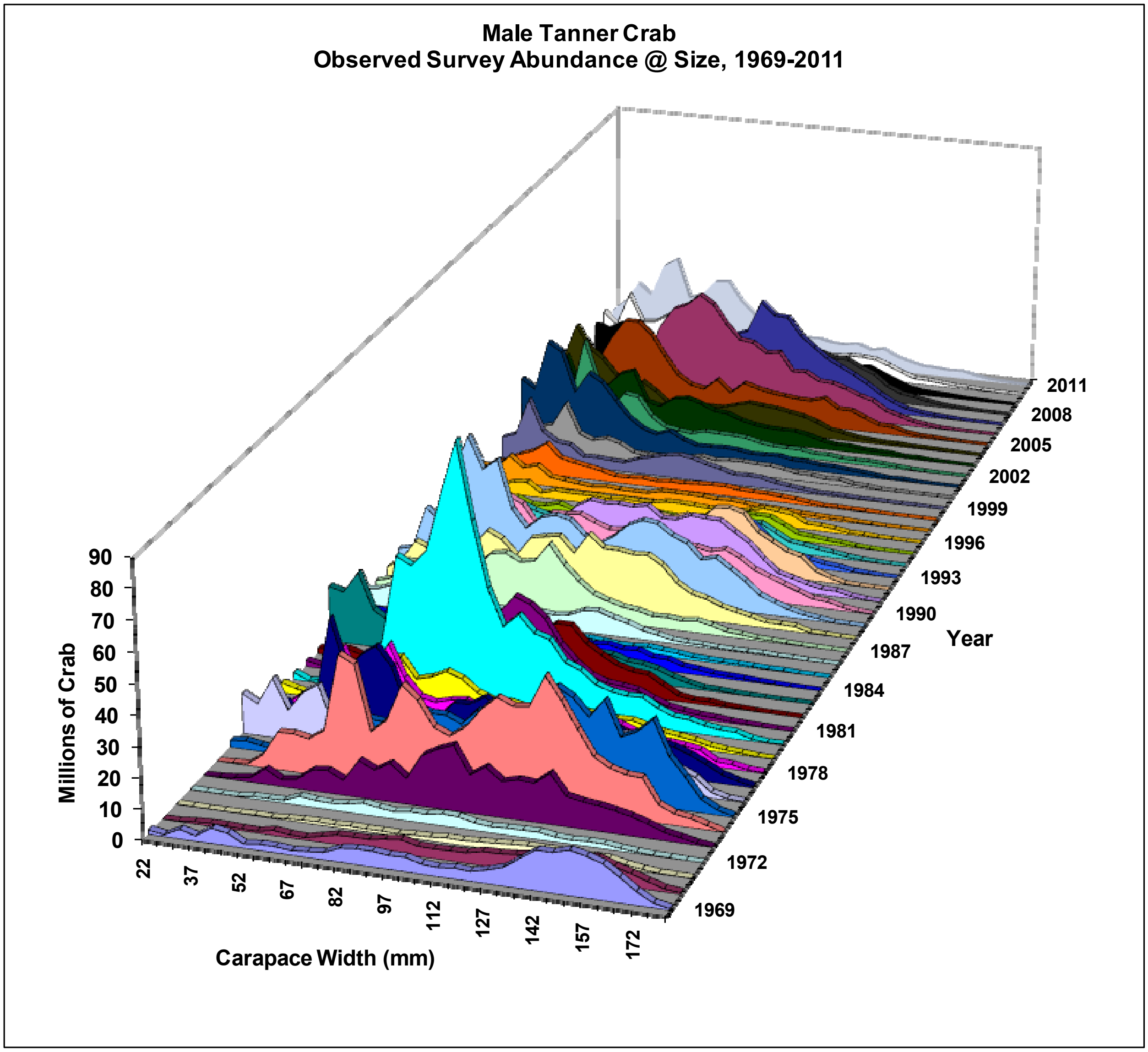


Figure 13. Observed male Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2010/11.

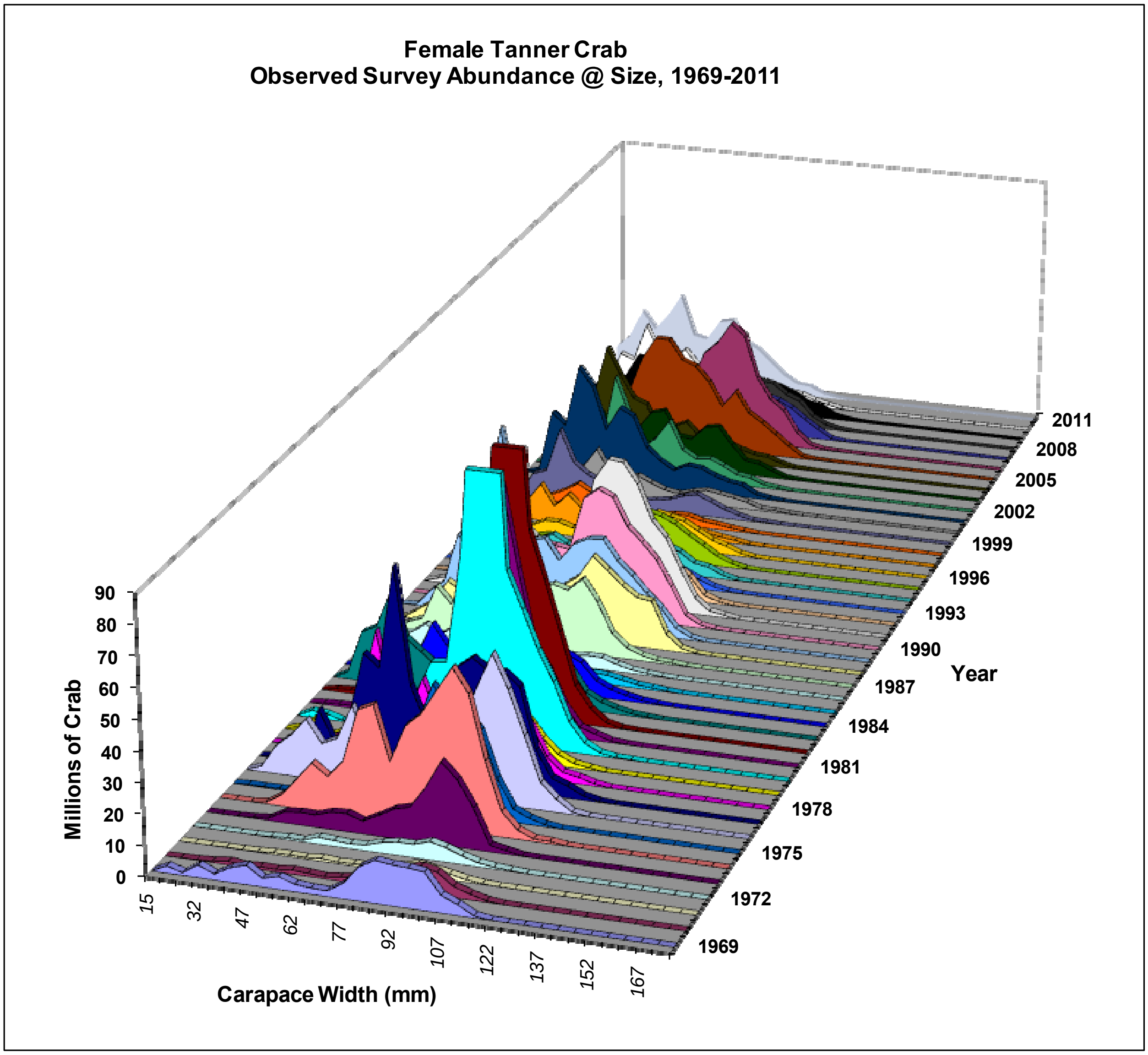


Figure 14 Observed female Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2010/11.

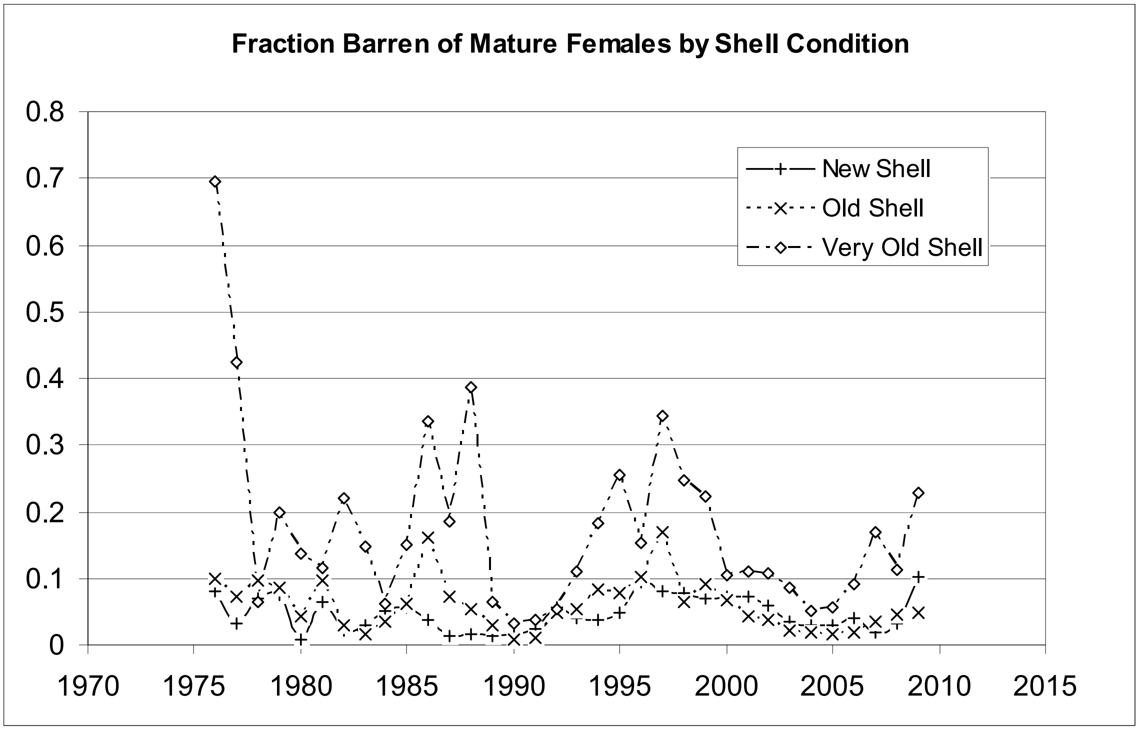


Figure 15. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

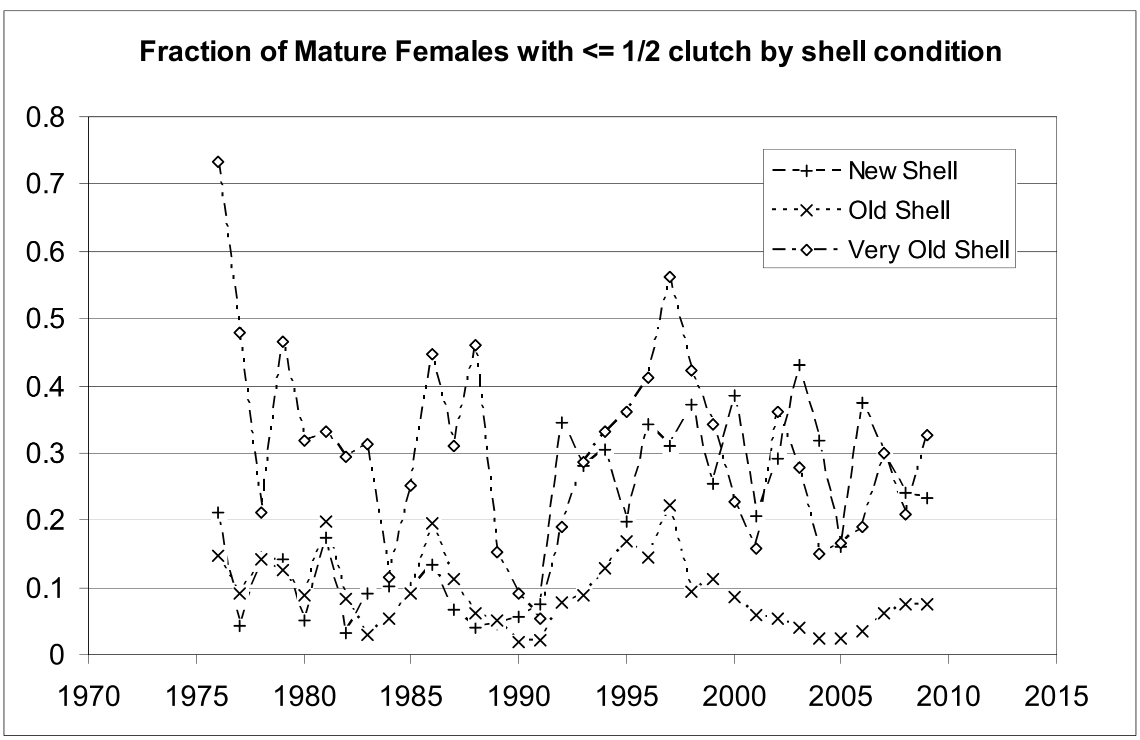


Figure 16. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

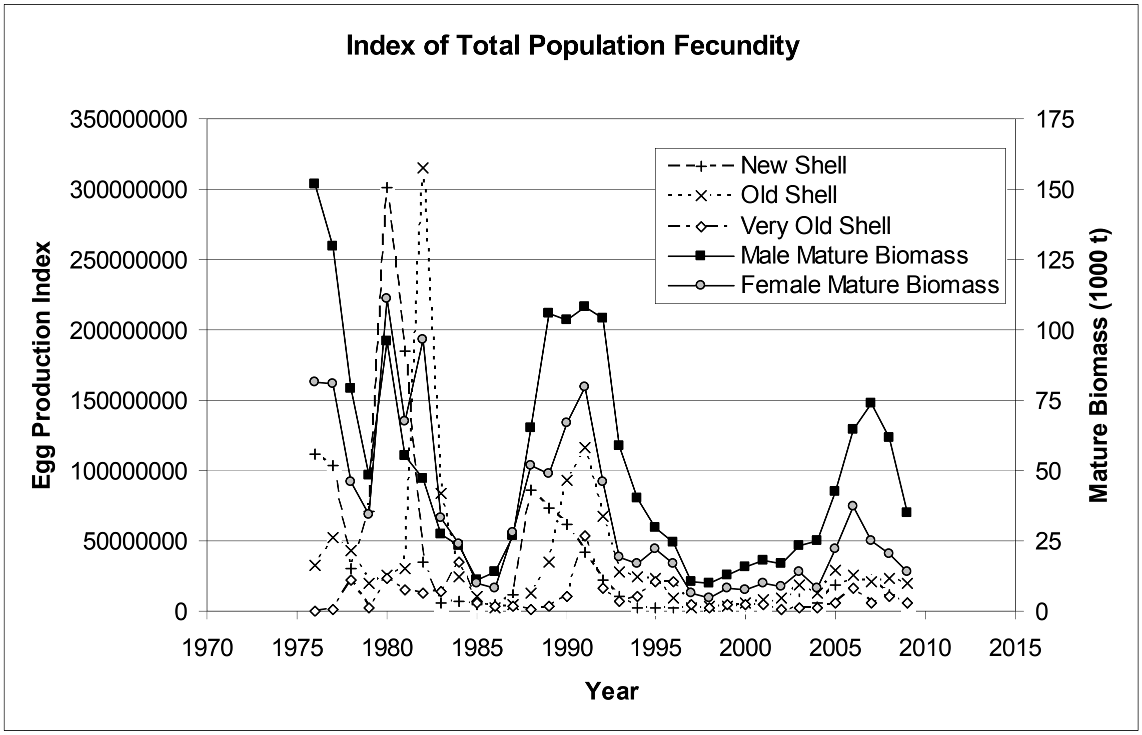


Figure 17. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

Appendix A.

Table A-1. Tanner crab management plan stock data table.

Year	Survey Recruit Biomass (1000 t)	MMB/B_{MSY}	Mature Biomass @Mating MMB (1000 t)	MFB (1000 t)	μ_{LMB} = Retained / LMB@ Fishery	Average F LMB@ Fishery (Retained)	Catch Biomass Retained (1000 t)	Total (1000 t)	Survey MMB Abundance (10^6 Crab)	Biomass (1000 t)	Survey FMB Abundance (10^6 Crab)	Biomass (1000 t)
1965/66							1.92	5.44				
1966/67							2.44	8.37				
1967/68							13.60	26.82				
1968/69							18.00	31.17				
1969/70							27.49	47.25				
1970/71							25.49	45.41				
1971/72							20.71	39.90				
1972/73							16.90	29.98				
1973/74							13.03	27.16				
1974/75	*n/a*	1.72	143.20	*n/a*	0.18	0.20	15.24	33.63	349.84	206.29	276.35	94.87
1975/76		2.28	189.99		0.12	0.12	17.65	30.41	356.07	257.02	198.31	65.99
1976/77		1.02	85.12		0.36	0.44	30.02	45.20	221.89	151.60	222.97	81.13
1977/78		0.71	58.90		0.51	0.72	35.52	52.28	205.74	129.63	247.22	80.82
1978/79		0.42	34.86		0.56	0.83	21.09	32.42	135.50	79.18	142.24	45.89
1979/80		0.14	11.71		0.94	2.81	19.01	29.98	95.10	48.14	120.22	34.19
1980/81		0.71	59.32		0.49	0.67	13.43	22.73	260.96	95.65	420.27	111.32
1981/82		0.47	39.17		0.54	0.77	4.99	8.45	147.92	55.51	253.33	67.31
1982/83		0.43	36.06		0.40	0.51	2.39	4.12	107.93	46.84	369.80	96.63
1983/84		0.26	21.94		0.14	0.15	0.55	1.42	63.84	27.22	113.08	32.89
1984/85		0.20	16.89		0.25	0.29	1.43	3.00	49.19	23.18	77.64	23.92
1985/86		0.11	8.78		0	0	0	0.66	23.12	11.01	29.29	9.68
1986/87		0.13	10.86		0	0	0	0.93	40.46	13.74	25.54	7.85
1987/88		0.24	19.66		0.19	0.21	1.00	3.30	84.02	26.76	103.68	28.12

Table A-1. Tanner Crab management plan stock data table. (continued)

Year	Survey Recruit Biomass (1000 t)	MMB/B_{MSY}	Mature Biomass @Mating MMB (1000 t)	MFB (1000 t)	μ_{LMB} = Retained / LMB@ Fishery	Average F LMB@ Fishery (Retained)	Catch Biomass Retained (1000 t)	Total (1000 t)	Survey MMB Abundance (10^6 Crab)	Biomass (1000 t)	Survey FMB Abundance (10^6 Crab)	Biomass (1000 t)
1988/89		0.56	46.81		0.22	0.25	3.18	8.97	164.21	65.02	156.57	51.64
1989/90		0.81	67.16		0.38	0.49	11.11	23.47	237.22	105.65	163.65	48.96
1990/91		0.57	47.86		0.45	0.60	18.19	41.01	202.23	103.60	219.80	66.72
1991/92		0.68	56.41		0.46	0.62	14.42	36.53	218.32	108.34	254.94	79.42
1992/93		0.72	59.89		0.45	0.60	15.92	29.61	184.41	104.33	147.10	45.65
1993/94		0.42	35.16		0.46	0.61	7.67	15.25	104.46	58.76	62.91	19.41
1994/95		0.32	26.36		0.26	0.30	3.54	8.06	68.19	40.12	53.78	17.06
1995/96		0.24	20.34		0.23	0.26	1.92	5.07	51.80	29.62	72.51	22.37
1996/97		0.22	18.70		0.11	0.11	0.82	2.13	44.51	24.28	55.53	17.05
1997/98		0.09	7.42		0	0	0	1.53	24.41	10.43	21.06	6.26
1998/99		0.08	7.07		0	0	0	1.50	26.36	9.99	16.66	4.67
1999/00		0.12	10.29		0	0	0	0.69	40.36	12.80	29.30	8.29
2000/01		0.16	13.20		0	0	0	0.46	39.30	15.93	25.75	7.78
2001/02		0.17	14.51		0	0	0	0.75	54.49	17.79	37.44	9.74
2002/03		0.17	13.98		0	0	0	0.66	48.85	17.06	36.18	8.90
2003/04		0.23	19.56		0	0	0	0.33	68.02	23.19	55.82	14.13
2004/05		0.25	20.83		0	0	0	0.39	70.04	24.73	30.85	8.06
2005/06		0.42	34.99		0.05	0.05	0.43	1.38	109.17	42.40	86.31	22.06
2006/07		0.63	52.84		0.08	0.09	0.96	2.67	181.26	64.72	145.98	37.07
2007/08		0.72	59.80		0.10	0.11	0.96	3.30	195.38	73.56	88.99	25.23
2008/09		0.61	50.80		0.07	0.07	0.88	2.05	133.15	61.60	73.05	20.62
2009/10		0.34	28.44		0.10	0.10	0.60	1.58	77.35	34.99	48.35	14.17
2010/11		0.32	26.73		0	0	0	0.79	70.71	32.08	36.88	10.25
2011/12									107.39	41.78	64.11	15.70

2011 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Red King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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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 steady or decreased in recent years to current levels with no bycatch.
3. Stock biomass: Stock biomass in recent years has decreased from 2007 to 2009 and increased in all size classes in 2010 and again in 2011.
4. Recruitment: Recruitment indices are not well understood for Pribilof red king crab. Pre-recruit have remained relatively consistent 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
2008/09	1,991 (4.39)	4,762[A] (11.06)	0	0	9.5 (0.021)	1,506 (3.32)	
2009/10	1,914 (4.22)	2,175[B] (4.46)	0	0	2.7 (0.006)	227 (0.50)	
2010/11	2,255 (4.97)	2,754[C] (5.44)	0	0	4.2 (0.009)	349 (0.77)	
2011/12		2,547[D*] (5.62)				453 (1.00)	362 (0.79)

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 2010/2011 and is hence not overfished. Overfishing did not occur during the 2010/2011 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
B – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
C – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches
D – Based on survey data available to the Crab Plan Team in September 2011
* – 2011/12 estimates based on 3 year running average

6. Basis for 2011/2012 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*
2011/12	4b	4,511 (9.95)	2,547 (5.62)	0.56	1.0	2000/2001-2010/2011	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 2011 survey mature male biomass CV of 0.645.
8. The ABC recommendation incorporated a σ_b of 0.4 to account for additional uncertainty the reducing the ABC from an ABC_{max} of 390 t (0.86 million lbs) to 362 t (0.79 million lbs).

9. Rebuilding analyses results summary: not applicable

Summary of Major Changes:
Major changes to this DRAFT 2010 stock assessment include removal of ecosystem chapter.

1. Management: There were no major changes to the 2010/2011 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series were updated with 2010/2011 data.
3. Assessment methodology: There were no changes to assessment methodology. A draft catch and survey model was developed in 2010/2011 and will continue development based on February 2011 modeling workshop recommendations. Assessment methodology for ABC calculations was included.
4. Assessment results: The projected MMB decreased and the OFL increased in this assessment. Total catch in 2010/2011 was 4.2 t.

Responses to SSC and CPT Comments

<u>SSC comments October 2010:</u>

General remarks pertinent to this assessment
none

Specific remarks pertinent to this assessment
The OFL method and tier determination were approved by the SSC for this stock in June. The SSC appreciates the concise nature of the stock assessment chapter. Based on the CPT's recommendation, we suggest that the author examine an average of recent survey biomasses when computing the OFL and look forward to a presentation of this in June 2011. The SSC continues to look forward to the implementation of a catch-survey analysis for this stock.
Responses to SSC Comments: Methodology for an average biomass from recent years provided. CSA model development provided in Appendix A.

<u>SSC comments June 2011:</u>

General remarks pertinent to this assessment
none

Specific remarks pertinent to this assessment
The SSC endorses the Crab Plan Team recommendation to use a 3 year moving average to estimate mature male biomass in the current year. We continue to look forward to seeing stock assessment models for these stocks, once the models are sufficiently developed for our review.
Responses to SSC Comments: Methodology for a three year moving average biomass used for this assessment. CSA model in development.

<u>CPT comments September 2010:</u>

General remarks pertinent to this assessment
none

Specific remarks pertinent to this assessment
The CPT recommended that the author base MMB estimates on moving averages when computing OFLs owing the high uncertainty associated with the survey estimates.

Responses to CPT Comments: Methodology for an average biomass from recent years provided.

CPT comments May 2011:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The team recommended that the survey and MMB data be plotted separately to better highlight differences in trends (if any). It also discussed the procedure for averaging survey biomass estimates, in particular the range of 2-7 years for averaging MMB, noting that the longer time frames for averaging were too long and average over too high (or low) of historical periods to truly reflect recent stock status. The CPT recommends a three-year moving average to estimate MMB in current year. Need to include CVs on graphs of MMB.

Responses to CPT Comments: The survey data was plotted separately. The use of a 3year moving average to estimate MMB was implemented in this assessment. CVs were included on figure.

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 only available stock structure of red king crabs in the North Pacific 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.

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 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 eastern Bering Sea 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 is on average 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 crabs *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 red and blue king crab fisheries which was implemented in 1998. From 1999 to 2008/2009 the Pribilof 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 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 red king crabs occur as bycatch in the eastern Bering Sea snow crab (*Chionocetes opilio*), eastern Bering Sea Tanner crab (*Chionocetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof blue king crab fisheries. Many of these fisheries have been closed or recently re-opened so the opportunity to catch Pribilof red king crab is limited. Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries.

Data

1. The standard survey time series data updated through 2011 and the standard groundfish discards time series data updated through 2011 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2010/2011 data.

2. a. Total catch:
   <u>Crab pot fisheries</u>
   Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (Table 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 2010/2011 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. 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 2011 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * \text{CL(mm)}^{B} \tag{1}$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \tag{2}$$

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 2010/2011, there were no Pribilof Islands red king crab incidentally caught in the crab fisheries (Table 3).

<u>Groundfish pot, trawl, and hook and line fisheries</u>
The 2010/2011 NOAA Fisheries Regional Office (J. Mondragon, 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. 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 2010 to June 2011. For Pribilof Islands red king crab, Areas 513 and 521 are included. It is noted that due to the extent of Area 513 into the Bristol Bay District, groundfish non-retained crab catches for Pribilof Islands red king crab may be overestimated. In 2011/2012 this data will be available in smaller units so that the management unit for each stock can be more appropriately represented. To estimate sex ratios for 2010/2011 catches, sex ratios by size and sex from the 2011 EBS bottom trawl survey were applied. 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).

In 2010/2011, 5.43 t of male and female blue king crab were caught in fixed gear (0.59 t) and trawl gear (4.84 t) groundfish fisheries which is 69% greater than was caught in 2009/2010 pot, trawl, and hook and line groundfish fisheries. The catch was mostly in non-pelagic trawls (89%) followed by longline (10%), and pot (0.5%) fisheries. The targeted species in these fisheries were Pacific cod (11%), flathead sole (53%), Alaska plaice (3%), and yellowfin sole (33%), and traces <1% found in the halibut, sablefish, and Greenland turbot fisheries. Unlike previous years no bycatch was observed in rock sole or pelagic pollock fisheries in 2010/2011.

c. Catch-at-length: NA

d. Survey biomass:
The 2011 NOAA Fisheries EBS bottom trawl survey results (Chilton et al. in press) are included in this SAFE report (Figure 6). Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock (Figure 5). Weight (equation 1) and maturity (equation 3) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass.

$$\text{Proportion mature male} = 1/(1 + (5.842 * 10^{14}) * e^{((CL(mm)+2.5) * -0.288)}$$
$$\text{Proportion mature female} = 1/(1 + (1.416 * 10^{13}) * e^{((CL(mm)+2.5) * -0.297)} \quad (3)$$

Historical survey data are available from 1975 to the present (Table 4, Figure 6). It should be noted that the survey data analyses were standardized in 1980.

In 2011, red king crab were caught at 7 of the 77 stations in the Pribilof District all of which were in the high-density sampling area (Chilton et al. in press, Figure 7). The density of legal-sized males caught at a station ranged from 74 to 2,219 crab/nmi^2. Legal-sized male red king crab were caught at 6 stations representing 49% of the total male abundance but were below the average from the previous 20 years (Figure 8). The majority of the legal-sized males were distributed south and west of St. Paul Island at stations G-21 and GH-2122. Mature males were encountered at 6 of the 77 stations. Mature males were distributed around St. Paul Island in the nearshore shallow water stations. The 2011 size-frequency for red king crab males shows an increase in the number of oldshell and very oldshell legal-sized males in comparison to the shell conditions from the previous two years. Seventeen percent of the legal-sized males had new hardshells and were distributed northeast of St. Paul Island. Eighty-three percent of the legal-sized males were in oldshell and very oldshell condition and primarily distributed southeast of St. Paul Island. The 2011 biomass (±95% CI) estimate of mature-sized red king crab females was 814 ± 1,165 t, representing 99.9% of the total female biomass with immature female red king crab biomass estimated at 3 ± 6 t. All of the mature females were carrying uneyed embryos with 96% of the mature females in new hard shell condition. The majority of mature females with uneyed embryos were in the130 mm CL to 140 mm CL size class.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and is in development.

Calculation of MMB

Taking a simple average biomass across previous years to calculate the MMB in the most recent year was considered to reduce the effect of high uncertainty in the survey based area swept estimates (Figure 9). A range of previous years from two to seven resulted in mean MMB over the time series from 2,724 to 2,773 t (Table 5). Using an average biomass of five to seven years resulted in the highest deviations from 162 to 365 t and dampened the distribution so that biomass peaks were skewed from the observed values. The three year average appeared to balance the deviations between the observed and averaged while reducing the annual variation in the MMB and was recommended by the CPT (May 2011) and SSC (June 2011) as the new method for estimating MMB (Figure 10). ***Therefore in this analysis the MMB will be estimated by a three year simple moving average MMB.*** Figure 11 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 averages for each major size class for males and females is presented in Table 6.

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 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 12). 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 estimating B_{MSY}. Previously, B_{MSY}^{prox} for Pribilof Islands red king crab 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. In this assessment, 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. It is noted however that the stock currently approaches MSST at the lowest biomass and therefore requires caution when considering fishery removals. It is recommended that in 2012 the time series for estimating $B_{MSYproxy}$ be reconsidered to stop at 2011

so that there is no trend influence on the reference point. During the remainder of the time series, the stock was either just developing or dropping under relatively higher exploitation. The recommendation for this alternate 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 13).
    2) An estimate of surplus production (ASP = $MMB_{t+1} - MMB_t$ + 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 (Figure 14).
    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 15).

B. Exploitation rates fluctuated during the open fishery periods from 1993 to 1998 (Figure 14) while total catch increased quickly in 1993 before declining rapidly until the fishery was closed in 1999 (Figure 16). 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. No trend is apparent when comparing the ln (recruits/MMB) with exploitation on MMB.

Cons to the use of the alternate time series for establishing $B_{MSYproxy}$ are:

A. The confidence intervals on data prior to 1980 are large so apparent trends in biomass are questionable however, the coefficients of variance on the survey biomass are relatively lower than earlier years.

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 12) 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. $\beta < B/B_{MSY}^{prox} \le 1.0$	$F_{OFL} = \gamma \cdot M\,[(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(5)
c. $B/B_{MSY}^{prox} \le \beta$	$F_{directed} = 0$; $F_{OFL} \le F_{MSY}$	(6)

b. The MMB_{Mating} projection is based on application of M from the 2011 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 2009/2010 to the 2010 survey biomass.

$$MMB_{Survey} \cdot e^{-PM(sm)} - \text{(projected legal male catch OFL)-(projected non-retained catch)} \quad (7)$$

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 (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).

$$\text{Projected Total Catch OFL} = [1 - e^{-Fofl}] \cdot \text{Total Crab Biomass}_{Fishery} \quad (8)$$

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:

$$\mu_{LMB} = \text{[Total LMB retained and non-retained catch]} / LMB_{Fishery} \quad (9)$$

$$\mu_{MMB} = \text{[Total MMB retained and non-retained catch]} / MMB_{Fishery} \quad (10)$$

5. Recommendations:
For ***2010/2011 B_{MSY}^{prox}=4,511 t of MMB_{mating} derived as the mean of 2000/2001 to 2010/2011***. The B_{MSY}^{prox} based on the mean MMB from 1990/1991 to 2010/2011 was 5,143 t. 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 2011/2012 was estimated at 2,547 t for B_{MSY}^{prox} based on the alternate years and 2,577 t based on the original B_{MSY}^{prox} years. The ***B/B_{MSY}^{prox} =0.56 and F_{OFL}=0.09 based on the alternate years for B_{MSY}^{prox}*** and B/B_{MSY}^{prox} =0.501 and F_{OFL}=0.08 based on the original years. The biomass reference option B/B_{MSY}^{prox} is < 1, therefore the ***stock status level is b*** (equation 5). For the 2011/2012 fishery, the ***total catch OFL was estimated at 453 t*** of crab and legal male catch OFL was estimated at 238 t of crab based on alternate years for B_{MSY}^{prox}. The total catch OFL was estimated at 393 t of crab and legal male catch OFL was estimated at 206 t of crab based on previous years for B_{MSY}^{prox}. The ***projected exploitation rates based on full retained catches up to the OFL for LMB and $MMB_{fishery}$ are 0.09 and 0.07 respectively based on the alternate B_{MSY}^{prox} years***.

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 $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$.

   Specification of the probability distribution of the OFL used in the ABC:
   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. 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 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 0.645 and has ranged between 0.357 and 0.786 since the 1995 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 1981-1988 and 1993-1999, so 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 2011/2012 using the recommended B_{MSY}^{prox}, the multiplier equivalent to a P* of 0.49 was 0.86. The ***ABC$_{max}$* was thus estimated to be 390 t**. Incorporating additional uncertainty by applying a σ_b of 0.4 resulted in a multiplier of 0.80 and a ***recommended ABC of 362 t***. Using the previously accepted B_{MSY}^{prox}, the multiplier equivalent to a P* of 0.49 was 0.87 resulting in an ABC_{max} of 340 t. Incorporating additional uncertainty by applying a σ_b of 0.4 resulted in a multiplier of 0.78 and a recommended ABC of 307 t.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2008/09	1,991	4,762[A]	0	0	9.5	1,506	
2009/10	1,914	2,175[B]	0	0	2.7	227	
2010/11	2,255	2,754[C]	0	0	4.2	349	
2011/12		2,547[D*]				453	362

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 2010/2011 and is hence not overfished. Overfishing did not occur during the 2010/2011 fishing year.

Notes:

A – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches

B – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches

C – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches

D – Based on survey data available to the Crab Plan Team in September 2011

* – 2011/12 estimates based on 3 year running average

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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)
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	0	0	0
2000/2001	0	0	0
2001/2002	0	0	0
2002/2003	0	0	0
2003/2004	0	0	0
2004/2005	0	0	0
2005/2006	0	0	0
2006/2007	0	0	0
2007/2008	0	0	0
2008/2009	0	0	0
2009/2010	0	0	0
2010/2011	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[a]	34,885
1996	66	90	2,730[a]	29,411
1997	53	110	2,230[a]	28,458
1998	57	57	2,398[a]	23,381
1999-2010/11	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).

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (t)	Sublegal male (t)	Female (t)	All fixed (t)	All trawl (t)
1991/1992	0.00	0.00	0.00	0.48	45.71
1992/1993	0.00	0.00	0.00	16.12	175.93
1993/1994	0.00	0.00	0.00	0.60	131.87
1994/1995	0.00	0.00	0.00	0.27	15.29
1995/1996	0.00	0.00	0.00	4.81	6.32
1996/1997	0.00	0.00	0.00	1.78	2.27
1997/1998	0.00	0.00	0.00	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
2010/2011	0.00	0.00	0.00	0.30	3.87

Table 4. 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	144	162	162	80
1977/1978	76159	116	103	0	253	120
1978/1979	367140	1228	686	1228	1228	42
1979/1980	279707	859	205	790	859	76
1980/1981	383898	1312	959	1312	1317	195
1981/1982	80928	299	246	299	299	97
1982/1983	331947	1440	1277	1440	1458	673
1983/1984	122661	518	460	486	544	216
1984/1985	64331	261	232	233	261	67
1985/1986	16823	60	54	60	60	0
1986/1987	38419	135	120	135	135	57
1987/1988	18611	53	47	53	53	25
1988/1989	66189	104	92	43	797	732
1989/1990	754994	1498	1328	854	2154	1846
1990/1991	617113	897	795	109	6815	1775
1991/1992	2435400	4335	3823	1295	4959	3860
1992/1993	1451102	3238	2780	2479	3505	2612
1993/1994	3532420	9687	7388	9017	9962	4837
1994/1995	3114248	9052	7436	7994	9600	3397
1995/1996	7098444	24282	21139	22428	24854	6199
1996/1997	555428	2323	1971	2292	2389	1456
1997/1998	1554857	6056	5035	5843	7528	1442
1998/1999	772660	2282	1778	1749	2688	1262
1999/2000	1939076	5422	4800	4394	8682	4762
2000/2001	1538502	4239	3757	3773	4393	734
2001/2002	3662559	8434	7476	5663	10714	4333
2002/2003	1891296	6916	6129	6894	6923	571
2003/2004	1470902	5280	4678	5184	5280	1644
2004/2005	811871	3563	3157	3563	3710	983
2005/2006	247739	1219	1067	1219	1272	2207
2006/2007	1370143	6762	5983	6484	6859	1406
2007/2008	1637966	7176	6362	6947	7378	2534
2008/2009	1305315	5375	4763	5022	5698	2099
2009/2010	887543	2454	2175	2088	2498	546
2010/2011	895960	3107	2754	2881	3137	468
2011/2012	1015866	3834		3751	3878	817

Table 5. Mean, standard deviation (SD) and deviations for alternative average year options for calculating MMB in the most recent year.

	0yr	2yr	3yr	4yr	5yr	7yr
Mean (t)	2724	2744	2766	2773	2766	2770
SD	2224	2023	1857	1740	1646	1496
Mean deviation		12	11	62	162	365
SD deviation		1001	1497	1722	1802	1861
Mean Absolute Deviation		747	1189	1382	1477	1485

Table 6. Three year simple running average 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	0	0	0	0	0	10
1976/1977	25389	81	72	81	81	45
1977/1978	42312	93	82	54	138	70
1978/1979	164692	502	43	463	548	81
1979/1980	241002	734	95	673	780	79
1980/1981	343582	1133	800	1110	1135	105
1981/1982	248178	824	711	800	825	123
1982/1983	265591	1017	902	1017	1025	322
1983/1984	178512	753	667	742	767	329
1984/1985	172980	740	656	720	754	319
1985/1986	67938	280	248	260	289	94
1986/1987	39858	152	135	143	152	41
1987/1988	24618	83	73	83	83	27
1988/1989	41073	97	86	77	328	271
1989/1990	279931	552	489	316	1001	868
1990/1991	479432	833	739	335	3255	1451
1991/1992	1269169	2243	1967	752	4643	2494
1992/1993	1501205	2823	2412	1294	5093	2749
1993/1994	2472974	5753	3900	4263	6142	3770
1994/1995	2699257	7326	5905	6497	7689	3615
1995/1996	4581704	14340	12321	13146	14805	4811
1996/1997	3589373	11886	10452	10905	12281	3684
1997/1998	3069576	10887	9320	10187	11590	3032
1998/1999	960982	3554	2906	3294	4202	1387
1999/2000	1422198	4587	4059	3995	6300	2489
2000/2001	1416746	3981	3528	3305	5254	2253
2001/2002	2380046	6032	5345	4610	7930	3277
2002/2003	2364119	6530	5787	5443	7343	1879
2003/2004	2341586	6877	6094	5913	7639	2183
2004/2005	1391356	5253	4656	5214	5304	1066
2005/2006	843504	3354	2961	3322	3421	1611
2006/2007	809918	3848	3398	3755	3947	1532
2007/2008	1085283	5053	4478	4883	5170	2049
2008/2009	1437808	6438	5706	6151	6645	2013
2009/2010	1276941	5002	4435	4686	5191	1726
2010/2011	1029606	3645	3231	3331	3778	1037
2011/2012	933123	3132		2907	3171	610

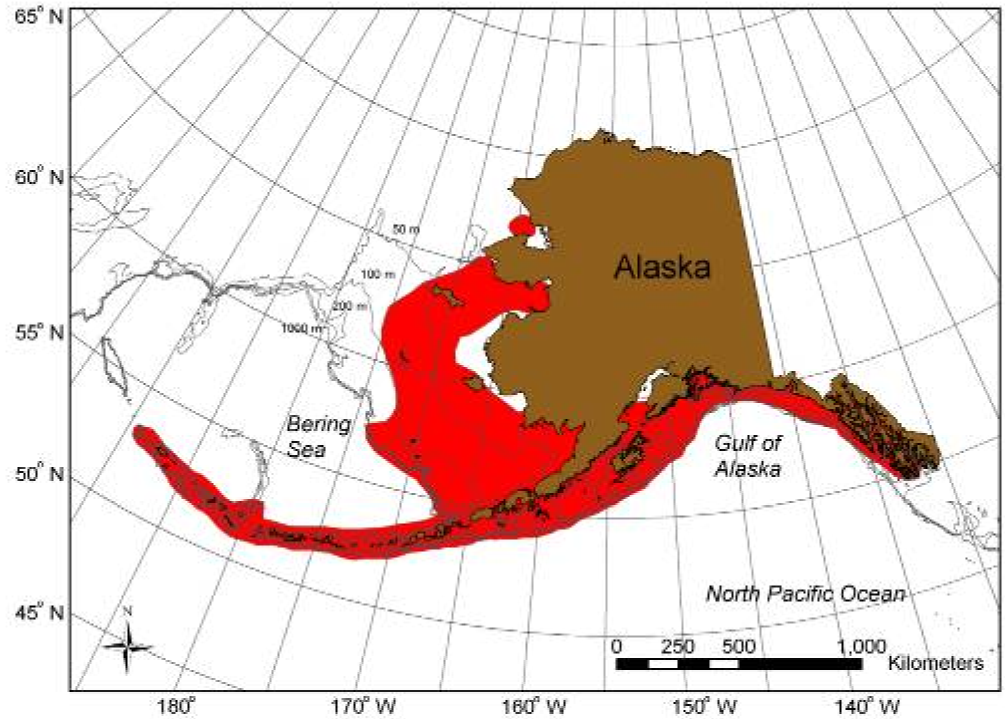

Figure 1. Red king crab distribution.

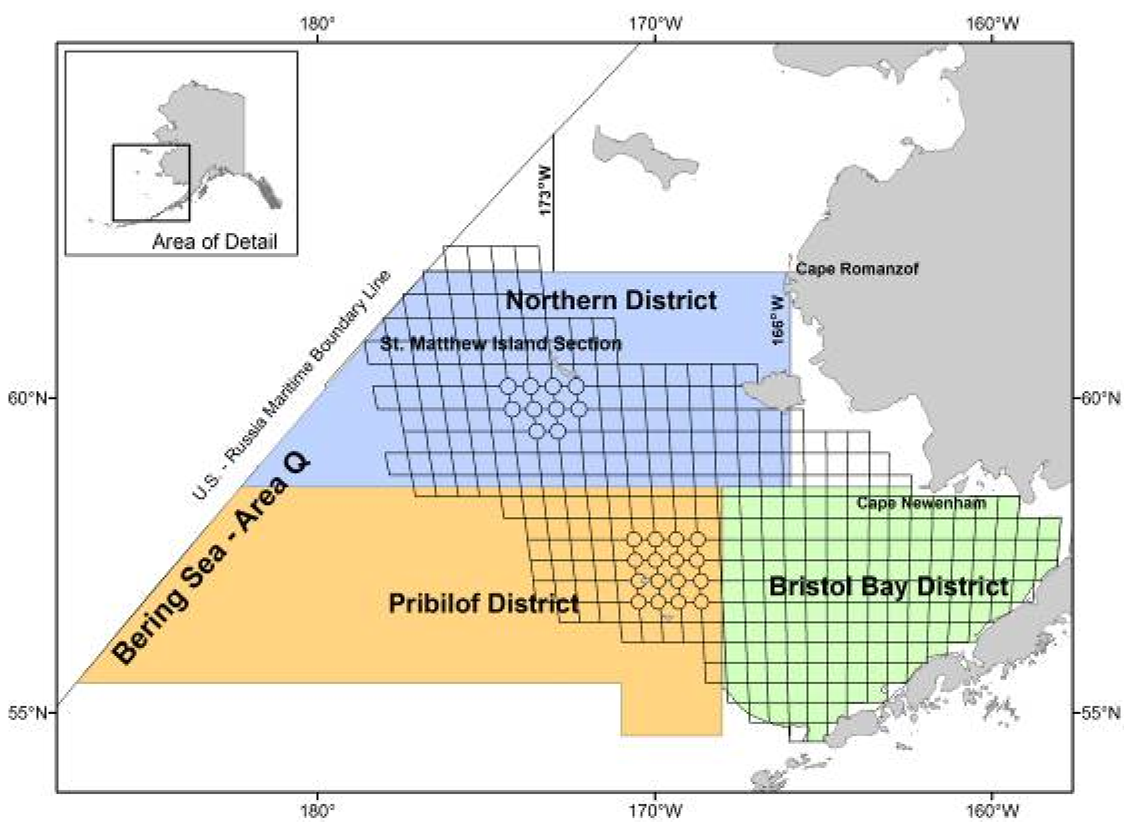

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

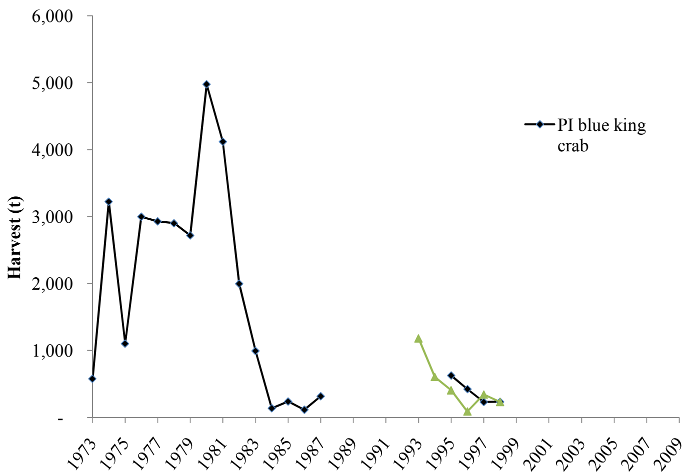

Figure 3. Historical harvests and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

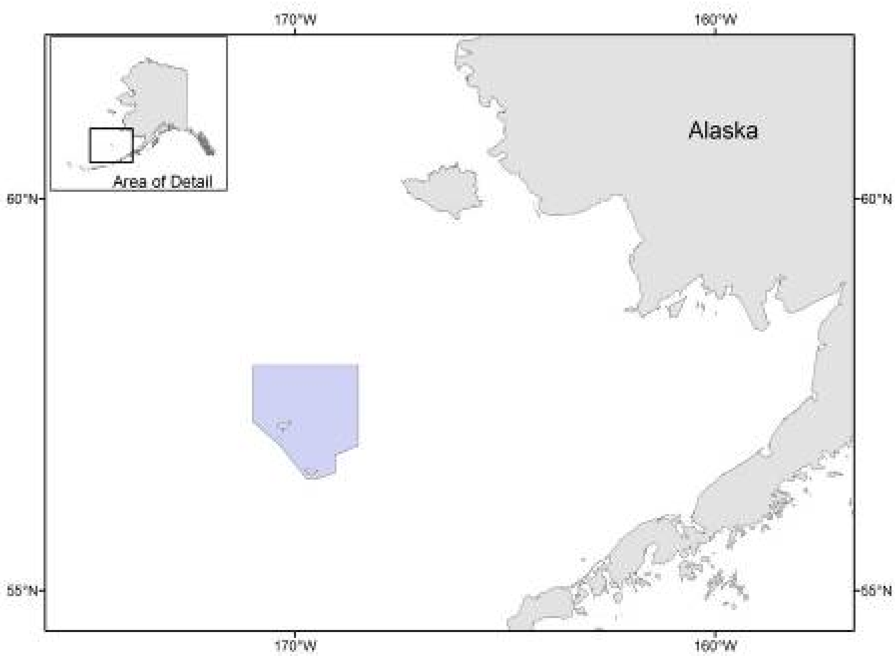

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area

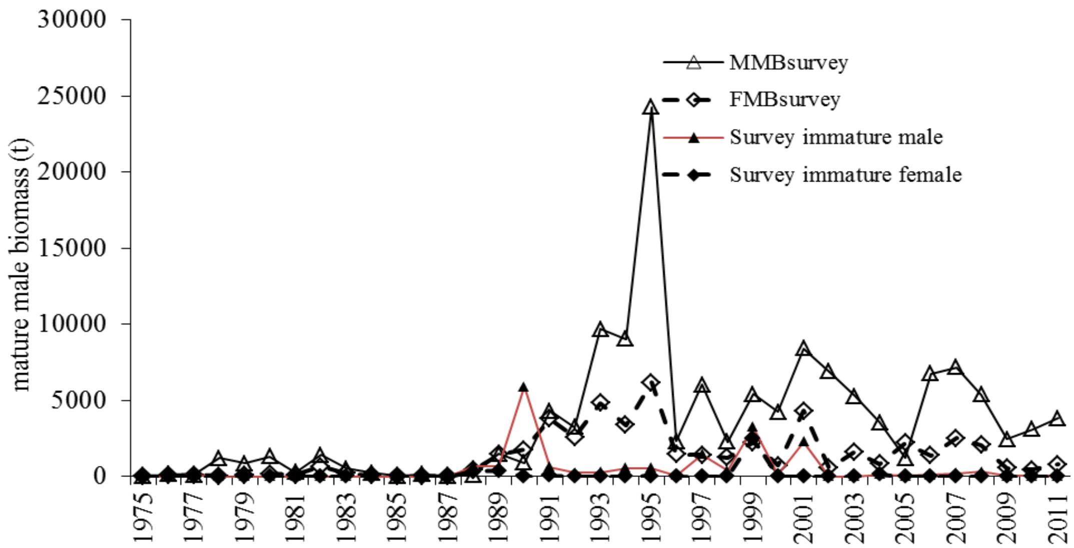

Figure 5. Time series of Pribilof Island blue king crab estimated from the NMFS annual EBS bottom trawl survey.

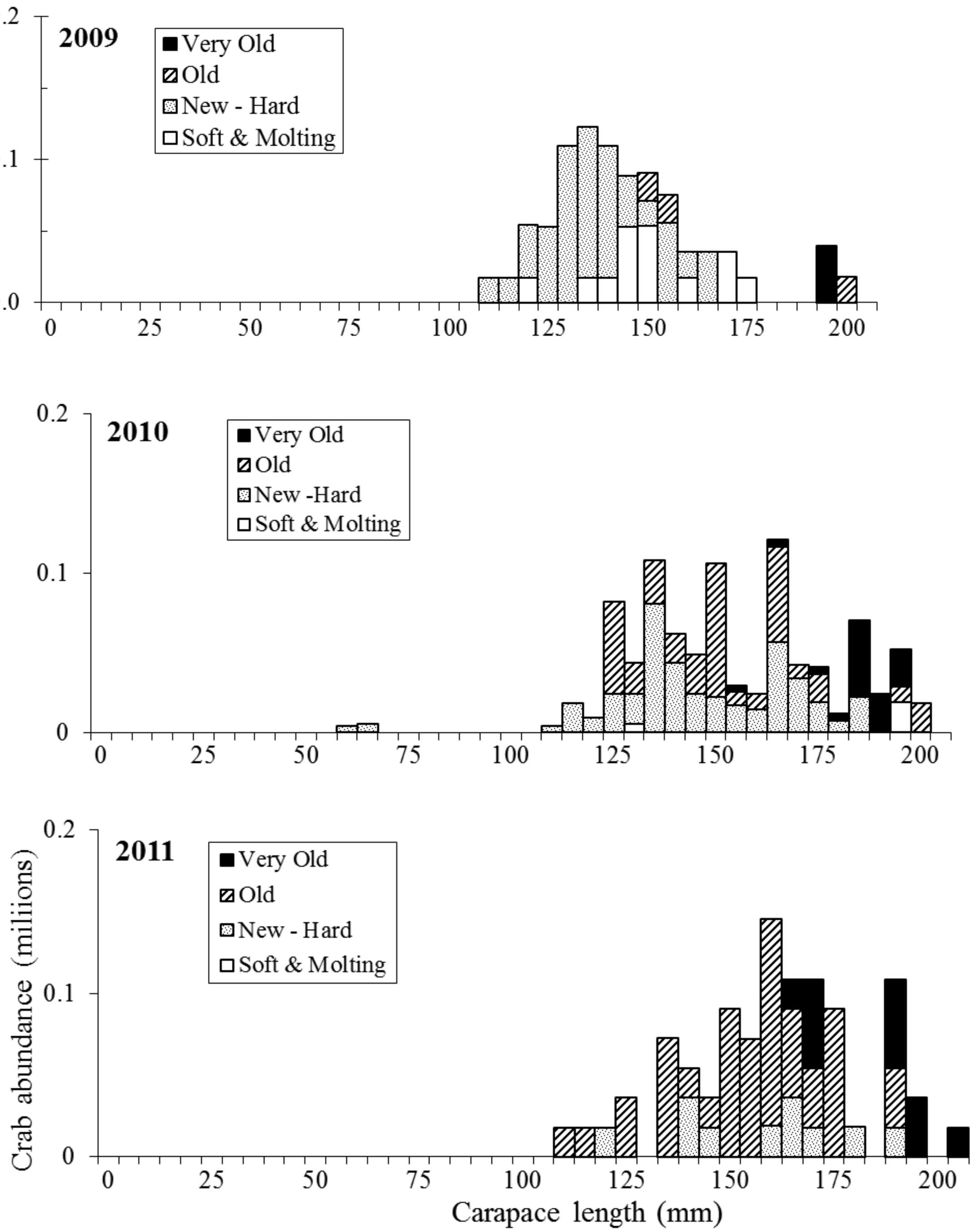

Figure 6. Distribution of Pribilof Island red king crab in 5 mm length bins by shell condition for the last 3 surveys.

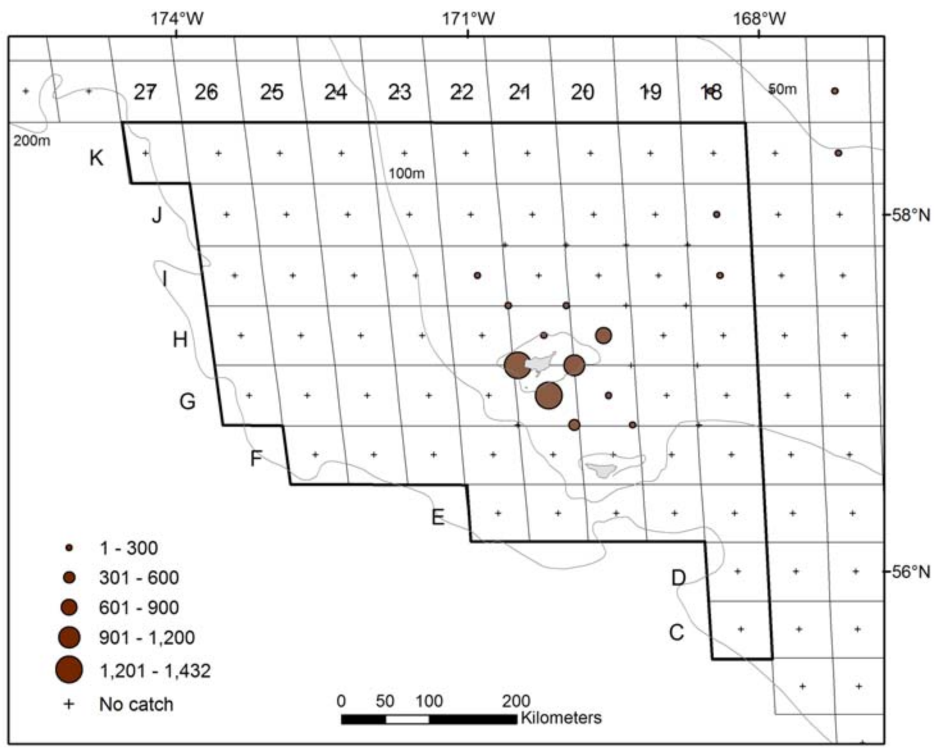

Figure 7. Total density (number/nm^2) of red king crab in the Pribilof District in the 2010 EBS bottom trawl survey.

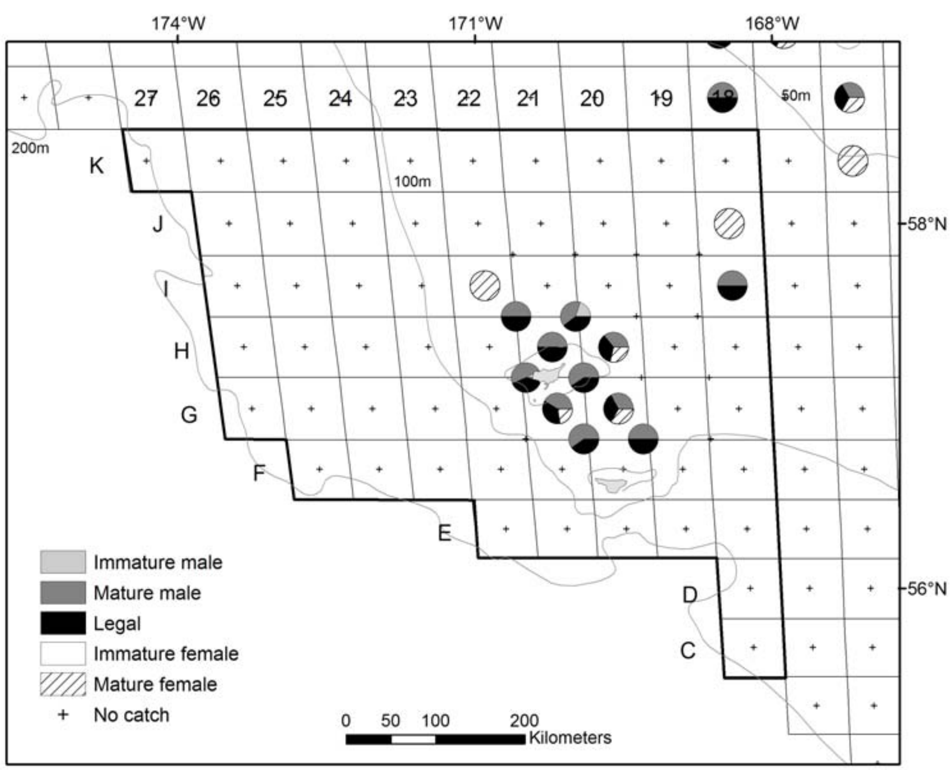

Figure 8. 2010 EBS bottom trawl survey size class distribution of red king crab in the Pribilof District.

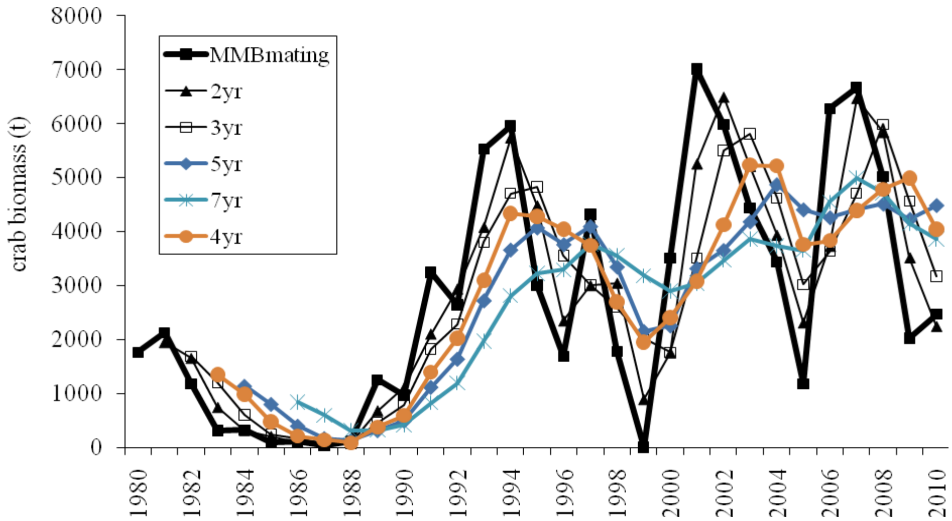

Figure 9. Alternative average biomass options ranging from two to seven year for calculating MMB in the most recent year.

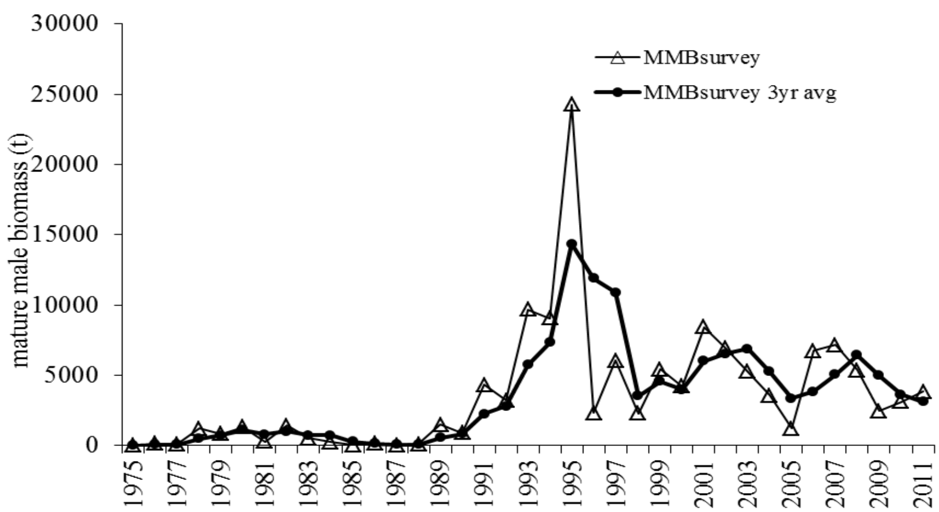

Figure 10. Time series comparison of MMB and the three year running average MMB at the time of the survey.

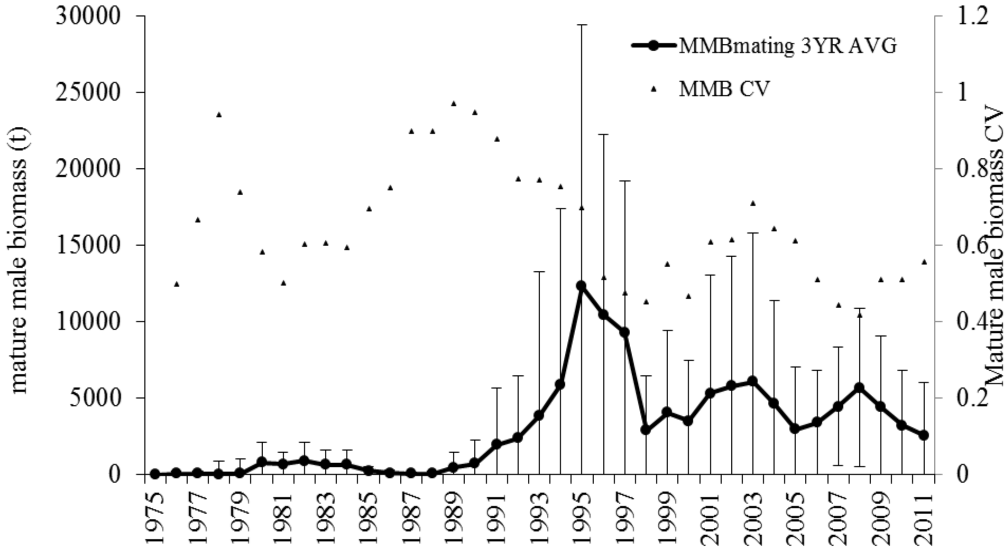

Figure 11. Time series of Pribilof Island red king crab 3 year moving averaged mature male biomass (95% C.I.) and mature male biomass CV estimated from the NMFS annual EBS bottom trawl survey.

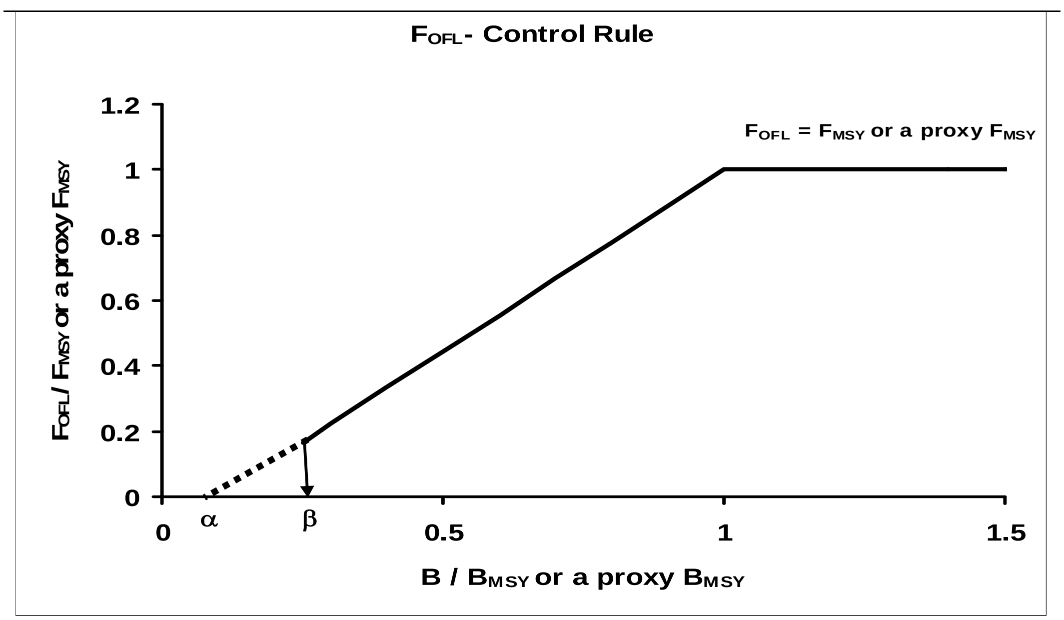

Figure 12. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

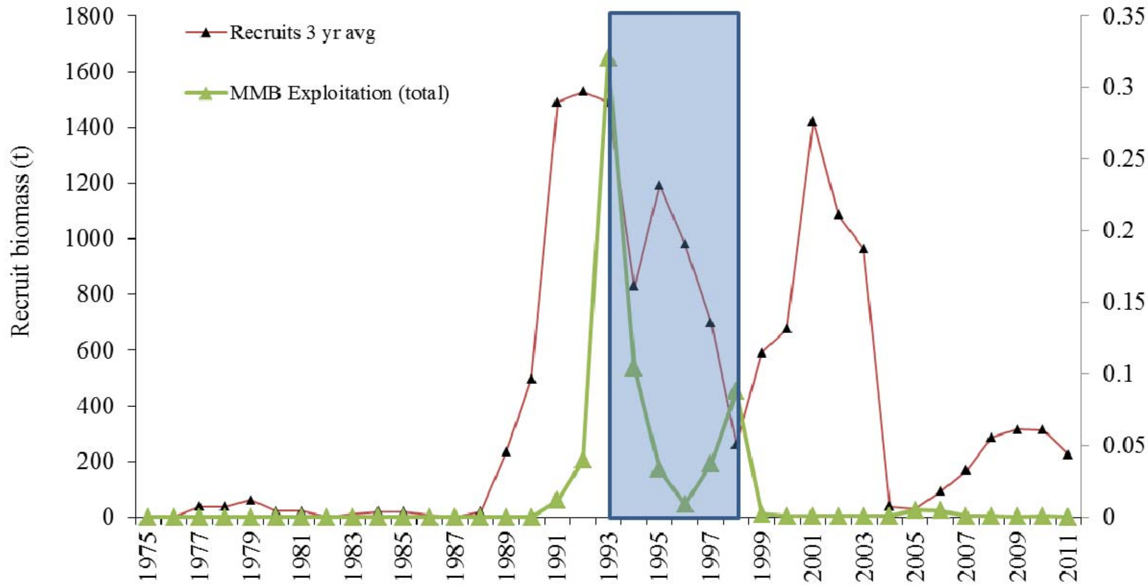

Figure 13. Time series of survey estimated recruit biomass (males 120-134 mm) and exploitation rate (based on total catch) of mature male biomass. The shaded region represents a period where commercial removals were occurring.

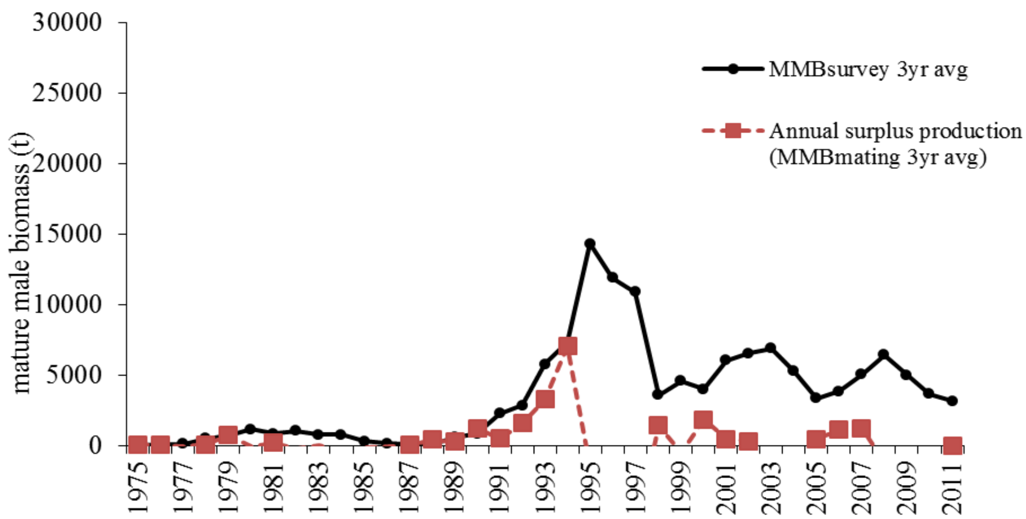

Figure 14. Time series of survey estimated mature male biomass and annual surplus production of mature male biomass.

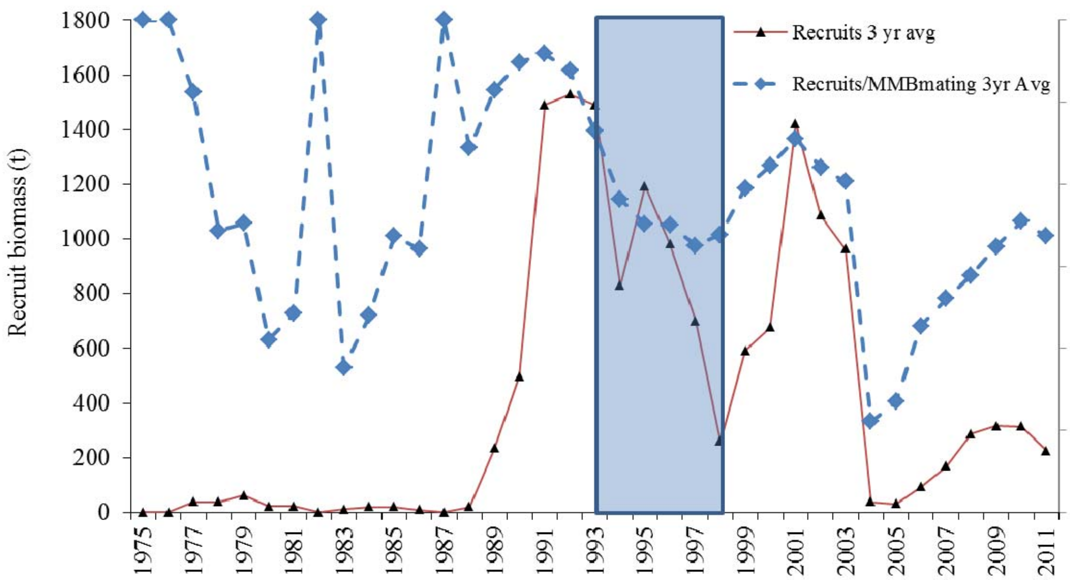

Figure 15. Time series of survey estimated recruit biomass (males 120-134 mm) and ln(Recruits/MMB). The shaded region represents a period where commercial removals were occurring.

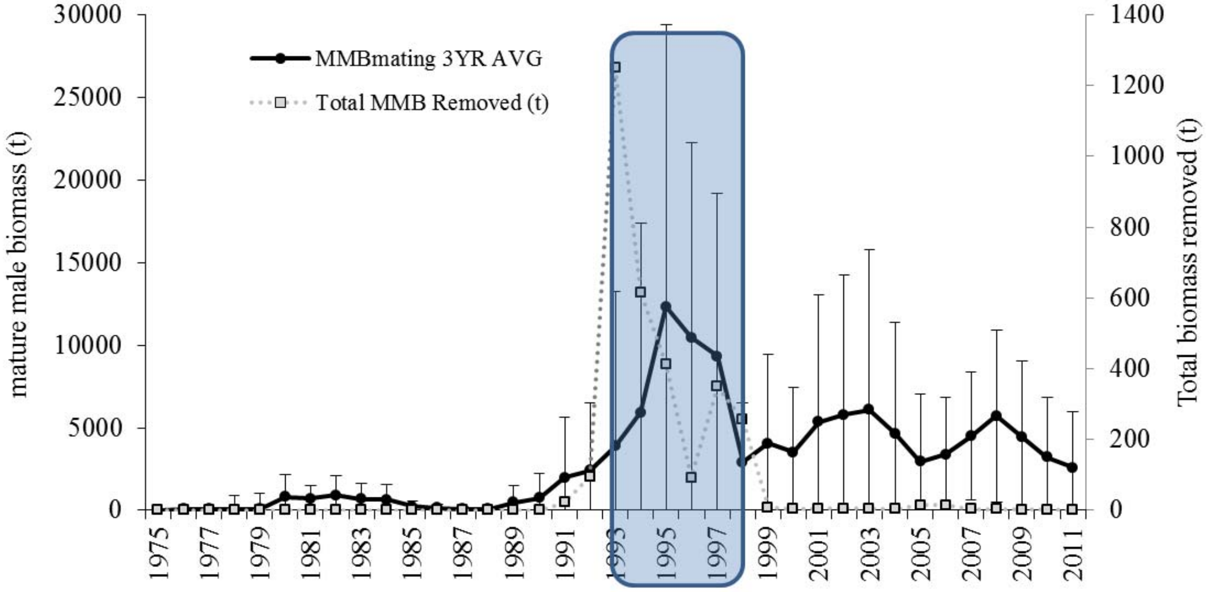

Figure 16. Time series of survey estimated Pribilof Island red king crab 3 year moving averaged mature male biomass at mating (95% C.I.) and total catch removals.

2011 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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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 to current levels near 0.18 t (0.0004 million lbs).
3. Stock biomass: Stock biomass in recent years was decreasing between the 1995 and 2008 surveys, and continues to fluctuate with an increase in most size classes in 2011 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 relatively consistent 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
2008/09	2,105 (4.64)	37[A] (0.08)	0	0	0.5 (0.001)	1.81 (0.004)	
2009/10	2,105 (4.64)	401[B] (0.88)	0	0	0.5 (0.001)	1.81 (0.004)	
2010/11	50,346 (110.99)	286[C] (0.63)	0	0	0.18 (0.004)	1.81 (0.004)	
2011/12		365[D*] (0.80)				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 2010/2011 and is hence overfished. Overfishing did not occur during the 2010/2011 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
B – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
C – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches
D – Based on survey data available to the Crab Plan Team in September 2011
* – 2011/12 estimates based on 3 year running average

6. Basis for 2011/2012 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}	
20011/12	4c	100,691 (221.99)	365 (0.80)	0.004	1.0	1975-1979	0.18	10% buffer

7. 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.
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: The Pribilof Island blue king crab stock was declared overfished on September 23, 2002. The minimum required rebuilding time with 50% probability is 9 years (2011) and the maximum rebuilding time is 10 years (2012). As a result of not making adequate progress towards rebuilding a new rebuilding plan was initiated in 2009/2010. The current draft of the rebuilding plan is in review with final action expected in fall 2011.

Summary of Major Changes:

1. Management: There were no major changes to the 2010/2011 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series were updated with 2010/2011 data.
3. Assessment methodology: There were no changes to assessment methodology. A draft catch and survey model was developed in 2010/2011 and will continue development based on February 2011 modeling workshop recommendations. Assessment methodology for ABC calculations was included.
4. Assessment results: The projected MMB increased in this assessment and remained below the MSST. Therefore, the OFL remained low with no directed fishery. Total catch in 2010/2011 was 0.18 t.

Responses to SSC and CPT Comments

<u>SSC comments October 2010:</u>

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The OFL method and tier determination were approved by the SSC for this stock in June 2010. As with the similar red king crab assessment for the Pribilof Islands, the SSC appreciates the concise nature of the document. The SSC agrees with the CPT that an average of recent survey biomasses be examined when computing the OFL. The SSC continues to look forward to the implementation of a catch-survey analysis for this stock.

Responses to SSC Comments: Methodology for an average biomass from recent years provided. CSA model in development.

<u>SSC comments June 2011:</u>

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The SSC endorses the Crab Plan Team recommendation to use a 3 year moving average to estimate mature male biomass in the current year. We continue to look forward to seeing stock assessment models for these stocks, once the models are sufficiently developed for our review.

Responses to SSC Comments: Methodology for a three year moving average biomass used for this assessment. CSA model in development.

<u>CPT comments September 2010:</u>

Specific remarks pertinent to this assessment

none

Responses to CPT Comments: *none*

CPT comments May 2011:

Specific remarks pertinent to this assessment

The team recommended that the survey and MMB data be plotted separately to better highlight differences in trends (if any). It also discussed the procedure for averaging survey biomass estimates, in particular the range of 2-7 years for averaging MMB, noting that the longer time frames for averaging were too long and average over too high (or low) of historical periods to truly reflect recent stock status. The CPT recommends a three-year moving average to estimate MMB in current year. Need to include CVs on graphs of MMB.

Responses to CPT Comments: The survey data was plotted separately. The use of a 3year moving average to estimate MMB was implemented in this assessment. CVs were included on figure.

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 et al. (In Prep). 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 and 2010 to support a genetic study on blue

king crab population structure by a graduate student at the University of Alaska. Additional collections will take place in 2011.

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 bycatch in flatfish and Pacific cod fisheries.

Data

1. The standard survey time series data updated through 2011 and the standard groundfish discards time series data updated through 2011 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2010/2011 data.

2. a. Total catch:
Crab pot fisheries
Retained pot fishery catches (live and deadloss landings data) are provided for 1973/1974 to 2010/2011 (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 2010/2011 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. 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).

$$\text{Weight (g)} = A * CL(mm)^{B} \qquad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \qquad (2)$$

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 2010/2011, an estimated 0.2 t of sublegal Pribilof blue king crab were incidentally caught based on two crab observed in the snow crab fishery in January and February and corresponding to a mortality of 0.09 when handling mortalities are applied (Table 2).

Groundfish pot, trawl, and hook and line fisheries
The 2010/2011 NMFS Alaska Region assessments of non-retained catch from all groundfish fisheries are included in this SAFE report (J. Mondragon, NMFS, personal communication). Groundfish catches of crab are reported for all males and females combined by federal reporting areas. 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 2010 to June 2011. For Pribilof Islands blue king crab, only Area 513 is included. It is noted that groundfish non-retained crab catches for Pribilof Islands blue king crab may exist in Area 521 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 2011/2012 this data will be available in smaller units so that the management unit for each stock can be more appropriately represented. To estimate sex ratios for 2010/2011 groundfish catches, sex ratios by size and sex from the 2010 EBS bottom trawl survey were applied. 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).

In 2010/2011, 0.2 t of male and female blue king crab were caught in fixed gear (0.14 t) and trawl (0.02 t) gear groundfish fisheries. The targeted species in these fisheries were flathead sole (*Hippoglossoides elassodon*) (13.7%) and Pacific cod (*Gadus macrocephalus*) (86.3%) (Table 3). Notably absent in 2010/2011 were catches in the yellowfin sole (*Limanda aspera*) fisheries. The catch was in non-pelagic trawls (13.7%), longline (3.8%), and pot (82.5%) fisheries. (Table 4).

c. Catch-at-length: NA

d. Survey biomass:
The 2010 NMFS EBS bottom trawl survey results (Chilton et al. in press) are included in this SAFE report (Table 5, Figure 7). 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 8). Weight (equation 1) and maturity (equation 3) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass.

$$\text{Proportion mature male} = 1/(1 + (3.726 * 10^{15}) * e^{((CL(mm)+2.5) * -0.332)}$$
$$\text{Proportion mature female} = 1/(1 + (8.495 * 10^{13}) * e^{((CL(mm)+2.5) * -0.332)} \qquad (3)$$

Historical survey data are available from 1975 to the present (Table 5). It should be noted that the survey data analyses were standardized in 1980.

In 2011, Pribilof Island District blue king crab were observed in five of the 77 stations in the Pribilof District, all of which were in the high-density sampling area (Chilton et al. in press, Figure 9). Legal-sized males were caught at two stations east of St. Paul Island and one station north of St. George, with a density ranging from 74 to 454 crab/nmi^2 (Figure 10). The 2011 abundance estimate (± 95% CI) of legal-sized males was 399 ± 693 t, representing 86% of the total male biomass and below the average of 1,603 ± 1,293 t for the previous 20 years (Figure 7). Blue king crab mature males were caught at three stations in the Pribilof District high-density sampling representing 100% of the total male abundance. No immature male blue king crab were caught in the Pribilof District. One mature female blue king crab brooding uneyed embryos was caught at a station in the Pribilof District high-density sampling area with a biomass estimate of 22 ± 43 t representing 60% of the total female biomass.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and is in development.

Calculation of MMB

Taking a simple average biomass across previous years to calculate the MMB in the most recent year was considered to reduce the effect of high uncertainty in the survey based area swept estimates (Figure 11). A range of previous years from two to seven resulted in mean MMB over the time series from 2,014 to 2,176 t (Table 6). Using an average biomass of four to seven years resulted in the highest deviations from -313 to -382 t and dampened the distribution so that biomass peaks were skewed from the observed values. The three year average appeared to balance the deviations between the observed and averaged while reducing the annual variation in the MMB and was recommended by the CPT (May 2011) and SSC (June 2011) as the new method for estimating MMB (Figure 12). ***Therefore in this analysis the MMB will be estimated by a three year simple moving average MMB.*** Figure 13 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 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 14). 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 this 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 based on assessment of following established criteria:
   A. Production potential
      1) Between 2006 and 2011 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 15).
      2) An estimate of surplus production ($ASP = MMB_{t+1} - MMB_t + \text{total catch}_t$) 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 (Figure 16).
      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 17).
   B. Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Figure 15) while total catch increased until 1980 before the fishery was closed in 1987 and increased again in 1995 before again closing in 1999 (Figure 18). 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.

Cons to the use of the alternate time series for establishing $B_{MSYproxy}$ are:
   A. The confidence intervals on data prior to 1980 are very large and suggest that the biomass estimates during that time period are highly variable.
   B. The coefficients of variance on the survey biomass are also relatively high with peaks in 1978, 1990, and 2009.
   C. The survey gear was not standardized with net mensuration data until 1984.

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 14) 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}.

<u>Stock Status Level</u>:	<u>F_{OFL}</u>:	
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 2011 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 2009/2010 to the 2010 survey biomass.

$$MMB_{survey} \cdot e^{-PM(sm)} – \text{(projected legal male catch OFL)-(projected non-retained catch)} \quad (7)$$

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 (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).

$$\text{Projected Total Catch OFL} = [1–e^{-F_{ofl}}] \cdot \text{Total Crab Biomass}_{fishery} \quad (8)$$

where $[1–e^{-F_{ofl}}]$ 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:

$$\mu_{LMB} = [\text{Total LMB retained and non-retained catch}] / LMB_{fishery} \quad (9)$$

$$\mu_{MMB} = [\text{Total MMB retained and non-retained catch}] / MMB_{fishery} \quad (10)$$

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).

$$\text{Projected Retained Catch OFL} = [1–e^{-F_{ofl}}] \cdot \text{Legal Crab Biomass}_{Fishery} \quad (11)$$

where $[1–e^{-F_{ofl}}]$ is the annual fishing mortality rate.

6. Recommendations:
   For 2010/2011, B_{MSY}^{prox} = 4,493 t of MMB_{mating} derived as the mean MMB from 1980 to 1984 and 1990 to 1997. ***The B_{MSY}^{prox} based on the mean MMB from 1975 to 1979 was 100,691 t***. 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 2011/2012 was estimated at 365 t for B_{MSY}^{prox}. The B/B_{MSY}^{prox} ratio corresponding to the previous and alternative biomass reference option is 0.08 and 0.004 respectively. ***The F_{OFL} corresponding to the previous and alternative biomass reference option was 0.00 under both options***. 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 alternative was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/2006 which was 1.81 t. This period was after a targeted fishery and did not include the most recent 2005/2006 and 2007/2008 changes to the groundfish fishery that led to increased blue king crab bycatch in those years. Subsequent corrections to the groundfish catch database leads to an ***average catch mortality of 1.16 t which is the author recommended OFL for 2011/2012***.

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 $\sigma_{total} = \sqrt{\sigma_b^2 + \sigma_w^2}$. 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 0.84 and has ranged between 0.17 and 0.80 in 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 if calculated as a Tier 4 stock would include an additional σ_b of 0.4.

4. For 2011/2012 the $F_{directed}$ = 0 and the total catch OFL was set to reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality. Because we calculate the OFL for this stock similar to that of a Tier 5 calculation 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***.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2008/09	2,105	37[A]	0	0	0.45	1.81	
2009/10	2,105	401[B]	0	0	0.45	1.81	
2010/11	50,346	286[C]	0	0	0.18	1.81	
2011/12		365[D]				1.16	1.04

All units are tons of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2010/11 and is hence overfished. Overfishing did not occur during the 2010/11 fishing year.
Notes:
A – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
B – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
C – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches
D – Based on survey data available to the Crab Plan Team in September 2011

Rebuilding Analyses

Under the current rebuilding plan, this stock has to recover to the B_{MSY} proxy in 2011/2012 and 2012/2013 to be defined as rebuilt. As the 2009/10 mature male biomass was smaller than B_{MSY} and has not shown signs of recovery in an adequate timeframe, the stock will likely fail to recover as planned. The current draft of the rebuilding plan is in review with final action expected in Fall 2011.

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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	0	0	0
2000/2001	0	0	0
2001/2002	0	0	0
2002/2003	0	0	0
2003/2004	0	0	0
2004/2005	0	0	0
2005/2006	0	0	0
2006/2007	0	0	0
2007/2008	0	0	0
2008/2009	0	0	0
2009/2010	0	0	0
2010/2011	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).

	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
2010/2011	0.00	0.09	0.00	0.07	0.02

Table 3. Proportion of the Pribilof Islands blue king crab bycatch from area 513 among target species between 2003/2004 and 2010/2011 crab fishing seasons.

Crab fishing season	Yellowfin sole %	Pacific cod %	Flathead sole %	Rocksole %	TOTAL (# crabs)
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
2010/2011		86	14		256

Table 4. Proportion of the Pribilof Islands blue king crab bycatch from area 513 among gear types between 2003/2004 and 2010/2011 crab fishing seasons.

Crab fishing season	hook and line %	non-pelagic trawl %	pot %	TOTAL (# crabs)
2003/04	21	79		252
2004/05	99	1		259
2005/06	18	3	79	757
2006/07	20	20		96
2007/08	1	3	95	2,950
2008/09	23	77		295
2009/10	21	61	18	487
2010/11	4	14	83	256

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.

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	15019937	34051	29138	24267	41393	12166
1976/1977	3549948	9543	5575	8595	13304	5773
1977/1978	13043983	38756	31552	36706	42137	13572
1978/1979	6140638	15798	11217	12291	18315	6492
1979/1980	5275966	13261	9142	11198	14582	4138
1980/1981	5630220	14782	8318	12418	16376	63676
1981/1982	3897456	10675	5501	9617	12893	9923
1982/1983	2286666	6584	3915	6185	7633	9376
1983/1984	1822397	4867	3359	4069	5744	10248
1984/1985	609592	1615	1298	1342	1713	2580
1985/1986	428076	959	620	687	995	523
1986/1987	480198	1368	1101	1340	1372	2394
1987/1988	903180	2659	2051	2529	2833	913
1988/1989	237868	766	679	766	920	697
1989/1990	239948	752	667	752	1914	1746
1990/1991	1676791	3121	2768	1411	5196	3806
1991/1992	1980317	4203	3725	3025	5458	2779
1992/1993	1922884	3982	3508	2790	5636	2649
1993/1994	1844170	4072	3599	2841	5064	2092
1994/1995	1263447	3028	2683	2491	3578	4858
1995/1996	3111858	7696	6220	6307	8558	4843
1996/1997	1712015	4221	3334	3522	4864	5585
1997/1998	1201296	2940	2384	2515	3288	3028
1998/1999	938796	2453	1944	2191	3083	2182
1999/2000	588718	1476	1308	1201	1623	2868
2000/2001	725050	1902	1687	1588	2005	1462
2001/2002	522239	1454	1289	1329	1533	1817
2002/2003	225476	618	548	588	618	1401
2003/2004	228897	638	566	610	656	1307
2004/2005	47905	97	86	44	130	121
2005/2006	91932	313	277	313	610	847
2006/2007	50638	137	122	115	205	553
2007/2008	100295	254	224	170	417	257
2008/2009	18256	42	37	42	235	672
2009/2010	248626	452	401	170	684	625
2010/2011	138787	322	286	202	420	433
2011/2012	165525	461		399	461	37

Table 6. Mean, standard deviation (SD) and deviations for alternative average year options for calculating MMB in the most recent year.

	0yr	2yr	3yr	4yr	5yr	7yr
Mean (t)	2242	2176	2095	2045	2014	2014
SD	2254	2034	1774	1579	1415	1184
Mean deviation		-131	-284	-342	-382	-313
SD deviation		654	946	1111	1265	1308
Mean Absolute Deviation		447	679	831	931	1069

Table 7. Three year simple running average of Pribilof Islands District blue 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	15019937	34051	29138	24267	41393	12166
1976/1977	9284943	21797	16444	16431	27349	8969
1977/1978	10537956	27450	21525	23189	32278	10504
1978/1979	7578190	21365	16155	19197	24585	8612
1979/1980	8153529	22605	17429	20065	25011	8068
1980/1981	5682275	14614	8168	11969	16424	24769
1981/1982	4934547	12906	7479	11078	14617	25912
1982/1983	3938114	10681	7548	9407	12301	27658
1983/1984	2668840	7376	5583	6624	8757	9849
1984/1985	1572885	4355	3729	3865	5030	7402
1985/1986	953355	2480	1969	2033	2817	4451
1986/1987	505955	1314	1052	1123	1360	1833
1987/1988	603818	1662	1168	1519	1733	1277
1988/1989	540415	1598	1417	1545	1708	1335
1989/1990	460332	1392	1235	1349	1889	1119
1990/1991	718202	1547	1372	977	2677	2083
1991/1992	1299019	2692	2385	1730	4189	2777
1992/1993	1859997	3769	3319	2409	5430	3078
1993/1994	1915790	4086	3610	2885	5386	2507
1994/1995	1676834	3694	3274	2707	4759	3200
1995/1996	2073158	4932	3769	3880	5733	3931
1996/1997	2029107	4982	4009	4107	5667	5095
1997/1998	2008390	4952	4168	4115	5570	4486
1998/1999	1284036	3205	2611	2743	3745	3598
1999/2000	909603	2290	2029	1969	2665	2693
2000/2001	750855	1944	1724	1660	2237	2171
2001/2002	612002	1611	1428	1372	1720	2049
2002/2003	490922	1325	1175	1168	1386	1560
2003/2004	325537	904	801	842	936	1508
2004/2005	167426	451	400	414	468	943
2005/2006	122911	350	309	322	465	758
2006/2007	63492	183	162	157	315	507
2007/2008	80955	235	207	199	411	552
2008/2009	56396	144	128	109	286	494
2009/2010	122392	249	221	127	445	518
2010/2011	135223	272	241	138	446	576
2011/2012	184313	412		257	522	365

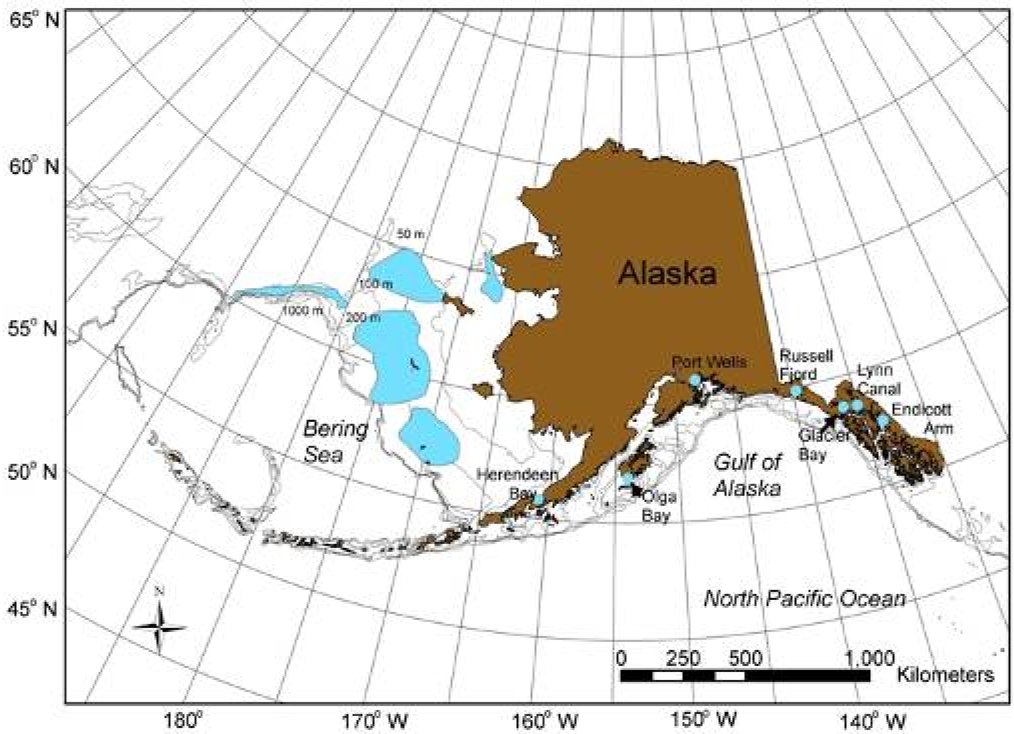

Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

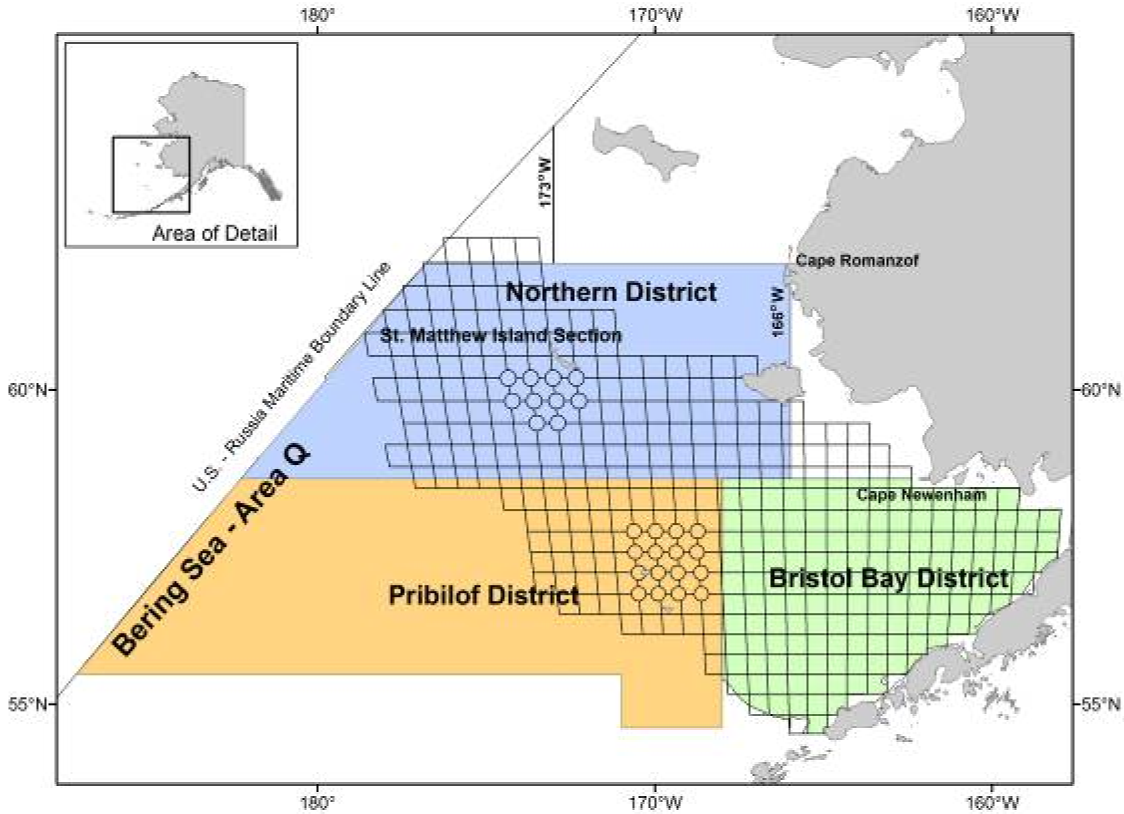

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

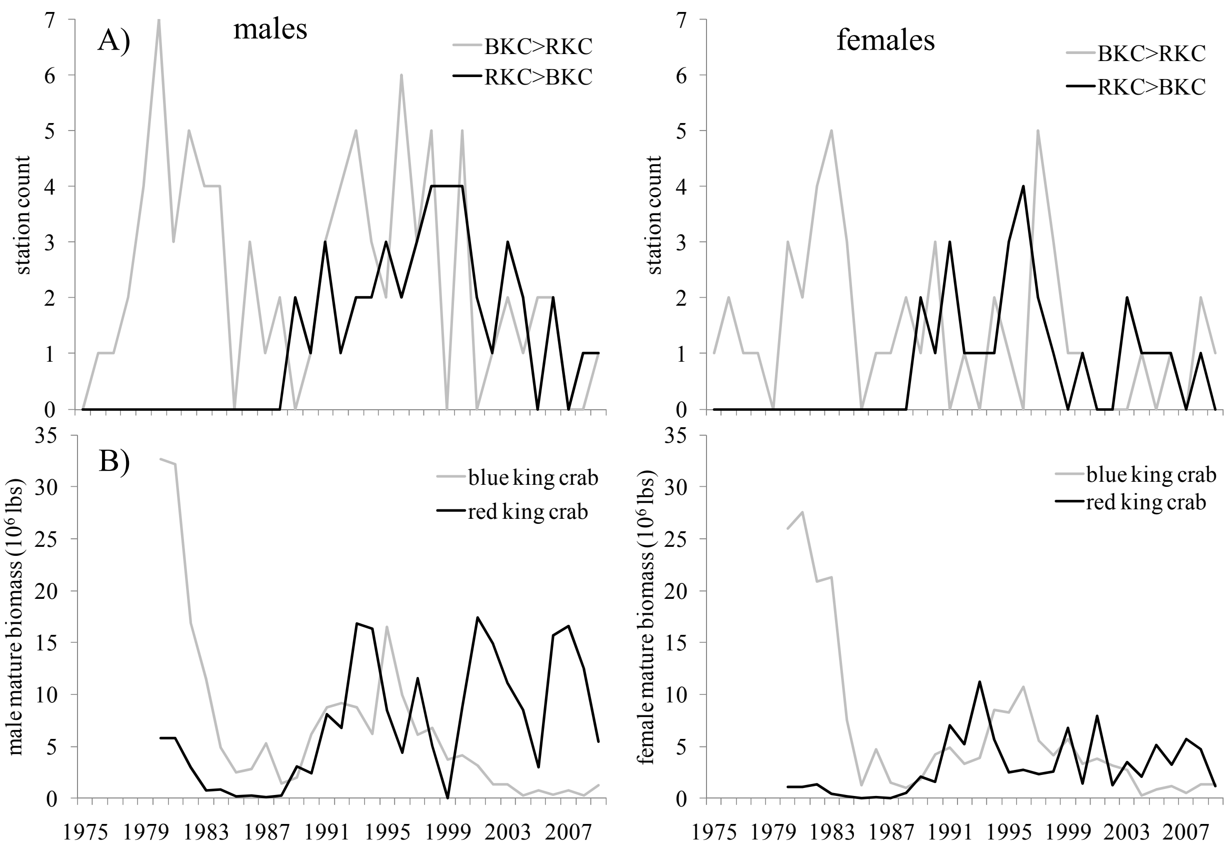

Figure 1. Time series of overlap between blue king crab and red king crab for males and females in the eastern Bering Sea showing A) the number of stations with blue king crab (BKC) or red king crab (RKC) as the dominant species and B) the mature biomass of both species.

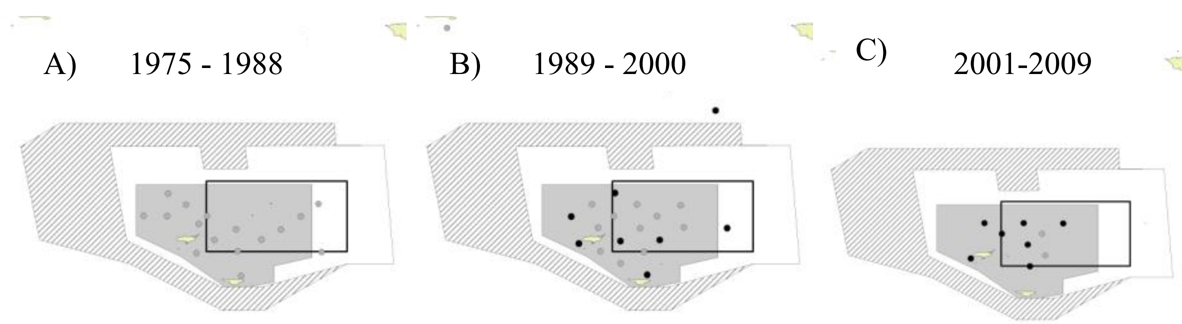

Figure 4. Spatial distribution of stations where there is overlap between blue king crab and red king crab males showing the dominant species (blue king crab=gray circles; red king crab=black circles) corresponding to time periods of major changes in biomass of both species.

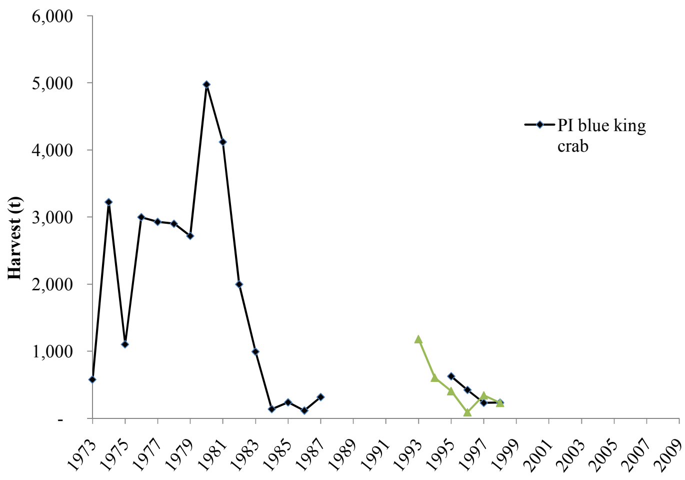

Figure 5. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

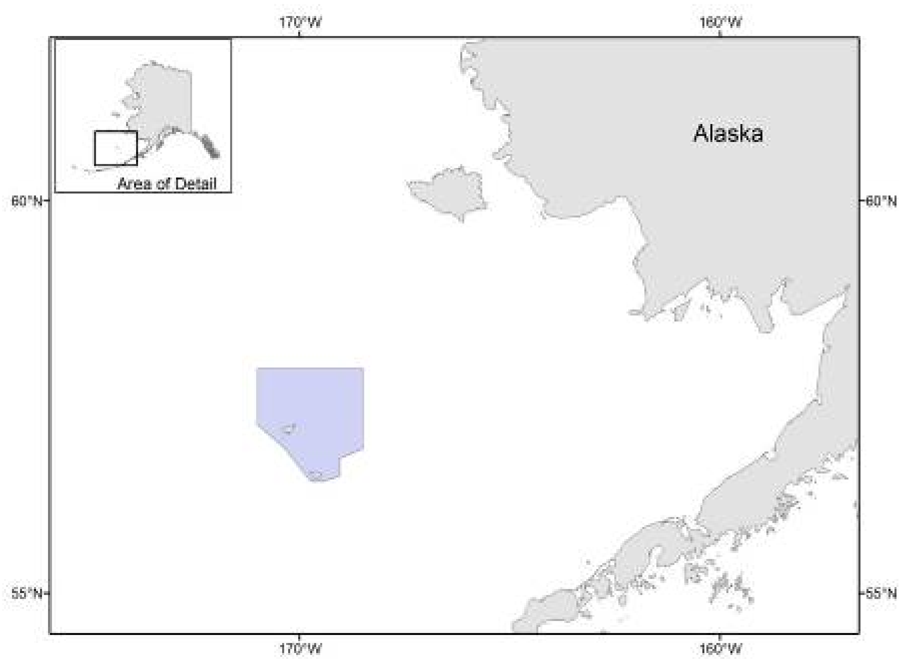

Figure 6. The shaded area shows the Pribilof Islands Habitat Conservation area. Trawl fishing is prohibited year-round in this zone.

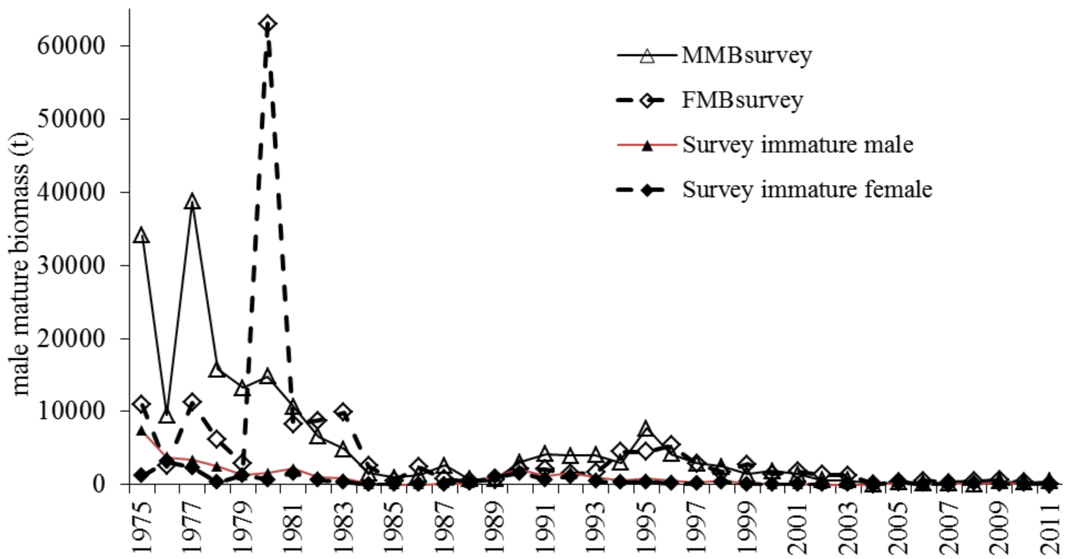

Figure 7. Time series of Pribilof Island blue king crab estimated from the NMFS annual EBS bottom trawl survey.

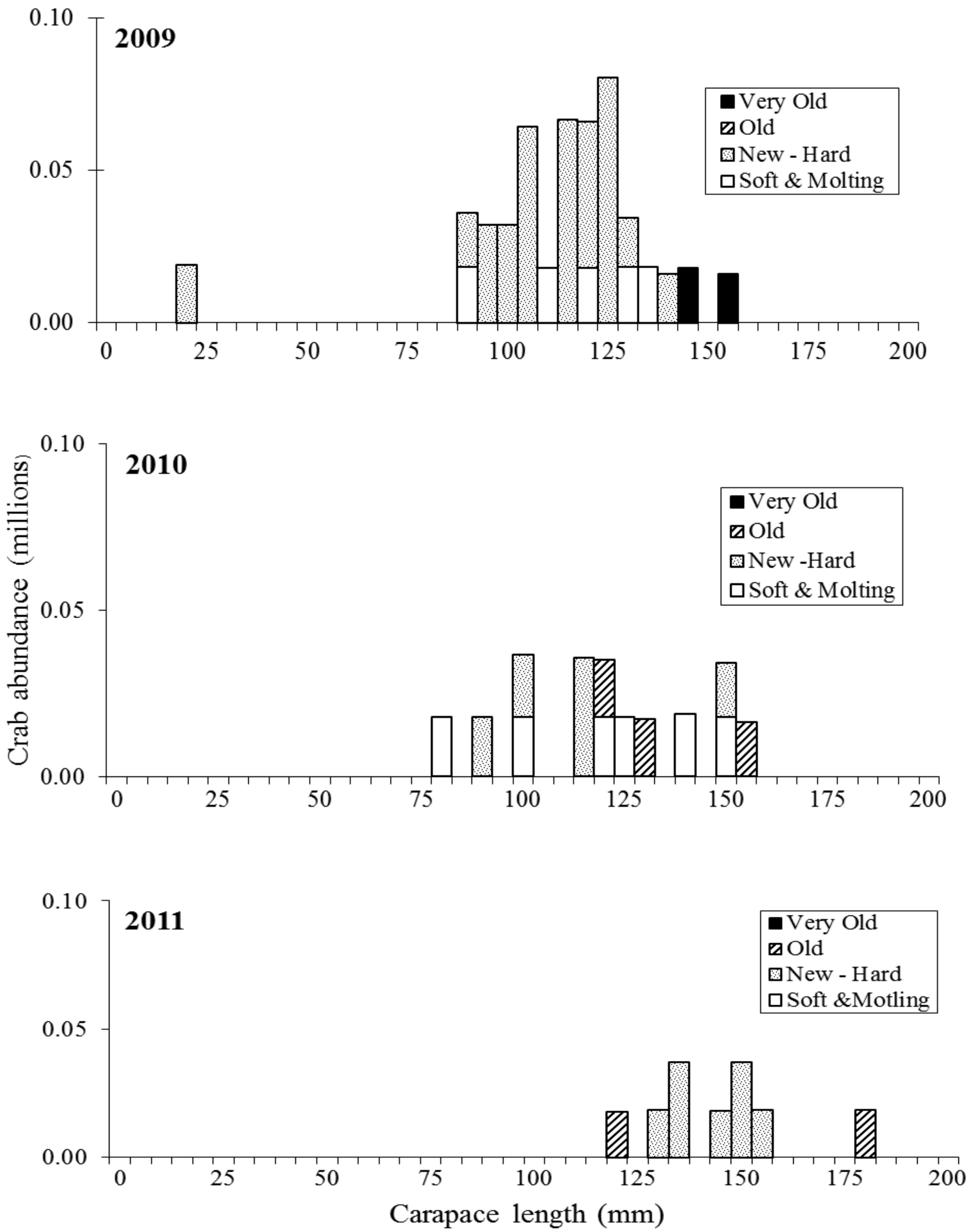

Figure 8. Distribution of Pribilof Island blue king crab in 5 mm length bins by shell condition for the last 3 surveys.

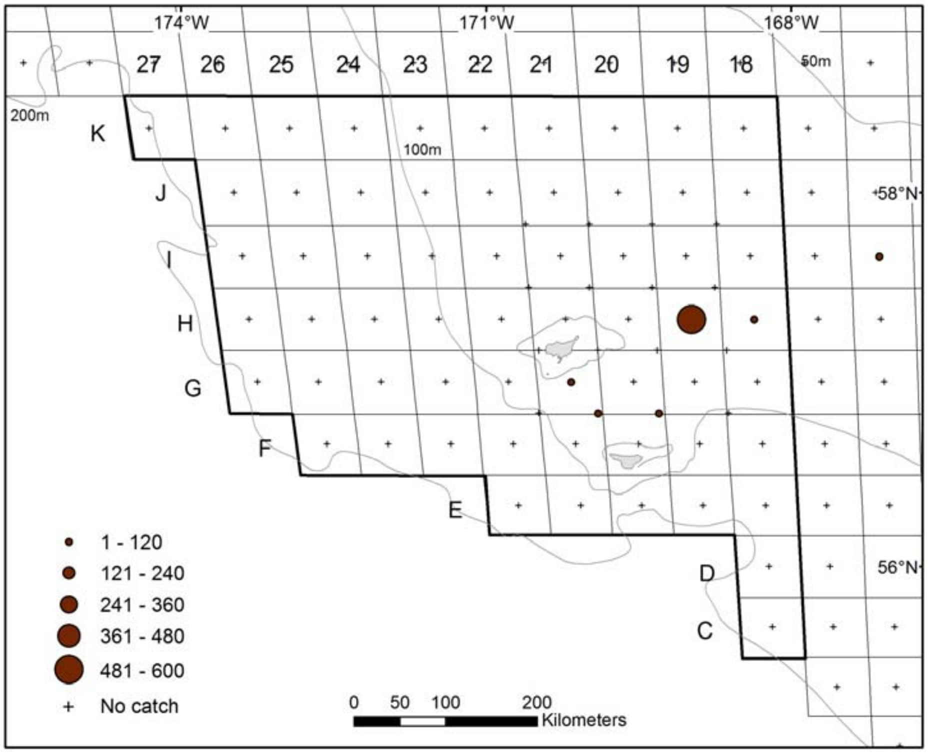

Figure 9. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2011 EBS bottom trawl survey.

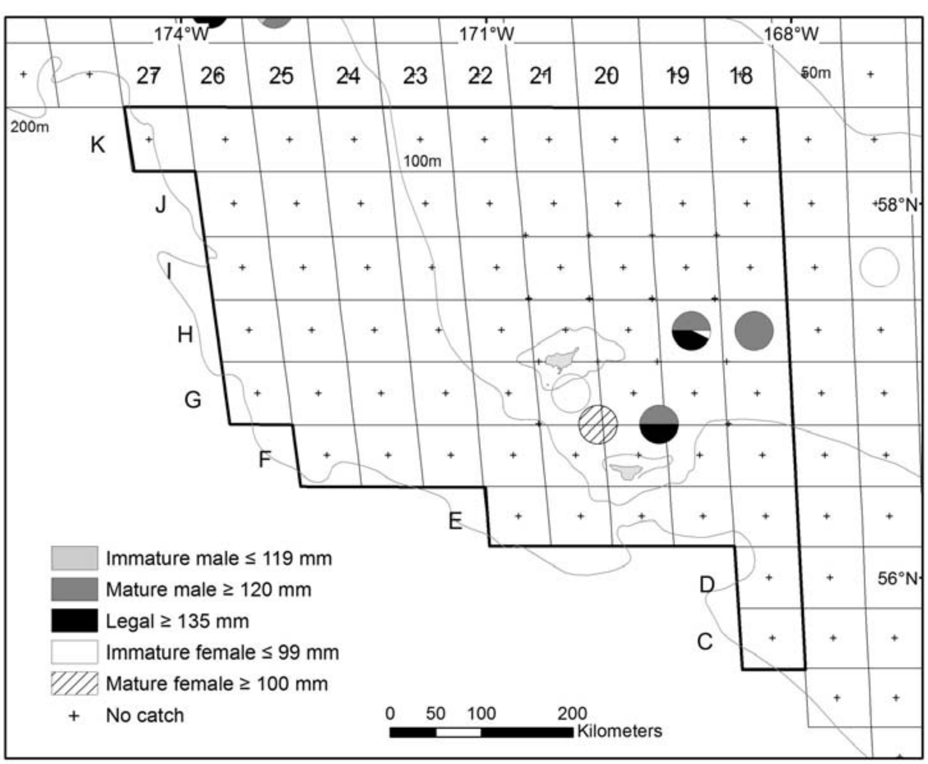

Figure 10. 2011 EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

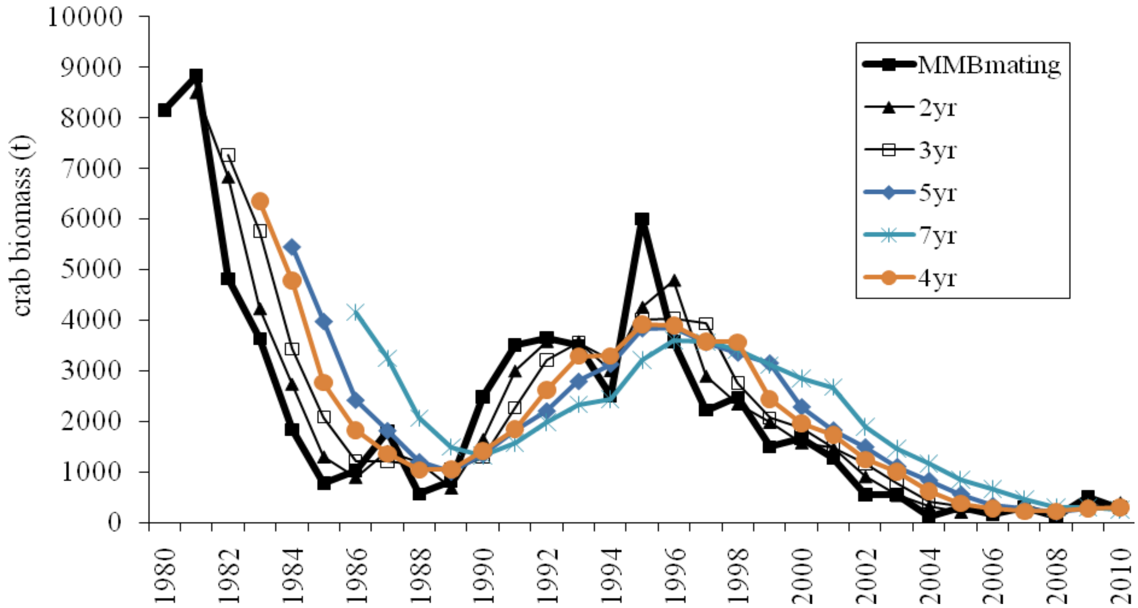

Figure 11. Alternative average biomass options ranging from two to seven year for calculating MMB in the most recent year.

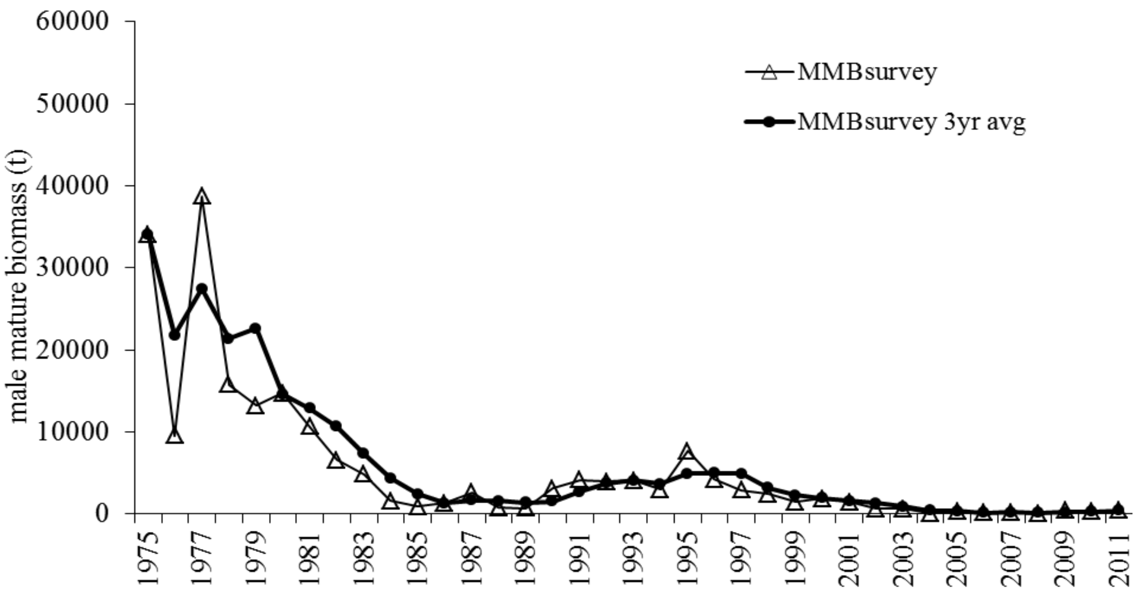

Figure 12. Time series comparison of MMB and the three year running average MMB at the time of the survey.

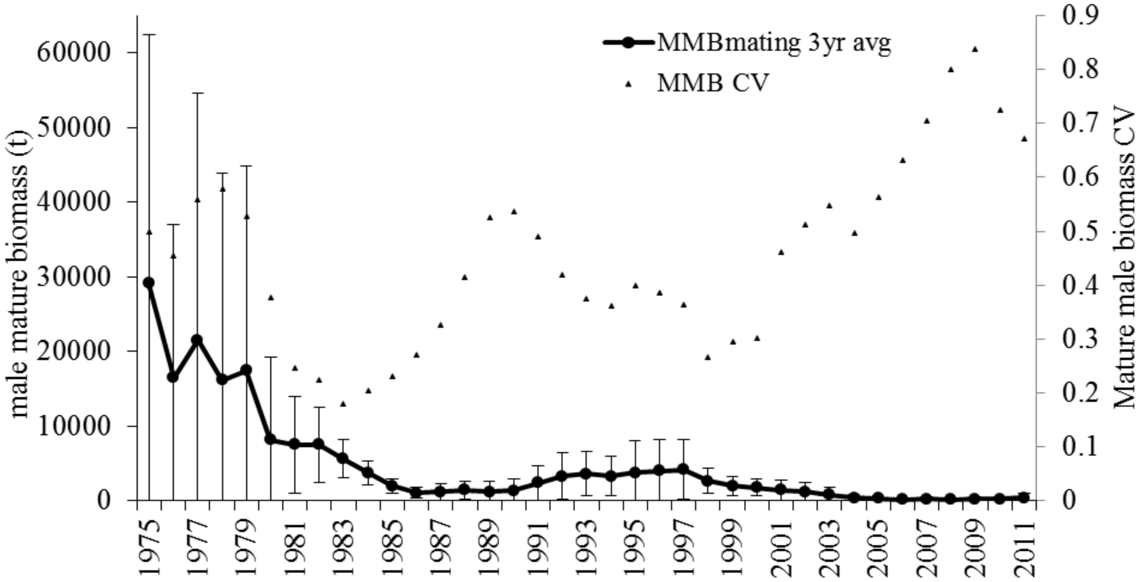

Figure 13. Time series of Pribilof Island blue king crab 3 year moving averaged mature male biomass (95% C.I.) and mature male biomass CV estimated from the NMFS annual EBS bottom trawl survey.

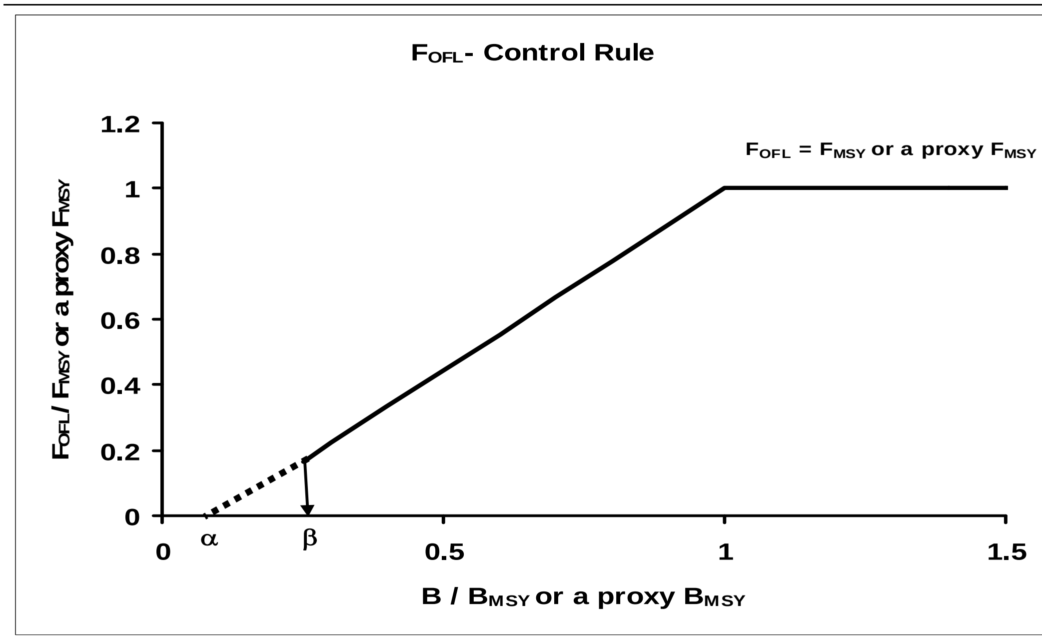

Figure 14. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

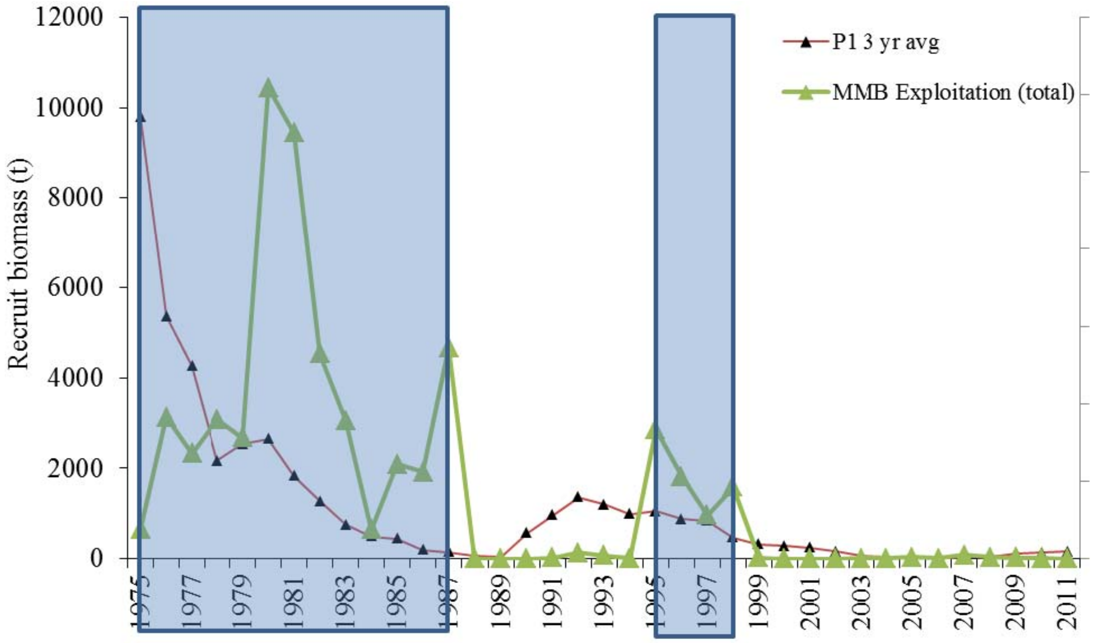

Figure 15. Time series of survey estimated recruit biomass (males 120-134 mm) and exploitation rate (based on total catch) of mature male biomass. The shaded region represents a period where commercial removals were occurring.

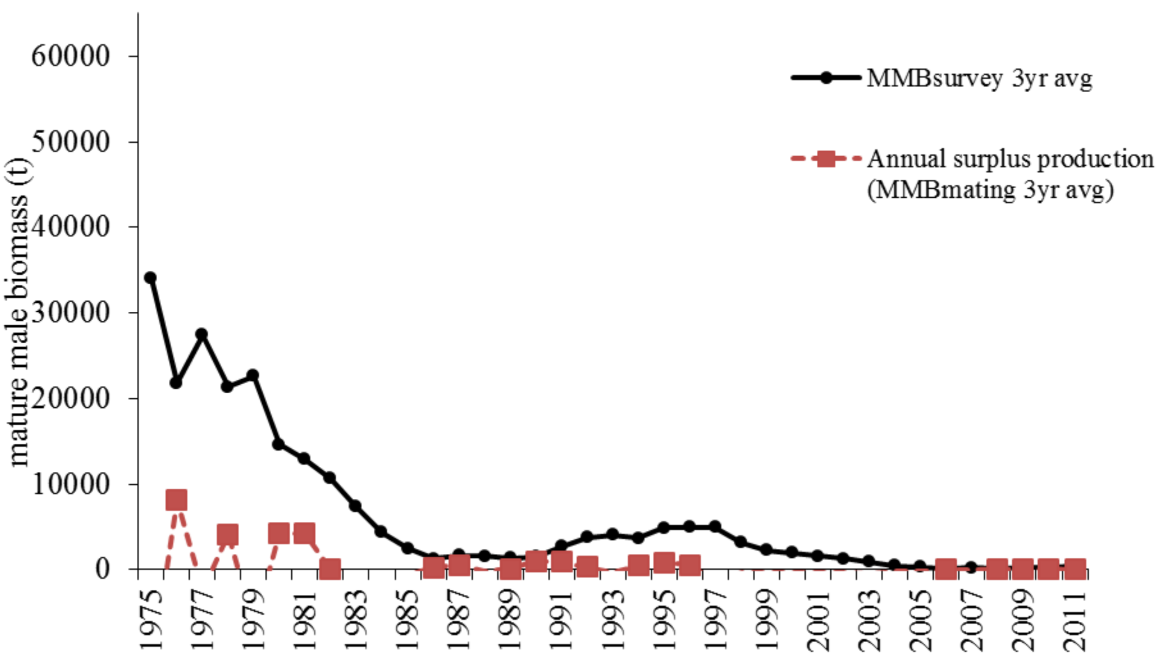

Figure 16. Time series of survey estimated mature male biomass and annual surplus production of mature male biomass.

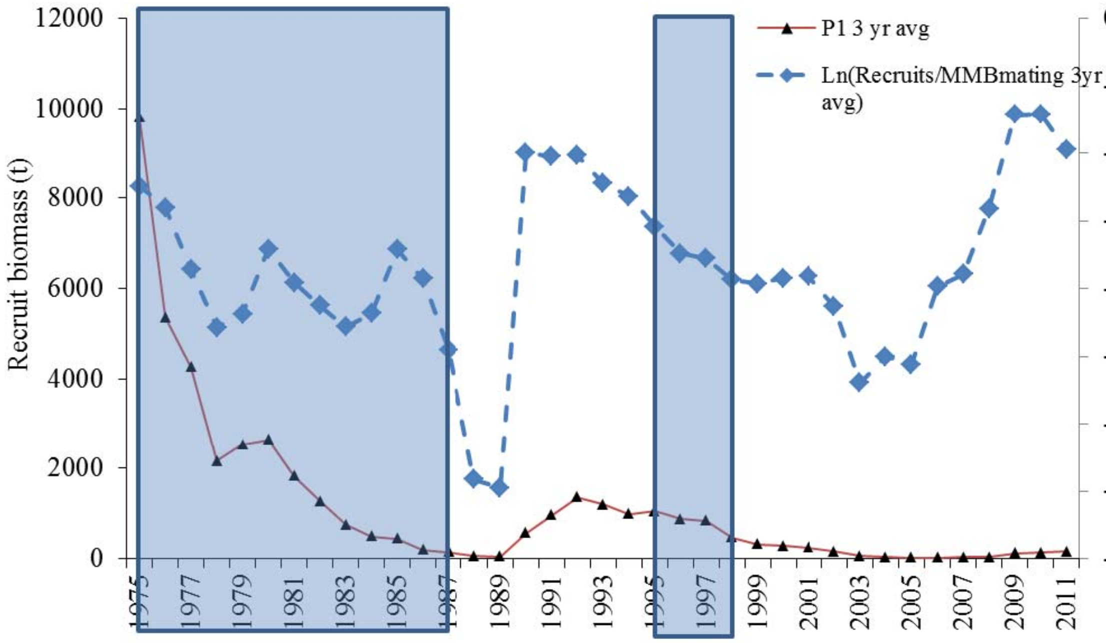

Figure 17. Time series of survey estimated recruit biomass (males 120-134 mm) and ln(Recruits/MMB). The shaded region represents a period where commercial removals were occurring.

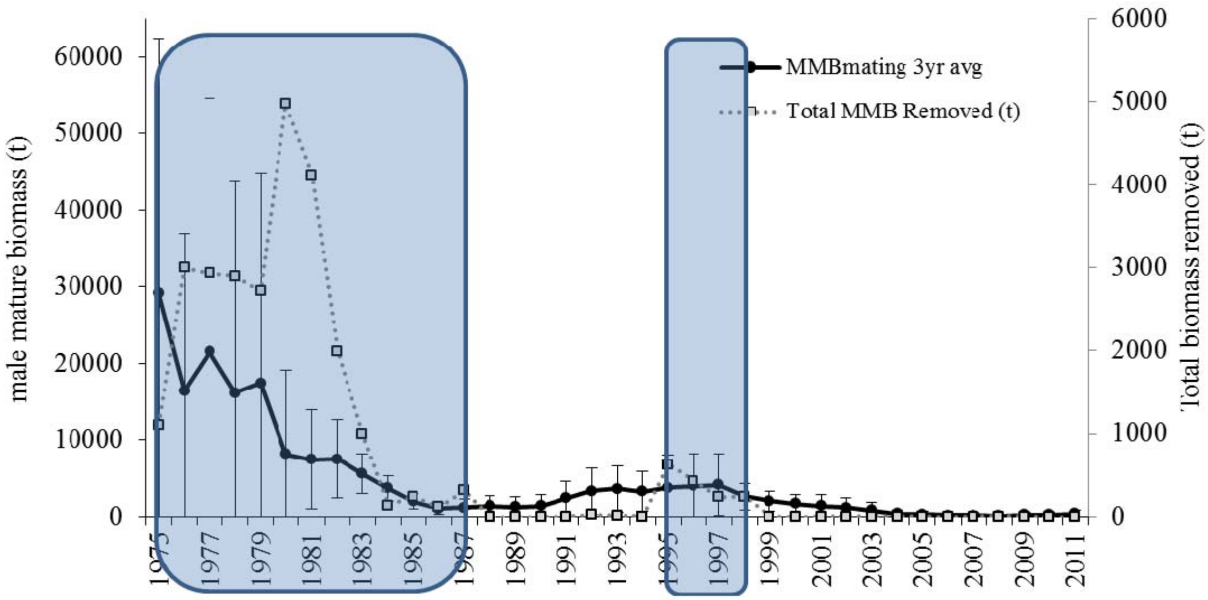

Figure 18. Time series of survey estimated Pribilof Island blue king crab 3 year moving averaged mature male biomass at mating (95% C.I.) and total catch removals.

2011 Saint Matthew Island Blue King Crab Stock Assessment

W. Gaeuman, ADF&G, Kodiak
September 2011

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. An apparent stock collapse in 1998/99 resulted in a ten-year closure of the fishery. The stock was declared rebuilt in 2009, and fishing resumed in 2009/10 with a TAC of 1.167 million pounds (529.3 t) and a fishery-reported retained catch of 0.461 million pounds (209 t). The 2010/11 TAC was 1.600 million pounds (725.7 t), and the fishery reported a retained catch of 1.264 million pounds (573.3 t). Total male discard mortality in the 2010/11 directed fishery is estimated from ADF&G crab-observer data at 0.140 million pounds (63 t), assuming 20% handling mortality. Total male bycatch mortality in the 2010/11 groundfish fisheries is estimated from NMFS observer data at 0.004 million pounds (2 t).

3. Stock biomass: Survey indices are generally consistent with increasing stock biomass in recent years. Trawl-survey estimated mature-male biomass has increased every year except one from 2.48 million pounds (1,130 t; estimated CV 0.32) in 2003, the lowest in the 34-year time series used in this assessment, to 17.95 million pounds (8,141 t; estimated CV 0.37) in 2010, and to 21.07 million pounds (9,557 t; estimated CV 0.53) in 2011. This latter value is the second highest in the time series after the 1982 estimate of 30.75 million pounds (13,950 t; estimated CV 0.32).

4. Recruitment: Information about recruitment is limited because of the generally small number of crab captured in the annual NMFS trawl-survey. Under the previous model-based assessment methodology, recruitment has been assessed in terms of the number of male crab entering the 90-104 mm CL size class in each year. Results from both the trawl and pot surveys suggest that recruitment has been strong in recent years, with the 2010 area-swept estimate of abundance in this size class at 3.927 million animals, the highest in the time series. Although the 2011 estimate of 1.693 million crab is less than half last year's number, it is still well above the 34-year average of 1.141 million.

5. Management performance: Estimated 2010/11 total male catch is 1.407 million pounds (638 t). This estimate sums fishery-reported retained catch, estimated total male discard mortality in the directed fishery, and estimated bycatch mortality in the groundfish fisheries. Given the 2010/11 OFL of 2.29 million pounds (1,040 t), there is thus no evidence of overfishing during the past fishery year; and with estimated 2010/11 stock biomass well above the MSST, neither is there evidence that the stock is overfished. See table below. (All biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC[e]
2008/09	4.0 (1,800)	10.74 (4,870)	Fishery Closed		0.20 (91)	1.63[c] (739)	-
2009/10	3.4 (1,500)	12.76 (5,790)	1.167 (529.3)	0.461 (209)	0.530 (240)	1.72[d] (780)	-
2010/11	3.4[a] (1,500)	14.77[a] (6,700)	1.600 (725.7)	1.264 (573)	1.408 (639)	2.29[d] (1,040)	-
2011/12	TBD	15.80[b] (7,167)	TBD	NA	NA	3.74[d] (1,700)	3.40[e] (1,530)

[a] Based on current fall 2011 assessment.
[b] Fall 2011 projection assuming $F=F_{OFL}$.
[c] Retained catch OFL.
[d] Total male catch OFL.
[e] Author/CPT recommendation (0.90 of estimated OFL).

6. <u>Basis for the OFL</u>: Estimated Feb 15 mature-male biomass (MMB_{mating}) is used as the measure of biomass for this Tier 4 stock, with males measuring 105 mm CL or more considered mature. Past recommendations were to compute the B_{MSY} proxy as average estimated 1989/99 – 2009/10 MMB_{mating}, determined to be 6.85 million pounds (3,110 t) under the current survey-based methodology. The F_{MSY} proxy is the assumed 0.18yr^{-1} instantaneous natural mortality. See table below. (All 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^*
2008/09	4a	7.39 (3,350)	10.74 (4,870)	1.45	0.18yr^{-1}	1	1989/90 - 2008/09	0.18yr^{-1}	-
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[a] (3,106)	15.80[b](7,167)	2.31	0.18yr^{-1}	1	1989/90 - 2009/10	0.18yr^{-1}	0.49

[a] Based on current fall 2011 assessment.
[b] Fall 2011 projection assuming $F = F_{OFL}$.

7. <u>Distribution of the OFL</u>: Estimated OFL is assumed to have a median-unbiased lognormal distribution, inherited from the NMFS trawl-survey estimate of total male biomass.

8. <u>Basis for the ABC</u>: Current recommendations are to use $P^* = 0.49$, where $P(ABC > OFL) = P^*$. In view of 7), $ABC = exp[\sigma\Phi^{-1}(0.49)]\widehat{OFL}$, where $\sigma^2 = var[\ln(\widehat{OFL})]$ and Φ denotes the standard-normal distribution function. An estimate of $var[\ln(\widehat{OFL})]$ is available in terms of the trawl-survey estimate of the coefficient of variation of survey total male biomass. However, the author and CPT recommend putting the ABC at 90% of the OFL estimate to account for additional sources of uncertainty, including that associated with natural mortality, survey catchability, and survey and fishery timing.

9. <u>Summary of rebuilding analyses</u>: The stock was declared rebuilt in 2009.

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
Time series used in the analysis have been updated to include the 2010/11 fisheries and the 2011 NMFS EBS trawl survey. In addition, ADF&G crab-observer data for the years 1990/91-1998/99, 2009/10, and 2010/11have been incorporated into this assessment. These data provide information on catch and catch composition of both retained and discarded crab in the directed pot fishery.

Changes in Assessment Methodology
To circumvent some of the difficulties associated with the existing stock assessment model, as described in SSC and CPT comments given in §B, and to arrange that the assessment process for this stock be robust, transparent, and well documented, the author has developed an alternative 3-stage CSA assessment model. Jim Ianelli provided the author with some helpful assistance in that effort prior to the Feb 2010 CPT meeting, where a preliminary version of the proposed model was presented. An updated description of the model, along with results for the 2011 assessment year, is presented in Appendix A to this report. Pending approval of the proposed model, a completed 2011 survey-based assessment is here presented as the default approach.

Changes in Assessment Results
In spite of the different methodologies employed, as well as prosecution of another SMBKC fishery, results from this 2011 assessment are in keeping with those from the 2010 assessment, which likewise indicated increasing stock biomass well above B_{MSY} and moderate to strong recruitment. However, with stock biomass potentially near historical highs and evidence of reduced recruitment, reason exists to anticipate an end to the positive trends of the last few years.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

- May 2010 CPT
  Comments: *Some assessments provided results in metric tons. The CPT recommendation to use metric tons refers only to the ACL analysis and traditional assessment currencies (lbs) should continue to be used in stock assessments.*

  The team requested that all assessments explain how the groundfish bycatch data are used in the assessment and that all assessment chapters should be consistent in distinguishing and separately presenting groundfish bycatch from fixed gear fisheries and trawl gear fisheries.

  Response: See June SSC comments below regarding use of metric tons. In this document, groundfish bycatch data from the fixed-gear and trawl fisheries are treated separately and their use explained.

- June 2010 SSC
  Comments: *In order to have greater consistency between assessments, the SSC recommends that catch statistics reported in the executive summary section contain both metric tons and pounds (millions).*

  Response: Catch statistics here reported in the executive summary section are given in both units.

- Sept 2010 CPT
  Comments: No new comments.

- Oct 2010 SSC
  Comments: No new comments.

- May 2011 CPT
  Comments: *Each assessment author will provide an 'author's ABC' (with appropriate rationale), along with the max ABC…*

  Response: Noted.

- June 2011 SSC
  Comments: No new comments.

CPT and SSC Comments Specific to SMBKC Stock Assessment

- Sept 2010 CPT
  Comments: *The CPT recommended that MSST should be recalculated using the BMSY estimate from the current assessment and the assessment document updated. For the May 2011 assessment, the CPT recommends that the authors: 1) analyze why some*

parameters in Table 11 appear not to change from initial values; 2) calculate F35% per the ACL analysis for the May model; 3) add a more detailed description of model changes as an appendix to the May model; and 4) incorporate the 2010 ADF&G pot survey data.

Response: The fall 2010 MSST was appropriately updated. The 2010 ADF&G St Matthew Island blue king crab pot-survey data have been presented in this report (and also included in the alternative model-based assessment). In addition, 1990/91-1998/99, 2009/10, and 2010/11 ADF&G crab-observer data have been integrated into the assessment. Regarding items 1 - 3, see comments and responses from Feb 2011 NPFMC crab modeling workshop and subsequent SSC review with respect to implementation of a revised model.

- Oct 2010 SSC
  Comments: *St. Matthew blue king crabs are assessed with a four-stage catch survey analysis of males only and managed under a Tier 4 designation. The authors have been responsive in addressing previous SSC comments. The SSC looks forward to the results of the author's ongoing efforts to reconcile discrepancies in recruits estimated by the model and those indicated by pot surveys (see SSC's comments in June 2010). The SSC endorses the Crab Plan Team's recommendations for the May 2011 assessment.*

  Response: See comments and responses from Feb 2011 NPFMC crab modeling workshop and subsequent SSC review.

- Feb 2011 NPFMC Crab Modeling Workshop
  Comments concerning proposed use of existing SMBKC model for Pribilof Island RKC and BKC stocks: *The model is initialized based on the survey data and assumes no observation errors in the initial abundances. Ideally these should be estimated within the model to allow for the inclusion of observation errors.*

  The existing code is not well documented and there are a large number of undocumented fixed constants throughout the code. There are a number of recommendations that involve either developing a simplified model (i.e., similar to the model Andre Punt showed during the workshop), to reducing the current model structure from four stages to three stages, to completely rewriting the code such that the investigators are much more intimate with the assessment model. The time commitment for each of these could be considerable and the SSC should advise priorities for modeling work. In any case, the existing model should not be used until it is fully documented and the code itself is peer reviewed by an independent expert who is familiar with ADMB and nonlinear parameter estimation. Note that during the workshop, a few participants examined the code and it was questionable if the actual objective function was continuous and differentiable (e.g., inappropriate use of if statements in the calculations).

  Short - term Recommendations: 1) Collapse the postrecruits and recruits into one category (i.e., develop a three-stage model); 2) Develop a simplified assessment model *based on single estimated growth increment matix G:* $N_{y+1}=G\,S_y\,N_y + R_{y+1}$ *where N is a vector of numbers at length, S is a vector of survival rates (incl. effects of fishing), and R is a vector of new recruits; 3) Completely rewrite the current assessment model such that the assessment authors are more intimate with the data inputs, model equations, and various undocumented constants can then be addressed; 4)* ***Pribilof Islands and St. Matthew stock assessments share similar issues, and model development for both of these areas should be consistent. There was a strong consensus that the development of the assessment model should be done in concert for both of these areas*** [bold type added].

Response: See June 2011 SSC comments and response.

- March 2011 SSC review of Feb 2011 NPFMC Crab Modeling Workshop
Comments concerning Pribilof Islands red and blue king crab and implications for St. Matthew Island blue king crab: *A preliminary 4-stage assessment model for Pribilof Island red and blue king crab was reviewed during the workshop. The workshop report highlighted issues with these models that relate to model initialization using survey data, code documentation and discontinuous objective function.*

  Workshop participants recommended that the existing model should not be used until it is fully documented and the code itself is peer reviewed by an independent expert who is familiar with ADMB and non-linear parameter estimation. The SSC concurs with this conclusion.

  Workshop participants made four short-term recommendations relating to treatment of post-recruits and recruits, simplification of models growth increment matrix, model documentation and consistency between stocks. The SSC agrees with these recommendations and encourages the stock assessment authors to move forward to address these issues. However, the SSC expresses some concern about the workshop recommendation to collapse post-recruits and recruits into one category so that the CSA model would become 3-stage instead of 4-stage. Estimates of recruits and post-recruits result from direct measurements of size and shell condition and include the highest quality data available from the survey and the only data available from commercial fishery. On the other hand, the two pre-recruit stages must be estimated based on size measurements, as well as estimates of molting probabilities and growth increments, both of which are estimated with error. The SSC would like to see results from both 3- and 4-stage CSA models prior to any change in assessment methodology.

  The highest priority should be placed on the workshop recommendations that encourage authors to carefully examine the assessment model equations, ensure constants are correct and documented and that the objective function is appropriate. ***Since directed fisheries for Pribilof red and blue king crab are closed, the most urgent issue is to document the model parameterization for St. Matthew blue king crab. This will ensure that the model provides an appropriate basis for OFL and ACL/ABC specifications. As a precaution against the possibility that the CPT does not approve use of the CSA***

model for St. Matthews blue king crab, the SSC requests that the authors also estimate biological reference points based on survey biomass or some other index of abundance.

Response: See June 2011 SSC comments and response.

- May 2011 CPT
  Comments: *Based on results of the NPFMC modeling workshop the author was requested to revise the stock assessment model, improve and or replace the model and prepare a survey-based assessment as a fallback.*

  The team recommends that the assessment author reformulate equations for survey-based assessment to be consistent with other Tier 4 assessments. The variance for the OFL is proposed to be based on the delta-method. If the author continue to use this approach, account will need to be taken of the variance of M (and hence the proxy for F_{MSY}). The OFL was computed in the assessment document as exploitation rate multiplied by legal biomass at the time the fishery with bycatch and discarded then added. This is incorrect and the retained catch OFL should be the total OFL less bycatch and discard mortality. The team recommends formulating a more generic model so that additional scenarios can be explored. The team recommends reviewing the model description and additional output from model in September to provide opportunity for additional feedback on model development.

  Response: It is unclear to the author exactly which equations are in need of reformulation or in what way they need to be reformulated. On the other hand, the author has revised both computation of the OFL and specification of its variance. See June 2011 SSC comments and response regarding proposed alternative model.

- June 2011 SSC
  Comments: *The St. Matthew Island blue king crab fishery has been managed under tier 4 based on a stock assessment using a four-stage catch-survey analysis (CSA). In June 2010, the SSC discussed difficulties of the model to duplicate the large proportion of recruits in the pot surveys. Other issues with the model have since emerged and were discussed during the crab modeling workshop held in Seattle in February 2011. In their report, the Crab Plan Team provided additional guidance to the author. The model and its code are currently being revised to address these problems, and a simpler three-stage version is also being developed as an alternative. As a precaution against the possibility that the Crab Plan Team does not approve the CSA model for use this year, in the SSC's March 2011 meeting report the author was advised to estimate biological reference points based on survey biomass or some other index of abundance. The April 2011 draft assessment for St. Matthew Island blue king crab contains such a proposed fall-back procedures for use in managing the fishery in 2012. Given the issues with the assessment model, the SSC wishes to receive a presentation on modeling efforts for St. Matthew Island blue king crab at the October 2011 meeting at which time OFL and ABC recommendations will be made.*

Response: The author has continued development of an alternative 3-stage CSA assessment model and included documentation and 2011 assessment-year results as an appendix to this report.

C. Introduction

Scientific Name
The blue king crab is a lithodid crab, *Paralithodes platypus* (Brant 1850).

Distribution
Blue king crab are sporadically distributed throughout their range in 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 based on a limited number of variable genetic markers using allozyme electrophoresis methods (1997, NOAA grant Bering Sea Crab Research II, NA16FN2621). Tag-return data from studies by the National Marine Fisheries Service (NMFS) on blue king crab in the Pribilof Islands (n = 317) and St. Matthew Island (n = 253) support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). St. Matthew Island blue king crab (SMBKC) tend to be smaller than their Pribilof conspecifics, and the two stocks are managed separately, with legal sizes of 5.5 in carapace width (CW) in the St. Matthew Island Section and 6.5 in CW in the Pribilof District.

Life History
Like the red king crab, *Paralithodes camtshaticus*, the blue king crab is considered a shallow water species by comparison with its lithodid cousin the golden or brown king crab, *Lithodes aequispinus* (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. Size at 50% maturity is estimated at 77 mm carapace length (CL) for SMBKC males and 81 mm CL for females. Otto and Cummiskey (1990) report an average growth increment of 14 mm CL for adult males.

The estimate of instantaneous natural mortality for all species of king crabs in the eastern Bering Sea is 0.2 as defined by the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). In the analysis described here, natural mortality is assumed to be 0.18 based on a maximum age of 25 and the 1% rule (Zheng 2005), consistent with recent model-based assessments for this stock (2009 and 2010 SAFE).

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (Table 1). The fishing seasons were generally short, lasting less than a month. From 1986 to 1990 the fishery was fairly stable, harvesting a mean of 1.252 million pounds. 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 commercial fishery and in the 1999 ADF&G near-shore 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. In November of 2000, Amendment 15 to the FMP for the 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 harvest strategy established in regulation (5 AAC 34.917), which was adopted by the BOF in March 2000 and modified in 2009 by the Alaska Board of Fisheries, and area closures to control bycatch, as well as gear modifications and an area closure for habitat protection. In addition, commercial crab fisheries near St. Matthew Island were scheduled in the fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the SMBKC stock rebuilt on Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC (total allowable catch) 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 10,484 pot lifts and an estimated CPUE of 9.9 retained crab per pot lift (Bowers et al. 2011). In 2010/11 ADF&G increased the TAC to 1.600 million pounds. Harvest again fell short of the TAC, with the fishery reporting total landings of 1,263,982 pounds in 29,344 pot lifts for a CPUE of 10.2 retained crab per pot lift (B. Bechler, ADF&G, pers. comm.).

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 as high or higher than total catch of legal crab (Moore et al. 2000). By comparison, pot-lift sampling by ADF&G crab observers in 2009/10 indicates a significant reduction in the bycatch of nontarget animals (Gaeuman 2011), which may be attributable to the later timing of the contemporary fishery (D. Pengilly, ADF&G, Kodiak, pers. comm.). In addition to bycatch in the directed fishery, some limited bycatch of non-retained SMBKC has historically been observed in the eastern Bering Sea snow crab fishery, although ADF&G crab observers recorded no blue king crab in 1,646 sampled pot lifts during the 2009/10 snow crab season and just two sublegal males in 2,142 sampled pot lifts during the 2010/11 season (ADF&G Crab Observer Database). The St. Matthew Island golden king crab fishery, the third commercial crab fishery in the area, typically occurs in areas with depths exceeding blue king crab distribution. Variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries.

D. Data

Summary of New Information

This assessment incorporates ADF&G crab observer data for the years 1990/91-1998/99, 2009/10, and 2010/11. These data provide information on catch and catch composition in the directed pot fishery. Trawl-survey and fisheries data time series have been updated.

Major Data Sources

Time series data sources used in this assessment are annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10, 2010/11; Table 1); the annual NMFS Eastern Bering Sea trawl survey (1978-2011; Table 2); ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10, 2010/11; Table 3); and NMFS groundfish-observer bycatch biomass data (1992/93-2010/11; Table 4). Information concerning the NMFS trawl survey as it relates to commercial crab species is available in Chilton et al 2011. Figure 3 maps stations from which SMBKC trawl-survey data were obtained. Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2010). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 4).

Other Data Sources

Key population, survey, and fishery parameters assumed in the survey-based assessment presented here are listed in the following table.

Parameter	Value	Justification
Natural Mortality	0.18 yr^{-1}	Zheng 2005.
Trawl Survey Catchability	1	Default.
Directed Fishery Handling Mortality	0.2	2010 SMBKC SAFE.
Directed Fishery Timing	Mid-season	Default.
GF Trawl and Fixed-gear Handling Mortalities	0.8, 0.5	2010 SMBKC SAFE.
GF Fishery Timing	Feb 15	Simplifying approximation.
SMBKC Length-to-weight Coefficients[a]	0.000502, 3.107158	Chilton and Foy 2010, unpublished.

[a] $W = 0.000502*CL^{3.107158}$, where weight W is in grams and carapace length CL is in millimeters.

Major Excluded Data Sources

Groundfish bycatch size-frequency data (various years; Tables 5 and 6), though used in the 2010 model-based assessment, played no direct role in this analysis. Data from the triennial ADF&G SMBKC pot survey (1995, 1998, 2001, 2004, 2007, 2010; Table 7) were likewise not directly incorporated into the assessment methodology described in this report. The pot-survey data are nevertheless useful in a comparative sense as a credible index of abundance, especially as they arguably represent a more intensive sampling of an important SMBKC population component than do data from the trawl survey (Figure 3). See Watson (2008) for a description of ADF&G SMBKC pot-survey methods. The pot-survey data are used in the alternative model-based assessment presented in Appendix A.

E. Analytic Approach

History of Modeling Approaches for this Stock

A four-stage catch-survey-analysis (CSA) assessment model has been used in recent years 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 (90-104mm 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). These stage definitions are motivated by 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 assumption that all stage-3 crab transition to stage 4 after one year (Z. Zheng, ADF&G, pers. comm.). To be of legal size in the SMBKC fishery, male crab must measure at least 5.5 in CW, including spines, for which 120 mm CL is considered a management proxy, whereas male crab measuring at least105 mm CL are considered mature. It follows that for assessment purposes stages 3 and 4 comprise the "legal" crab, whereas stages 2, 3, and 4 comprise the "mature" crab. The model was implemented using the software AD Model Builder (ADMB Project 2009).

Since the 2010 assessment, various concerns have arisen about use of the existing model, culminating in NPFMC crab modeling workshop, CPT, and SSC recommendations that include development of an alternative potentially simpler model and provisional assessment based on survey biomass or some other index of abundance (NPFMC March 2011, CPT May 2011, SSC June 2011). In the wake of discussions at the 2011 NPFMC crab modeling workshop, the author began development of an alternative 3-stage CSA model along the lines of Collie et al (2005) and presented a description of that model to the CPT in May 2011. The author has continued development of the alternative model and included documentation and 2011 assessment year results in Appendix A. The survey-based assessment described in what follows is intended as the default pending acceptance of the alternative model.

Assessment Methodology

For estimation of required management quantities, the approach used here relies primarily on directed-fishery reported catch (Table 1) and results from the annual NMFS EBS trawl survey (Table 2). ADF&G crab-observer data (Table 3) are used to develop estimates of discard mortality biomass in the directed fishery, whereas estimates of groundfish bycatch mortality are based on NMFS groundfish observer bycatch biomass data (Table 4). Note that NMFS survey area-swept estimates of SMBKC abundance and biomass come with considerable uncertainty and that any assessment methodology based primarily on them will necessarily suffer the same limitation.

State harvest strategy (5 AAC 34.917) requires estimates of assessment-year mature-male biomass MMB_{survey} and mature and legal-male abundances MMA_{survey} and LMA_{survey} at the time of the survey. Such estimates are directly available from NMFS trawl-survey results (Table 2), as are measures of their uncertainty. Determination of the federal overfishing level (OFL), including specification of a B_{MSY} proxy, requires estimation of mature-male biomass at time of mating MMB_{mating}, the Tier-4 proxy measure of stock biomass.

To estimate MMB_{mating}, the survey estimate of mature-male biomass MMB_{survey} is first discounted to the midpoint τ of the fishery under natural mortality M, assumed equal to 0.18 yr^{-1}. Fishery-reported retained-catch biomass B_{ret} (Table 1) is then subtracted, along with estimated directed-fishery mature-male discard mortality MMB_{dis} (Table 3). After further discounting the resulting biomass to Feb 15, the assumed time of mating, estimated bycatch mortality MMB_{GFmort} in the groundfish fisheries (Table 4) is additionally subtracted on the assumption that groundfish bycatch impacts primarily the mature population, approximately as a Feb 15 pulse effect. Figure 5 displays the four biomass time-series inputs. The calculation is given by

$$MMB_{mating} = (MMB_{survey}\exp(-\tau M) - B_{ret} - MMB_{dis})\exp[-(0.63-\tau)M] - MMB_{GFmort}\,. \qquad [1]$$

Directed-fishery mature-male discard mortality MMB_{dis} is estimated from fishery-reported retained catch and ADF&G crab-observer size-frequency sampling of animals in sampled pot lifts by the proportion of retained catch corresponding to the sample ratio ρ (Table 3) of estimated total mature-male discard weight to estimated total retained weight, after accounting for an assumed 20% handling mortality. Length-to-weight computations employ coefficients developed by Chilton and Foy (2010). For fishery years lacking observer data, i.e. 1978/79-1989/90 and the projection year 2011/12, the ratio is imputed from years with data. Groundfish bycatch mortality B_{GFmort} is estimated by ½ the sum of 80% of the blue-king-crab bycatch estimates reported for trawl, pelagic trawl, and non-pelagic trawl gear types and 50% of the estimates for all other gear types. The multipliers 0.80 and 0.50 represent assumed handling mortalities, whereas the factor ½ adjusts (crudely) for the male component of the bycatch. Groundfish bycatch estimates used in these computations come from NMFS reporting areas 521 and 524 (Figure 4.)

As Figure 5 shows, the magnitudes of retained catch, discard mortality, and groundfish bycatch mortality are typically small by comparison with mature-male biomass so that [1] leads to the approximation

$$MMB_{mating} \cong \exp[-(0.63)M]MMB_{survey}, \qquad [2]$$

which allows variance estimation and construction of approximate confidence intervals under the assumption that the survey estimate is lognormally distributed around the true value. It follows in any case that

$$\widehat{var}(MMB_{mating}) \cong 0.8\widehat{var}(MMB_{survey}), \qquad [3]$$

with M = 0.18 yr^{-1} considered given. Additional uncertainty is of course associated with, among other things, the natural mortality parameter M, which is not in fact known–and is almost certainly not identically 0.18 yr^{-1}.

Model Selection and Evaluation

The survey-based approach offered here is presented as a basic, comparatively simple, and more transparent alternative to what is at this time possible in terms of a model-based approach. It is expected that substantive results will be in line with those likely to come out of any reasonable model, modulo the considerable inherent uncertainty associated with trawl-survey area-swept estimates of crab abundance and biomass.

Results

Figure 6 displays the 34-year time series of estimated mature-male biomass at time of mating MMB_{mating}, together with approximate 95% confidence intervals based on [2] and the further assumption that MMB_{mating} inherits a median-unbiased lognormal distribution from the survey estimate; Table 8 provides the numbers. The time series indicates a period of low stock biomass after an abrupt 1998/99 decline, which prompted a ten-year closure of the directed fishery and near-zero total fishing mortality. Stock biomass appears to begin rebuilding about midway through the closure, estimated MMB_{mating} showing a nearly monotone-increasing trend from 2003/04 through the 2011/12 OFL projection of 15.80 million pounds, second in the 34-year time series only to the 1982/83 estimate of 18.97 million pounds. In light of the high uncertainty associated with these estimates, it is worth noting here that the triennial ADF&G SMBKC pot survey data from 1995 – 2010 tell a similar story (Table 7): the 2001 and 2004 surveys signal a precipitous decline in stock biomass from 1998, followed by substantial increases in both 2007 and 2010. On the other hand, modest CPUEs and harvests falling well short of the TAC in each of the two fisheries prosecuted since its reopening in 2009 (Table 1) give some reason for skepticism. Nevertheless, the author believes the collective evidence supports the conclusion that stock biomass is at a high level relative to its status over the last three to four decades and that it is likely well above any reasonable B_{MSY} candidate.

Figure 7 shows survey-estimated mature and recruit abundances, as well as estimates of mature-male fishing mortality F relative to the F_{MSY} proxy $M = 0.18$ yr^{-1}. See Table 9 for the corresponding numbers. F was computed as $F = -\ln(1 - r)$ from the exploitation rate r determined by the ratio of estimated mature-male total fishing mortality biomass to estimated mature-male biomass from the survey discounted to the time of the fishery under natural mortality M. Both abundance time series generally reflect the same behavior described for MMB_{mating}, though the considerable 2011 down turn in recruitment compared to last year's estimate is a perhaps noteworthy exception. If real, it could portend decreasing stock biomass in the next year or two. By default, recruitment for this stock is poorly characterized in terms of males 90 – 104 mm CL. For that reason and given the available information, eg. Figure 7, it is unclear what link might exist between fishing pressure and recruitment, or between stock biomass and recruitment. For the time being, it can be expected that the limited knowledge of SMBKC biology and stock dynamics along with the considerable lack of precision associated with inputs needed for standard fisheries stock analysis methods will continue to trump meaningful application of many of those methods.

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 considered Tier 4 (NPFMC 2007). 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 specified to be mature-male biomass at mating MMB_{mating}. Note that as B is itself a function of F_{OFL}, here taken to be

$$B=MMB_{survey}exp(-0.63M)exp(-F_{OFL}), \qquad [4]$$

in case b) numerical approximation of F_{OFL} is required. Previous recommendations for the stock are to use the period 1989/90-2009/10 to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ 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 F_{OFL} determined via the control rule, the total male catch OFL is then calculated as

$$OFL = TMB_{survey}\exp(-\tau M)[1-\exp(-F_{OFL})], \qquad [5]$$

where TMB_{survey} is the survey estimate of total male biomass and τ is the time from the survey to the midpoint of the directed fishery.

For this stock there are three catch biomass components to consider: 1) directed-fishery retained catch B_{ret}; 2) directed-fishery male discard mortality B_{dis}; and 3) male bycatch mortality $B_{GFTmort}$ and $B_{GFFmort}$ in the groundfish trawl and fixed-gear fisheries. Accordingly, the OFL can be partitioned as

$$OFL = B_{ret} + B_{dis} + B_{GFTmort} + B_{GFFmort}\ , \qquad [6]$$

with B_{ret} constituting the retained catch portion of the OFL. For projection of assessment year quantities, groundfish bycatch mortalities are estimated by the averages $\bar{B}_{GFTmort}$ and $\bar{B}_{GFFmort}$ of estimates of male groundfish bycatch mortality from the prevous three years, and male discard mortality B_{dis} is estimated using $0.2\rho B_{ret}$, where $\rho = 0.5520$ is the ratio of male discard weight to retained-catch weight from 2010/11 crab-observer size-frequency data and 0.2 is the assumed handling mortality in the directed fishery. Substitution into [6] then yields a retained-catch OFL of

$$OFL_{ret} = \frac{OFL-\bar{B}_{GFTmort}-\bar{B}_{GFFmort}}{1+0.2\rho}. \qquad [7]$$

Associated *OFL* directed-fishery discard mortality is back calculated as $0.2\rho OFL_{ret}$.

For the 2011/12 assessment year, averaging over 1989/90-2009/10 estimates of MMB_{mating} results in a B_{MSY} proxy of 6.85 million pounds. (This compares to 6.86 million pounds from last year's four-stage model-based assessment.) Using [4] gives $B = MMB_{mating}$ = 15.80 million pounds with $F_{OFL} = 0.18$, so that B/B_{MSY} = 2.31 > 1 and case a) of the control rule applies. The total catch *OFL* is thus 3.74 million pounds by [5], with the retained-catch portion equal to 3.37 million pounds by [7]. Complete partitioning of the 2011/12 OFL is provided in Table 9.

G. Calculation of The ABC

Given that stock biomass is very likely well above B_{MSY}, it may be assumed that, with high probability, the control rule would result in F_{OFL} equal to the F_{MSY} proxy under replication of the current assessment methodology. Assuming further that the survey estimate of male biomass is lognormally distributed around the true value and treating τ (time to midpoint of fishery) and M (natural mortality) as known, we have by way of [5] that

$$\ln\left(\widehat{OFL}\right) = \ln\left(\widehat{MMB}_{survey}\right) - \tau M + \ln([1 - \exp(-M)]), \qquad [8]$$

so that $\ln\left(\widehat{OFL}\right)$ is normal with $\mathrm{var}[\ln\left(\widehat{OFL}\right)] = \mathrm{var}[\ln\left(\widehat{MMB}_{survey}\right)]$, which we can estimate using the survey estimate of survey-biomass coefficient of variation $\widehat{CV}_{survey}$ by $\ln(1 + \widehat{CV}^2_{survey})$. In setting the allowable biological catch (ABC), current recommendation is to take $P^* = 0.49$, where $P^* = P(ABC > OFL)$. Under the above assumptions, it then follows that

$$ABC = \exp[\sigma \Phi^{-1}(0.49)]\widehat{OFL}, \qquad [9]$$

where $\sigma^2 = var[\ln\left(\widehat{OFL}\right)]$ and Φ denotes the standard-normal distribution function. Putting τ = 0.44 and M = 0.18 yr^{-1}, this formulation then yields

$$ABC_{max} = \exp\left[\sqrt{\ln(1 + 0.56^2)}\,(-0.0251)\right](3.74) \text{ million pounds}$$
$$= 3.64 \text{ million pounds.} \qquad [10]$$

consistent with the requirement that $P^* = 0.49$. The author acknowledges that the full set of assumptions underlying this analysis, including, for example, that τ and M are known, is probably untenable and that some amount of additional uncertainty should therefore be included. The Crab Plan Team recommendation is to put the ABC at 90% of the OFL estimate to provide an additional buffer, so that ABC = 3.37 million pounds. The author concurs with this recommendation.

A more general approach to setting the ABC is needed in the event that stock biomass appears more likely to be close to B_{MSY}.

H. Rebuilding Analysis

This stock is not currently under a rebuilding plan.

I. Data Gaps and Research Priorities

Currently, no recommendations regarding research priorities for this stock have been advanced.

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Table 1. The 1978/79 – 2009/10 directed St. Matthew Island blue king crab pot fishery. (Source: Bowers et al. 2011 and B. Bechler, ADF&G)

			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	4.8	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	441,479	2,200,781	47,748	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	302,098	1,325,185	23,058	30	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	4.6	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	4.6	133.3
1995/96	09/15-09/20	2.4	666,905	3,166,093	48,560	14	4.8	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	9	4.7	135.8
1999/00-2008/09				**FISHERY CLOSED**				
2009/10	10/15-02/01	1.17	103,376	460,859	10,697	9.9	4.5	134.9
2010/11	10/15-02/01	1.60	298,669	1,263,982	29,344	10.2	4.2	129.3

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Average number of retained crab per pot lift.
[d] Pounds.
[e] Average Carapace Length of retained crab in millimeters.

Table 2. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^3 crab) by size class and mature male (≥ 105 mm CL) biomass (10^3 lb) and estimated CV. Total number of captured male crab ≥ 90 mm CL is also given. (Source: J.Zheng, ADF&G and R.Foy, NMFS)

Year	Recruit (90-104mm CL)	Sublegal Mature (105-119mm CL)	Mature (105mm+ CL)	Legal (120mm+ CL)	Mature Male Biomass	CV	Number of Crab
1978	2.384	2.268	4.032	1.764	11.876	0.391	163
1979	2.939	2.225	4.448	2.223	12.864	0.391	187
1980	2.539	2.456	5.322	2.867	16.724	0.474	188
1981	0.477	1.233	3.579	2.346	12.833	0.404	140
1982	1.713	2.495	8.482	5.987	30.748	0.316	269
1983	1.078	1.663	5.027	3.363	17.921	0.282	231
1984	0.410	0.499	1.977	1.478	7.684	0.187	104
1985	0.381	0.376	1.500	1.124	5.750	0.217	93
1986	0.206	0.457	0.833	0.377	2.578	0.389	46
1987	0.325	0.631	1.346	0.715	4.060	0.285	71
1988	0.410	0.816	1.772	0.957	5.693	0.242	81
1989	2.164	1.158	2.951	1.792	9.675	0.250	211
1990	1.053	1.031	3.370	2.338	11.955	0.264	170
1991	1.135	1.680	3.916	2.236	12.255	0.245	198
1992	1.074	1.382	3.672	2.291	12.649	0.204	220
1993	1.521	1.828	5.104	3.276	16.959	0.163	324
1994	0.883	1.298	3.555	2.257	11.696	0.176	211
1995	1.025	1.188	2.929	1.741	9.843	0.173	178
1996	1.238	1.891	4.956	3.064	17.112	0.241	285
1997	1.165	2.228	6.017	3.789	20.143	0.329	296
1998	0.660	1.661	4.510	2.849	15.054	0.359	243
1999	0.223	0.222	0.780	0.558	2.871	0.182	52
2000	0.282	0.285	1.025	0.740	3.795	0.309	61
2001	0.419	0.502	1.440	0.938	5.064	0.255	91
2002	0.111	0.230	0.870	0.640	3.311	0.322	38
2003	0.449	0.280	0.745	0.465	2.483	0.316	65
2004	0.247	0.184	0.746	0.562	2.705	0.286	48
2005	0.319	0.310	0.811	0.501	2.812	0.360	42
2006	0.917	0.642	1.882	1.240	6.494	0.357	126
2007	2.518	2.020	3.212	1.193	9.157	0.348	250
2008	1.352	0.801	2.257	1.457	7.354	0.287	167
2009	1.573	2.161	3.571	1.410	10.189	0.264	251
2010	3.927	3.253	5.711	2.458	17.948	0.373	385
2011	1.693	3.215	6.467	3.252	21.073	0.525	315

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling and estimated fishery mature male discard mortality (pounds). (Source: ADF&G Crab Observer Database)

Year	Pot Lifts (Sampled/Total)	Number of Crab	90-104mm CL	105-119mm CL	120mm+ CL	ρ[a]	Mature Discard Mortality[b]
1990/91	10/26,264	150	0.1133	0.3933	0.4933	0.587	202,559
1991/92	125/37,104	3,393	0.1329	0.1768	0.6902	0.188	126,675
1992/93	71/56,630	1,606	0.1905	0.2677	0.5417	0.309	153,353
1993/94	84/58,647	2,241	0.2806	0.2097	0.5095	0.263	158,152
1994/95	203/60,860	4,735	0.2941	0.2713	0.4344	0.397	298,629
1995/96	47/48,560	663	0.1478	0.212	0.6395	0.255	161,585
1996/97	96/91,085	489	0.1595	0.2229	0.6175	0.242	149,108
1997/98	133/81,117	3,195	0.1818	0.2053	0.6127	0.610	566,970
1998/99	135/91,826	1,322	0.1925	0.2162	0.5912	0.364	215,845
2009/10	989/10,484	19,802	0.1413	0.3235	0.5352	0.452	41,706
2010/11	2,419/29,356	45,466	0.1314	0.3152	0.5534	0.406	102,692

[a] Mature-discard-to-legal-retained weight ratio using crab observer size frequency data and SMBKC length-to-weight coefficient from Chilton and Foy 2010.
[b] Product of ρ, fishery reported retained catch weight, and assumed 20% handling mortality.

Table 4. Groundfish SMBKC male bycatch biomass (pounds) data. (Source: J.Zheng, ADF&G and R.Foy, NMFS)

Year	Bycatch: Trawl[a]	Bycatch: Fixed Gear	Total Groundfish Bycatch Mortality[b]
1992/93	993	5,355	3,472
1993/94	5,232	57	4,214
1994/95	808	199	746
1995/96	2,191	446	1,976
1996/97	64	30	66
1997/98	18	769	399
1998/99	0	2,566	1,283
1999/00	24	6,922	3,480
2000/01	46	91	82
2001/02	70	4,380	2,246
2002/03	3,157	2,154	3,603
2003/04	3,510	4,914	5,265
2004/05	394	3,087	1,859
2005/06	0	2,845	1,423
2006/07	5,962	6,783	8,161
2007/08	286	299,895	150,176
2008/09	705	25,797	13,535
2009/10	1,722[c]	18,281[c]	10,518
2010/11	75[c]	7,471[c]	3,796

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gear.
[c] Half the total estimate from NMFS reporting areas 521 and 524.

Table 5. Groundfish trawl SMBKC male byctach size-class proportions data. (Source: J.Zheng, ADF&G)

Year	90-104mm CL	105-119mm CL	120mm+ CL (legal)	Number of Crab
1989/90	0.0000	0.0000	1.0000	3
1990/91	0.0000	0.0000	1.0000	27
1991/92	0.0385	0.2692	0.6923	26
1992/93	0.0370	0.0741	0.8889	27
1995/96	0.2917	0.1905	0.5179	168
1996/97	0.0000	0.1429	0.8571	7
1998/99	0.0000	0.0000	1.0000	3
1999/00	0.0000	0.2500	0.7500	4
2002/03	0.0000	0.0769	0.9231	13
2003/04	0.0455	0.1364	0.8182	22
2004/05	0.2000	0.2000	0.6000	5
2006/07	0.1667	0.2083	0.6250	24

Table 6. Groundfish fixed-gear SMBKC male bycatch size-class proportions data. (Source: J.Zheng, ADF&G)

Year	90-104mm CL	105-119mm CL	120mm+ CL (legal)	Number of Crab
1996/97	0.0000	0.0000	1.0000	3
1997/98	0.0270	0.0649	0.9081	185
1998/99	0.1006	0.1538	0.7456	169
1999/00	0.0167	0.1172	0.8661	239
2000/01	0.0264	0.0793	0.8943	416
2001/02	0.1083	0.1529	0.7388	471
2002/03	0.1310	0.2018	0.6672	1,893
2003/04	0.0703	0.1333	0.7964	825
2004/05	0.0321	0.0856	0.8823	374
2005/06	0.0330	0.0858	0.8812	303
2006/07	0.0824	0.1412	0.7764	340
2007/08	0.3835	0.1770	0.4395	1,017
2008/09	0.1905	0.2381	0.5714	21

Table 7. Size-class CPUE and estimates of mean pot biomass (pounds) and its CV from the 96 common stations surveyed during the six triennial ADF&G SMBKC pot surveys. (Source: D.Pengilly and R.Gish, ADF&G)

Year	90-104mm CL	105-119mm CL	120mm+ CL (legal)	Biomass	CV	Number of Crab
1995	1.919	3.198	6.922	38.219	0.130	4,624
1998	0.964	2.763	8.804	44.458	0.062	4,812
2001	1.266	1.737	5.487	28.994	0.079	3,255
2004	0.112	0.414	1.141	5.886	0.152	640
2007	1.086	2.721	4.836	26.841	0.097	3,319
2010	1.326	3.276	5.607	34.255	0.125	3,920

Table 8. Estimated mature male biomass (10^6 lb) at time of mating (Feb 15) with approximate 95% confidence intervals based on assuming median unbiased lognormality of the survey estimate of mature male biomass. The 2011 value is from the 2011/12 OFL projection.

Survey Year	MMBmating	Lower	Upper
1978	8.719	3.521	21.593
1979	11.333	5.262	24.409
1980	14.856	5.989	36.851
1981	7.020	2.101	23.462
1982	18.969	7.904	45.524
1983	6.784	2.012	22.871
1984	3.205	1.478	6.954
1985	2.986	1.446	6.167
1986	1.322	0.385	4.541
1987	2.615	1.217	5.620
1988	3.798	2.014	7.163
1989	7.527	4.278	13.245
1990	8.949	4.825	16.598
1991	7.750	3.944	15.227
1992	8.926	5.359	14.869
1993	12.281	8.233	18.318
1994	6.727	3.924	11.533
1995	5.746	3.407	9.691
1996	12.360	6.880	22.205
1997	13.237	5.616	31.199
1998	10.553	4.398	25.321
1999	2.572	1.792	3.692
2000	3.404	1.861	6.227
2001	4.541	2.748	7.504
2002	2.967	1.582	5.565
2003	2.222	1.197	4.125
2004	2.425	1.383	4.250
2005	2.521	1.254	5.070
2006	5.818	2.908	11.641
2007	8.065	4.053	16.048
2008	6.584	3.746	11.570
2009	8.643	4.996	14.950
2010	14.771	6.756	32.298
2011	15.800	4.985	50.074

Table 9. OFL determination based on directed-fishery retained catch, directed-fishery discard mortality, and groundfish bycatch mortality. Catches are in millions of pounds, with metric ton equivalents in parentheses.

			OFL				
			Directed Fishery		Groundfish Bycatch Mortality		
Year	Tier	F_{OFL}	Retained	Discard Mortality	Trawl	Fixed Gear	Total Male
2009/10	4a	$0.18yr^{-1}$	1.53 (694)	NA	NA	NA	1.72 (782)
2010/11	4a	$0.18yr^{-1}$	1.90 (902)	0.263 (119)	0.003 (0.1)	0.038 (17)	2.29 (1,040)
2011/12	4a	$0.18yr^{-1}$	3.36 (1,530)	0.296[a] (134)	0.001[b] (0.5)	0.009[b] (4)	3.74 (1,700)

[a] Assumes 2010/11 male bycatch ratio from crab observer data.
[b] Average of estimates from previous three years.

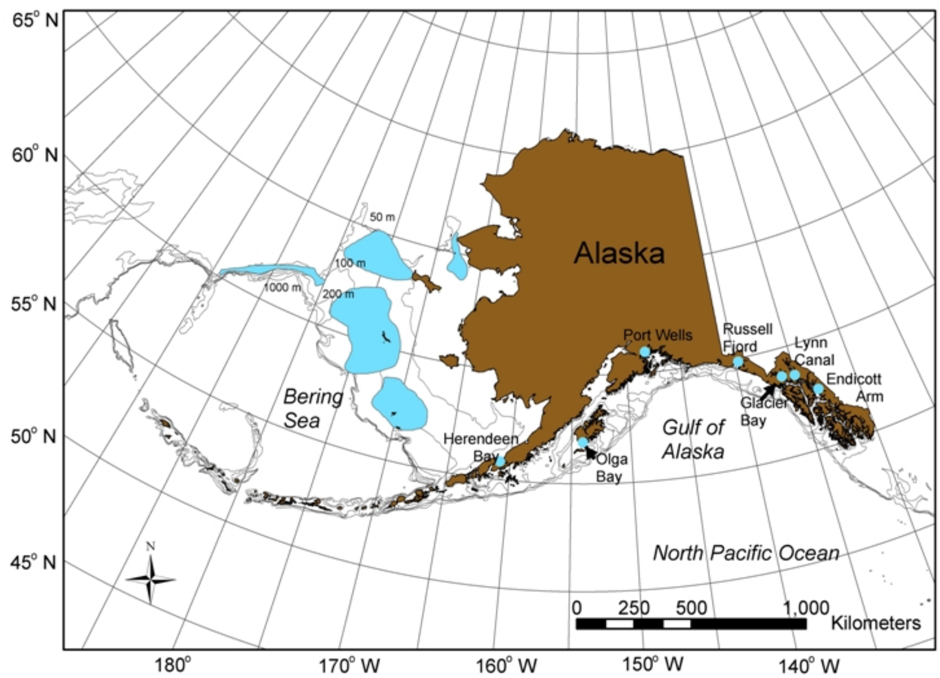

Figure 1. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

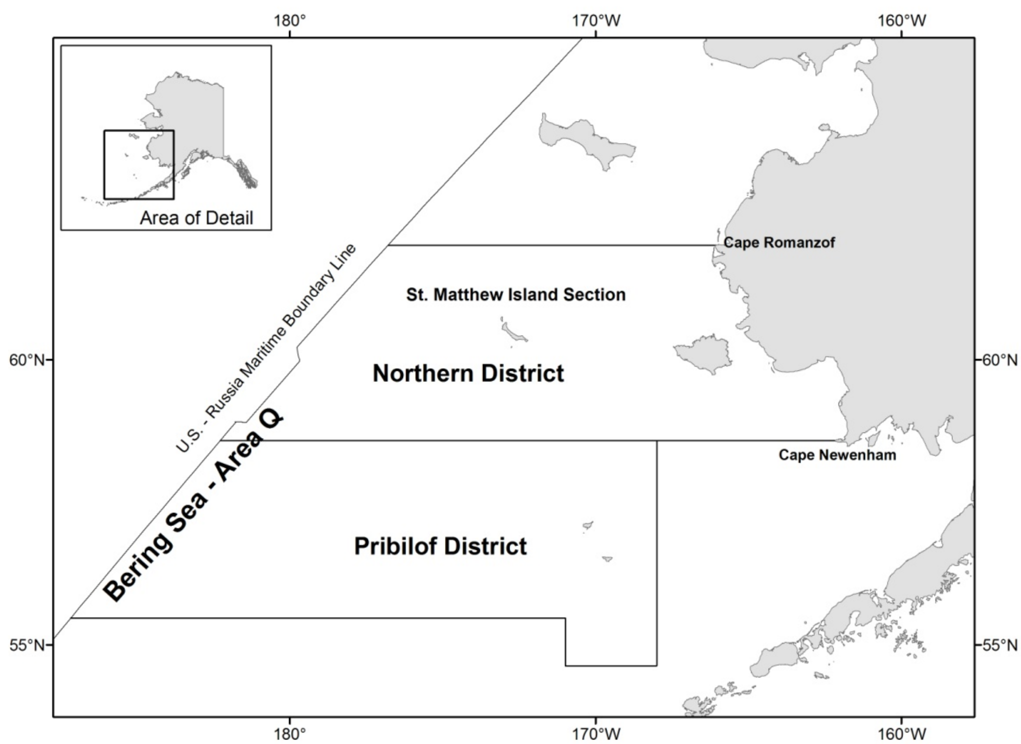

Figure 2. King crab Registration Area Q (Bering Sea).

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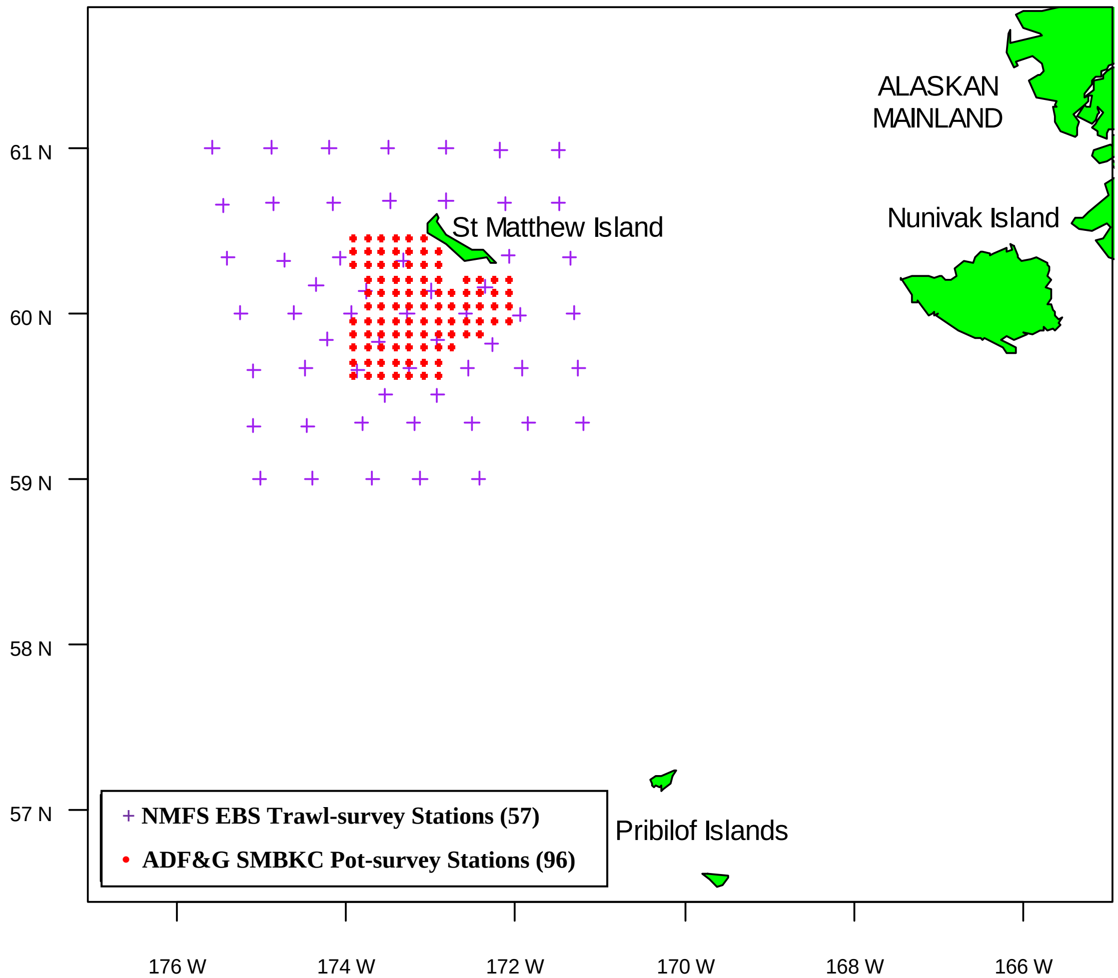

Figure 3: Trawl and pot-survey stations used in the SMBKC stock assessment.

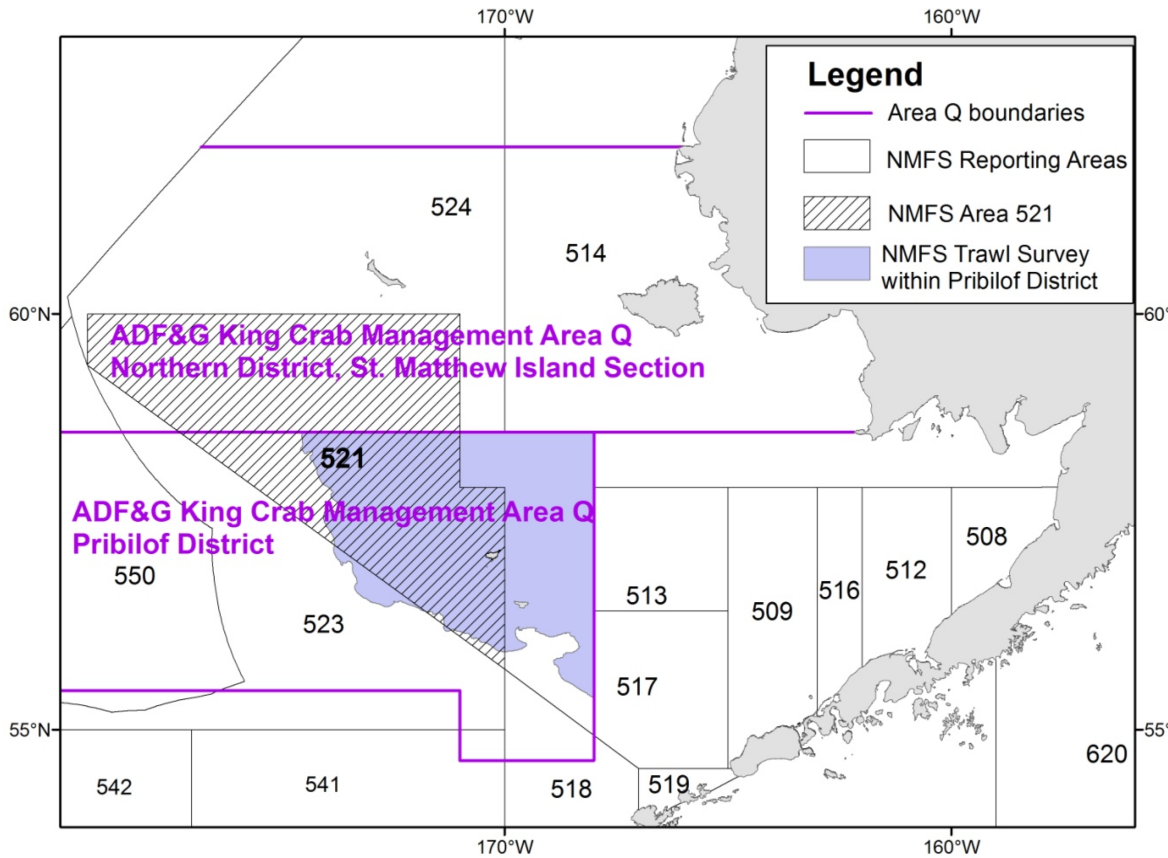

Figure 4. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

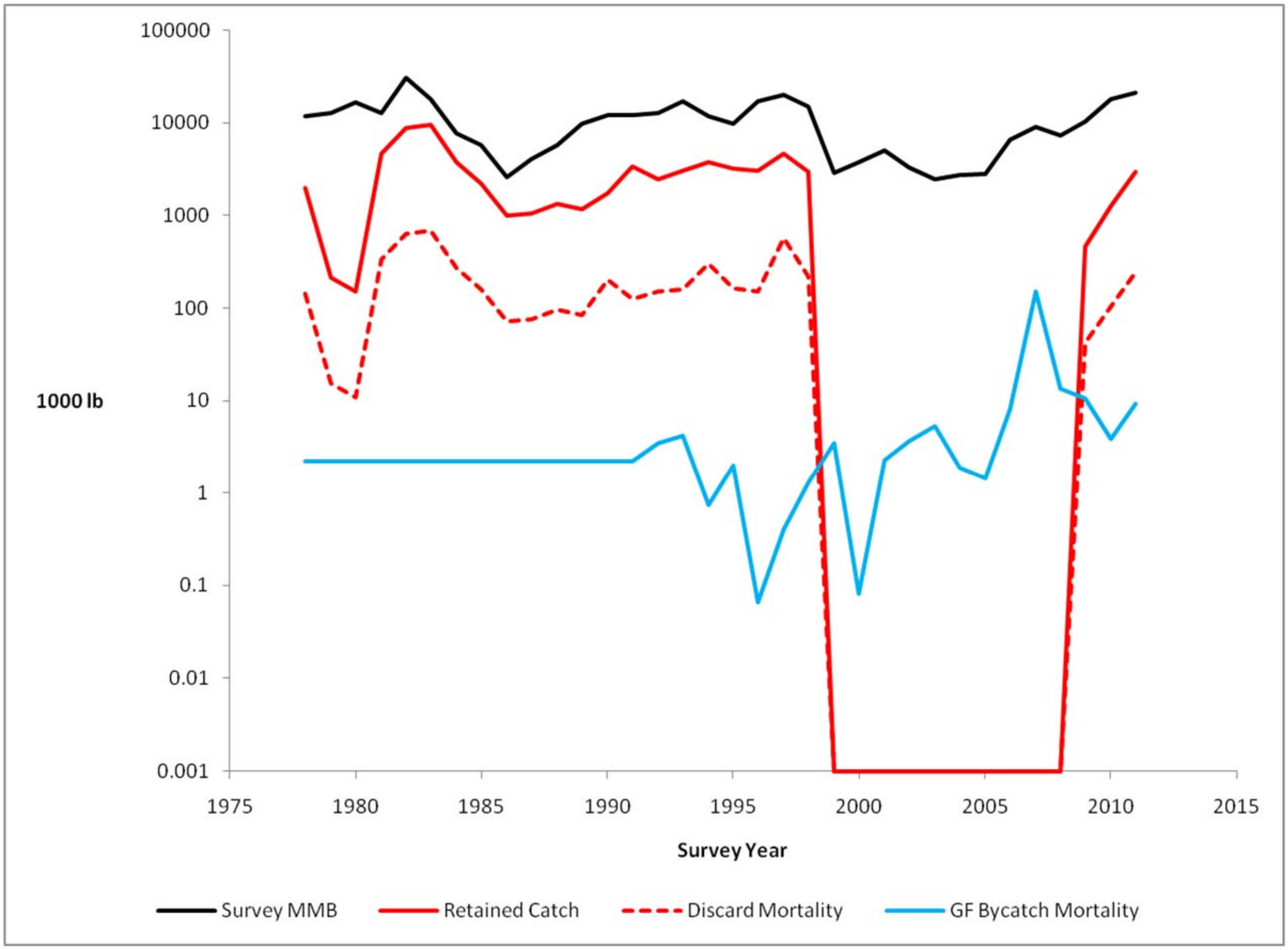

Figure 5. Inputs to computation of estimated 1978/79-2011/12 mature-male biomass at time of mating (Feb 15). Retained catch and discard and bycatch mortality biomasses for the last survey year 2011 are 2011/12 OFL projections. Note log scale on vertical axis.

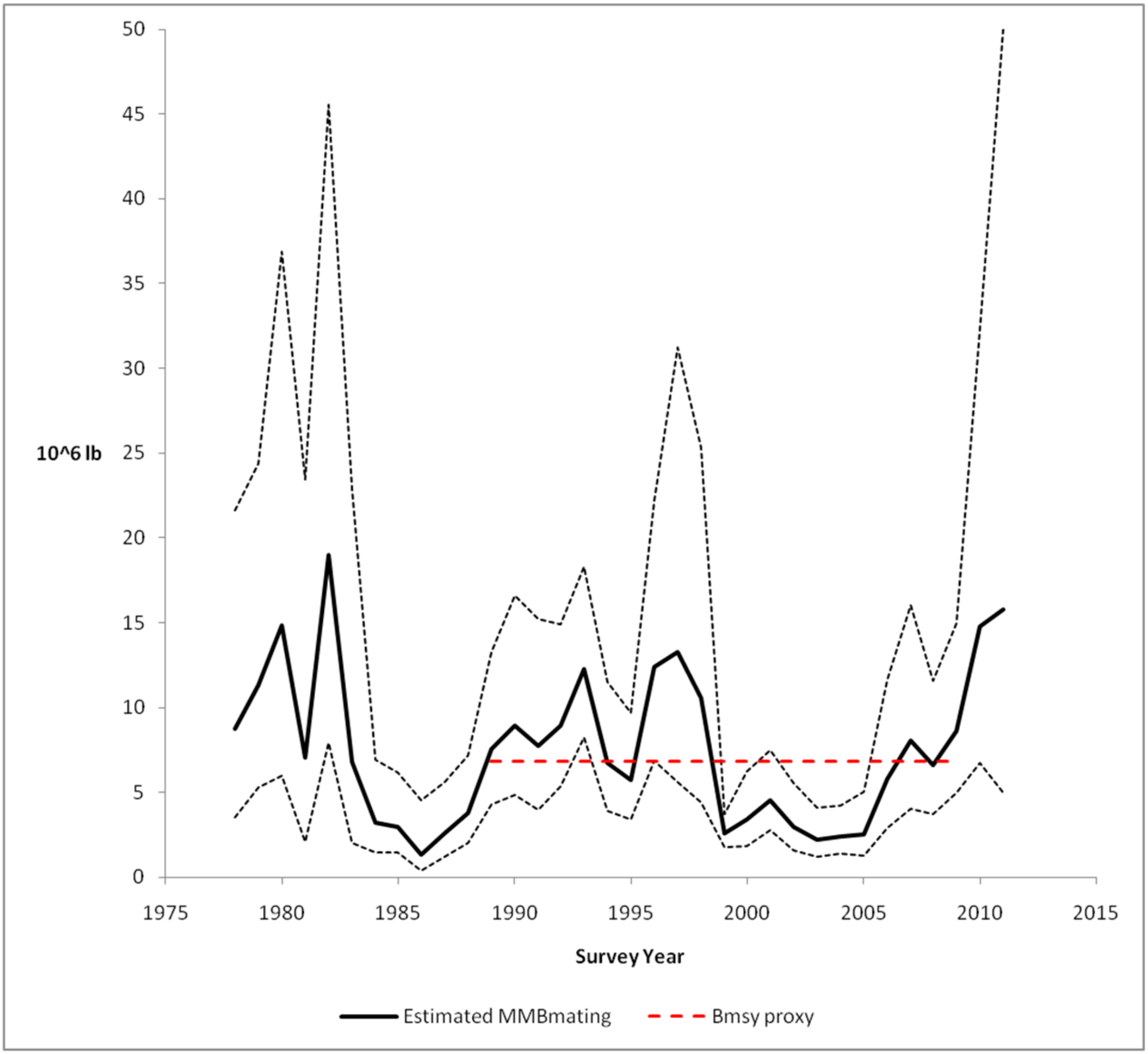

Figure 6. Estimated mature-male biomass at time of mating (Feb 15) with approximate 95% confidence intervals based on [2] and assumed median-unbiased lognormality of the survey estimate of mature-male biomass. The 2011 value is from the 2011/12 OFL projection. Displayed B_{MSY} proxy is 1989/90-2009/10 average.

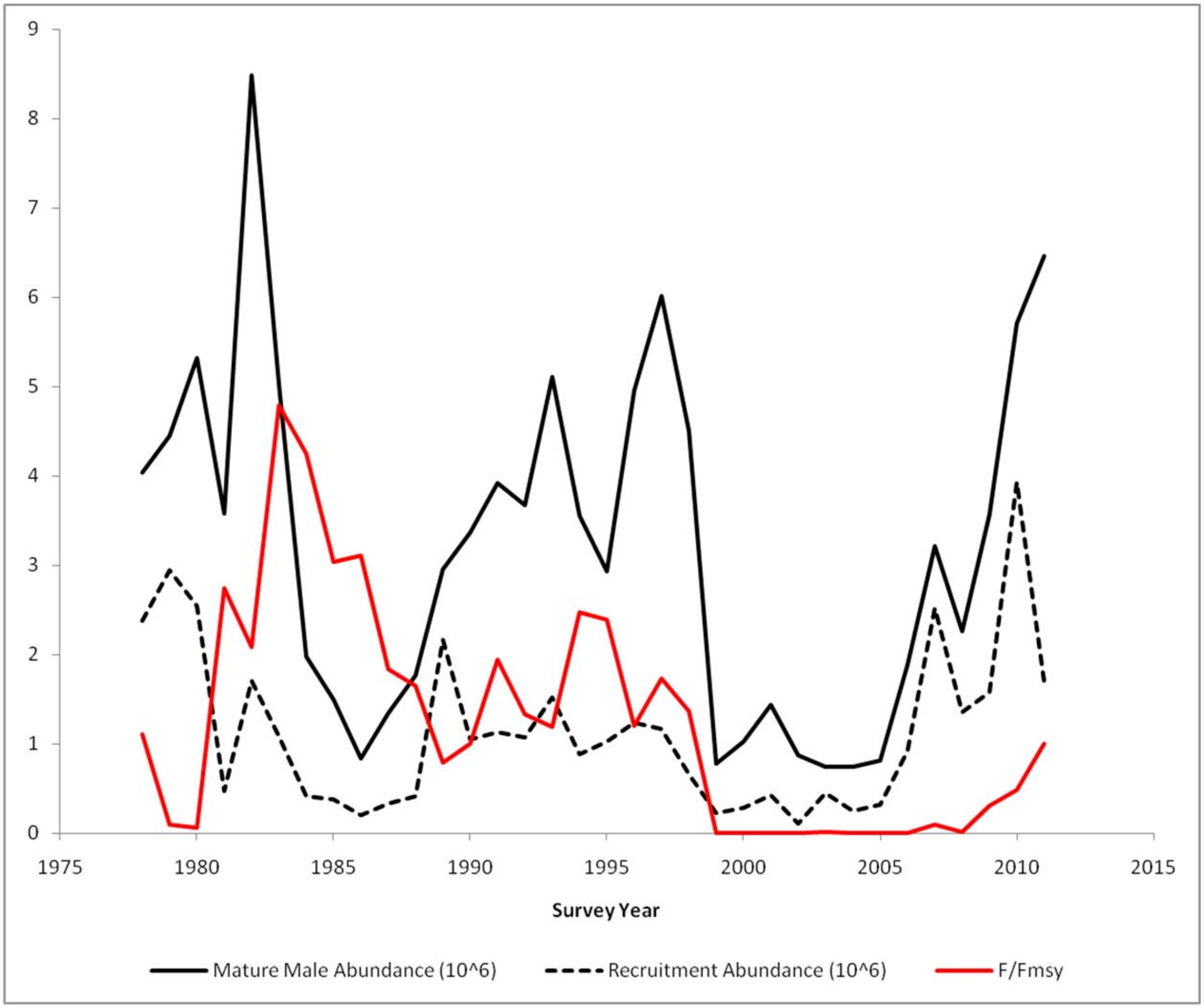

Figure 7. Survey estimates of mature-male (105 mm+ CL) and recruitment (90 – 104 mm CL) abundances and relative estimated mature-male fishing mortality *F* during the subsequent fishery year. Survey year 2011 $F = F_{MSY}$ proxy = 0.18 yr^{-1} for 2011/12 OFL determination. See text for details regarding computation of F.

Appendix A: Alternative 3-Stage Model-Based 2011 Assessment

Introduction

The model is a variant of the one previously developed by Zheng for the St Matthew Island blue king crab (SMBKC) stock (2010 Crab SAFE). Like the earlier model, it considers only male crab at least 90mm in carapace length (CL). The model employs three male size classes (stages) determined by carapace length measurements of (1) 90-104mm, (2) 105-119mm, and (3) 120mm+. By contrast, Zheng partitioned the last stage into "recruits," consisting of new-shell crab measuring 120-133mm CL, and "post recruits," consisting of all crab measuring at least 134mm CL and old-shell crab at least 120mm CL. Consolidation of these two groups into a single stage was heavily driven by concern about the accuracy and consistency of shell-condition information. For management of the SMBKC fishery, male crab measuring at least 105mm CL are considered mature, whereas 120mm CL is considered a proxy for the legal size of 5.5in carapace width, including spines. Accordingly, in what follows the three stages will be referred to as "recruits," "sublegal mature," and "legal."

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

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-M_t}\boldsymbol{N}_t + \boldsymbol{N}^{new}{}_{t+1}, \qquad [1]$$

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

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12} & \pi_{12} & 0 \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \qquad [2]$$

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 entering the model in 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. 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

$$\boldsymbol{R}_t^{df} = \boldsymbol{H}^{df}\boldsymbol{S}^{df}(1-e^{-F_t^{df}})e^{-\tau_t M}\boldsymbol{N}_t, \qquad [3]$$

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 independent of year. 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

$$\boldsymbol{R}_t^{gt} = e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})\frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}}(1-e^{-(F^{gt}+F^{gf})})h^{gt} \quad [4]$$

$$\boldsymbol{R}_t^{gf} = e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})\frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}}(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \quad [5]$$

These last two computations assume that the groundfish fisheries affect all stages proportionally, i.e. all stage selectivities equal one, and that handling mortalities h^{gt} and h^{gf} are constant across both stages and years. My belief is that the available composition data from these fisheries are of such dubious quality as to preclude meaningful use in estimation. Moreover, the impact of these fisheries on the stock is typically very small. These considerations suggest that more elaborate efforts to model that impact are unwarranted. Model population dynamics are thus completely determined by the equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \quad [6]$$

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.

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-fishery retained-catch number	1978/79-1998/99 2009/10-2010/11	Fish tickets (no fishery 1999/00-2008/09)
Trawl-survey abundance index and estimated CV	1978-2011	NMFS EBS trawl survey
Pot-survey abundance index and estimated CV	Triennial 1995-2010	ADF&G SMBKC pot survey
Trawl-survey stage proportions and total number of measured crab	1978-2011	NMFS EBS trawl survey
Pot-survey stage proportions and total number of measured crab	Triennial 1995-2010	ADF&G SMBKC pot survey
Pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2010/11	ADF&G crab observer program
Groundfish trawl bycatch biomass	1992/93-2010/11	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2010/11	NMFS groundfish observer program

Extending the previous notation, let Q^{ts} and Q^{ps} denote trawl-survey and pot-survey abundance-index proportionality constants, and let s_j^{ts} and s_j^{ps} denote stage-j trawl-survey selectivities. Model-predicted retained-catch number C_t , trawl and pot-survey abundance indices $A_t^{ts}$and A_t^{ps}, and trawl-survey, pot-survey, and directed-fishery stage proportions $\boldsymbol{P}_t^{ts}$, $\boldsymbol{P}_t^{ps}$, and $\boldsymbol{P}_t^{df}$ are given by

$$C_t = e^{-\tau_t M_t} N_{3,t}(1 - e^{-F^{df}}) \qquad [7]$$

$$A_t^{ts} = Q^{ts}(s_1^{ts} N_{1,t} + s_2^{ts} N_{2,t} + N_{3,t}) \qquad [8]$$

$$A_t^{ps} = Q^{ps}(s_1^{ps} N_{1,t} + s_2^{ps} N_{2,t} + N_{3,t}) \qquad [9]$$

$$\boldsymbol{P}_t^{ts} = \frac{Q^{ts}}{A_t^{ts}} \begin{bmatrix} s_1^{ts} & 0 & 0 \\ 0 & s_2^{ts} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \qquad [10]$$

$$\boldsymbol{P}_t^{ps} = \frac{Q^{ps}}{A_t^{ps}} \begin{bmatrix} s_1^{ps} & 0 & 0 \\ 0 & s_2^{ps} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \qquad [11]$$

$$\boldsymbol{P}_t^{df} = \frac{1}{[s_1^{df}, s_2^{df}, 1](e^{-\tau_t M_t}\boldsymbol{N_t} - \frac{1}{2}\boldsymbol{R}_t^{df})} \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix} (e^{-\tau_t M_t}\boldsymbol{N_t} - \tfrac{1}{2}\boldsymbol{R}_t^{df}). \qquad [12]$$

Note that the model analogue of retained catch is assumed to be precisely those stage-3 crab captured in the directed fishery. With $\boldsymbol{wt}_t = [wt_{1,t}, wt_{2,t}, wt_{3,t}]^T$ 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

$$B_t^{gt} = \boldsymbol{wt_t}^T \boldsymbol{R}_t^{gt} \text{ and } B_t^{gf} = \boldsymbol{wt_t}^T \boldsymbol{R}_t^{gf}. \qquad [13]$$

Model Objective Function

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. 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. Table 2 lists all components of the objective function. Upper and lower case letters designate model predicted and data computed quantities, respectively. As above, boldface letters indicate vector quantities.

Table 2. Components of model objective function. The w_k are weights, described in text.

Component		Form
Legal retained-catch number	Normal	$w_1 \sum (c_t - C_t)^2$
Trawl-survey abundance index	Lognormal	$\frac{w_2}{\ln(1+\widehat{cv_t^{ts}}^2)} \sum [\ln(a_t^{ts}) - \ln(A_t^{ts})]^2$
Pot-survey abundance index	Lognormal	$\frac{w_3}{\ln(1+\widehat{cv_t^{ps}}^2)} \sum [\ln(a_t^{ps}) - \ln(A_t^{ps})]^2$
Trawl-survey stage proportions	Multinomial	$\sum w_4(t) n_t^{ts} (\boldsymbol{p}_t^{ts})^T \ln(\boldsymbol{P}_t^{ts})$
Pot-survey stage proportions	Multinomial	$\sum w_5(t) n_t^{ps} (\boldsymbol{p}_t^{ps})^T \ln(\boldsymbol{P}_t^{ps})$
Directed-fishery stage proportions	Multinomial	$\sum w_6(t) n_t^{df} (\boldsymbol{p}_t^{df})^T \ln(\boldsymbol{P}_t^{df})$
Groundfish trawl mortality biomass	Lognormal	$w_7 \sum [\ln(b_t^{gt}) - \ln(B_t^{gt})]^2$
Groundfish fixed-gear mortality biomass	Lognormal	$w_8 \sum [\ln(b_t^{gf}) - \ln(B_t^{gf})]^2$
$\ln(N_{1,t}^{new})$ deviations	Quadratic	$w_9 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{df})$ deviations	Quadratic	$w_{10} \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gft})$ deviations	Quadratic	$w_{11} \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gff})$ deviations	Quadratic	$w_{12} \sum \Delta_t^2$, with $\sum \Delta_t = 0$

The weights/weighting functions w_j appearing in the above expressions play the role of "tuning" parameters in the modeling procedure. The particular weights w_1, w_9, w_{10}, w_{11}, and w_{12} are interpretable as reciprocals of normal variances. The weighting functions $w_4(t), w_5(t)$, and $w_6(t)$ can be viewed as the effective sample sizes for the multinomial distributions describing empirical stage-proportion error structure with respect to model predicted values. Each depends on two parameters N_{max} and N_o in such way that effective sample size n_{eff} is given as a piecewise linear function of the observed number of crab n by $n_{eff} = \frac{N_{max}}{N_o} n$ for $n < N_o$ and $n_{eff} = n_{max}$ if $n \geq N_o$, as shown in Figure 1. N_{max} and N_o will in general vary between data sources, whereas n will depend also on year.

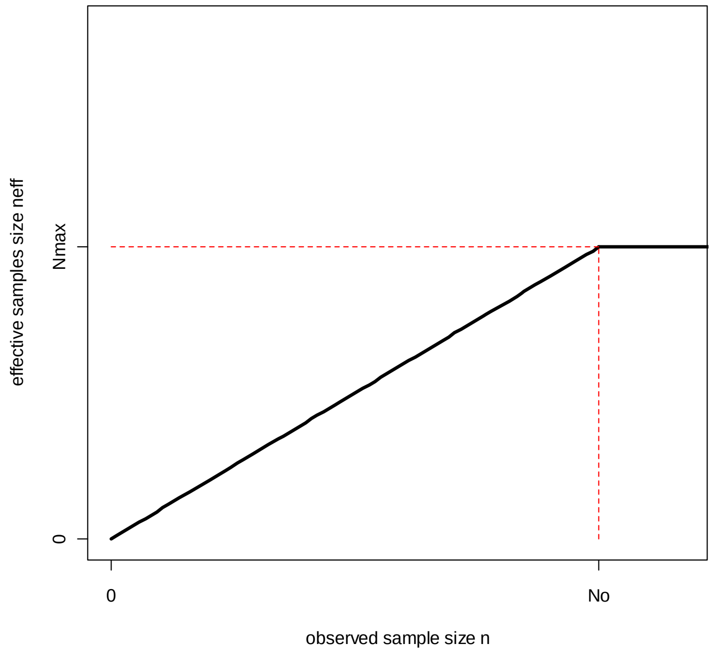

Figure 1. Relation between observed sample size and effective sample size for stage-proportion multinomial distributions, given data-dependent parameters N_{max} and N_o.

Model Parameters

Model estimated parameters are listed in Table 3. Note that 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 4 lists additional externally determined parameters used in model computations.

Table 3. Model estimated parameters.

Parameter	Number
Log initial stage abundances	3
Logit transition probabilities	2
1998/99 natural mortality	1
Pot-survey "catchability"	1
Trawl-survey selectivities	2
Pot-survey selectivities	2
Directed-fishery selectivities	2
Mean log recruit abundance	1
Log recruit abundance deviations	33[a]
Mean log directed-fishery mortality	1
Log directed-fishery mortality deviations	23[a]
Mean log groundfish trawl fishery mortality	1
Log groundfish trawl fishery mortality deviations	19[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	19[a]
Total	111

[a] Subject to zero-sum constraint.

Table 4. Fixed parameters used in model computations.

Parameter	Value	Source
Trawl-survey "catchability", i.e. abundance-index proportionality constant	1.0	Previous CPT, SSC recommendations.
Natural mortality (except 1998/99)	0.18 yr^{-1}	Previous CPT, SSC recommendations.
Stage-1 and 2 mean weights	1.65, 2.57 lb	Chilton and Foy (2010) length-weight equation applied to stage mid-lengths.
Stage-3 mean weights	depend on year	Fishery-reported average retained weight from fish tickets.
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 (?)

2011 Results

The model was implemented in AD Model Builder (ADMB Project 2009). Figures 2-11 document basic model results using the objective-function weighting scheme presented in Table 5. Associated model parameter estimates and AD Model Builder reported asymptotic normal standard errors based on maximum likelihood theory are given in Table 6. Table 7 lists the contributions of each component of the objective function, including weights, to the minimized value.

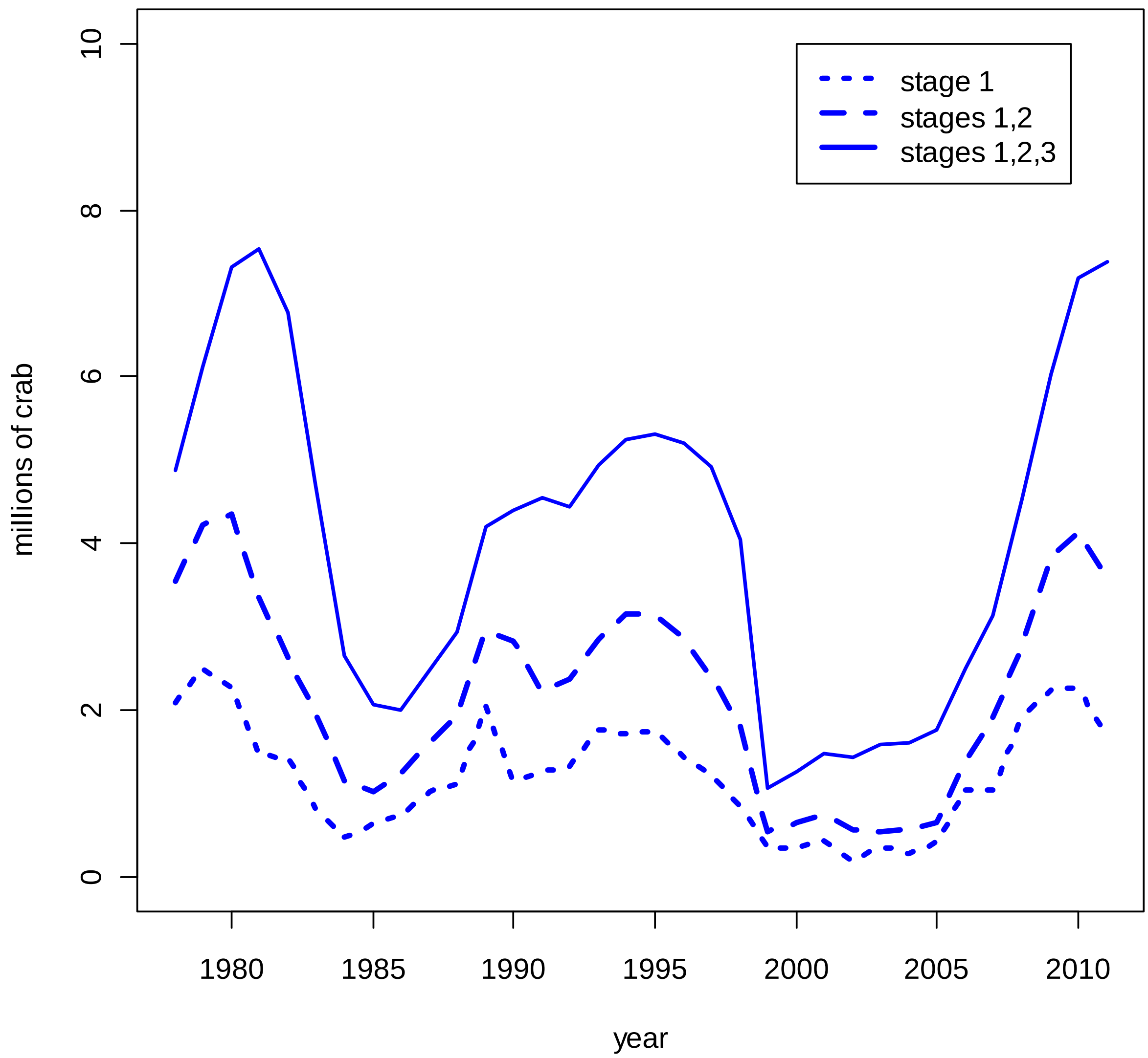

Figure 2. Model-estimated SMBKC stage abundances at time of survey. See text for stage definitions.

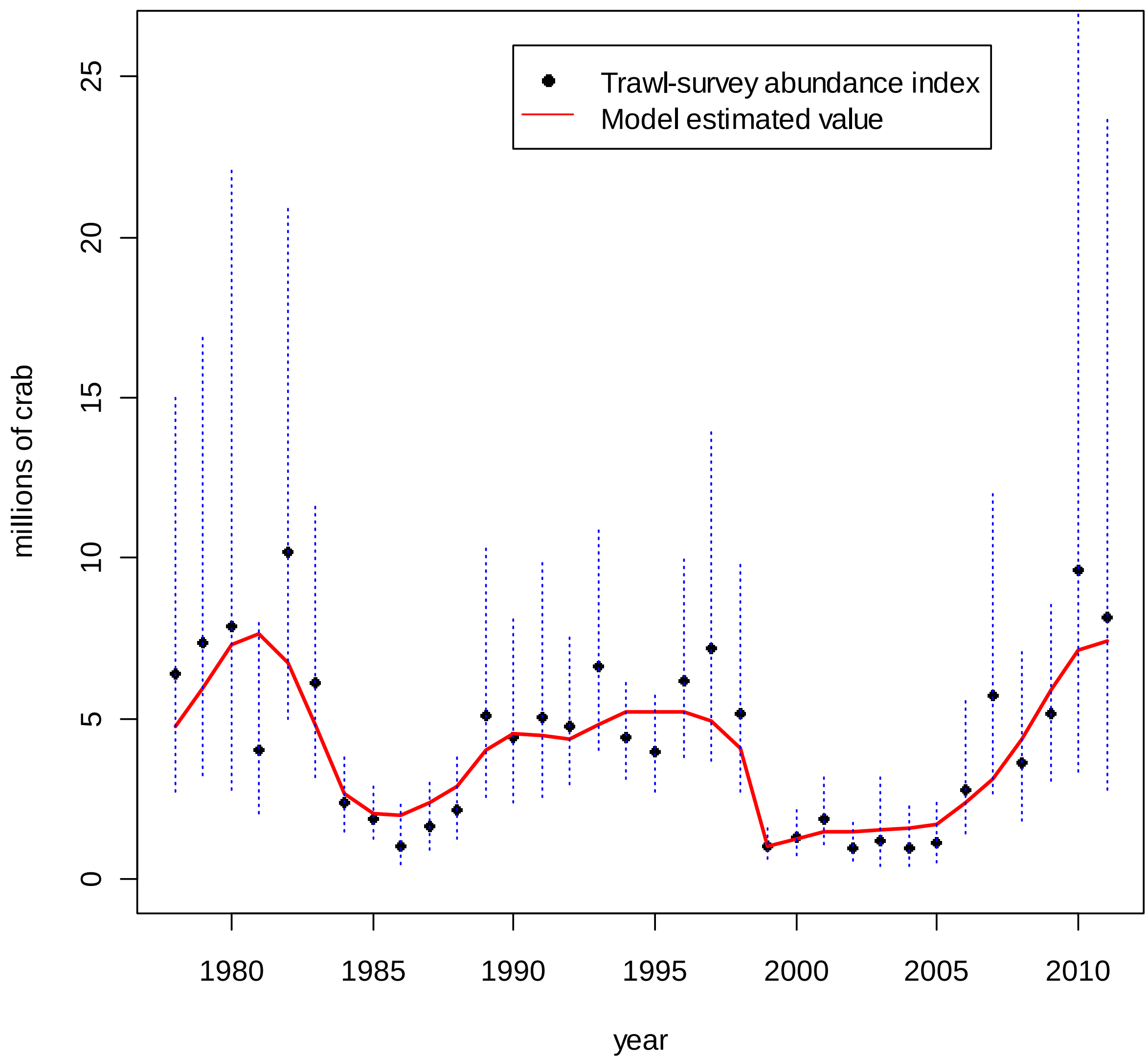

Figure 3. Total abundance of male SMBKC crab ≥ 90mm CL. Approximate 95% confidence intervals (dotted blue lines) based on trawl-survey estimated CV.

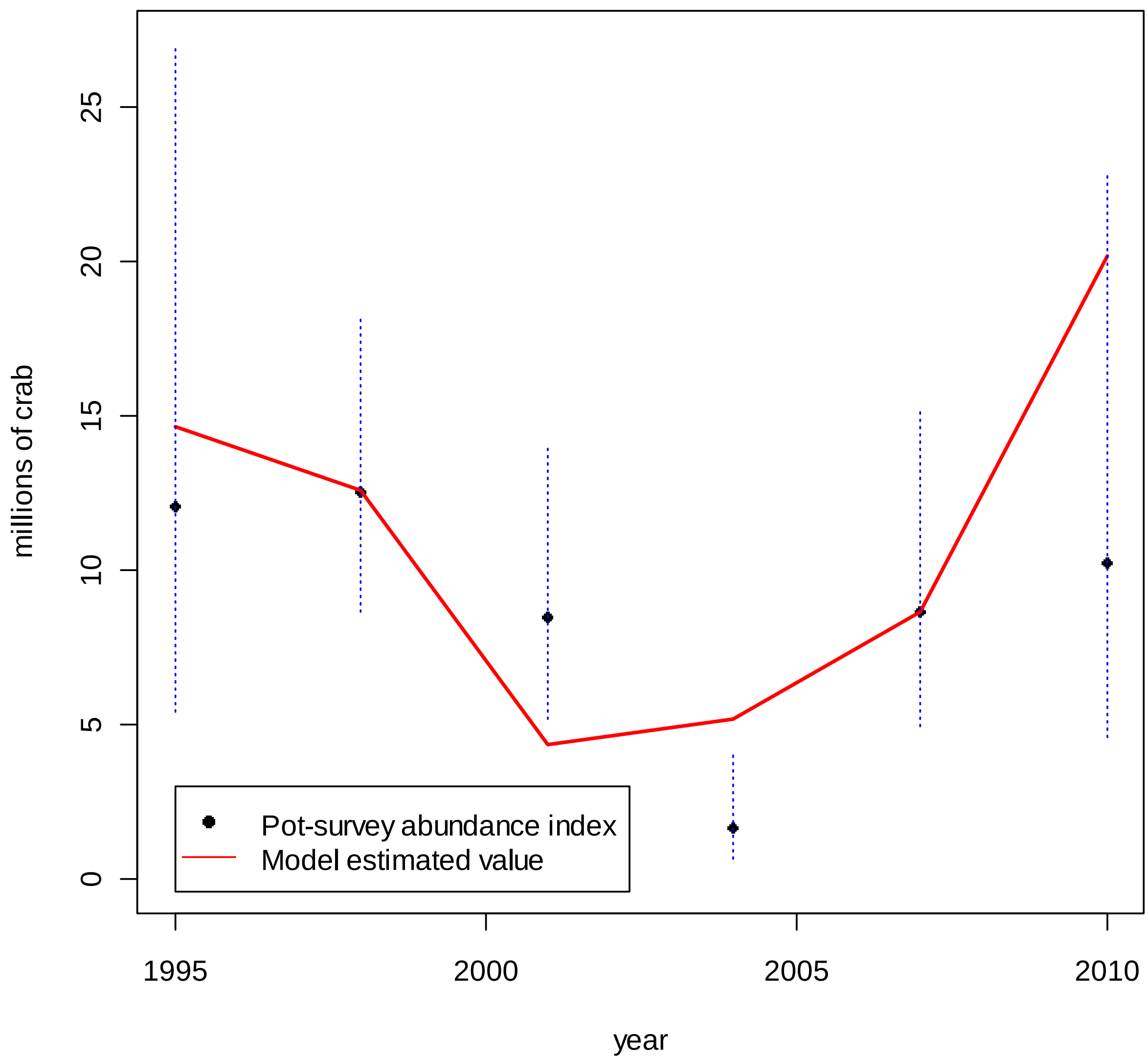

Figure 4. Model-estimated and observed abundance index from ADF&G triennial SMBKC pot survey. Approximate 95% confidence intervals (dotted blue lines) are based on pot-survey estimated CV and reflect model likelihood weighting.

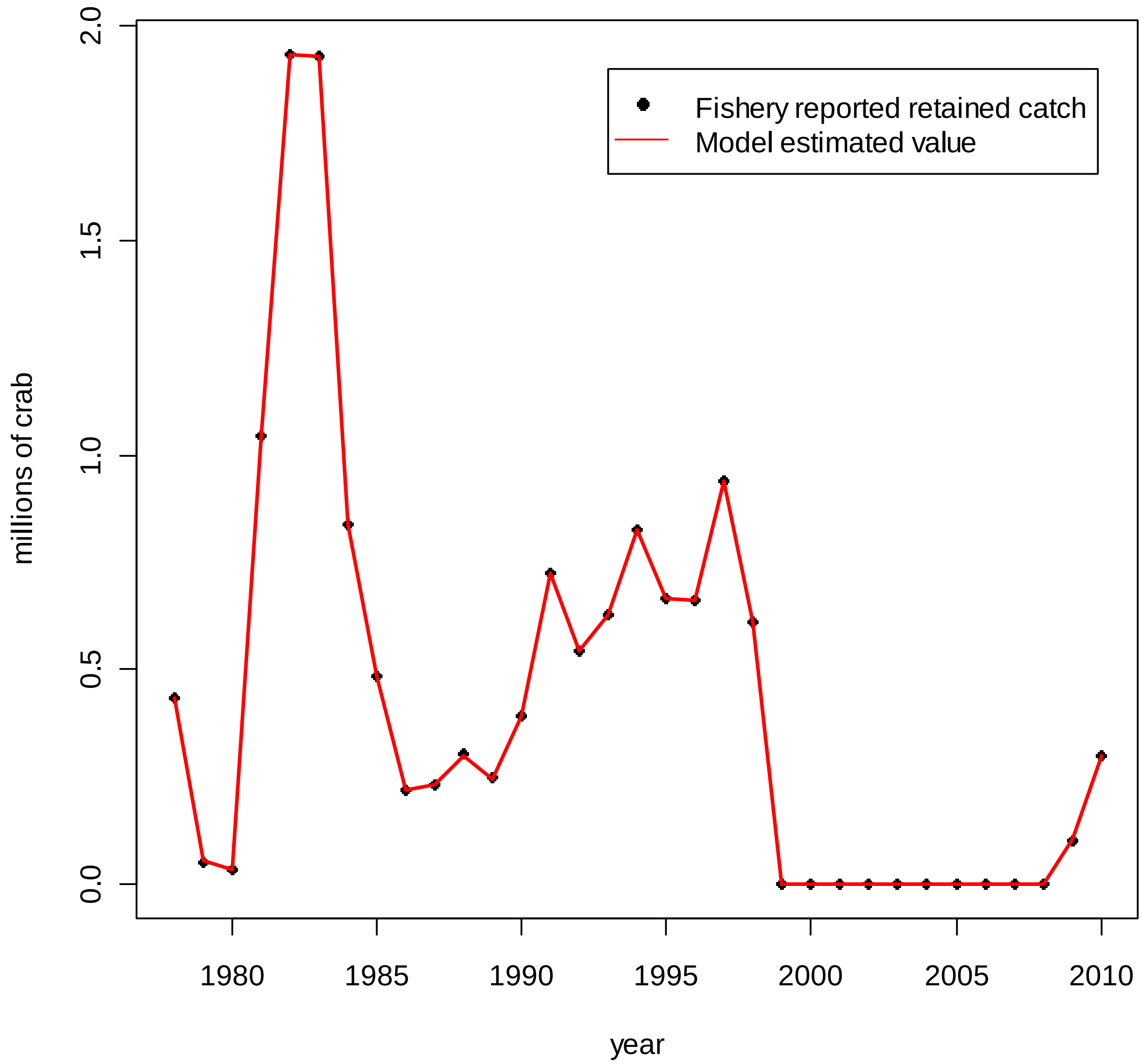

Figure 5. Directed SMBKC fishery catch. The fishery was closed 1999/00 – 2008/09.

Figure 6. Trawl-survey stage-proportion studentized residuals. Dotted red lines indicate approximate 95% confidence intervals.

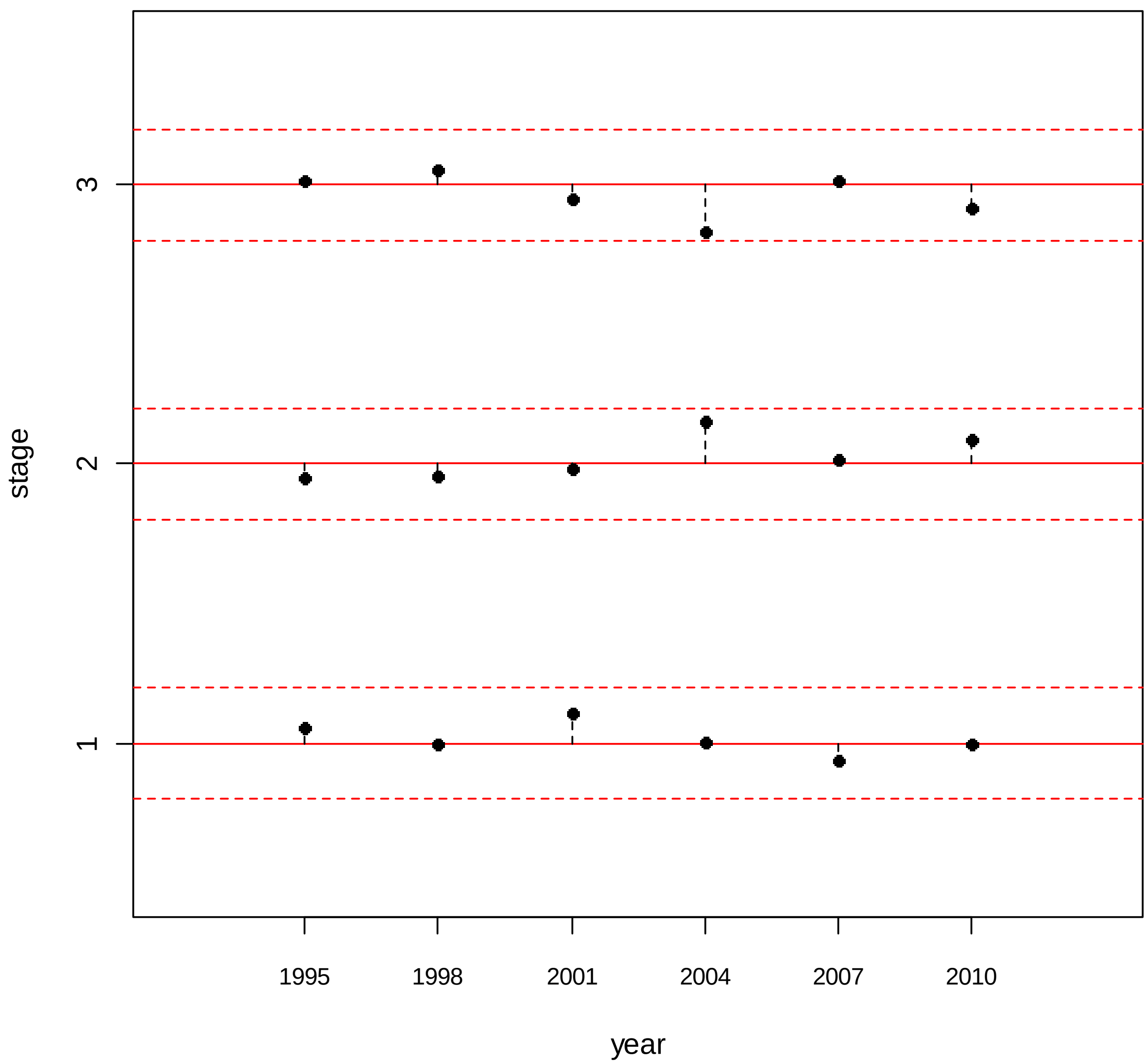

Figure 7. Pot-survey stage-proportion studentized residuals. Dotted red lines indicated approximate 95% confidence intervals.

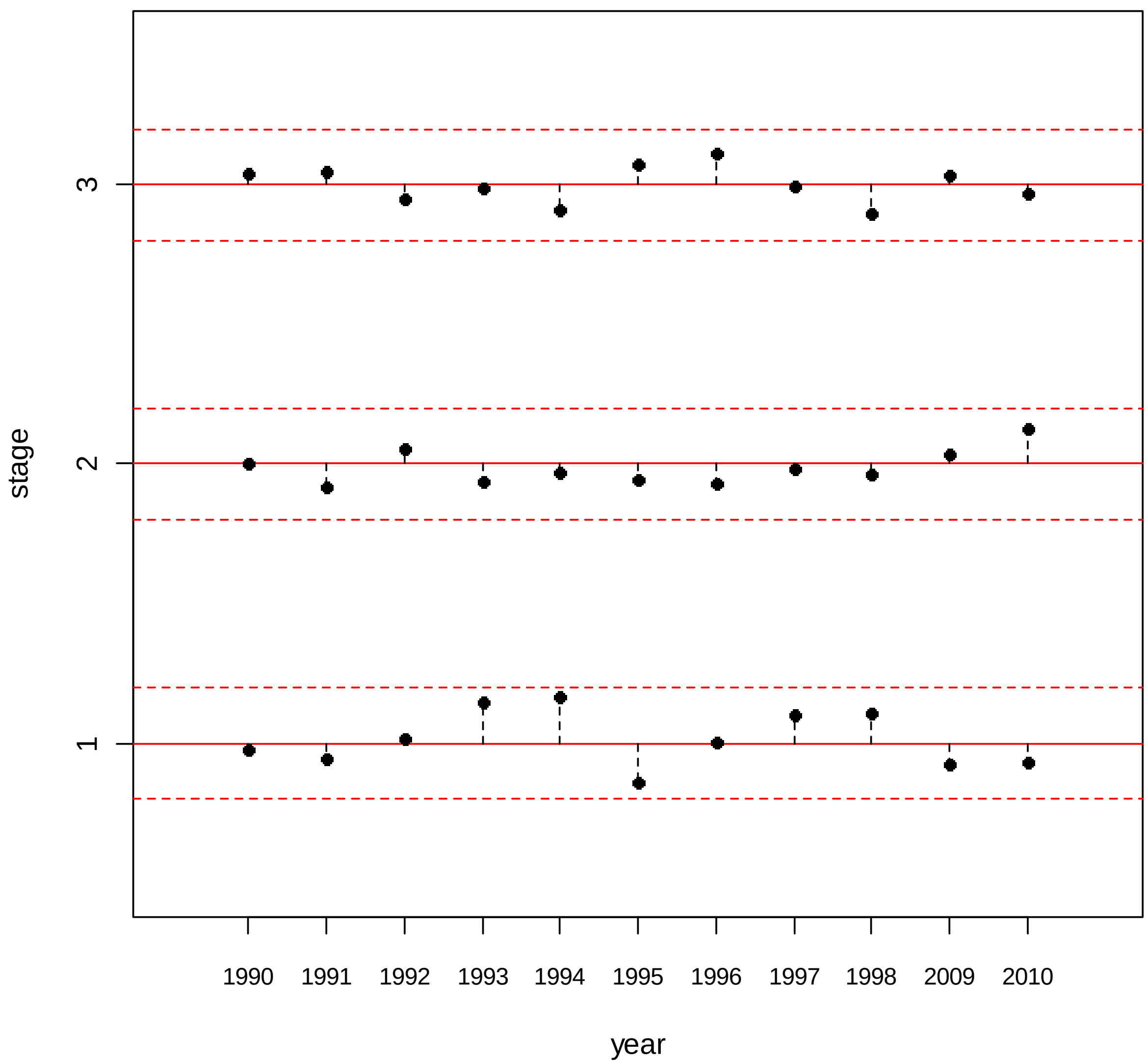

Figure 8. Stage-proportion studentized residuals from pot-lift sampling by ADF&G crab observers. Dotted red lines indicate approximate 95% confidence intervals.

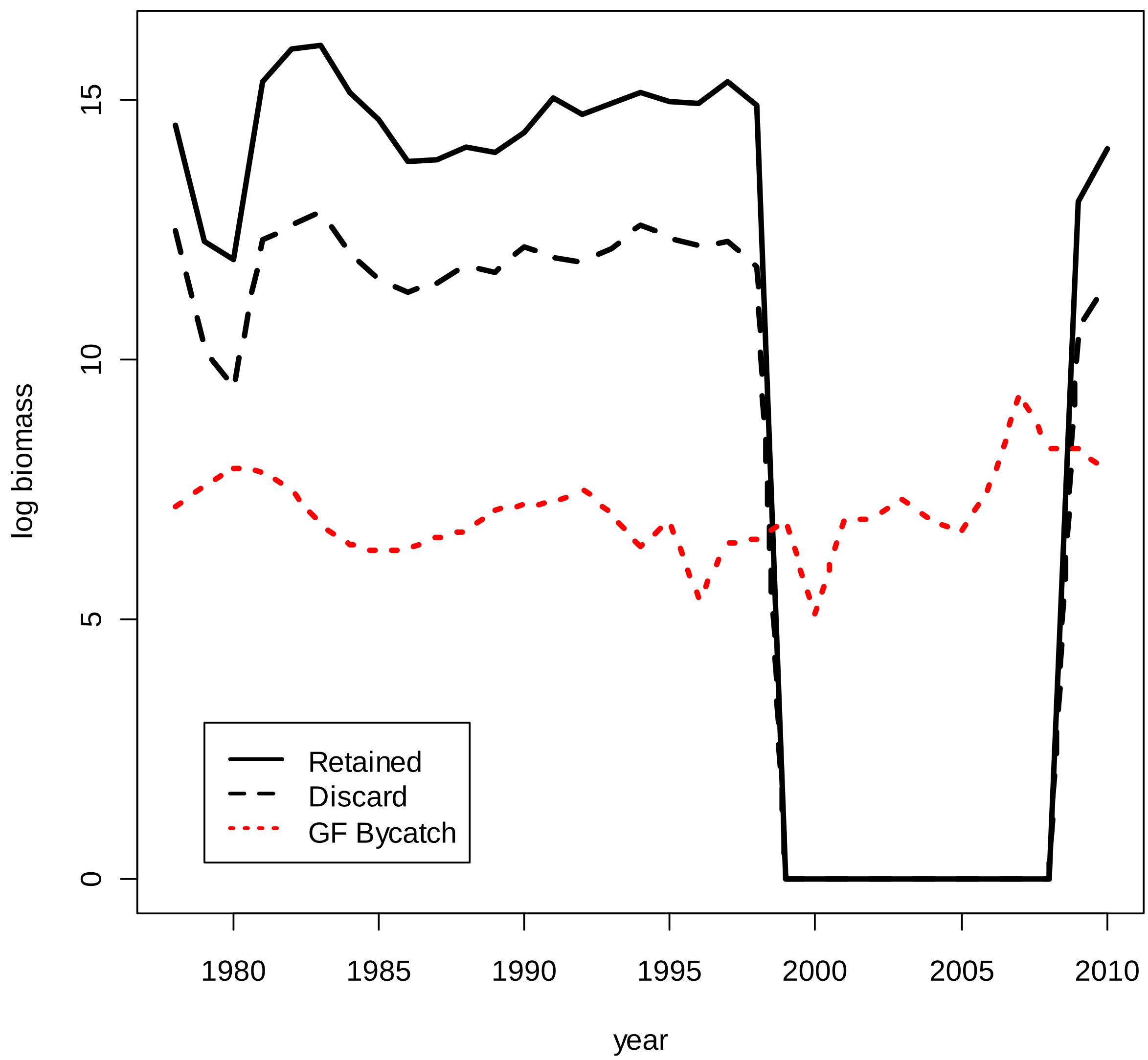

Figure 9. Yearly SMBKC fishing-mortality biomass. The directed fishery was closed 1999/00 – 2008/09.

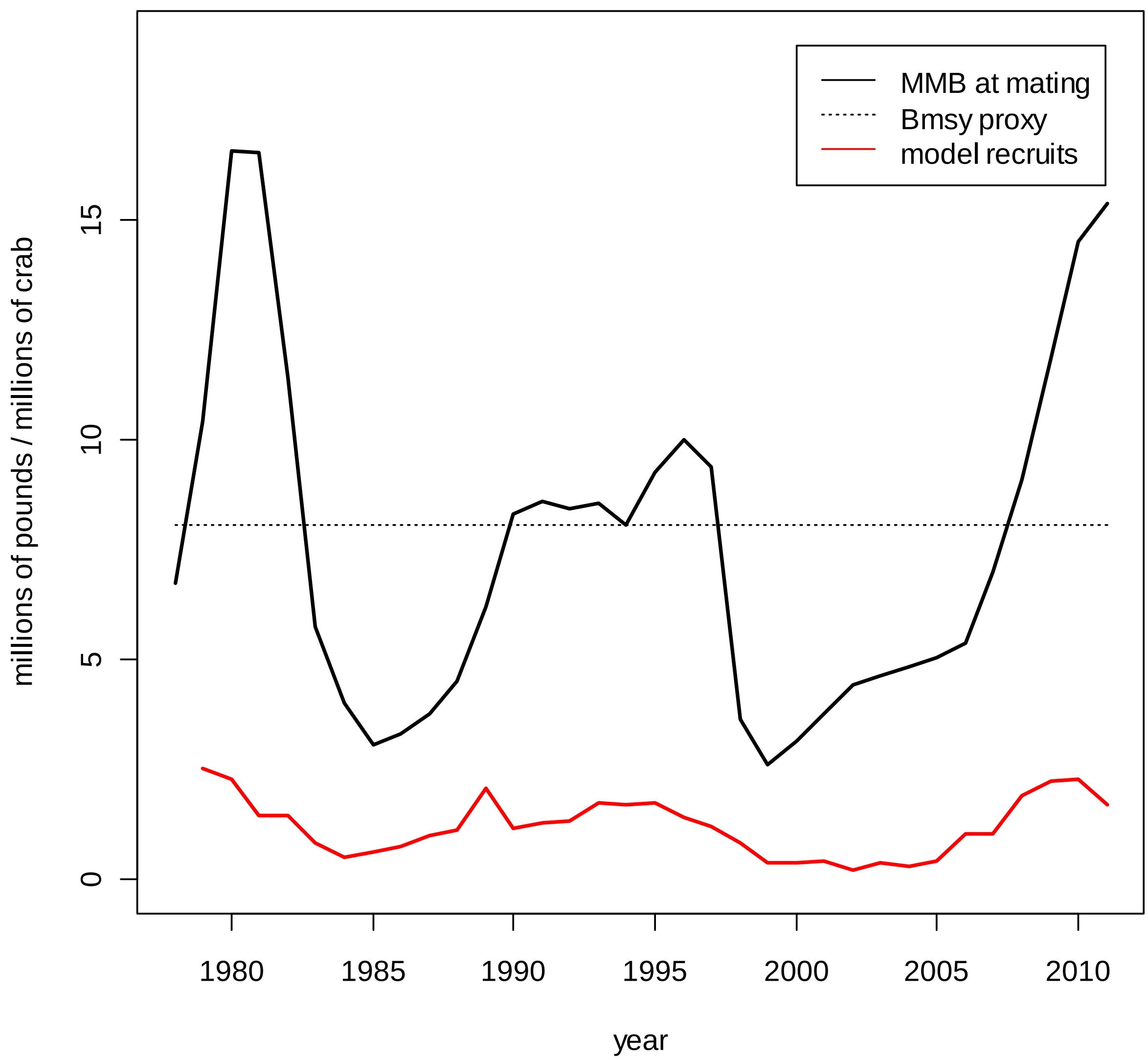

Figure 10. Model-estimates of mature-male biomass at time of mating and model recruit abundance. The model-estimated $F_{35\%}$ B_{MSY} proxy (8.05 million pounds) is also shown. MMB_{mating} for 2011/12 is the OFL projection. The retained-catch portion of the OFL is 4.78 million pounds.

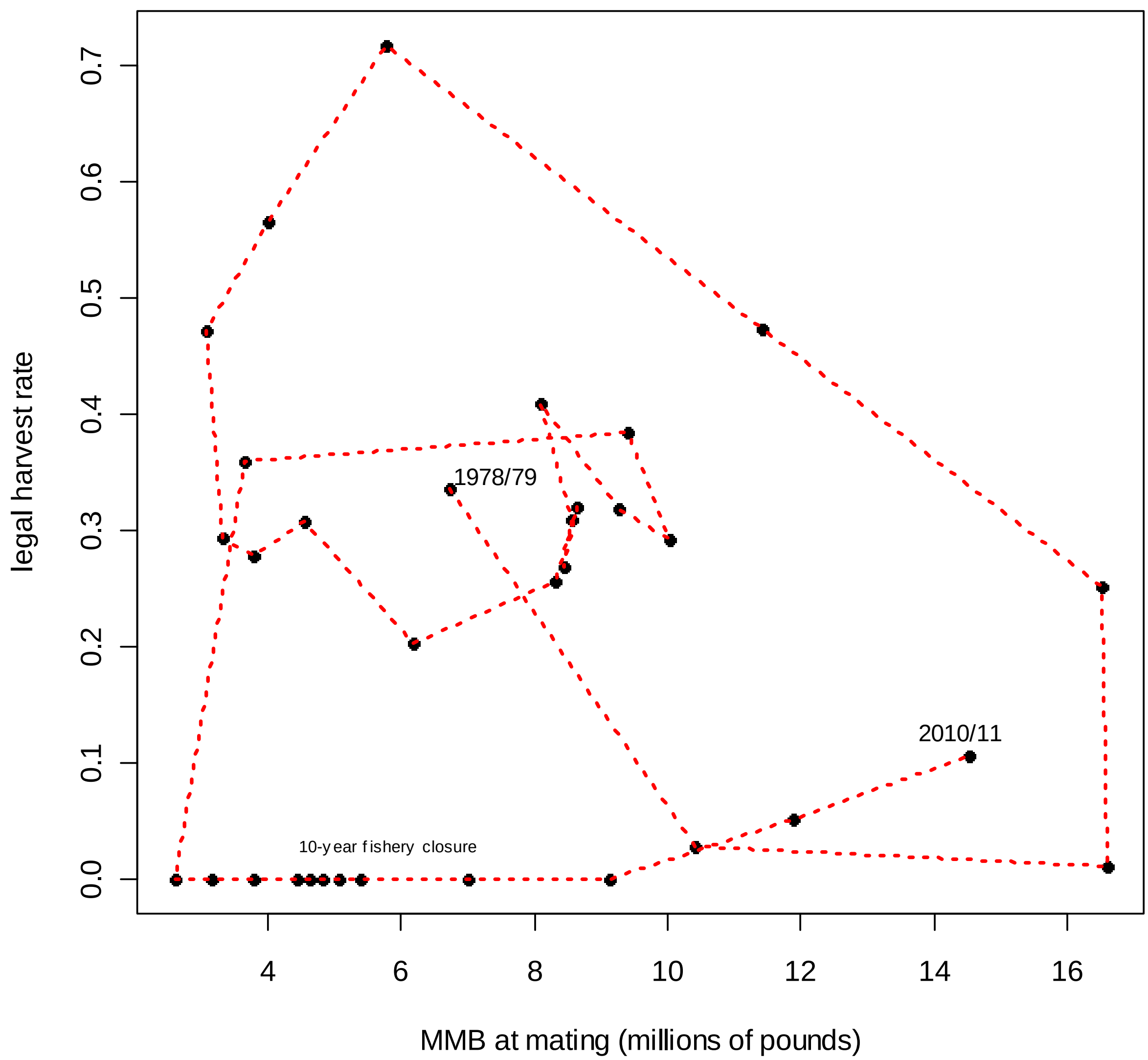

Figure 11. Model-estimated legal harvest rate vs model-estimated MMB_{mating}.

Table 5. Objective-function weighting scheme generating 2011 example results.

Objective-Function Component	Weight w_j
Legal retained-catch number	0.005
Trawl-survey abundance index	1.0
Pot-survey abundance index	0.1
Trawl-survey stage proportions	$N_o = 300$; $N_{max} = 30$
Pot-survey stage proportions	$N_o = 3000$; $N_{max} = 100$
Directed-fishery stage proportions	$N_o = 5000$; $N_{max} = 100$
Groundfish trawl mortality biomass	0.1
Groundfish fixed-gear mortality biomass	0.1
Log model recruit-abundance deviations	1.0
Log directed fishing mortality deviations	0.1
Log groundfish trawl fishing mortality deviations	0.1
Log groundfish fixed-gear fishing mortality deviations	0.1

Table 6. Model-based parameter estimates and standard errors from 2011 example results.

Parameter	Value	Standard Error
Log initial stage abundances	7.650, 7.284, 7.182	0.288, 0.390, 0.417
Logit p1,2 and p2,3 transition probabilities	32.8, 26.8	10^7, 10^5
Pot-survey abundance index proportionality constant	3.87	0.60
1998/99 natural mortality	1.49	0.30
Trawl-survey selectivities	0.81, 1.19	0.08, 0.11
Pot-survey selectivities	0.31, 0.78	0.06, 0.12
Directed-fishery selectivities	0.39, 0.70	0.06, 0.10
Mean log recruit abundance	6.899	0.068
Log recruit abundance deviations	[-1.599, 0.930]	[0.134, 0.412]
Mean log directed fishing mortality	-1.269	0.099
Log directed fishing mortality deviations	[-3.148, 1.501]	[0.134, 0.485]
Mean log groundfish trawl fishing mortality	-10.920	0.717
Log groundfish trawl fishing deviations	[-2.411, 1.663]	[2.175, 2.206]
Mean log grounfish fixed-gear fishing mortality	-9.058	0.718
Log groundfish fixed-gear fishing mortality deviations	[-2.392, 2.420]	[2.177, 2.254]

Table 7. Component contributions to the optimized objective function value. Listed values include weights.

Component	Value	Percent
Retained catch	< 0.1	< 0.1
Trawl-survey abundance index	13.7	0.8
Pot-survey abundance index	7.9	0.5
Trawl-survey stage proportions	637.7	36.4
Pot-survey stage proportions	543.5	31.0
Directed-fishery stage proportions	530.6	30.3
Groundfish trawl bycatch mortality biomass	7.5	0.2
Groundfish fixed-gear bycatch mortality biomass	2.71	0.2
Log recruit deviations penalty	1.3	0.4
Log directed fishing morality deviations	1.3	<0.1
Log groundfish trawl fishing mortality deviations	1.1	< 0.1
Log groundfish fixed-gear fishing mortality deviations	1.2	< 0.1
Total	1,751	100

Determination of The OFL

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently considered Tier 4 (NPFMC 2007). 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 specified to be mature-male biomass at time of mating MMB_{mating}. Note that since B is itself a function of fishing mortality and hence of F_{OFL}, in case b) numerical approximation of F_{OFL} is required. Previous recommendations for the SMBKC stock are to use the period 1989/90-2009/10 to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ in setting the F_{MSY} proxy value γM. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$.

In the approach used here, the F_{MSY} proxy is taken to be $F_{35\%}$, the fishing mortality that would result in a stable per-recruit mature-male biomass $SBPR_{35\%}$ equal to 35% of its pristine or unfished value $SBPR_0$ under model dynamics. A corresponding alternative *Bmsy* proxy is then the product of $SBPR_{35\%}$ and mean, i.e. average estimated, recruit abundance. In all of this, it is full-selection fishing mortality F^{df} in the directed fishery that is treated as the control variable in determining F_{OFL}, with fishing mortality in the groundfish fisheries assumed constant and equal to the geometric means $\exp(mean\_ln\_F^{gt})$ and $\exp(mean\_ln\_F^{gf})$ of the yearly model-estimated values. Assessment-year OFL is then projected as the sum of 1) directed- fishery retained-catch biomass B_{ret}, 2) directed-fishery discard-mortality biomass B_{dis}, and 3) groundfish bycatch-mortality biomasses $B_{GFTmort}$ and $B_{GFFmort}$ assuming full-selection fishing mortality F_{OFL} in the directed fishery, so that

$$OFL = B_{ret} + B_{dis} + B_{GFTmort} + B_{GFFmort} \ ,$$

with B_{ret} constituting the retained-catch portion of the OFL.

For the 2011/12 assessment example presented here, this approach leads to a B_{MSY} proxy of 8.05 million pounds, an OFL of 5.05 million pounds, 4.80 of which is allotted to retained catch, and an OFL-projected MMB_{mating} equal to 15.40 million pounds. By contrast, the B_{MSY} proxy based on 1989/90-2009/10 average model-estimated MMB_{mating} is 6.78 million pounds, though its use has no effect on the other $F_{35\%}$ quantities resulting from the model-based analysis presented here.

Norton Sound Red King Crab Stock Assessment for the fishing year 2011/12

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. The summer commercial fishery catch reached a peak in the late 1970s at a little over 2.9 million pounds retained catch. Since 1982, retained catches have been below 0.5 million pounds, averaging 275,000 pounds, including several low years in the 1990s. Retained catches in the past two years have been about 400,000 pounds.

3. Stock Biomass. Mature male biomass is estimated to be on an upward trend following a recent low in 1997 and an historic low in 1982 following a crash from the peak in 1977. Uncertainty in biomass is driven in part by infrequent trawl surveys (every 3 to 5 years).

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. Biomass quantities are in millions of pounds.

Status and catch specifications (millions lbs.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch[D]	OFL	ABC
2005/06		3.89	0.37	0.40	0.41		
2006/07		3.62	0.45	0.45	0.47		
2007/08		4.40	0.32	0.31	0.36		
2008/09	1.78[A]	5.24[A]	0.41	0.39	0.43	0.68[A]	
2009/10	1.54[B]	5.83[B]	0.38	0.40	0.43	0.71[B]	
2010/11	1.56[C]	5.44[C]	0.40	0.42	0.46	0.73[C]	
2011/12		4.70	0.40			0.68	0.67

Status and catch specifications (kt)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2005/06		1.76	0.17	0.18	0.19		
2006/07		1.64	0.20	0.20	0.23		
2007/08		2.00	0.15	0.14	0.18		
2008/09	0.81[A]	2.38[A]	0.19	0.18	0.21	0.31[A]	
2009/10	0.70[B]	2.64[B]	0.17	0.18	0.22	0.32[B]	
2010/11	0.71[C]	2.47[C]	0.18	0.19	0.22	0.33[C]	
2011/12		2.13	0.18			0.306	0.304

Notes:
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2008
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2009
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2010
D- See Table 18

6. Basis for the OFL

Biomass in millions of pounds

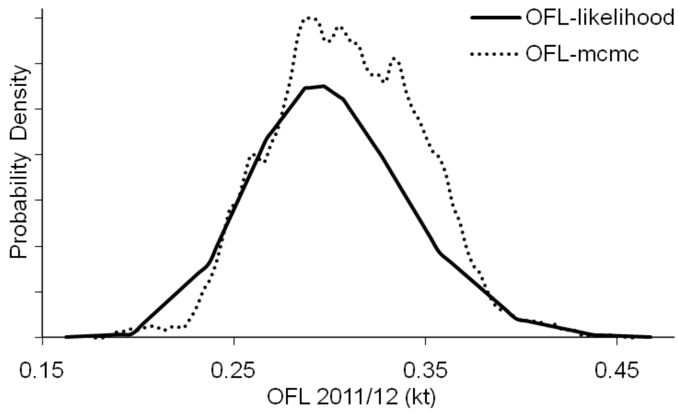
Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality (M)	P*	ABC
2008/09	4a	3.57[A]	5.24[A]	1.5	0.18	1983-2008	0.18		
2009/10	4a	3.07[B]	5.83[A]	1.9	0.18	1983-2009	0.18		
2010/11	4a	3.12[C]	5.44[C]	1.7	0.18	1983-2010	0.18		
2011/12	4a	2.97	4.70	1.6	0.18	1983-2011	0.18	0.49	0.671

Biomass in kt

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality (M)	P*	ABC
2008/09	4a	1.62[A]	2.38[A]	1.5	0.18	1983-2008	0.18		
2009/10	4a	1.39[B]	2.64[A]	1.9	0.18	1983-2009	0.18		
2010/11	4a	1.42[C]	2.47[C]	1.7	0.18	1983-2010	0.18		
2011/12	4a		2.18	1.6	0.18	1983-2011	0.18	0.49	0.305

[A] Calculated from the assessment model agreed on by the Crab Plan Team in May 2008; $\gamma = 1$.
[B] Calculated from the assessment model agreed on by the Crab Plan Team in May 2009; $\gamma = 1$.
[C] Calculated from the assessment model agreed on by the Crab Plan Team in May 2010; $\gamma = 1$.
[D]

7. Probability Density Function of the OFL



8. The basis for the ABC recommendation
   See OFL

9. A summary of the results of any rebuilding analyses.
   N/A

A. Summary of Major Changes in 2011

1. Changes to the management of the fishery**:** None.
2. Changes to the input data
   a. Data update: the 2011 winter pot survey, 2010 summer commercial fishery, and 2010/2011 winter commercial and subsistence catch.
   b. New Data: Abundance estimate and proportion of size classes estimated from the 2010 NOAA trawl survey was included.
3. Changes to the assessment methodology: None. The 2010 model was used.
4. Changes to the assessment results.

B. Response to SSC and CPT Comments

CPT Review May 10-14

Jie Zheng presented the Norton Sound red king crab assessment. Jie identified the SSC and CPT recommendations regarding the 2009/10 assessment and the subsequent changes made in this year's assessment. Major changes include specification of M=0.18yr-1 and γ=1.0. ***The CPT recommended that the next iteration explain the derivation of weights on fishing effort data.*** *Jie presented seven model alternatives, including the 2009/10 selected model and six model configurations with different assumptions. The conclusion that selectivity is uniform across all sizes should be re-evaluated for model 5, which specified a maximum effective sample size of*

100 for the commercial catch and winter surveys. ***Further biological justification should be provided for the value of M to 0.288yr-1 for last length group in model 6.*** *It was noted that the assumption that M is higher for the largest crab is not made in the assessments of other RKC stocks and alternative explanations include the potential that last length group moves to inaccessible area, resulting in lower selectivity. The lack of large individuals in the catch and survey is dealt with in two different ways in the assessment: dome-shaped selectivity (models 1-5) and higher M (models 6 and 7). The analysis should isolate effect of selectivity.* **No additional comments outside of general changes.**

Authors' response: The rationales for increasing the last length group higher and changing weight of fishing efforts were included in the modeling section.

This assumption higher mortality rate for the last length class (>123 mm) is based on the observation that the observed length frequency in all summer trawl survey is less than 10% (Table 6), which cannot be explained by the constant mortality assumptions. It is possible, that the last length group may move to inaccessible area, or that their catch selectivity is lower. However, the trawl survey is conducted most of the area, except for a few rocky bottom areas and shallow near coastal zone, so that it is unlikely that the trawl survey misses catching the largest crabs. It is possible that the catch selectivity of the largest crabs is lower than other length groups; however, attempts of lowering catch selectivity did not yield to improved fit (CPT 2010). High proportion of the > 123 mm crab (30-45%) in survey occurred during in 1980 and 1981 summer pot survey, and in 1980-1982 summer commercial fishery (56-75%). Since then, high proportion of the large length has not been observed. It is unknown, why they disappeared.

SSC Review on June 7-9, 2010

The assessment updated the length-based model presented in the 2009 SAFE. In response to previous SSC comments, the model now includes discard mortality and pot fishery PSC. In response to SSC comments, the author applied a handling mortality rate of 0.2. ***The CPT recommended and the SSC agrees that the assessment model output should be used as the basis for estimating biological reference points for the 2010/11 season.***

Authors' response: As directed, the recommended model configuration was used.

The author considered seven models. **The CPT recommended, and the SSC agrees, that Model 6 should be used for estimation of the 2010/11 OFL.** *While the SSC agrees with the use of Model 6 for the 2010/11 season,* ***we request that the author provides a rationale for why larger crab would have a higher natural mortality rate (M=0.288), and why this added mortality at large sizes is applied to only this population.*** *The CPT also recommended, and the SSC concurs, that this stock qualifies for Tier 4 management and that the reference natural mortality rate for estimation of the OFL should be 0.18.* ***The SSC continues to recommend that the reference time period for estimation of B_{MSY} proxy should be 1983-2009, and that gamma should be set at 1. The SSC continues to encourage the author to work on the Norton Sound red king crab assessment model with a long-term goal of moving this stock to Tier 3.***

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) (Soong et al. 2008). 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. Our 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 the summer. Norton Sound red king crab are consistently abundant offshore of Nome, and hence the coastal area is closed for summer crab fishery (Figure 2).

   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. They are assumed to mate during March-June. Offshore migration is considered to begin in May-July. Trawl surveys during 1976-2010 show that crab distribution is dynamic. Recent surveys show high abundance on the southeast side of the Sound, offshore of Stebbins and Saint Michael. However, it is unknown whether this is due to a migratory shift because of oceanographic change or due to changes in stock composition.

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) (Soong et al. 2008). The majority of red king crabs (0.3 mil lb) are harvested by the summer commercial fisheries, whereas the majority of the winter fisheries are subsistence fishery with occurring near coast (0.023 mil lb).

   <u>Summer Commercial Fishery</u>

   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 1992, the summer commercial fishery resumed. 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. Commercial fisheries history and catch data are summarized in Table 1.

CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before they make their first delivery. Fishers operate under authority of the CDQ group and each CDQ group decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations were adopted that affected the CDQ crab fishery and relaxed closed-water boundaries in eastern Norton Sound and waters west of Sledge Island. At its March 2008 meeting, 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, by emergency order.

Winter Commercial Fishery

The Norton Sound winter commercial fishery is a small fishery using hand lines and pots through the nearshore ice. Approximately 10 fishers involve in this fishery harvesting 2,400 crabs on average annually during 1978-2007 (Soong 2007). The winter commercial fishery catch is influenced not only by crab abundance, but also by changes in near shore crab distribution, and ice conditions.

Subsistence Fishery

The Norton Sound subsistence crab fishery mainly occurs during winter using hand lines and pots through the nearshore ice. Average annual subsistence harvest is 5,300 crabs (1978-2007). Subsistence fishers need to obtain a permit before fishing and record their daily effort and catch. There is no size limit in 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).

Harvest Strategy

Norton Sound red king crab have been conservatively managed since 1997 through varying harvest rates from 5% to 10% of estimated legal male abundance. 19999, the guideline harvest lever (GHL) for the summer fishery is adopted. GHL consists of three levels: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.5 million lbs; (2) ≤ 5% when the estimated legal biomass range 1.5 - 2.5 million lbs; and (3) ≤ 10% when estimated legal biomass >2.5 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. Since then, the majority of commercial fishery shifted to the 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)
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Changed the start date to the Open access fishery from July1 to after June 15 by emergency order. Pot configuration requirement: installation of a minimum of 4 escape rings (>4½ diameter) per pot located within one mesh size from 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 inch.

D. Data

1. Summary of new information:
   a. The model was updated with new data from the 2010 summer trawl survey, 2011 winter pot survey, 2010 summer commercial fishery, and 2010/2011 winter commercial and subsistence fisheries.
   b. Included abundance and length composition estimates form the 2010 Trawl survey conducted by the NOAA fisheries.

2. Available survey, catch, and tagging data.

Data Set	Years	Data Types
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10	Abundance and prop. by length and shell condition
Summer pot survey	80-82,85	Abundance and prop. by length and shell condition
Winter pot survey	81-87, 89-91,93,95-00,02-11	Proportion by length and shell condition
Summer preseason survey	95	Proportion by length and shell condition
Summer commercial fishery	76-90,92-11	Catch, effort, and prop. by length and shell condition
Observer bycatch data	87-90,92,94	Proportion by length and shell condition
Winter commercial fishery	76-11	Catch
Subsistence fishery	76-11	Catch
Tagging data	80-07	Mean and standard deviation of growth increment

a. Summer commercial fishery and winter commercial and subsistence catch, effort (potlifts) (ADF&G 1976-2010) (Table 1, 2).

b. Bycatch and discards of sublegal males (observer data) from the summer fishery (ADF&G 1987-90, 1992, 1994). In those, amounts of bycatch were not recorded. Only catch-at-length and shell condition were recorded. In Norton Sound, no other crab, ground fish, or shellfish fisheries exist.

	Fishery	Data availability
Directed pot fishery (males)	Summer commercial	Not available
Directed pot fishery (females)	Winter commercial/subsistence	Not available
Bycatch in other crab fisheries	Fishery does not exist	NA
Bycatch in ground pot	Fishery does not exist	NA
Bycatch in ground fish trawl	Fishery does not exist	NA
Bycatch in the scallop fishery	Fishery does not exist	NA

c. Catch at length data for summer commercial fisheries (Table 3).

d. Survey biomass estimates:
Triennial trawl surveys (NMFS: 1976-1991, ADF&G: 1996-2008, NMFS: 2010) (Tabe 5). Total population abundances and length and shell compositions for males >73 mm CL were estimated by "area-swept" methods from the trawl survey data (Alverson and Pereyra 1969). The compositions consisted of six 10-mm length groups. If multiple hauls were conducted for a single station (10×10 nmi, 20×20 nmi for the 2010 NOAA Fisheries survey) during a survey, then the average of abundances from all hauls within the station was used. Some trawl surveys occurred during September, the molting period for males. To make survey abundances comparable with premolt abundances, we adjusted trawl survey abundances by subtracting the average growth increment of each length class from the length of each soft-shell crab (assumed to have molted within the past 2 months).

Summer pot survey was conducted in 1980-92, 85. Survey biomass CV was not reported.

e. Survey catch-at-length data for triennial Trawl survey (Table 5) and winter pot survey (Table 6). Other survey catch-at-length data includes summer pot survey (1980-92, 85) and summer preseason survey (1995).

f. Other miscellaneous data: None.

3. Growth-per-molt (Table 7), estimated from tagging data (1991-2007).

E. Analytic Approach

1. History of the modeling approach.

The Norton Sound red king crab was assessed using a length-based synthesis model (Zheng et al. 1998). The model was updated in 2009-2010 to provide information for the federal OFL. At May 2010 CPT meeting, the 7 alternative models were presented: 1) Based on 2009 model reviewed by Andre Punt, 2) the model 1 and Include bycatch mortality, 3) the model 2 and increase weight of fishing effort increased from 5 to 20, 4) the model 3 and change fishery selectivity of the last length group from 0.6 to being estimated from the model, 5) the model 4 and reduce the maximum effective sample size for commercial catch and winter surveys from 200 to 100, 6) the model 5 and increase M of the last length group from the default 0.18 to 0.228, and 7) the model 6 but change M to 0.34. The CPT and subsequent SSC recommended using the Model 6 for the 2010/11 iteration. In this iteration, the model 6 was also used.

2. Model Description

a. Description of overall modeling approach: The model is a male only age/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. Instantaneous natural mortality *M* is 18% 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).

ii. Natural mortality for the last length group (> 123mm) is 60% higher (28.8%) than the other length groups (Zheng et al. 1998). This assumption is based not on biological data, but rather a working hypothesis attempting to explain the low proportion (< 10%) of this group in summer trawl surveys (Table 6). It is possible, that the last length group may move into inaccessible area from commercial fisheries, resulting in lower selectivity (CPT review 2010). However, this does not explain the lower proportion observed in the summer trawl fishery, where entire Norton Sound Area was surveyed. Furthermore, lowering the catch selectivity did not result in lower log likelihood than increasing the mortality (CPT 2010). Model estimated selectivity was also 1.0 for the last length class.

iii. Trawl survey catchability is 1.0 for legal males and a sigmoid function of length for the first 2 length groups. It is constant over time and shell condition. For winter survey, selectivity of the last length group is less than 1 (Table 7).

iv. Summer commercial fisheries selectivity is a sigmoid function of length peaking at the length class 5 (104-113mm). It has two curves: before 1993 and after 1992. This is due to changes in fishing vessel composition and pot limits.

v. Winter commercial and subsistence fishery selectivity and length-shell conditions are the same as those of Winter pot survey.

vi. Growth is a function of length and is constant over time.

vii. Molting probabilities are an inverse logistic function of length for males.

viii. A summer fishing season for the directed fishery is short.

ix. Bycatch handling mortality is 20%.

x. Annual retained catch is measured without error.

xi. Trawl survey catchability is 1.0 for legal males.

xii. Male crabs mature at sizes ≥94 mm CL.

xiii. Length compositions have a multinomial error structure, and abundance has a log-normal error structure.

xiv.

h. Changes since last assessment: None

i. Code validation. The base model structure was error checked by A. Punt (University of Washington, pers. communication). Model code is available from the author.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

Following the CPT and SSC's directives, no alternative model configurations were considered at this iteration.

b. NA

c. NA

d. NA

e. Sample sizes for length composition data (Table 2,3,5,6, 9).

f. Parameter estimates: Assuming M = 0.18 for all length classes resulted in an unrealistic build-up of abundance in the last length class. Setting M = 0.288 in the last length class helps reducing this bias.

g. Model selection criteria. The Likelihood values were used to evaluate model.

h. Residual analysis. Residual plots for length compositions are shown in Figures 5 and 6.

i. Model evaluation is provided under Results, below.

4. Results

1. Effective sample sizes and weighting factors.

Data	Weighting Factor
Summer Trawl Survey	200
Summer Pot Survey	200
Summer fishing effort	20
Recruitment	0.01
Maximum effective sample size for length proportion	200
Maximum effective sample size for length proportion: Summer commercial and winter pot	100

a. Effective sample sizes for length compositions are given in Tables 2, 3, 5, 6, and 9.

2. Tables of estimates.

a. Parameter estimates are provided in Table 10.

The parameters estimates were categorized as: Recruitment, catchability functions, and molting functions. Among those, CV of the Recruitment parameter ranged from 18% to 3576%, averaging 238%. For catchability function parameters, catchability of trawl survey (log_Sst) was the worst, followed by summer commercial and winter pot.

b. Abundance and biomass time series are provided in Table 10 and Figure 3.

c. Recruitment time series are in Table 10 and Figure 3.

d. Time series of catch/biomass are in Table 11.

3. Graphs of estimates.

a. Selectivities, molting probabilities, and proportions of legal crabs by length are provided in Table 8.

b. Estimated male abundances (recruits, legal, and total) are plotted in Figure 3 and 4.

c. Estimated harvest rates are shown in Figure 5 upper .

d. Harvest rates are plotted against mature male biomass in Figure 5 lower.

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. Instead, summer commercial catch efforts were modeled (Figure 6).

The modeled efforts were generally followed the actual efforts, except in 1986 and 1988 when the observed effort was higher than the model and in 1977 and 1992 when the observed effort was lower than the model.

b. Model fits to survey numbers (Figure 7).

The majority of model estimated abundance of legal and sublegal crabs was within 95% confidence interval of the survey observed abundance, except in 1979 when the model estimated legal crab abundance was higher than the observed abundance and in 1991 and 1999 when the model estimated legal crab abundance was lower than the observed abundance. For sublegal crab, model estimated abundance was generally within the observed estimates; however, the model estimates tended to be lower than the observed.

c. Model fits to catch and survey proportions by length (Figure 8).

The residuals of length compositions were generally large, especially for the largest size class (>123 mm). The model had the two fishing selectivity curves, 1977-1992 and 1993-2010. During 1977-1992 periods, the model tend to overestimates the proportion of 104-114 length class (negative residual) and underestimate the last length class (>123mm). During 1993-2010 periods, the model tend to overestimate the last and the 94-103 length classes, and thus underestimates the proportion of 104-113 and 114-123 length classes.

d. Model fits to survey proportions by length
Winter pot survey, Summer trawl survey, Summer pot survey, and summer observer survey (Figure 9).

Residual plot for winter pot survey showed that model tended to overestimate (negative residual) proportion of large length classes (>103mm), and thus underestimate the proportion of the small length classes. However, during 1991-1995 periods, the pattern was opposite.

Plots of summer trawl, pot, and observer data did not seem show noticeable patterns. Similar to the winter pot survey, the model tend to overestimate proportion of large length classes. This tendency was the most prominent during the last 3 trawl surveys.

e. Marginal distribution for the fits to the composition data: Not provided
f. Plots of implied versus input effective sample sizes and time-series of implied effective sample sizes: Not provided
g. Tables of RMSEs for the indices: Not provided
h. QQ plots and histograms of residuals: not provided.

5. Retrospective and historic analyses.

a. Retrospective analysis (Figure 10).

The retrospective plots of 2000-2011 show that the model's tendency to overestimate the Norton Sound red king crab abundance. Abundance estimates of all the retrospective models converged for estimation 1976-1983, which seems to suggest that abundance estimates of a particular year become stable after more than 17 years of subsequent data are collected.

b. Historic analysis (Figure 11).

We compared the performance of current model with that of old models used in the past by creating retrospective predicted abundance estimate of legal crab with that of historical predicted estimates. If current model is superior to the old models, then the retrospective predicted estimates should be closer to the actual legal crab abundance or the legal abundance estimated by the 2011 model. Comparing the performance of the current model with historical during 2000-2010 periods, historical predicted estimates (old model) were closer to actual or 2011 model estimated historical abundance, than the retrospective predicted estimate using the current model. On average (2000-2008), historical predicted estimates were 37% higher than actual/estimated historical estimates, whereas retrospective predicted estimates were 61% higher.

6. Uncertainty and sensitivity analyses.

As described in the above retrospective and historic analyses, the major deficiency of the current model is that the model predicted abundance is the most likely biased high (~ 60%) (Figure 11). This issue has been present since inception of the model in 1999. The residual analyses have been showing that this overestimation is more likely to be due to the model overestimating the proportion of large length groups (i.e., negative residuals) in summer surveys and fisheries and in winter Pot surveys (Figure 8, 9). High model estimates of large length group would result in high abundance; however, trawl survey did not show high abundance as predicted by the model.

Throughout the iteration, many attempts have been made to correct this bias, including model revisions, updates of growth matrix, inclusion of bycatch mortality, changing model weights, evaluation of *M* (CPT 2010). Despite those efforts, the overestimation issue remained. Followings discuss the past attempts.

a. Evaluation of selectivity

The discrepancy can be due to misconfiguration of the selectivity, in which the assumption of constant selectivity for large class may be incorrect. Since the selectivity function applied in this model is a sigmoid form, selectivity of the large length group is 1.0. In the 2010 CPT review, attempts were made to make the selectivity into dorm shape (model 4); however, this did not improve the likelihood and thus abandoned. Exception was the selectivity of the Winter pot

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survey, which showed that selectivity of the last length class was 0.39. For the summer trawl survey was assumed to be 1.0 for legal sizes, and that of small size classes (1 and 2) were estimated from the model. However, estimates of selectivity parameters (log_S_{st1}, log_S_{st2}) had high standard deviation and resulting selectivity equal to 1.0. Attempts to extend selectivity model to all size class selectivity also resulted in 1.0.

b. Weighting factors

Changing weighting factors and effective sample size affect reliability of data. Among the data, summer fishery data were more reliable, and thus given heavier weight. On the other hand, the maximum effective sample size for commercial catch and winter surveys was reduced because of the uncertainties about representativeness of the data, especially for the large length size. It has been often suspected that the length proportion of the winter pot survey is biased because the survey pots were located only near Nome area where majority of subsistence fisheries occur. While there is no size limits in subsistence fisheries, the majority fishermen would retain only large (e.g., legal size) crabs, which may resulted in under representation of large length groups in the winter pot survey. However, comparison of the size frequencies between Winter pot survey and subsequent trawl survey suggests that the bias may not be strong (Figure 12). For summer commercial length proportion data, because of market changes, not all legal crabs were retained (Soong ADF&G personal comm.). Proportion of sub-marketable legal crab discarded is unknown; however, this would affect length class of 104-113mm. Reducing the effective sample size improved model fitting (CPT 2010). Zheng et al. (1998) examined sensitivity of weighting factors and concluded that estimates of parameters and legal crab abundance were not very sensitive to weighting factors for survey abundances and fishing effort, and maximum effective sample size. Those conclusions may not apply to the current model. Zheng et al. (1998) assumed M = 0.3.

c. Uncertainties in the survey abundance

In the model, trawl survey abundance data are weighted highly, and measurement errors from a single trawl survey could also affect the model results greatly. However, the abundance survey is conducted every 3 or 4 years, and the survey coverage varies (Table 3). It is difficult to determine whether the large projection errors were due to sampling errors in winter pot surveys or measurement errors in summer trawl surveys.

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) because it is not possible to estimated the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that capture the essential population dynamics. Explicit to Tier 4 stock are reliable estimates of current survey biomass and the instantaneous M. However, the Norton Sound red king crab stock does have neither. Estimate of survey biomass is based on triennial trawl survey with CV ranging 15-42% (Table 4). The Natural mortality of 18% adopted by the CPT

(2010) is based on the 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 the 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:

$$F_{OFL} = \gamma M, \quad when\ B/B_{MSY^{prox}} > 1, \qquad (a)$$

$$F_{OFL} = \gamma M\,(B/B_{MSY^{prox}} - 0.1)/0.9, \quad when\ \ 0.25 < B/B_{MSY^{prox}} \le 1, \qquad (b)$$

$$F_{OFL} = bycatch\,mortality\,\&\,directed\ fishery\ F = 0, \quad when\ B/B_{MSY^{prox}} \le 0.25, \qquad (c)$$

$$OFL = (1 - \exp(-F_{OFL}))B$$

Where B is a mature male biomass, B_{MSY} proxy is average mature male biomass over a specified time period. $M = 0.18$ and $\gamma = 1$.

For the Norton Sound red king crab, MMB is CL > 94mm and legal size is CL > 103 mm.

$$OFL = \sum_l \left[(N_{s,l} + O_{s,l})\, legal_l\, w_l\, (1 - \exp(-F_{OFL})) \right]$$

where $N_{s,l}$ and $O_{s,l}$ are summer abundances of newshell and oldshell crabs in length class l in the terminal year, $legal_l$ is the proportion of legal males in length class l, and w_l is the weight in length class l.

For the selection of the B_{MSY} proxy, we chose period between 1983 to present because the year classes after the 1976/77 regime shift (Overland et al. 1999) were expected to reach the mature population after 1982. This resulted in B_{MSY} of (2.940 MMB). Although the CPT and SSC agreed our choice of the period in 2010, it should be noted the choice of the period is essentially arbitrary. We examined alternative periods; however, because the current population has been showing increasing trend since 1997, the condition of B/B_{MSY} >1 is met at any choices of periods.

Estimated legal male abundance and mature male biomass in 2011 are:

Legal males: 1.471 million crabs with a standard deviation of 0.199 million crabs.

Mature male biomass: 4.699 million lbs with a standard deviation of 0.644 million lbs.

Average of model estimated mature male biomasses during 1983-2011 was used as the B_{MSY} proxy. Using the formula (a) for calculation of the OFL

Estimated B_{MSY} proxy, F_{OFL} and retained catch limit in 2011 are:

B_{MSY} proxy = 2.940 million lbs,

$F_{OFL} = 0.18$,

The model predicted legal male abundance in 2011 is 1.471 million crabs or 3.976 million lbs. Hence, the overfishing limits for retained catch in 2011 are F_{OFL} = 0.18 (γ=1.0), 0.242 million crabs (1.471×(1-exp(-0.18)) or 0.655 million lbs (3.976×(1-exp(-0.18)). Directly calculating OFL ADMB –mcmc showed the probability profile, the P* = 50% legal male abundance in 2011 is 1.512 million crabs or 4.096 million lbs, and the OFL was 0.675 million lbs.

Thus, we determined 2011

OFL = 0.675 million lbs.

Based on the above, current summer commercial GHL is set to ≤ 10% of the legal crab biomass or up to 0.41 million lbs in 2011.

G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

We calculated density using ADMB likelihood profile and –mcmc option (Figure 10). At this time of writing, no clear directives of determining ABC is established for the Tier 4 stock. P* = 0.49 is suggested.

Using the P*= 0.49 for the probability density of the OFL derived from –mcmc probability density profile, ABC was estimated as:

ABC = 0.671 million lbs

History of catch and estimated harvest rates (Figure 5) shows that the estimated harvest rate since GHL has established (1998-2010) ranged 10.4 to 17.2% exceeding the maximum GHL harvest rates of 10%. This occurred not because harvests exceeded the GHL, but primarily because the model projected abundance at the time of setting GHL was higher than the "actual" abundance (Figure 10, 11). Considering this model overestimation problem persisting, the "actual" OFL and ABC would probably be found lower in later years.

Despite this, the model indicates that stock is increasing since 1996. Higher harvest rates may drive the stock abundance to decline. One may argue that heavy fishing during 1979-1981 might have driven the stock abundance to be too low. However, red king crabs take several years from spawning to recruiting to the mature stock; it will take 6 or 7 years of heavy fishing to cover this time lag. Poor recruitment was estimated for Norton Sound red king crab even before the fishing started. Even without fishing, estimated number of recruits would not be able to sustain the high abundance during the late 1970s. These high abundances were the result of exceptionally strong recruitments, which were also observed for other king crab stocks in the eastern Bering Sea (Zheng and Kruse 2000, 2006).

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

The major data gaps of the Norton Sound red king crab are: estimate of abundance, estimate of bycatch from the summer commercial fisheries, and estimate of the instantaneous Natural mortality, M. Estimates of the Norton Sound red king crab abundance is based on triennial trawl survey. Due to weather conditions and availability of survey vessel, survey coverage was inconsistent, with inconsistent survey coverage and CV of 14-40%. Historical tendency of the prediction model overestimating projected abundance, is probably due to biased size composition in the Winter pot survey. Better winter size composition estimates are needed. Bycatch data from commercial fishery is absent.

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Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2010.

	Guideline Harvest Level	Commercial Harvest (lbs) [a, b]		Total Number (incl. CDQ)			Total Pots		Total Exvessel	Total Fishery Value	Season Length	
Year	**(lbs) [b]**	**Open Access**	**CDQ**	**Vessels**	**Permits**	**Landings**	**Registered**	**Pulls**	**Price/lb**	**(millions $)**	**Days**	**Dates**
1977	[c]	0.52		7	7	13		5,457	0.75	0.229	60	[c]
1978	3.00	2.09		8	8	54		10,817	0.95	1.897	60	6/07-8/15
1979	3.00	2.93		34	34	76		34,773	0.75	1.878	16	7/15-7/31
1980	1.00	1.19		9	9	50		11,199	0.75	0.890	16	7/15-7/31
1981	2.50	1.38		36	36	108		33,745	0.85	1.172	38	7/15-8/22
1982	0.50	0.23		11	11	33		11,230	2.00	0.405	23	8/09-9/01
1983	0.30	0.37		23	23	26	3,583	11,195	1.50	0.537	3.8	8/01-8/05
1984	0.40	0.39		8	8	21	1,245	9,706	1.02	0.395	13.6	8/01-8/15
1985	0.45	0.43		6	6	72	1,116	13,209	1.00	0.427	21.7	8/01-8/23
1986	0.42	0.48		3	3		578	4,284	1.25	0.600	13	8/01-8/25
1987	0.40	0.33		9	9		1,430	10,258	1.50	0.491	11	8/01-8/12
1988	0.20	0.24		2	2		360	2,350	[c]	[c]	9.9	8/01-8/11
1989	0.20	0.25		10	10		2,555	5,149	3.00	0.739	3	8/01-8/04
1990	0.20	0.19		4	4		1,388	3,172	[c]	[c]	4	8/01-8/05
1991	0.34			No Summer Fishery								
1992	0.34	0.07		27	27		2,635	5,746	1.75	0.130	2	8/01-8/03
1993	0.34	0.33		14	20	208	560	7,063	1.28	0.430	52	7/01-8/28
1994	0.34	0.32		34	52	407	1,360	11,729	2.02	0.646	31	7/01-7/31
1995	0.34	0.32		48	81	665	1,900	18,782	2.87	0.926	67	7/01-9/05
1996	0.34	0.22		41	50	264	1,640	10,453	2.29	0.519	57	7/01-9/03
1997	0.08	0.09		13	15	100	520	2,982	1.98	0.184	44	7/01-8/13
1998	0.08	0.03	0.00	8	11	50	360	1,639	1.47	0.041	65	7/01-9/03
1999	0.08	0.02	0.00	10	9	53	360	1,630	3.08	0.073	66	7/01-9/04
2000	0.33	0.29	0.01	15	22	201	560	6,345	2.32	0.715	91	7/01- 9/29
2001	0.30	0.28	0.00	30	37	319	1,200	11,918	2.34	0.674	97	7/01- 9/09
2002	0.24	0.24	0.01	32	49	201	1,120	6,491	2.81	0.729	77	6/15-9/03
2003	0.25	0.25	0.01	25	43	236	960	8,494	3.09	0.823	68	6/15-8/24
2004	0.35	0.31	0.03	26	39	227	1,120	8,066	3.12	1.063	51	6/15-8/08
2005	0.37	0.37	0.03	31	42	255	1,320	8,867	3.14	1.264	73	6/15-8/27
2006	0.45	0.42	0.03	28	40	249	1,120	8,867	2.26	1.021	68	6/15-8/22
2007	0.32	0.29	0.02	38	30	251	1,200	9,118	2.49	0.750	52	6/15-8/17
2008	0.41	0.36	0.03	23	30	248	920	8,721	3.20	1.231	73	6/23-9/03
2009	0.38	0.37	0.03	22	27	359	920	11,934	3.17	1.225	98	6/15-9/20
2010	0.40	0.39	0.03	23	32	286	1,040	9,698	3.73	1.528	58	6/28-8/24

[a] Deadloss included in total. [b] Millions of pounds. [c] Information not available.

Table 2. Historical winter commercial and subsistence red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2010.

	Commercial			Subsistence					
				Permits			Total Crab		Average
Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Issued	Returned	Fished	Caught[c]	Retained[d]	Permit Fished
1978	37	9,625	1977/78	290	206	149	[e]	12,506	84
1979	1[f]	221[f]	1978/79	48	43	38	[e]	224	6
1980	1[f]	22[f]	1979/80	22	14	9	[e]	213	24
1981	0	0	1980/81	51	39	23	[e]	360	16
1982	1[f]	17[f]	1981/82	101	76	54	[e]	1,288	24
1983	5	549	1982/83	172	106	85	[e]	10,432	123
1984	8	856	1983/84	222	183	143	15,923	11,220	78
1985	9	1,168	1984/85	203	166	132	10,757	8,377	63
1985/86	5	2,168	1985/86	136	133	107	10,751	7,052	66
1986/87	7	1,040	1986/87	138	134	98	7,406	5,772	59
1987/88	10	425	1987/88	71	58	40	3,573	2,724	68
1988/89	5	403	1988/89	139	115	94	7,945	6,126	65
1989/90	13	3,626	1989/90	136	118	107	16,635	12,152	114
1990/91	11	3,800	1990/91	119	104	79	9,295	7,366	93
1991/92	13	7,478	1991/92	158	105	105	15,051	11,736	112
1992/93	8	1,788	1992/93	88	79	37	1,193	1,097	30
1993/94	25	5,753	1993/94	118	95	71	4,894	4,113	58
1994/95	42	7,538	1994/95	166	131	97	7,777	5,426	56
1995/96	9	1,778	1995/96	84	44	35	2,936	1,679	48
1996/97	2[f]	83[f]	1996/97	38	22	13	1,617	745	57
1997/98	5	984	1997/98	94	73	64	20,327	8,622	135
1998/99	5	2,714	1998/99	95	80	71	10,651	7,533	106
1999/2000	10	3,045	1999/2000	98	64	52	9,816	5,723	107
2000/01	3	1,098	2000/01	50	27	12	366	256	21
2001/02	11	2,591	2001/02	114	61	45	5,119	2,177	48
2002/03	13	6,853	2002/03	107	70	61	9,052	4,140	68
2003/04[g]	2	522	2003/04[g]	96	77	41	1,775	1,181	29
2004/05	4	2,091	2004/05	170	98	58	6,484	3,973	112
2005/06	1[f]	75[f]	2005/06	98	97	67	2,083	1,239	18
2006/07	8	3,313	2006/07	129	127	116	21,444	10,690	92
2007/08	9	5,796	2007/08	139	137	108	18,621	9,485	88
2008/09	7	4,951	2008/09	105	105	70	6,971	4,752	68
2009/10		4,834	2009/10					7,044	
2010/11		4,834[i]	2010/11					8,288[i]	

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.
e Information not available.
f Confidential under AS 16.05.815.
g 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.
i Preliminary

Table 3. Summer commercial catch size/shell composition.

					New Shell					Old Shell					
Year	Sample	Model	Eff. N	Model	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1977	1549	100	25	100	0	0.0032	0.4196	0.3422	0.122	0	0	0	0.0626	0.04	0.0103
1978	389	39	157	39	0	0.0103	0.1851	0.473	0.3059	0	0	0	0.0051	0.0103	0.0103
1979	1660	100	43	100	0	0.0253	0.2325	0.3831	0.3217	0	0	0	0.0253	0.0006	0.0114
1980	1068	100	34	100	0	0.0037	0.0983	0.3062	0.5543	0	0	0	0.0028	0.0112	0.0234
1981	1748	100	11	100	0	0.0039	0.0734	0.1541	0.509	0	0	0	0.0045	0.0504	0.2046
1982	1093	100	20	100	0	0.0421	0.1921	0.1647	0.505	0	0	0.0037	0.0128	0.022	0.0576
1983	802	80	28	80	0	0.0387	0.4127	0.3579	0.0973	0	0	0.0037	0.0362	0.01	0.0436
1984	963	96	28	96	0	0.0966	0.4195	0.2804	0.0717	0	0	0.0104	0.0654	0.0488	0.0073
1985	2691	100	57	100	0.0004	0.0643	0.3122	0.3716	0.1747	0	0	0.0026	0.0334	0.0312	0.0097
1986	1138	100	70	100	0	0.029	0.3559	0.3937	0.1353	0	0	0.0018	0.0202	0.0378	0.0264
1987	1542	100	11	100	0	0.0166	0.1788	0.2912	0.3798	0	0	0.0025	0.0267	0.065	0.0393
1988	1522	100	252	100	0	0.0237	0.2004	0.3003	0.2181	0	0	0.0059	0.0644	0.0972	0.0894
1989	2595	100	96	100	0	0.0127	0.1643	0.3185	0.2148	0	0	0.0042	0.0555	0.1215	0.1084
1990	1289	100	53	100	0	0.0147	0.1435	0.3468	0.3251	0	0	0.0008	0.0372	0.0737	0.0582
1991															
1992	2566	100	62	100	0	0.0172	0.201	0.2662	0.2244	0	0	0.0027	0.0792	0.1292	0.08
1993	1813	100	31	100	0	0.0142	0.2312	0.3939	0.263	0	0	0.0004	0.0173	0.0437	0.0362
1994	404	40	78	40	0	0.0248	0.0941	0.0817	0.0891	0	0	0.0248	0.1881	0.25	0.2475
1995	1174	100	34	100	0	0.0392	0.2615	0.2853	0.207	0	0	0.0077	0.0486	0.0741	0.0767
1996	787	79	26	79	0	0.0318	0.2236	0.2389	0.141	0	0	0.014	0.1194	0.136	0.0953
1997	1198	100	14	100	0	0.0292	0.3656	0.3414	0.1244	0	0	0.0033	0.0559	0.0417	0.0384
1998	1055	100	71	100	0	0.0284	0.2332	0.2427	0.1071	0	0	0.0218	0.1118	0.1431	0.1118
1999	561	38	11	38	0	0.0026	0.2434	0.2698	0.3836	0	0	0	0	0.0423	0.0582
2000	17213	100	49	100	0	0.0194	0.2991	0.3917	0.1249	0	0	0.0028	0.0531	0.0654	0.0436
2001	20030	100	645	100	0	0.0243	0.2232	0.3691	0.2781	0	0	0.0008	0.0241	0.0497	0.0304
2002	5198	100	180	100	0	0.0442	0.2341	0.2814	0.3253	0	0	0.0046	0.0282	0.0419	0.0402
2003	5220	100	110	100	0	0.0232	0.368	0.3197	0.1523	0	0	0.0011	0.0218	0.0465	0.0674
2004	9605	100	46	100	0	0.0087	0.3811	0.388	0.1395	0	0	0.0004	0.0255	0.0347	0.0221
2005	5360	100	30	100	0	0.0022	0.2539	0.4709	0.1823	0	0	0	0.0205	0.0451	0.025
2006	6707	100	54	100	0	0.0021	0.1822	0.3484	0.199	0	0	0.0003	0.0498	0.1375	0.0807
2007	6125	100	48	100	0	0.0111	0.3574	0.3407	0.1714	0	0	0.0008	0.0247	0.0573	0.0366
2008	5766	100	22	100	0	0.0047	0.3512	0.3476	0.0668	0	0	0.0014	0.0895	0.0928	0.0461
2009	6026	100	58	100	0	0.0105	0.3445	0.3294	0.1339	0	0	0.0012	0.0768	0.0795	0.0242
2010	5902	100	46	100	0	0.0053	0.3855	0.3617	0.1095	0	0	0.0019	0.0546	0.0546	0.0271

Table 4. 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).

Year	Dates	Survey Agency	Survey method	Survey coverage		Abundance (1000s)	
				Number of Survey stations	n mile^2 covered	>73 mm Males	CV
1976	9/02 - 9/05	NMFS	Trawl	70	6957	4580.637	0.201
1979	7/26 - 8/05	NMFS	Trawl	47	4621	757.550	0.316
1980	7/04 - 7/14	ADF&G	Pots			2082.986	N/A
1981	6/28 - 7/14	ADF&G	Pots			2427.557	N/A
1982	7/06 - 7/20	ADF&G	Pots			1020.387	N/A
1982	9/05 - 9/11	NMFS	Trawl	58	5721	2096.418	0.256
1985	7/01 - 7/14	ADF&G	Pots			2291.085	N/A
1985	9/16 -10/01	NMFS	Trawl	78	7388	2553.083	0.263
1988	8/16 - 8/30	NMFS	Trawl	78	7421	2335.195	0.298
1991	8/22 - 8/30	NMFS	Trawl	71	7083	2207.410	0.350
1996	8/07 - 8/18	ADF&G	Trawl	28	2800	1271.023	0.230
1999	7/28 - 8/07	ADF&G	Trawl	30	3000	2276.095	0.142
2002	7/27 - 8/06	ADF&G	Trawl	31	3100	1747.581	0.265
2006	7/25 - 8/08	ADF&G	Trawl	51	5083	2611.617	0.208
2008	7/24 - 8/11	ADF&G	Trawl	61	6630	2712.776	0.202
2010[*]	7/27 - 8/09	NMFS	Trawl	35	13749	2041.020	0.424

[*]: 20×20 n mile^2 grid survey

Table 5. Summer Trawl Survey size composition.

Year	Sample	Model	Eff N	New Shell						Old Shell					
				74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1976	1311	200		0.0214	0.1053	0.1915	0.3455	0.1831	0.029	0.0046	0.0114	0.0252	0.032	0.0366	0.0145
1979	133	66.5	35	0.015	0.0075	0.0301	0.0752	0.0827	0.0602	0	0.0075	0.0301	0.1203	0.3835	0.188
1982	256	128	25	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	155.5	117	0.119	0.2122	0.1865	0.1768	0.0643	0.0193	0	0	0.0193	0.0514	0.0868	0.0643
1988	306	153	33	0.2255	0.1405	0.1536	0.1275	0.0686	0.0392	0	0.0065	0.0131	0.0392	0.0882	0.098
1991	250	125	38	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	98	57	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	137	135	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	115	83	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	104	95	0.3235	0.2614	0.1405	0.0752	0.0458	0.0294	0	0	0.0196	0.0458	0.0458	0.0131
2008	242	121	76	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	68	51	0.1202	0.1366	0.2077	0.1257	0.1093	0.0437	0.0109	0.0328	0.082	0.071	0.0383	0.0219

Table 6. Winter pot survey length composition.

				New Shell						Old Shell					
Year	Sample	Model	Eff N	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	24	130	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	100	115	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	100	418	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	77	38	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	57	59	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	14	68	0.0556	0.1597	0.1944	0.0694	0.0417	0	0	0	0.0417	0.2986	0.1111	0.0278
1987/88								No winter pot survey							
1988/89	492	49	282	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	100	84	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	100	105	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	18	13	0.0055	0.0331	0.0552	0.1271	0.116	0.0276	0	0	0.0166	0.1934	0.2707	0.1547
1993/94								No winter pot survey							
1994/95	850	85	24	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	78	325	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	100	69	0.2297	0.2351	0.1189	0.1568	0.1216	0.0676	0	0	0	0.0189	0.027	0.0243
1997/98	399	40	22	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	88	59	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	100	215	0.0885	0.1062	0.1646	0.3345	0.1788	0.0372	0	0	0.0018	0.0513	0.023	0.0142
2000/01								No winter pot survey							
2001/02	832	83	22	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	83	146	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	29	73	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	41	110	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	51	63	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	16	51	0.1486	0.2095	0.3784	0.1419	0.0473	0	0	0	0.0068	0.0203	0.0405	0
2007/08	3482	100	91	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	53	96	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	58	202	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	56	115	0.0786	0.1368	0.2103	0.1744	0.1333	0.0513	0	0.012	0.0325	0.1128	0.0462	0.012

Table 7. Estimated selectivities, molting probabilities, and proportions of legal crabs by length (mm CL) class for Norton Sound male red king crab.

Length Class	Proportion of Legal	Selectivity					Molting Probability
		Summer Trawl	Summer Pot Survv	Winter Pot Survv	Summer Fishery		
					77-92	93-09	
74 - 83	0.00	1.00	0.80	0.65	0.30	0.13	1.00
84 - 93	0.00	1.00	0.88	1.00	0.41	0.22	0.82
94 - 103	0.15	1.00*	1.00*	1.00*	0.55	0.41	0.66
104 - 113	0.92	1.00*	1.00*	1.00*	0.74	0.67	0.53
114 - 123	1.00	1.00*	1.00*	1.00*	1.00*	1.00*	0.41
124+	1.00	1.00*	1.00*	0.39	1.00	1.00	0.32

*: Assumed to be 1.0

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Table 8. Growth matrix (proportion of crabs molting from a given premolt carapace length range into postmolt length ranges) for Norton Sound male red king crab. Length is measured as mm CL. Results are derived from mark-recapture data from 1991 to 2007.

Pre-molt		Post-molt Length Class					
Length Class	Mean weight (lb)	74-83	84-93	94-103	104-113	114-123	124+
74-83	0.854	0	0.33	0.67	0	0	0
84-93	1.210	0	0	0.56	0.44	0	0
94-103	1.652	0	0	0	0.76	0.24	0
104-113	2.187	0	0	0	0.18	0.61	0.21
114-123	2.825	0	0	0	0	0.33	0.67
124+	3.697	0	0	0	0	0	1.00

Table 9. Sample sizes for length compositions in the summer pot survey.

Year	Observed	Model	Effective N
1980	3619	200	32
1981	4588	200	52
1982	6354	200	343
1985	9900	200	80

Table 10. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab. Total number of free parameters: 51.

Parameter	Value	Std	Parameter	Value	Std
Log_N_{76}	8.7206	0.0204	Log_R_{01}	0.9583	0.2893
Log_mean	5.6240	0.2474	Log_R_{02}	1.0371	0.2751
Log_R_{77}	-3.4071	3.2374	Log_R_{03}	0.4663	0.3488
Log_R_{78}	-3.4422	3.0373	Log_R_{04}	-1.1208	0.9987
Log_R_{79}	-1.7157	0.6418	Log_R_{05}	0.5566	0.3263
Log_R_{80}	-0.6860	0.3383	Log_R_{06}	1.3648	0.2751
Log_R_{81}	1.2753	0.2644	Log_R_{07}	0.8164	0.3534
Log_R_{82}	0.6183	0.2832	Log_R_{08}	1.5052	0.2760
Log_R_{83}	0.8752	0.2944	Log_R_{09}	0.6533	0.4270
Log_R_{84}	1.0452	0.2721	Log_R_{10}	0.5697	0.3898
Log_R_{85}	0.6439	0.2758	log_q_1	-10.8560	0.0677
Log_R_{86}	-0.0442	0.3498	log_q_2	-10.9410	0.1036
Log_R_{87}	0.2205	0.2853	r1	0.5901	0.0219
Log_R_{88}	-0.0183	0.2829	log_α	-3.5647	0.3781
Log_R_{89}	0.3653	0.2802	log_β	3.9625	1.4105
Log_R_{90}	-0.0082	0.2932	log_Sst_1	-1.3954	135.2700
Log_R_{91}	-0.8723	0.3479	log_Sst_2	1.8486	999.5400
Log_R_{92}	0.2298	0.3596	log_Ssp_1	-2.7799	1.6095
Log_R_{93}	-0.7765	0.7009	log_Ssp_2	4.0327	0.7207
Log_R_{94}	-0.0801	0.3484	log_Sw_1	0.1098	0.2805
Log_R_{95}	-0.4781	0.3543	log_Sw_2	4.3560	0.0038
Log_R_{96}	0.2334	0.2819	Sw_6	0.3866	0.0450
Log_R_{97}	0.7508	0.2968	log_ϕ□	-3.5035	0.1466
Log_R_{98}	0.9294	0.2708	log_ω□	6.6126	270.0200
Log_R_{99}	-2.0872	0.6052	log_ϕ_2	-2.7150	0.3012
Log_R_{00}	-0.3781	0.4078	log_ω_2	4.7885	0.1373

Data Component	Neg.Likelihood
Trawl immat. Indices	18.260
Trawl mat. indices	0.093
Pot immat. Indices	1.661
Pot mat. Indices	3.491
Total effort	5.448
Trawl length compos.	2313.58
Pot length compos.	1283.06
Winter length compos.	2716.38
Summer length compos	3546.70
Observed length comp.	531.865
Recruitment deviation	0.482945
Total	10511.5

Table 11. Annual abundance estimates (million crabs) and mature male biomass (MMB, million lbs) for Norton Sound red king crab estimated by length-based analysis from 1976-2011.

				Legal (> 103 mm)				MMB	
Year	Recruitment	Total (> 73 mm)	Matures (> 93 mm)	Abundance	St. Dev.	Biomass	St. Dev.	Biomass	St. Dev.
1976		6.030	5.254	3.940	0.080	9.772	0.199	12.041	0.246
1977	0.009	5.000	4.857	4.117	0.075	11.032	0.196	12.335	0.227
1978	0.009	3.916	3.886	3.579	0.068	10.242	0.188	10.798	0.201
1979	0.050	2.672	2.620	2.505	0.058	7.535	0.167	7.752	0.173
1980	0.139	1.478	1.338	1.280	0.048	3.972	0.145	4.077	0.148
1981	0.992	1.831	0.881	0.804	0.039	2.537	0.122	2.670	0.127
1982	0.514	1.635	0.954	0.544	0.038	1.508	0.113	2.194	0.148
1983	0.664	1.892	1.138	0.740	0.047	1.923	0.126	2.599	0.172
1984	0.788	2.159	1.271	0.842	0.052	2.168	0.138	2.895	0.177
1985	0.527	2.136	1.461	0.965	0.057	2.478	0.149	3.318	0.190
1986	0.265	1.867	1.484	1.058	0.063	2.753	0.166	3.481	0.208
1987	0.345	1.706	1.311	1.024	0.065	2.744	0.176	3.238	0.202
1988	0.272	1.560	1.225	0.969	0.063	2.675	0.175	3.114	0.198
1989	0.399	1.575	1.136	0.917	0.061	2.583	0.172	2.959	0.195
1990	0.275	1.460	1.112	0.863	0.060	2.444	0.170	2.869	0.196
1991	0.116	1.239	1.060	0.839	0.060	2.384	0.169	2.762	0.193
1992	0.349	1.314	0.956	0.813	0.058	2.357	0.165	2.605	0.182
1993	0.127	1.164	0.968	0.770	0.053	2.247	0.154	2.584	0.178
1994	0.256	1.076	0.801	0.660	0.050	1.916	0.146	2.157	0.159
1995	0.172	0.932	0.714	0.557	0.046	1.603	0.135	1.871	0.154
1996	0.350	0.992	0.623	0.485	0.046	1.374	0.132	1.610	0.150
1997	0.587	1.292	0.669	0.472	0.047	1.302	0.134	1.635	0.162
1998	0.702	1.679	0.894	0.574	0.053	1.524	0.146	2.064	0.193
1999	0.034	1.401	1.203	0.777	0.064	2.019	0.172	2.739	0.216
2000	0.190	1.314	1.106	0.893	0.069	2.401	0.188	2.770	0.214
2001	0.722	1.650	0.936	0.779	0.066	2.178	0.186	2.450	0.208
2002	0.781	1.993	1.111	0.761	0.066	2.095	0.187	2.685	0.230
2003	0.442	1.966	1.371	0.898	0.078	2.378	0.211	3.176	0.269
2004	0.090	1.621	1.417	1.026	0.087	2.715	0.236	3.383	0.283
2005	0.483	1.671	1.186	0.981	0.086	2.682	0.241	3.040	0.269
2006	1.084	2.258	1.146	0.876	0.083	2.435	0.236	2.896	0.273
2007	0.627	2.298	1.476	0.931	0.093	2.476	0.255	3.393	0.333
2008	1.248	2.942	1.618	1.116	0.113	2.918	0.303	3.772	0.387
2009	0.532	2.791	2.013	1.305	0.142	3.375	0.373	4.573	0.496
2010	0.490	2.621	2.013	1.477	0.176	3.875	0.462	4.793	0.583
2011		2.755	1.892	1.471	0.200	3.976	0.536	4.699	0.644

Table 12. Summary of catch and bycatch (million lbs) for Norton Sound red king crab. The bycatch is estimated from the model. Summer commercial catches are from ADF&G fish ticket database during 1985-2009 and from Soong et al. (2008) during 1977 to 1984. Winter commercial and subsistence catches are from ADF&G permit reporting and average weight of 2.5 lbs for the winter commercial catch and 2.0 lbs for the subsistence catch were assumed to estimate total weight.

Year	*Summer*	*Winter*	*Subsistence*	*Bycatch*	*Total*	*Catch/MMB*
1977	0.5200	0.0241	0.0250	0.0080	0.5775	0.05
1978	2.0900	NA	0.0004	0.0132	2.1041	0.19
1979	2.9300	NA	0.0004	0.0122	2.9425	0.38
1980	1.1900	0.0000	0.0007	0.0060	1.1966	0.29
1981	1.3800	NA	0.0026	0.0389	1.4219	0.52
1982	0.2300	0.0014	0.0209	0.0153	0.2674	0.12
1983	0.3700	0.0021	0.0224	0.0239	0.4182	0.16
1984	0.3900	0.0029	0.0168	0.0248	0.4342	0.15
1985	0.4270	0.0054	0.0141	0.0225	0.4686	0.14
1986	0.4795	0.0026	0.0115	0.0175	0.5108	0.14
1987	0.3271	0.0011	0.0054	0.0088	0.3424	0.10
1988	0.2367	0.0010	0.0123	0.0060	0.2561	0.08
1989	0.2465	0.0091	0.0243	0.0066	0.2865	0.09
1990	0.1928	0.0095	0.0147	0.0052	0.2222	0.08
1991	Closed	0.0187	0.0235	0.0000	0.0422	0.01
1992	0.0740	0.0045	0.0022	0.0011	0.0820	0.03
1993	0.3358	0.0144	0.0082	0.0057	0.3645	0.13
1994	0.3289	0.0188	0.0109	0.0053	0.3645	0.16
1995	0.3227	0.0044	0.0034	0.0062	0.3374	0.16
1996	0.2235	NA	0.0015	0.0054	0.2302	0.12
1997	0.0930	0.0025	0.0172	0.0037	0.1161	0.07
1998	0.0297	0.0068	0.0151	0.0014	0.0531	0.02
1999	0.0235	0.0076	0.0114	0.0008	0.0433	0.01
2000	0.3125	0.0027	0.0005	0.0053	0.3210	0.11
2001	0.2877	0.0065	0.0073	0.0065	0.3080	0.12
2002	0.2596	0.0171	0.0083	0.0097	0.2951	0.10
2003	0.2672	0.0013	0.0024	0.0098	0.2811	0.08
2004	0.3407	0.0053	0.0079	0.0081	0.3620	0.10
2005	0.4011	NA	0.0025	0.0072	0.4111	0.13
2006	0.4517	0.0083	0.0214	0.0142	0.4966	0.16
2007	0.3129	0.0145	0.0190	0.0134	0.3607	0.10
2008	0.3951	0.0124	0.0095	0.0161	0.4346	0.10
2009	0.3976	0.0121	0.0141	0.0151	0.4329	0.08
2010	0.4173	0.0121	0.0166	0.0108	0.4568	0.10

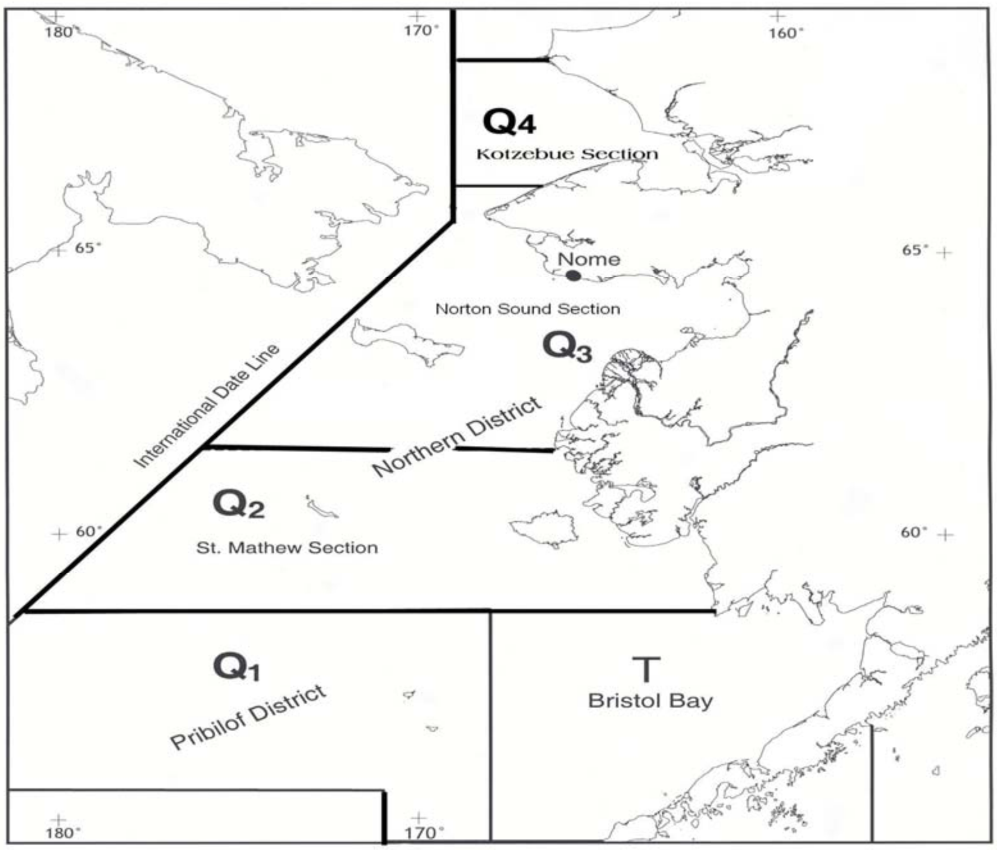


Figure 1. King crab fishing districts and sections of Statistical Area Q.

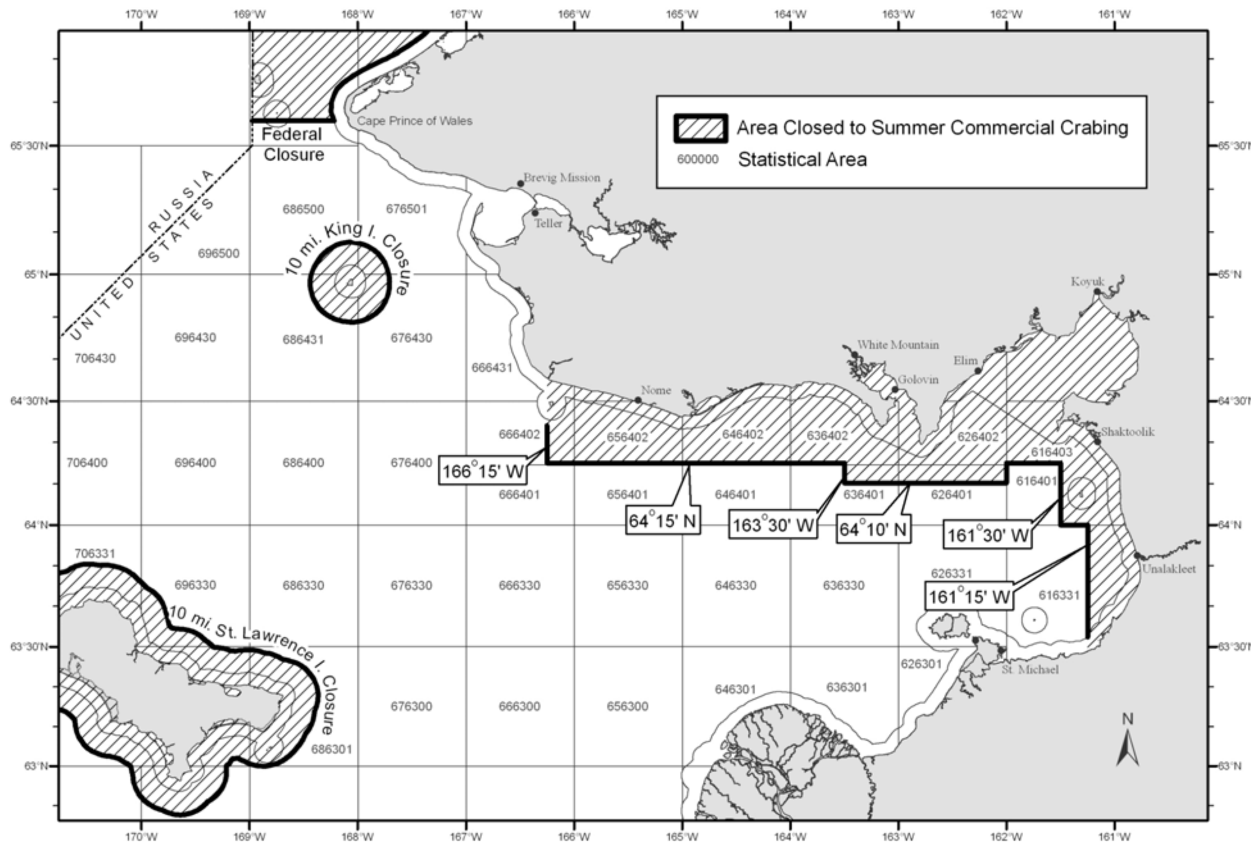


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery.

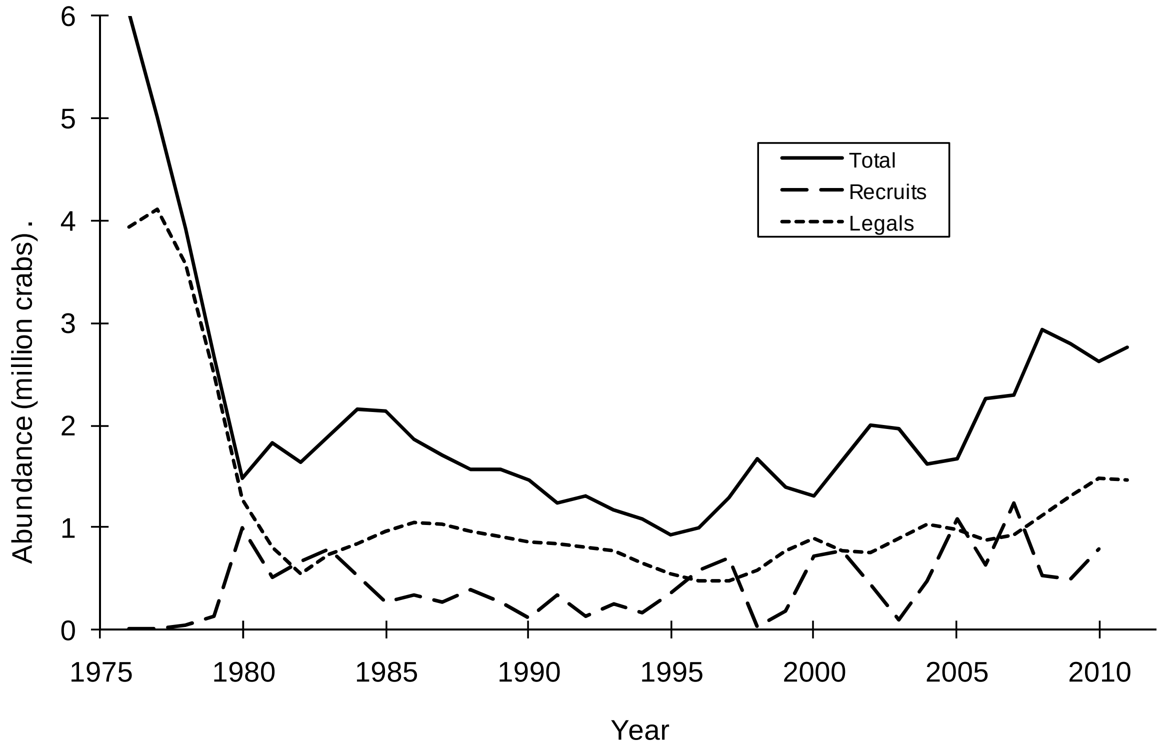


Figure 3. Estimated abundance of total (crabs > 74 mm CL), legal male, and recruits from 1976-2010.

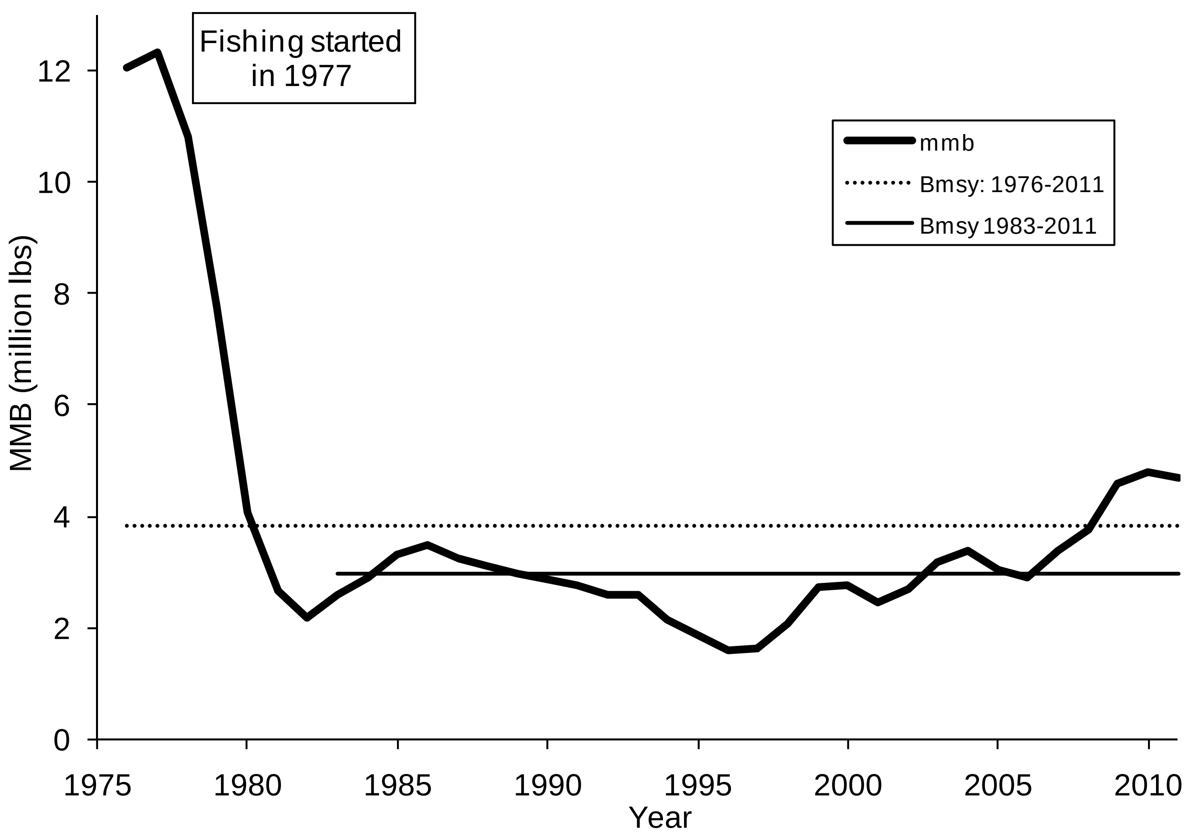
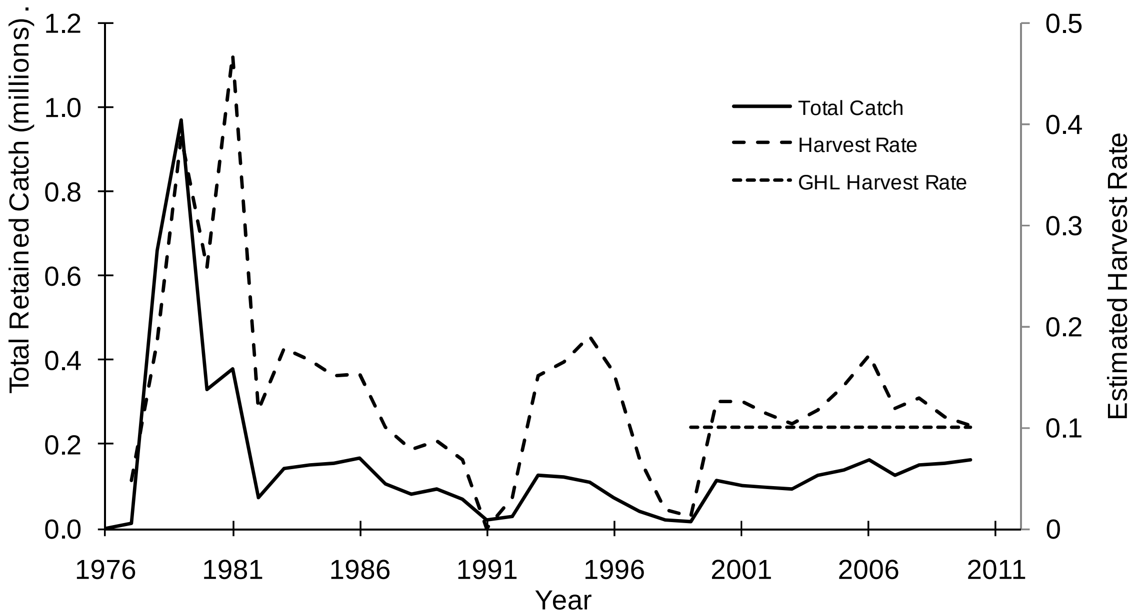


Figure 4. Estimated mature male biomass from 1976-2011.



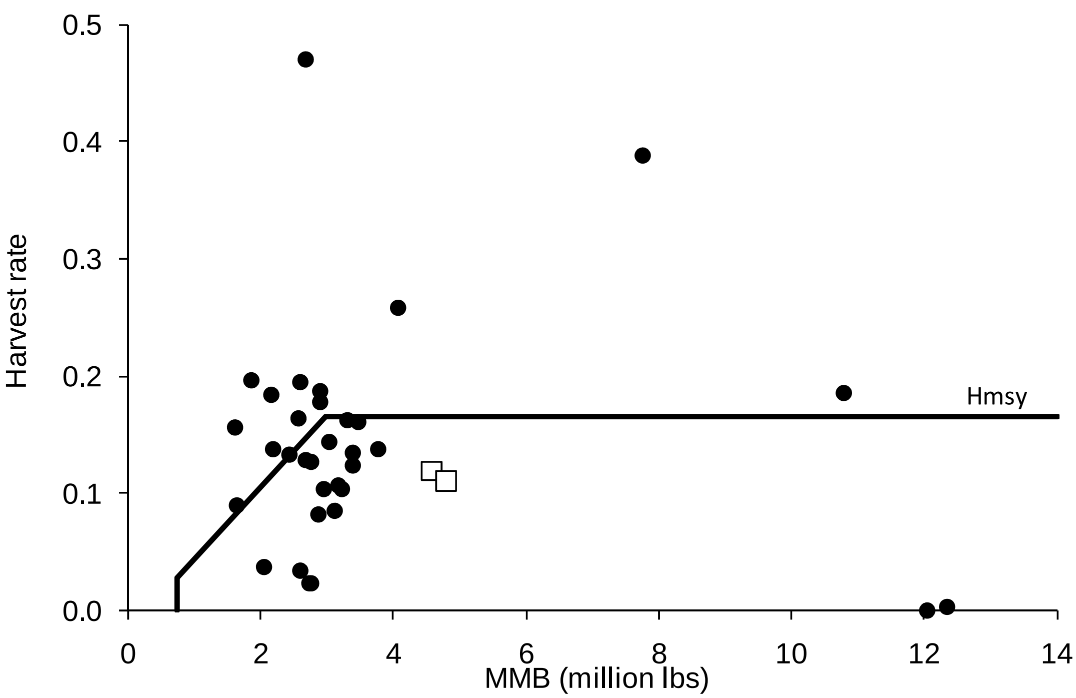


Figure 5. Total retained catches and harvest rates (upper plot) and relationship between harvest rates and mature male biomass (lower plot) of Norton Sound red king crab from June 1, 1976 to May 31, 2011. *Hmsy* is a proxy MSY harvest rate corresponding to *Fmsy* with γ=1.0 and M=0.18. White box are data for 2009 and 2010.

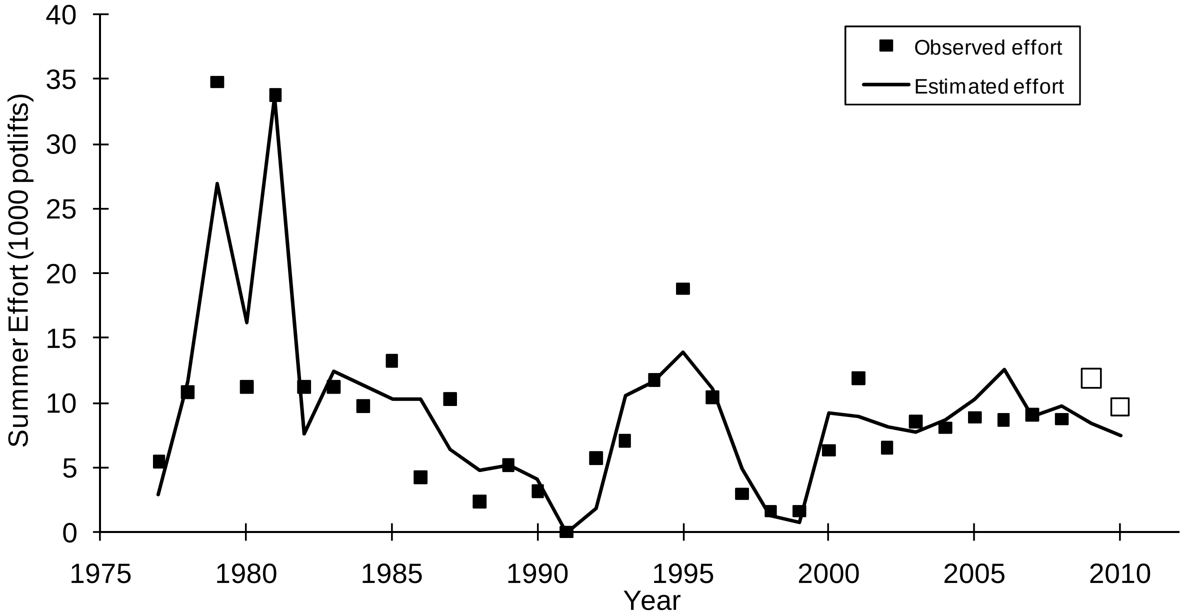


Figure 6. Comparison of observed and estimated summer fishing efforts (upper plot) during 1977-2010. White boxes are 2009 and 2010 data points.

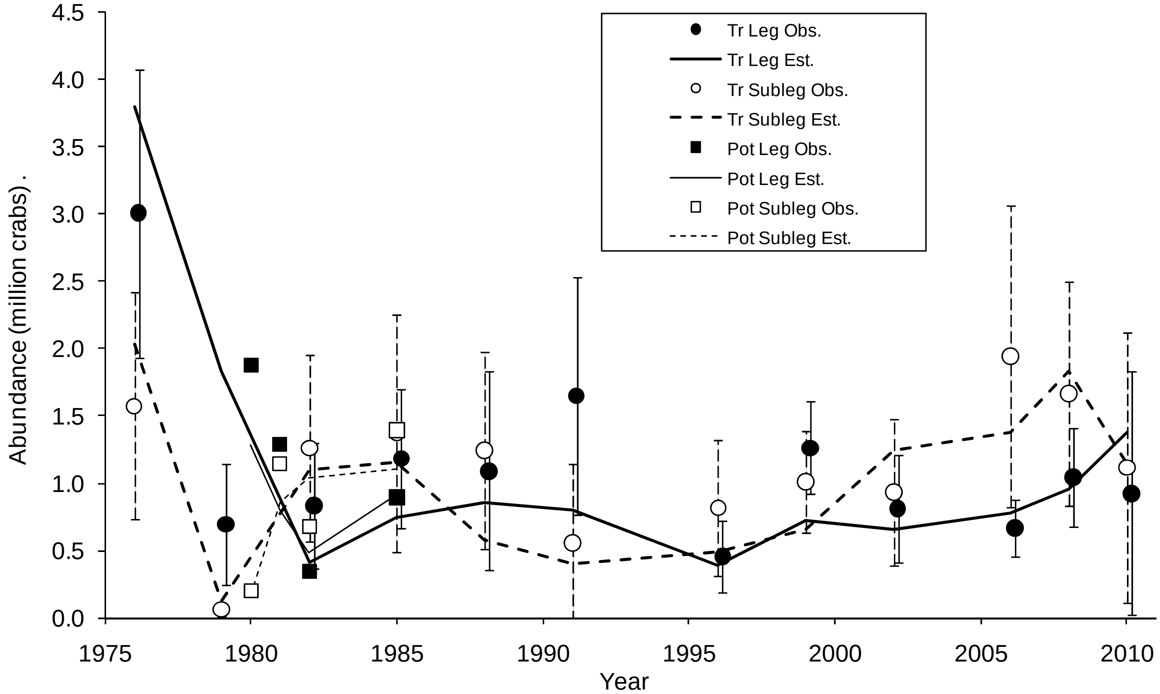


Figure 7. Comparison of observed and estimated Norton Sound red king crab abundances (legal and sublegal males) by summer trawl and pot surveys (upper plot). "Tr" is trawl, "Leg" is legal, "Obs." is observed or survey abundance, and "Est." is estimated catchable abundance. The 95% C.I. were plotted separately for sublegal and legal crabs from the summer trawl surveys.

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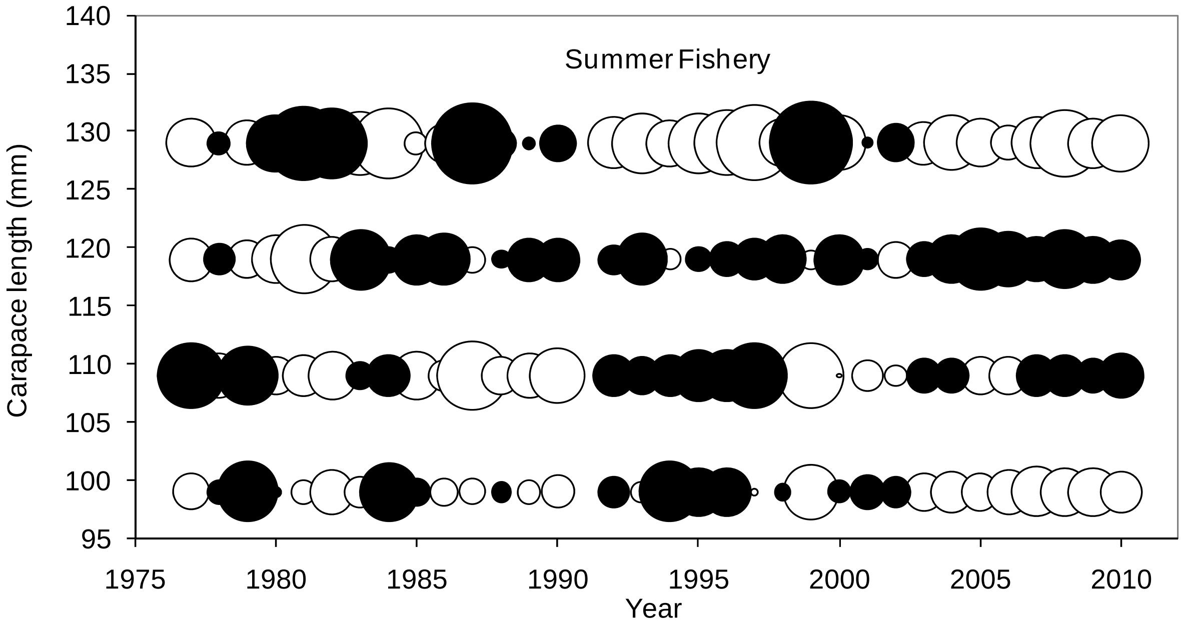
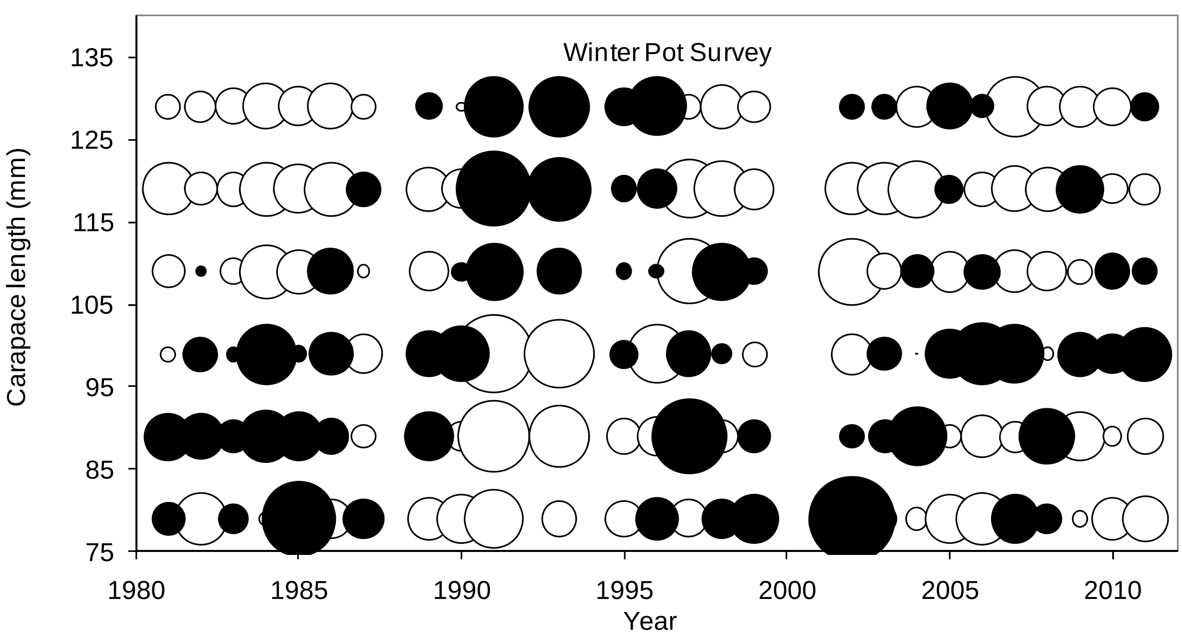


Figure 8. Residuals of catch length compositions by year for summer fishery for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.



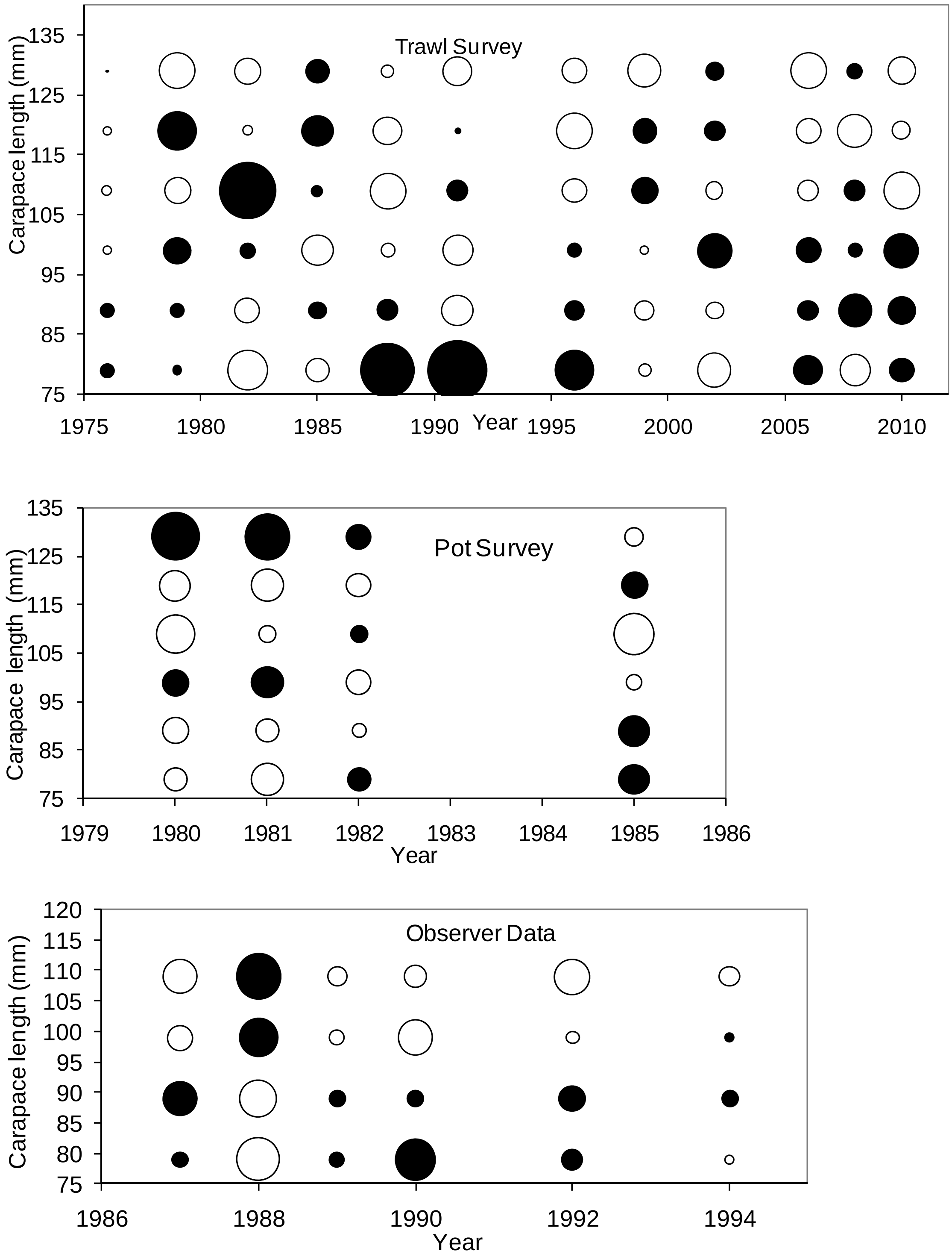


Figure 9. Residuals of length compositions by year for winter pot survey, summer trawl and pot surveys and observer data for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.

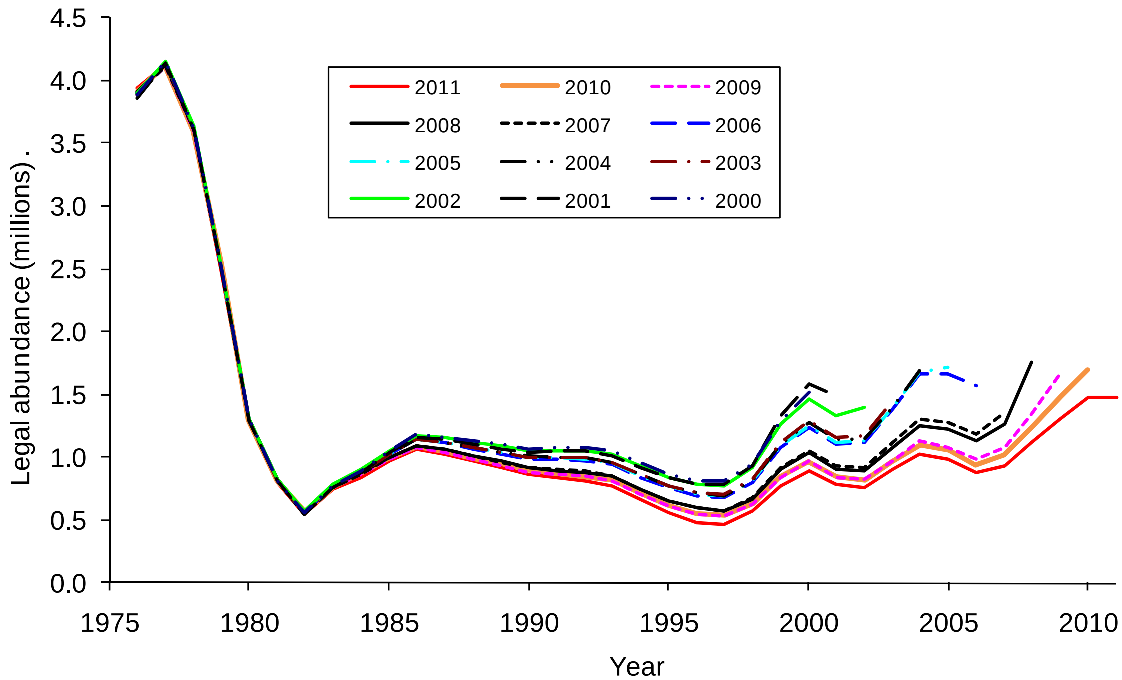


Figure 10. Comparison of estimates of legal male abundance of Norton Sound red king crab from 1976 to 2011 made with terminal years 2000-2011. Legend shows the year in which the assessment was conducted.

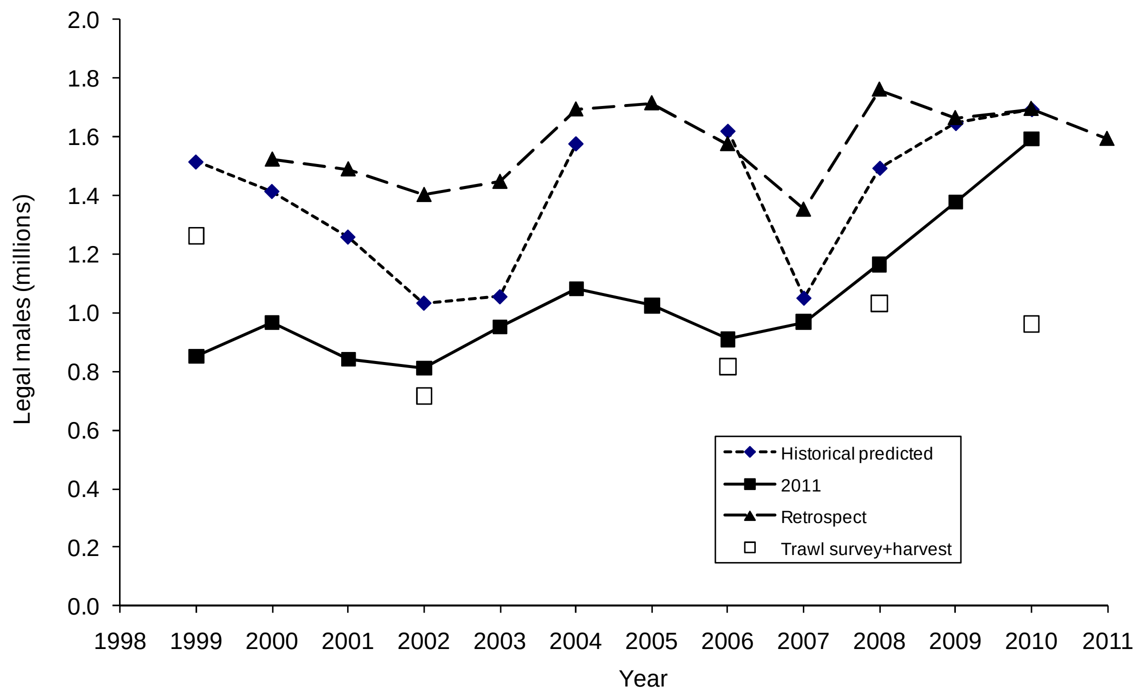


Figure 11. Comparison of estimates of legal male abundance of Norton Sound red king crab with terminal years 1999-2011. These are results of historical assessments. Legend shows the year in which the assessment was conducted.

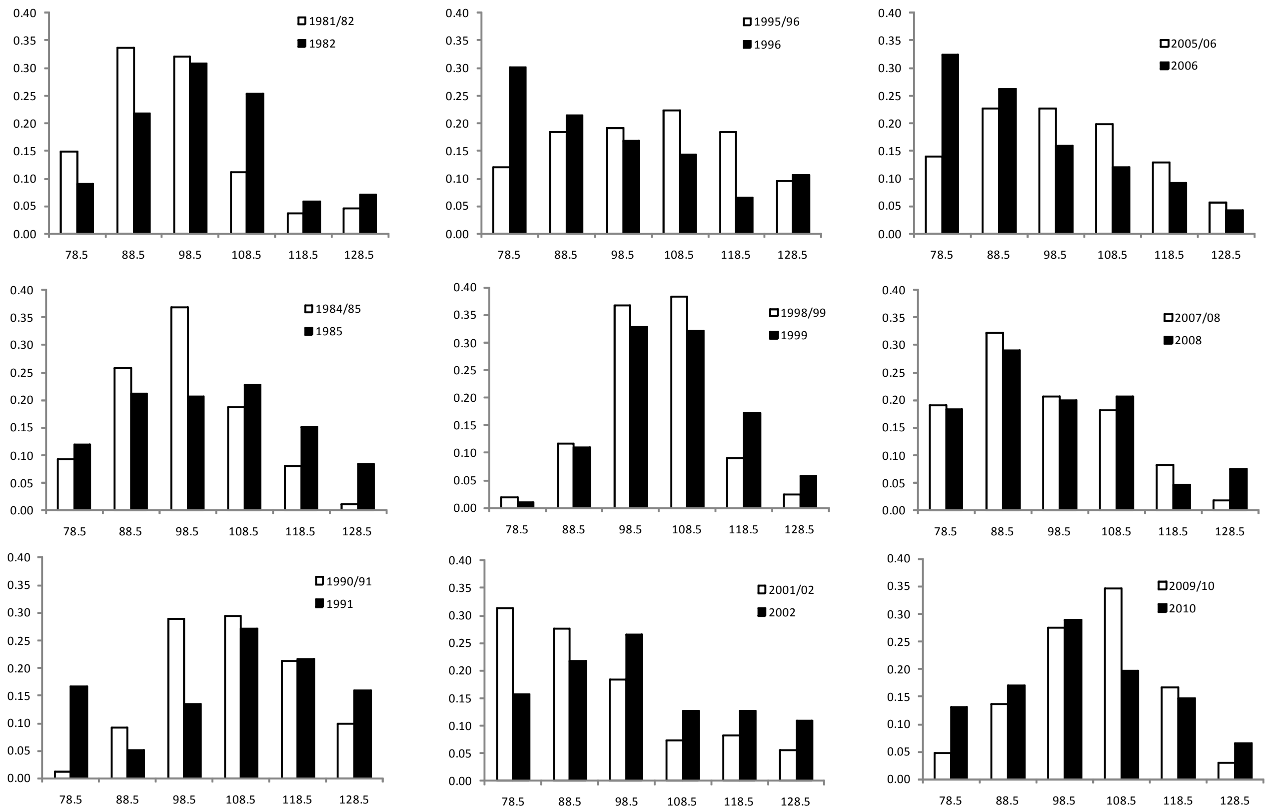


Figure 12. Comparison of length composition between Winter pot survey (white) and summer trawl survey (black) 1981-2010.

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.

Summer crab abundance

Summer crab abundances are the survivors of crabs from the previous winter:

$$N_{s,l,t+1} = (N_{w,l,t} - C_{w,t} P_{w,n,l,t} - C_{p,t} P_{p,n,l,t}) e^{-0.417 M_l}$$
$$O_{s,l,t+1} = (O_{w,l,t} - C_{w,t} P_{w,o,l,t} - C_{p,t} P_{p,o,l,t}) e^{-0.417 M_l} \quad (1)$$

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 and subsistence catches in year *t*,
$P_{w,n,l,t}$, $P_{p,n,l,t}$: Length proportion of winter 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 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 except for the last length class, in which *M* is 60% higher than the other classes.
0.417 : proportion of the year from Feb. 1 to July 1 is 5 months, or 0.417

Winter crab abundance

Winter crab abundance for newshell, $N_{w,l,t}$, is the combined result of growth, molting probability, mortality, and recruitment from the summer population:

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} [G_{l',l}((N_{s,l',t} + O_{s,l',t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l',t} + P_{s,o,l',t}) - D_{l',t}) m_{l'} e^{-(0.583-y_t)M_l}] + R_{l,t} \quad (2)$$

Winter abundance of oldshell crabs $O_{s,l,t}$ is the non-molting portion of survivors of crabs from summer:

$$O_{w,l,t} = [(N_{s,l,t} + O_{s,l,t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l,t} + P_{s,o,l,t}) - D_{l,t}]\,(1 - m_l)\,e^{-(0.583 - y_t) M_l} \quad (3)$$

where

$G_{l',l}$: a growth matrix representing the expected proportion of crabs molting from length class l' to length class l,
$C_{s,t}$: total summer catch in year t,
$P_{s,n,l,t}$, $P_{s,o,l,t}$: Compositions of summer catch for newshell and oldshell crabs in length class l in year t,
$D_{l,t}$: bycatches in length class l in year t,
m_l : molting probability in length class l,
y_t : the time in year from July 1 to the mid-point of the summer fishery
0.583: Proportion of the year from July 1 to Feb. 1 is 7 months, or 0.583 year
$R_{l,t}$: recruitment into 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)

$$m_l = 1 - \frac{1}{1 + e^{-\alpha(i-\beta)}} \quad (4)$$

where
α and β are parameters, and i is the mid-length of length class l.
m_l was re-scaled such that $m_1 = 1$.

Discards

In summer commercial fisheries, sublegal males (<104 mm CL) are not legally retained but are sorted and discarded, which are subject to handling mortality. Due to complexity and lack of data, we did not model handling mortality, but assumed to be 0.2.

Discards of length class l in year t from the commercial pot fishery were estimated as:

$$D_{l,t} = (N_{s,l,t} + O_{s,l,t})\,S_{s,l}\,(1 - legal_l)\,hm\,[C_{s,t} / \sum_l (N_{s,l,t} + O_{s,l,t})\,legal_l] \quad (5)$$

where
hm: handling mortality rate assumed to be 0.2
$legal_l$: the proportion of legal males in length class l.
$S_{s,l}$: Selectivity of the summer commercial fishery.

Selectivity of summer commercial fishery

Selectivity of the summer commercial fishery for length class l, $S_{s,l}$, was calculated a logistic function with parameters ϕ and ω, where i is the mid-length of the length class l.

$$S_{s,l} = \frac{1}{1 + e^{-\phi(i-\omega)}} \qquad (6)$$

$S_{s,l}$ was re-scaled such that $S_{s,5} = 1$ and $S_{s,6} \leq 1$. Two sets of parameters (ϕ_1, ω_1) and (ϕ_2, ω_2) were estimated for selectivities before 1993 and after 1992 to reflect the vessel changes and pot limits.

Recruitment Estimation

Because sample size of the mark-recapture data was too small to estimate annual molting probabilities, we modeled recruitment of year t, R_t, as a stochastic process around the mean, R_0:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2) \qquad (7)$$

R_t was assumed to come from only length classes 1 ($R_{1,t}$) and 2 ($R_{2,t}$) , and was calculated as

$$R_{1,t} = r\, R_t$$
$$R_{2,t} = (1-r)\, R_t \qquad (8)$$

where r is a parameter with a value less than or equal to 1. $R_{l,t} = 0$ when $l \geq 3$.

Length compositions of 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 selectivity for pots, and proportion of legal crabs for each length class:

$$P_{w,n,l,t} = N_{w,l,t} S_{w,l} L_l / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l]$$
$$P_{w,o,l,t} = O_{w,l,t} S_{w,l} L_l / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l] \qquad (9)$$

where
L_l : proportion of legal crabs for length class l, estimated from the observer data
$S_{w,l}$: winter selectivity for pots for length class l.
$S_{w,3}$ - $S_{w,5}$ were assumed to be 1, and $S_{w,1}$ and $S_{w,2}$ were estimated from (6). $S_{w,6}$ was directly estimated from the model.

Length compositions of 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 estimated length compositions of subsistence catch (l >2) as follows

$$P_{p,n,l,t} = N_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$P_{p,o,l,t} = O_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \quad (10)$$

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 $P_{sw,o,l,t}$ ($l \geq 1$).

$$P_{sw,n,l,t} = N_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$P_{sw,o,l,t} = O_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \quad (11)$$

Length composition of 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;

$$P_{s,n,l,t} = N_{s,l,t} S_{s,l} L_l / A_t$$
$$P_{s,o,l,t} = O_{s,l,t} S_{s,l} L_l / A_t \quad (12)$$

Where A_t is exploitable legal abundance in year t, estimated as

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} L_l] \quad (13)$$

Summer commercial fishing effort

Summer fishing effort (f_t) measured as the number of pot-lifts was calculated as total summer catch, C_t, divided by the product of catchability coefficient q and mean exploitable abundance:

$$f_t = C_t / [q_i (A_t - 0.5 C_t)] \quad (14)$$

Because fishing fleet and pot limit changed in 1993, q_1 is for fishing efforts before 1993 and q_2 is after 1992.

Length/shell compositions of Observer bycatch in 87-90, 92, 94 were estimated as

$$P_{b,n,l,t} = N_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)]$$
$$P_{b,o,l,t} = O_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)] \quad (15)$$

Summer pre-season survey (1976)

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:

$$P_{sf,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]$$
$$P_{sf,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \quad (16)$$

Length/shell composition of summer pot survey (1980-82, 85)

The length/shell condition compositions of summer pot survey were estimated as

$$P_{sp,n,l,t} = N_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}]$$
$$P_{sp,o,l,t} = O_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}] \quad (17)$$

Where fishing selectivity, $S_{sp,l}$ was assumed to be 1 for $l \geq 3$ and $S_{sp,1}$ and $S_{sp,2}$ were estimated the data using the equation (6).

Length/shell compositions of 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

$$P_{st,,l,t} = N_{s,l,t} S_{st,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{st,l}] \quad (18)$$

Where catch selectivity, $S_{st,l}$ was assumed to be 1 for $l \geq 3$, and $S_{st,1}$ and $S_{st,2}$ were estimated from the data using the equation (6).

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

c. Likelihood components.

Under assumptions that measurement errors of annual total survey abundances and summer commercial fishing efforts follow lognormal distributions and each type of length composition has a multinomial error structure (Fournier and Archibald 1982; Methot 1989), the log-likelihood function is:

$$\sum_{i=1}^{i=5}\sum_{t=1}^{t=n_i}\{K_{i,t}\sum_{l=1}^{l=6}[\hat{P}_{i,l,t}\,ln(P_{i,l,t}+\kappa)]\}-\sum_{i=1}^{i=2}\sum_{k=1}^{k=2}\sum_{t=1}^{t=n_i}[ln(\hat{B}_{i,k,t}+\kappa)-ln(B_{i,k,t}+\kappa)]^2/(2*ln(CV_{i,k,t}^2+1))$$
$$-W_f\sum_{t=1}^{t=32}[ln(\hat{f}_t+\kappa)-ln(f_t+\kappa)]^2-W_R\sum_{t=1}^{t=32}\tau_t^2 \quad (18)$$

where

i: length/shell compositions of :

1 triennial summer trawl survey
2 summer pot survey (1980-82, 85)
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 : 1 legal crabs, 2 sub-legal crabs
$K_{i,t}$: 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 for legal, sub-legal, and total.
$B_{i,k,t}$: observed and estimated annual total abundances for data set i and year t
W_f : the weighting factor of the summer fishing effort
f_t : observed and estimated summer fishing efforts
W_R : the weighting factor of recruitment.

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. Variances for total survey abundances and summer fishing effort were not estimated; rather, we used weighting factors to reflect these variances.

d. Population state in year 1.

Length and shell compositions from the first year (1976) summer trawl survey data approximated the true relative compositions.

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 is based on an assumed maximum age of about 25 and the 1% rule (Zheng 2005). Tagging data were used to estimate mean growth increment per molt, standard deviation for each pre-molt length class, and the growth matrix (Table 3). Proportions of legal males by length group were estimated from the observer data (Table 4).

Natural mortality was based on an assumed maximum age, t_{max}, and the 1% rule (Zheng 2005):

$$M = -\ln(p)/t_{\max}, \qquad (19)$$

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.

ii. Parameters Estimated Conditionally

Estimated parameters are listed in Table 5 in the primary document. Selectivities and molting probabilities based on these estimated parameters are summarized in Table 4 (also in the primary document).

A likelihood approach was used to estimate parameters, which include fishing catchability, parameters for selectivities 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).

Crabs usually aggregate, and this increases the uncertainty in survey estimates of abundance. To reduce the effect of aggregation, annual total sample sizes for summer trawl and pot survey data sets were reduced to 50% and all other sample sizes were reduced to 10%. Also, annual effective sample sizes were capped at 200 for summer trawl and pot surveys and 100 for the other data to avoid overweighting the data with a large sample size (Fournier and Archibald 1982). Weighting factors represent prior assumptions about the accuracy or the variances of the observed data or random variables. W_f was set to be 20, and W_R was set to be 0.01. According to the fishery manager, the estimate of fishing effort in 1992 was not as reliable as in the other years (C. Lean, ADF&G, personal communication). Thus, we weighted the effort in 1992 half as much as in the other years. W_f and maximum effective sample size was investigated.

To reduce the number of parameters, we assumed that length and shell compositions from the first year (1976) summer trawl survey data approximated the true relative compositions. Abundances by length and shell condition in all other years were computed recursively from abundances by length and shell condition in the first year and by annual recruitment, catch, and model parameters. Initial parameter estimates were an educated guess based on observation and current knowledge.

f. Definition of model outputs.

i. Biomass: mature males are defined as those 94 mm carapace length and above (size classes 3 to 6). The mean weights for size classes 1-6 are 0.854, 1.210, 1.652, 2.187, 2.825 and 3.697 lbs.

ii. Recruitment: number of males in the 1st two length classes.

iii. Fishing mortality: applied as an annual exploitation rate to the legal segment of the stock per equations 2 and 3 (above), including bycatch mortality according to equation 4 (above).

Aleutian Islands Golden King Crab

May 2011 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak

Executive Summary

1. **Stock:** Golden king crab *Lithodes aequispinus*/Aleutian Islands

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 pounds, 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 pounds (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 pounds (2,676 t) was established for the 1996/97 season, which was subsequently reduced to 5.700-million pounds (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 pounds (2,585 t) through the 2007/08 season, but was increased to 5.985-million pounds (2,715 t) for 2008/09–2010/11 seasons. Average annual retained catch for the period 1996/97–2007/08 was 5.623-million pounds (2,550 t). Average annual retained catch in 2008/09–2009/10 was 5.796-million pounds (2,629 t). Catch per pot lift of retained legal males decreased from the 1980s into the mid-1990's, but increased steadily following the 1994/95 season, markedly so during the 2005/06 season with the advent of the Crab Rationalization program. Non-retained bycatch occurs mainly during the directed fishery. Although some 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 pounds (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 and estimated total bycatch in groundfish fisheries during 2009/10 was lower at 0.062-million pounds (28 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 1990's. Annual estimated weight of discarded bycatch during crab fisheries decreased from 13.824-million pounds (6,270 t) in 1990/91 (representing 199% of the retained catch during that season), to 9.100-million pounds (4,128 t) in 1996/97 (representing 156% of the retained catch for that season), and to 4.321-million pounds (1,960 t) in the 2004/05 season (representing 78% of the retained catch for that season). During the five seasons prosecuted as rationalized fisheries, estimated weight of discarded bycatch has ranged from 2.524-million pounds (1,145 t) for the 2005/06 season (representing 46% of the retained catch for that season) to 3.035-million pounds (1,376 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 pounds (2,638 t) to 9.375-million pounds (4,252 t) during 1995/96–2009/10, the period for which such estimates can be made.

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 2009/10; the retained catch was less than the retained-catch OFL established for 2009/10 (see tables below). No ABC was established prior to the 2011/12 season.

See tables below; retained catch for 2010/11 is preliminary, the OFL and ABC values for 2011/12 are the author's Tier 5 recommendations, and the 2011/12 TAC is according to current SOA regulations.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a, c]	ABC[a, c]
2007/08	N/A	N/A	5.70	5.51	6.25	N/A	N/A
2008/09	N/A	N/A	5.99	5.68	6.31	9.18, R	N/A
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	TBD	11.06, T	N/A
2011/12	N/A	N/A	5.99	TBD	TBD	11.40, T	10.26, T

a. Millions of pounds.
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]
2007/08	N/A	N/A	2,585	2,498	2,833	N/A	N/A
2008/09	N/A	N/A	2,715	2,576	2,860	4,163, R	N/A
2009/10	N/A	N/A	2,715	2,682	2,591	4,163, R	N/A
2010/11	N/A	N/A	2,715	2,707	TBD	5,017, T	N/A
2011/12	N/A	N/A	2,715	TBD	TBD	5,173, T	4,655, T

a. Metric tons.
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.

6. **Basis for the OFL and ABC:** See table, below; 2011/12 values are the author's recommendations.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality[a]	Buffer
2008/09	5	1985/86–1995/96[b]	0.18	N/A
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%

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.

7. **PDF of the OFL:** Sampling distribution of the alternative Tier 5 OFLs was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 1.04-million pounds (CV = 0.09). See section G.1.

8. **Basis for the ABC recommendation:** A 10% buffer on the OFL; 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.

2. **Changes to the input data:**
   - Fishery data has been updated with the results for 2009/10: retained catch for the directed fishery and bycatch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries. Preliminary statistics for the 2010/11 season are included. Bycatch data from the 1990/91–1992/93 and 1995/96 crab fisheries (1993/94 and 1994/95 not included due to insufficient data) and from the 1993/94–1995/96 groundfish fisheries have been added to the assessment.

3. **Changes to the assessment methodology:** None. This assessment follows the methodology recommended by the CPT in May 2010 and the SSC in June 2010, but incorporates additional historical data that was not available for review in 2010.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:**
   - The OFL established for each of 2008/09 and 2009/10 was 9.18-million pounds 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 pounds 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 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 recommended OFL for 2011/12 is a total-catch OFL of 11.40-million pounds. The author follows the June 2010 SSC recommendations by using 1985/86–1995/96 data for retained catch, incorporating as much data on bycatch as is available, and freezing years 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 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.

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 2010:
  1. *"Some assessments provided results in metric tons. The CPT recommendation to use metric tons refers only to the ACL analysis and traditional assessment currencies (lbs) should continue to be used in stock assessments."*
     - Response: That was done.
  2. *"The team requested that all assessments explain how the groundfish bycatch data are used in the assessment and that all assessment chapters should be consistent in distinguishing and separately presenting groundfish bycatch from fixed gear fisheries and trawl gear fisheries."*
     - Response: Explanations were made and statistics from fixed gear and trawl gear fisheries are distinguished and presented separately.
  - SSC, June 2010: *"In order to have greater consistency between assessments, the SSC recommends that catch statistics reported in the executive summary section contain both metric tons and pounds (millions)."*
     - Response: That was done.
  - CPT, September 2010: [*None.*]
  - SSC, October 2010: [*None.*]

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

- CPT, May 2010: *"The CPT recommended that a total-catch OFL be established for the 2010/11 Aleutian Islands golden king crab season."* [*Plus extended verbiage and presentation of tables and graphs pertaining to alternative approaches that were not used to compute the 2010/11 OFL. The May 2010 CPT minutes do not provide the recommendation for the 2010/11 total OFL that appears in the Executive Summary of the 2010 SAFE. The reader is directed to the June 2010 SSC minutes and the Executive Summary of the 2010 SAFE for information on this matter.*]

- <u>Response</u>: The author recommends a total-catch OFL for 2011/2012. See also the SSC June 2010 comments and response.

- <u>SSC, June 2010</u>: [*Verbiage on rejecting the alternatives for accounting for bycatch mortality in the 2010/11 total-catch OFL considered by the CPT in May 2010*]*"In the end, the SSC resolved that basing this bycatch mortality on the full time period (1996/1997–20082009) may be most robust, as it includes the most data. Thus the SSC recommends its own alternative [for the 2010/11 total-catch OFL]:*

  $OFL_{TOT(4)} = (1+RATE_{96/97\text{-}08/09}) \bullet OFL_{RET(85/86\text{-}95/96)} + MGF_{96/97\text{-}08/09}$ *= 11.0 million lbs., where*

  $RATE_{96/97\text{-}08/09}$ *= mean annual rate = (bycatch mortality in crab fisheries)/(retained catch) over the period 1996/97-2008/09,*

  $OFL_{RET(85/86\text{-}95/96}$ *= mean annual retained catch over the period 1985/86-1995/96, and*

  $MGF_{96/97\text{-}08/09}$ *= mean of annual bycatch mortality in groundfish fisheries over the period 1996/97-2008/09.*

  The SSC recommends that this time period be frozen to stabilize the control rule."

  - <u>Response</u>: The author follows this recommended approach. In computing the recommended total-catch OFL for 2011/12, the time period for retained catch data is "frozen" at 1985/86–1995/96 and the last year of bycatch data included is "frozen" at 2008/09. Following the "more data = more robust" rule of thumb for estimating the bycatch mortality component of the total-catch, available data on bycatch in the crab and groundfish fisheries prior to 1996/97 are also included in the computation of the OFL.

- <u>CPT, September 2009</u>: None – this stock was not reviewed at the September 2010 CPT meeting.
- <u>SSC, October 2010</u>: None – this stock was not reviewed at the June 2010 SSC meeting.

C. Introduction

1. **<u>Scientific name</u>:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **<u>Description of general distribution</u>:**

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). Bowers et al. (2011, page 8) 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; Bowers et al. 2011). 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 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 we use “Aleutian Islands Area” to mean 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 2009/10 season the pots sampled by at-sea observers were fished at an average depth of 183 fathoms (335 m; N=411) in the area east of 174° W longitude and 174 fathoms (318 m; N=893) for the area east of 174° W longitude (Gaeuman 2011).

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 within the area in which available habitat is attenuated are suggested by regions of low fishery effort and catch (Figures 3 and 4); for example the southern side of islands between 174° W longitude and 177° W longitude (i.e., from Atka I. west to Adak I.) as compared to the area surrounding islands between 170°W longitude and 173° W longitude (i.e., between the Islands of the Four Mountains and Seguam Pass). 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, Watson 2007) have provided no evidence of substantial movements by crab in the size classes that were tagged (males and females ≥90-mm 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 of 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, Fishery Biologist, ADF&G, Kodiak, retired; personnel communication).

3. 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 (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. <u>Brief summary of management history</u>:

A complete summary of the management history is provided in Bowers et al. (2011, pages 14–19). The first commercial landing of golden king crab in the Aleutian Islands was in 1975/76, but directed fishing did not occur until 1981/82. Peak harvest occurred during 1986/87 when 14.739-million pounds 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 pounds.

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 pound guideline harvest level (GHL), with 3.200-million pounds apportioned to the area east of 174° W longitude and 2.700-million pounds apportioned to the area west of 174° W longitude. The 1998/99–2004/05 seasons were managed under a 5.700-million pound GHL, with 3.000-million pounds apportioned to the area east of 174° W longitude and 2.700-million pounds apportioned to the area west of 174° W longitude. The 2005/06–2007/08 seasons were managed under a 5.700-million pound total allowable catch (TAC), with 3.000-million pounds apportioned to the area east of 174° W longitude and 2.700-million pounds 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 beginning with the 2008/09 has been 5.985-million pounds (apportioned as 3.150-million pounds for the area east of 174° W longitude and 2.835-million pounds for the area west of 174° W longitude). Over the period 1996/97–2009/10 the total of the annual retained catch has been 2% below the total of the annual GHL/TACs. By season, retained catch has been as much as 13% below the GHL/TAC (the 1998/99 season) and as much as 6% above the GHL/TAC (the 2000/01 season). The retained catch for the 2009/10 season was <1% below the 5.985-million pound TAC.

A summary of relevant 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 beginning in the 2005/06 season of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., east of 174° W longitude) and Adak Community Allocation fishery for golden king crab in the western Aleutians (i.e., west of 174° W longitude; Milani 2008). 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. Note that, because Adak is not a CDQ community, the ACA fishery in the western Aleutians is not a formal CDQ fishery. Both the CDQ fishery in the eastern Aleutians and the ACA fishery in the western Aleutians are prosecuted concurrently with the IFQ fishery and 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 State of Alaska 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 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 (as defined in 5 AAC 34.050). Pots used to fish for golden king crab in the Aleutian Islands Area my be operated only 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") 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" escape web on the door of over 95% of Golden Crab pot orders we manufactured."

By State of Alaska regulation (**5 AAC 34.610 (b)**), the commercial fishing season for golden king crab in the Aleutian Islands Area is 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).

D. Data

1. <u>Summary of new information</u>:

- Fishery data on retained catch and non-retained bycatch during 2009/10 crab fisheries (retained catch during 2010/11 is reported but is considered preliminary). Data on bycatch during the 1990/91–1992/93 and 1995/96 directed and non-directed 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 1991/92–1995/96 and 2009/10 (however, the 1991/92–1992/93 appears suspect and is not included in the analysis).

- Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 1995/96 and 2009/10 have been added.

2. Data presented as time series:

a. Total catch and b. Information on bycatch and discards:

- Fish ticket data on retained catch numbers, retained catch weight, pot lifts, CPUE, and average weight of retained catch for the 1981/82–2010/11 seasons (2010/11 statistics considered preliminary) 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 1995/96–2009/10 (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. Only one vessel was observed during the directed fishery only in the area west of 171° W longitude in each of the 1993/94 and 1994/95 seasons, disallowing for estimation of bycatch during the directed fishery for those two seasons east of of 171° W longitude and for the Aleutian Islands as a whole. Data on bycatch of non-retained legal males appears to be less reliable in the seasons prior to 1998/99 than in later seasons; however, bycatch of non-retained legal males accounts for only ≤2% of the estimated total weight in the crab fisheries annually in seasons prior to 2005/06. 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 bycatch of golden king crab obtained by at-sea observers during groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5) for crab fishery years 1993/94–2009/10 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 1995/96–2009/10 directed and non-directed crab fisheries and 1993/94–2009/10 groundfish fisheries are presented in Table 4. Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 1995/96–2009/10 are presented (Table 4). Following Siddeek et al. (2010), 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 (2010a, 2010b), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8.

c. Catch-at-length: Not used in a Tier 5 assessment; none are presented.

d. Survey biomass estimates: Not used in a Tier 5 assessment; none are presented.

e. Survey catch at length: Not used in a Tier 5 assessment; none are presented (see section D.4).

f. Other data time series: See section D.4 on other time-series data that are available, but not presented here.

3. <u>Data which may be aggregated over time</u>:

a. <u>Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):</u>

Growth per molt 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:

$$P(molt) = \exp(17.930 - 0.129*CL)/[1 + \exp(17.930 - 0.129*CL)].$$

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. <u>Weight-at length or weight-at-age (by sex)</u>:

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007b) 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 pounds by dividing by 453.6.

c. <u>Natural mortality rate</u>:

The default natural mortality rate assumed for king crab species by NPFMC (2007b) is M=0.18. Note, however, that this natural mortality assumption was not used in this Tier 5 stock assessment.

4. <u>Information on any data sources that were available, but were excluded from the assessment:</u>

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. 2010).

2. **Model Description:** *Subsections a–i are not applicable to a Tier 5 stock.*

It has been recommended by NPFMC (2007b) and by the CPT and SSC in 2009 that the Aleutian Islands golden king crab stock be managed as a Tier 5 stock until the assessment model (e.g., Siddeek et al. 2010) is accepted for use. 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 OFL for this stock. This assessment recommends – and only considers – use of a total-catch OFL for 2011/12.

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." Prior to 2008, two time periods considered for computing the average retained catch for Aleutian Islands golden king crab: 1985–2005 (NPFMC 2007a) and 1985–1999 (NPFMC 2007b). NPFMC (2007b) suggested using the average retained catch over the years 1985 to 1999 as 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 pounds for the 1996/97 and 1997/98 seasons to 5.7-million pounds for the 1998/1999 season; the GHL or TAC has remained at 5.7-million pounds for all subsequent seasons until it was increased to 5.985-million pounds 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). Of those, the Crab Plan Team at the May 2008 recommended using the period 1990/91–1995/96 for computing the 2008/09 OFL to address concerns raised by a decline in retained catch and CPUE that occurred from 1985/86 into the mid-1990's, the first five seasons of the full period 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. Although the not explicitly stated in the SSC minutes their choice was apparently based on the desire for 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 time period recommended by the SSC for the 2008/09 OFL); 1990/91–1995/96; (the time 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-1990's could be interpreted as resulting from fishery that relied increasingly on annual recruitment to legal size as it fished on 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):

"$OFL_{TOT(4)} = (1+RATE_{96/97\text{-}08/09})\bullet OFL_{RET(85/86\text{-}95/96)} + MGF_{96/97\text{-}08/09}$ = 11.0 million lbs.,

where
$RATE_{96/97\text{-}08/09}$ = mean annual rate = (bycatch mortality in crab fisheries)/(retained catch) over the period 1996/97-2008/09,
$OFL_{RET(85/86\text{-}95/96}$ = mean annual retained catch over the period 1985/86-1995/96, and
$MGF_{96/97\text{-}08/09}$ = mean of annual bycatch mortality in 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."

Given the most recent recommendations from the SSC (June 2010) the author considers all debate and questions concerning alternative time periods to computing a Tier 5, total-catch OFL for this stock to be closed and will follow the June 2010 recommendation of the SSC unless instructed to do otherwise. In particular, only the retained catch data for the period 1985/86–1995/96 and only the available estimates on bycatch mortality for seasons preceding 2008/09 will be used in calculation of the 2011/2012 total-catch OFL. Data and estimates that are used in calculation of alternative total-catch OLFs for 2011/12 and that are available for the period 1985/86–2008/09 are plotted in Figures 6–9.

3. Model Selection and Evaluation:

a. *Description of alternative model configurations*

Two alternatives are presented. Alternative 1 is the author's recommended alternative.

Alternative 1 (author's recommendation). The recommended OFL is set as a total-catch OFL following the June 2010 recommendation of the SSC, but uses additional historical data on bycatch that was not available for review in 2010:

$$OFL_{TOT(1),\ 2010/11} = (1+R_{90/91\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09}\ ,$$

where,

- $R_{90/91\text{-}08/09}$ is the average of the estimated average annual ratio of pounds of bycatch mortality to pounds of retained in the crab fisheries during the period 1990/91-2008/09 (excluding 1993/94–1994/95, due to data insufficiencies)
- $RET_{85/86\text{-}95/96}$ 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 estimated average annual bycatch mortality in groundfish fisheries during the period 1993/94-2008/09.

Statistics on the data and estimates used to calculate, $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}08/09}$, and $BM_{GF,93/94\text{-}08/09}$ are provided in Table 5; the column means in Table 5 are the calculated values of $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}08/09}$, and $BM_{GF,93/94\text{-}08/09}$. Using those calculated values of $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}08/09}$, and $BM_{GF,93/94\text{-}08/09}$, $OFL_{TOT(1),\ 2010/11}$ is,

$$OFL_{TOT(1),\ 2010/11} = (1+0.240)\bullet(9{,}178{,}438) + 23{,}359 = 11.40\text{-million pounds.}$$

Alternative 2 (status quo). This alternative is the same total-catch OFL that was recommended by the SSC in June 2010 and which was established as the OFL for 2010/11:

$$OFL_{TOT(2),\ 2010/11} = (1+R_{96/97\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,96/97\text{-}08/09},$$

where,

- $R_{96/97\text{-}08/09}$ is the average of the estimated average annual ratio of pounds of bycatch mortality to pounds of retained in the crab fisheries during the period 1996/97-2008/09,
- $RET_{85/86\text{-}95/96}$ 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 estimated average annual bycatch mortality in groundfish fisheries during the period 1996/97-2008/09.

Statistics on the data and estimates used to calculate, $RET_{(85/86\text{-}95/96}$, $R_{96/97\text{-}08/09}$, and $BM_{GF,96/97\text{-}08/09}$ are provided in Table 6; the column means in Table 6 are the calculated values of $RET_{(85/86\text{-}95/96}$, $R_{96/97\text{-}08/09}$, and $BM_{GF,96/97\text{-}08/09}$. Using those calculated values of $RET_{(85/86\text{-}95/96}$, $R_{96/97\text{-}08/09}$, and $BM_{GF,96/97\text{-}08/09}$, $OFL_{TOT(2),\ 2010/11}$ is,

$OFL_{TOT(2),\,2010/11}$ = (1+0.202)•(9,178,438) + 27,546 = 11.06-million pounds.

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 pounds)**
Alt. 2 – status quo	Total-catch	1985/86–1995/96	11.06
Alt. 1 - recommended	Total-catch	1985/86–1995/96	11.40

Given the June 2010 recommendation to freeze the time periods to stabilize the control role and the June 2010 argument of the SSC that the approach that "includes the most data... may be the most robust" [*with ordering of the two quoted phrases (separated by ellipses) switched by the author for clarity of exposition!*], the author recommends Alternative 1.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** N/A – both alternatives have the same number of parameters; see the 2008–2010 Crab SAFEs for discussion on realism.

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. However, temporal trends exist in the retained catch (Figure 6), in the ratio of the estimated bycatch mortality in crab fisheries to the retained catch (Figure 7), the estimated bycatch mortality in groundfish fisheries (Figure 8), during that period. Additionally, an interesting relationship exists between the ratio of the estimated bycatch mortality in crab fisheries to the retained catch and the retained weight for the season (Figure 9). Estimates of total retained catch (pounds) during a season are from fish tickets landings recorded at 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 2010). 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 5–7.

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. See Figures 6–9.
- The bycatch mortality rates used in estimation of total catch.

See also Tables 5–7 and Figure 10.

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 portion of the OFL: 1985/86–1995/96.
  - o The recommended time period follows the recommendation of the SSC in June 2010. Morover, the SSC in June 2009 also noted that, "the management system was relatively constant from 1985 onward" [until 1996/97]. The SSC in June 2010 recommended that data from 1996/97–2008/09 be used to estimate the bycatch mortality component of the total-catch OFL and to "freeze" time periods henceforth. This assessment uses estimates of bycatch mortality during the 1990/91–1992/93 and 1995/96–2008/09 crab fisheries and during the 1993/94–2008/09 groundfish fisheries.

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 (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. ***<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. 2011/12 values are author's recommendations.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a, c]	ABC[a, c]
2007/08	N/A	N/A	5.70	5.51	6.25	N/A	N/A
2008/09	N/A	N/A	5.99	5.68	6.31	9.18, R	N/A
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	TBD	11.06, T	N/A
2011/12	N/A	N/A	5.99	TBD	TBD	11.40, T	10.26, T

a. Millions of pounds.
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 pounds (9.18-million pounds).

5. **<u>Recommended F_{OFL}, OFL total catch and the retained portion for the coming year</u>:** See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. Bootstrap estimates of the sampling distributions (assuming no error in estimation of bycatch) of the Alternative 1 and Alternative 2 OFLs are shown in Figure 10 (1,000 samples drawn with replacement independently from each of the three columns of values in Table 5 to calculate $R_{90/91\text{-}08/09}$, $RET_{85/86\text{-}95/96}$, $BM_{GF,93/94\text{-}08/09}$ and $OFL_{TOT(1),2010/11}$ and 1,000 samples drawn with replacement independently from each of the three columns of values in Table 6 to calculate $R_{96/97\text{-}08/09}$, $RET_{85/86\text{-}95/96}$, $BM_{GF,96/97\text{-}08/09}$ and $OFL_{TOT(2),2010/11}$). Table 7 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 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.
- 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. (1-0.1)·11,404,670 pounds = 10.26-million pounds.

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 2010) to estimate spawning biomass or a proxy will identify data gaps and research priorities.

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Table 1. Harvest history for the Aleutian Islands golden king crab fishery (GHL/TAC, pounds 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 2010/11 season (includes the CDA and ACA fisheries for the 2005/06–2010/11 seasons; from Pengilly 2010, updated with 2009/10 and 2010/11 data from H. Fitch, ADF&G, 8 April 2011 email; data for 2010/11 should be considered preliminary).

Season	GHL/TAC Millions of Pounds	Harvest Pounds[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	1,297,231	55,786	23.3	4.6[f]

a. Includes deadloss.
b. Catch (number of crab) per pot lift.
c. Average weight (pounds) 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. Estimated weight (pounds) of the catch of retained legal males, non-retained legal male, non-retained sublegal male, non-retained female, and total non-retained Aleutian Islands golden king crab during directed and non-directed commercial crab fisheries by season for the 1990/91–2010/11 seasons (from Pengilly 2010, updated with: 2009/10 retained catch data and preliminary 2010/11 retained catch data from H. Fitch, ADF&G, 8 April 2011 email; 2009/10 bycatch estimates from Gaeuman 2011 and data from the ADF&G Crab Observer Database, 25 April 2011; 1990/91–1995/96 bycatch estimates from the ADF&G Crab Observer Database, 25 April 2011).

		Non-retained catch			
Season	Retained Catch	Legal male	Sublegal male	Female	Total
1990/91	6,950,362	12,017	6,406,866	7,404,919	13,823,802
1991/92	7,702,141	213,613	5,532,854	5,510,334	11,256,802
1992/93	6,291,197	62,275	5,874,729	7,145,218	13,082,222
1993/94	5,551,143	—	—	—	—
1994/95	8,128,511	—	—	—	—
1995/96	6,960,406	63,679	6,054,126	5,931,746	12,049,551
1996/97	5,815,772	24,756	4,221,753	4,853,795	9,100,304
1997/98	5,945,683	39,929	4,198,607	4,494,061	8,732,597
1998/99	4,941,893	41,325	4,303,406	3,043,543	7,388,274
1999/00	5,838,788	63,877	3,930,277	3,557,417	7,551,570
2000/01	6,018,761	35,432	4,782,427	4,083,675	8,901,534
2001/02	5,918,706	26,541	3,787,239	3,074,681	6,888,462
2002/03	5,462,455	41,621	3,113,341	2,516,355	5,671,318
2003/04	5,665,828	38,870	2,663,899	2,270,716	4,973,484
2004/05	5,575,051	76,100	2,511,523	1,733,391	4,321,014
2005/06	5,520,318	140,493	1,478,601	904,642	2,523,737
2006/07	5,262,342	119,590	1,263,303	1,190,147	2,573,040
2007/08	5,508,100	127,560	1,504,738	1,402,333	3,034,632
2008/09	5,680,084	174,866	1,365,338	1,223,469	2,763,673
2009/10	5,912,287	164,133	1,363,549[i]	1,259,504	2,787,186
2010/11	5,968,849	—	—	—	—

Table 3. Estimated annual weight (pounds) of discarded bycatch and total fishery mortality of golden king crab (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543, 1991/92–2009/10 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries); *estimates for 1991/92 and 1992/93 appear suspect and are not included in assessment analysis* (1991/92–2008/09 data provided by R. Foy, AFSC, Kodiak Laboratory, 7 August 2009 email; 2009/10 data provided by R. Foy, AFSC, Kodiak Laboratory, 13 August 2010 email).

Year	Fixed	Trawl	Total Bycatch	Total Bycatch Mortality
1991/92	0	0	0	0
1992/93	5	3	7	4
1993/94	3,960	8,164	12,124	8,511
1994/95	1,346	2,674	4,020	2,812
1995/96	367	5,165	5,532	4,315
1996/97	26	13,862	13,887	11,102
1997/98	539	1,071	1,610	1,126
1998/99	3,901	1,381	5,282	3,055
1999/00	10,572	1,422	11,995	6,424
2000/01	7,166	669	7,836	4,119
2001/02	1,387	417	1,804	1,027
2002/03	75,952	871	76,823	38,673
2003/04	86,186	1,498	87,684	44,291
2004/05	2,450	2,452	4,903	3,187
2005/06	1,246	4,151	5,397	3,944
2006/07	72,306	3,077	75,382	38,614
2007/08	254,225	3,641	257,867	130,026
2008/09	108,683	22,712	131,395	72,511
2009/10	44,226	18,061	62,287	36,562

Table 4. Estimated annual weight (pounds) of total fishery mortality to Aleutian Islands golden king crab, 1990/91–2009/10, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries; see 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
1990/91	6,950,362	2,764,760	—	—
1991/92	7,702,141	2,251,360	—	—
1992/93	6,291,197	2,616,444	—	—
1993/94	5,551,143	—	8,511	
1994/95	8,128,511	—	2,812	—
1995/96	6,960,406	2,409,910	4,315	9,374,631
1996/97	5,815,772	1,815,110	11,102	7,641,984
1997/98	5,945,683	1,738,534	1,126	7,685,343
1998/99	4,941,893	1,477,655	3,055	6,422,603
1999/00	5,838,788	1,510,314	6,424	7,355,526
2000/01	6,018,761	1,780,307	4,119	7,803,187
2001/02	5,918,706	1,377,692	1,027	7,297,425
2002/03	5,462,455	1,134,264	38,673	6,635,392
2003/04	5,665,828	994,697	44,291	6,704,816
2004/05	5,575,051	864,203	3,187	6,442,441
2005/06	5,520,318	504,747	3,944	6,029,009
2006/07	5,262,342	514,608	38,614	5,815,564
2007/08	5,508,100	606,926	130,026	6,245,052
2008/09	5,680,084	552,735	72,511	6,305,330
2009/10	5,912,287	557,437	36,562	6,506,286

Table 5. Data for calculation of $RET_{85/86-95/96}$ and estimates used in calculation of $R_{90/91-08/09}$ and $BM_{GF,93/94-08/09}$ for calculation of the recommended Alternative 1 Aleutian Islands golden king crab Tier 5 2011/12 total-catch OFL; values under $RET_{85/86-95/96}$ under from Table 1, values under $R_{90/91-08/09}$ were computed from the retained catch data and the crab bycatch mortality estimates in Table 4, and values under $BM_{GF,93/94-08/09}$ are from Table 4.

Season	$RET_{85/86-95/96}$	$R_{90/91-08/09}$	$BM_{GF,93/94-08/09}$
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		0.313	11,102
1997/98		0.294	1,126
1998/99		0.299	3,055
1999/00		0.259	6,424
2000/01		0.296	4,119
2001/02		0.233	1,027
2002/03		0.208	38,673
2003/04		0.176	44,291
2004/05		0.155	3,187
2005/06		0.091	3,944
2006/07		0.098	38,614
2007/08		0.110	130,026
2008/09		0.097	72,511
N	11	17	16
Mean	9,178,438	0.240	23,359
S.E.M.	896,511	0.026	8,827
CV	0.10	0.11	0.38

Table 6. Data for calculation of $RET_{85/86\text{-}95/96}$ and estimates used in calculation of $R_{96/97\text{-}08/09}$ and $BM_{GF,96/97\text{-}08/09}$ for calculation of the Alternative 2 Aleutian Islands golden king crab Tier 5 2011/12 total-catch OFL; values under $RET_{85/86\text{-}95/96}$ are from Table 1, values under $R_{96/97\text{-}08/09}$ were computed from the retained catch data and the crab bycatch mortality estimates in Table 4, and values under $BM_{GF,96/97\text{-}08/09}$ are from Table 4.

Season	$RET_{85/86\text{-}95/96}$	$R_{96/97\text{-}08/09}$	$BM_{GF,96/97\text{-}08/09}$
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		
1991/92	7,702,141		
1992/93	6,291,197		
1993/94	5,551,143		
1994/95	8,128,511		
1995/96	6,960,406		
1996/97		0.313	11,102
1997/98		0.294	1,126
1998/99		0.299	3,055
1999/00		0.259	6,424
2000/01		0.296	4,119
2001/02		0.233	1,027
2002/03		0.208	38,673
2003/04		0.176	44,291
2004/05		0.155	3,187
2005/06		0.091	3,944
2006/07		0.098	38,614
2007/08		0.110	130,026
2008/09		0.097	72,511
N	11	13	13
Mean	9,178,438	0.202	27,546
S.E.M.	896,511	0.024	10,582
CV	0.10	0.12	0.38

Table 7. Statistics for 1,000 bootstrap OFLs calculated according to Alternatives 1 and 2, with the computed OFLs for comparison.

	Alternative 1	Alternative 2
Computed OFL	11,404,670	11,061,356
Mean of 1,000 bootstrapped OFLs	11,433,908	11,072,214
Std. dev. of 1,000 bootstrapped OFLs	1,040,981	1,012,992
CV = (std. dev.)/(Mean)	0.09	0.09

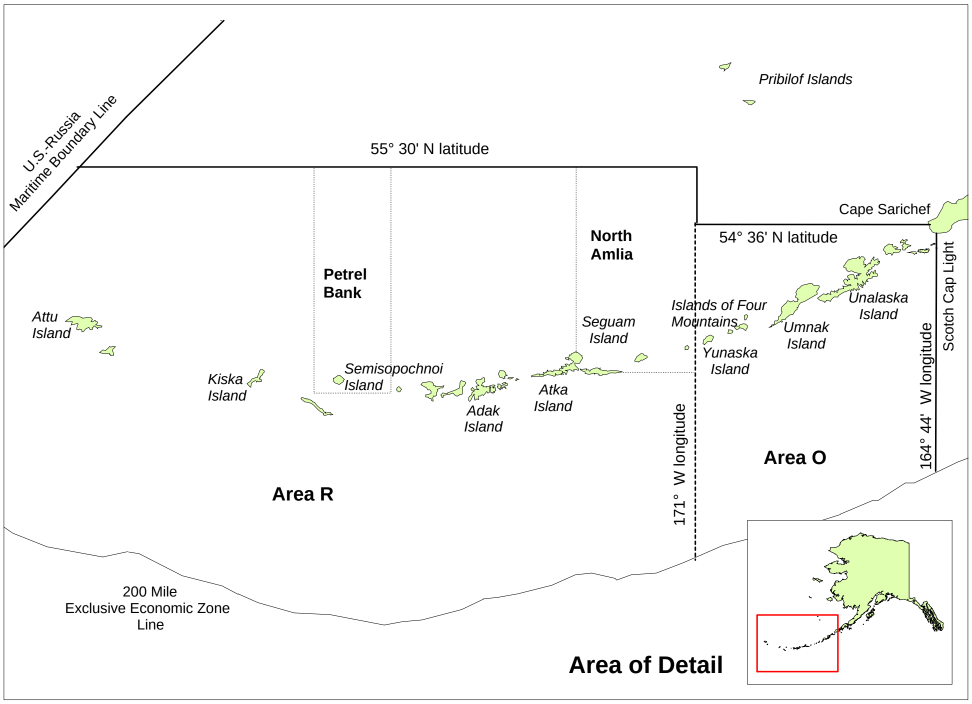

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Bowers et al. 2011).

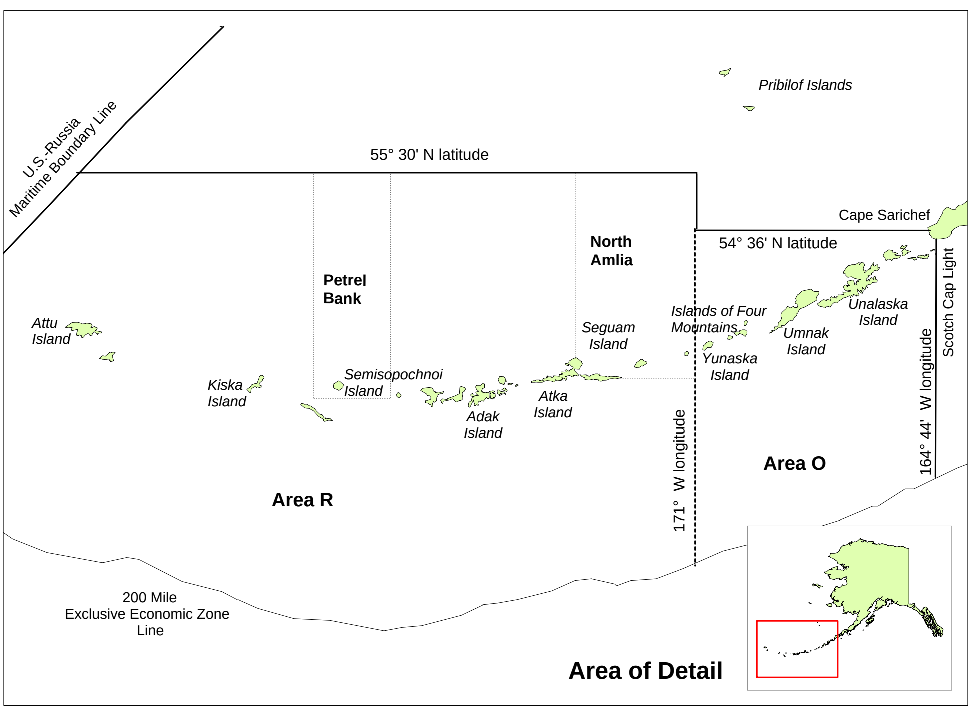

Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85 – 1995/96 seasons (Bowers et al. 2011).

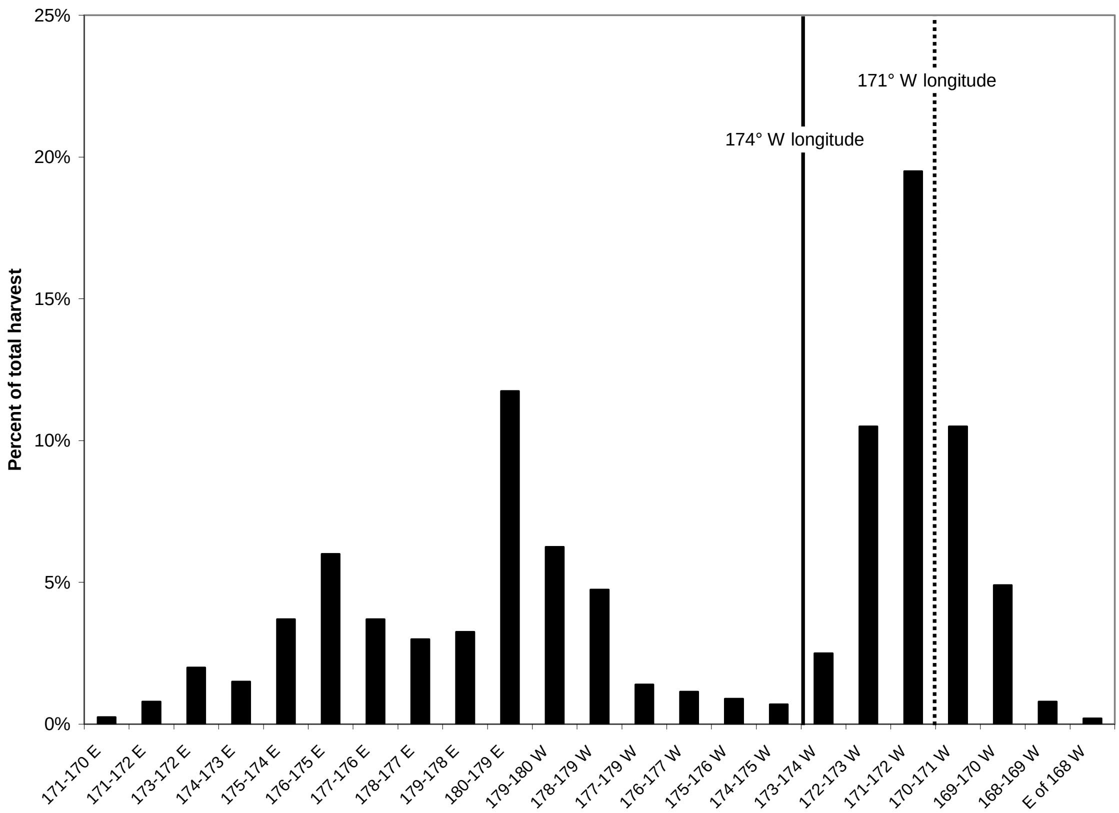

Figure 3. Percent of total 1982–1996 golden king crab harvest by one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude that was used until the end of the 1995/96 season to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude) and solid line denoting the border at 174° W longitude 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).

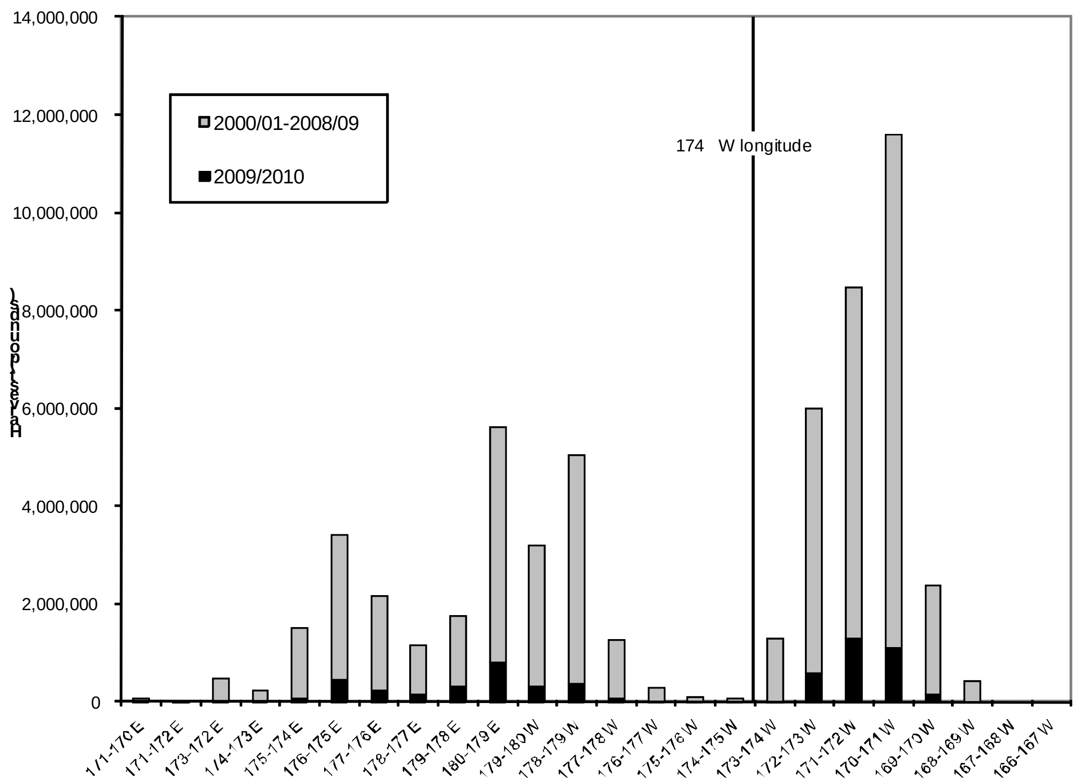

Figure 4. Harvest (pounds) of golden king crab by one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2009/10 commercial fishery seasons, with the harvest for the 2009/10 season distinguished from the total harvest for the 2000/01–2008/09 seasons; solid line denotes the 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 (2000/01–2008/09 data from Pengilly 2010; 2009/10 data from H. Fitch, ADF&G, 8 April 2011 email).

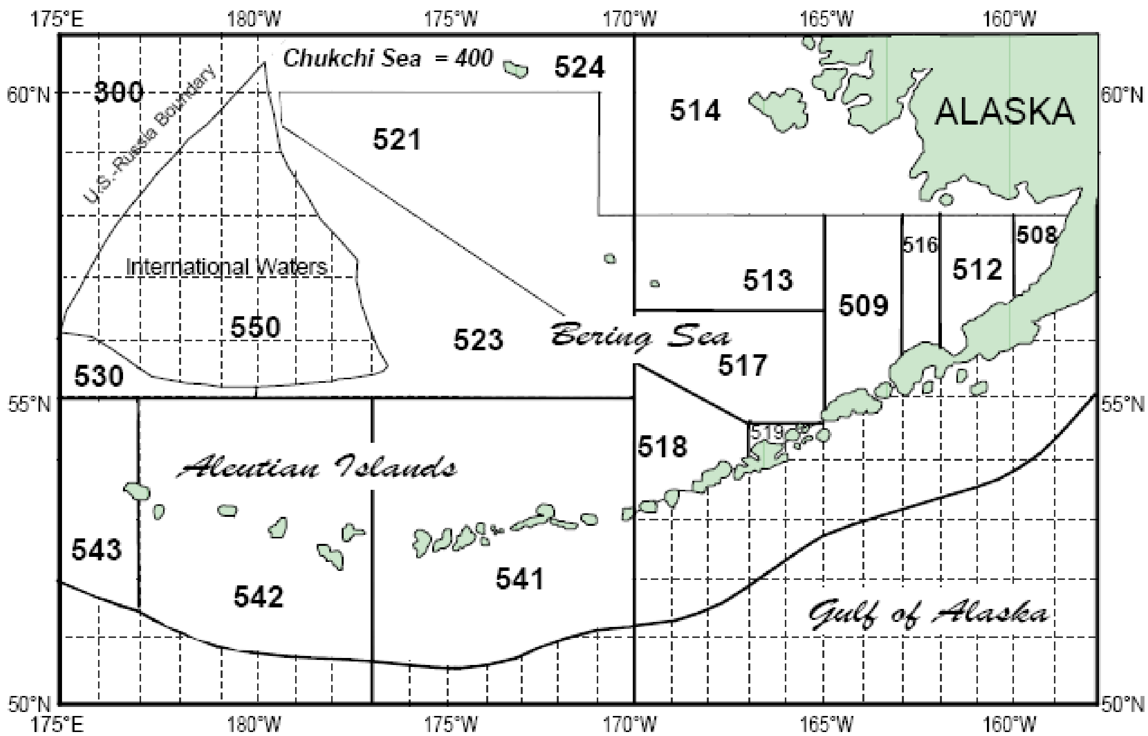

Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to obtain data on bycatch of Aleutian Islands golden king crab during groundfish fisheries (from http://www.fakr.noaa.gov/rr/figures/fig1.pdf).

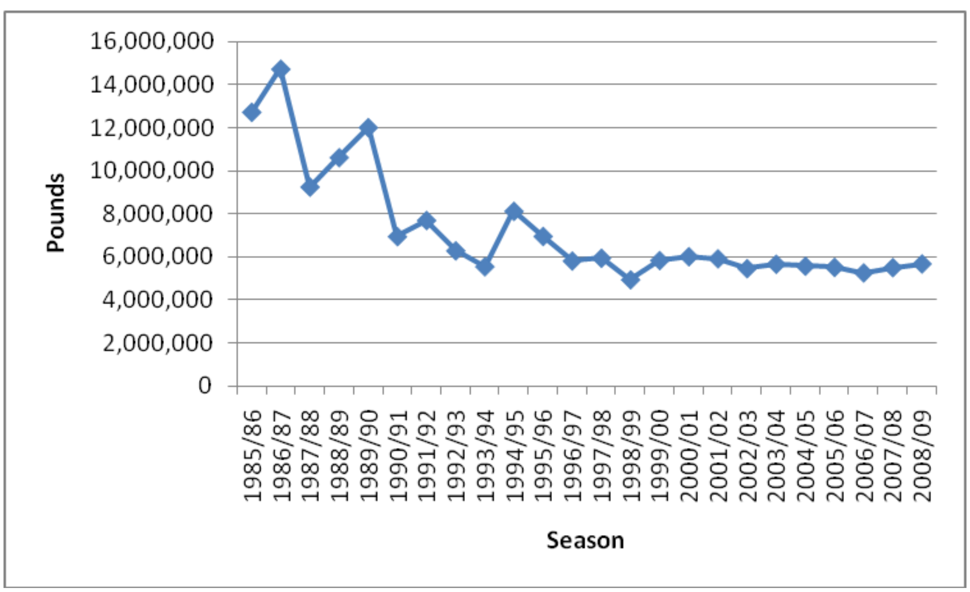

Figure 6. Retained catch (pounds) in the Aleutian Islands golden king crab fishery, 1985/86–2008/09.

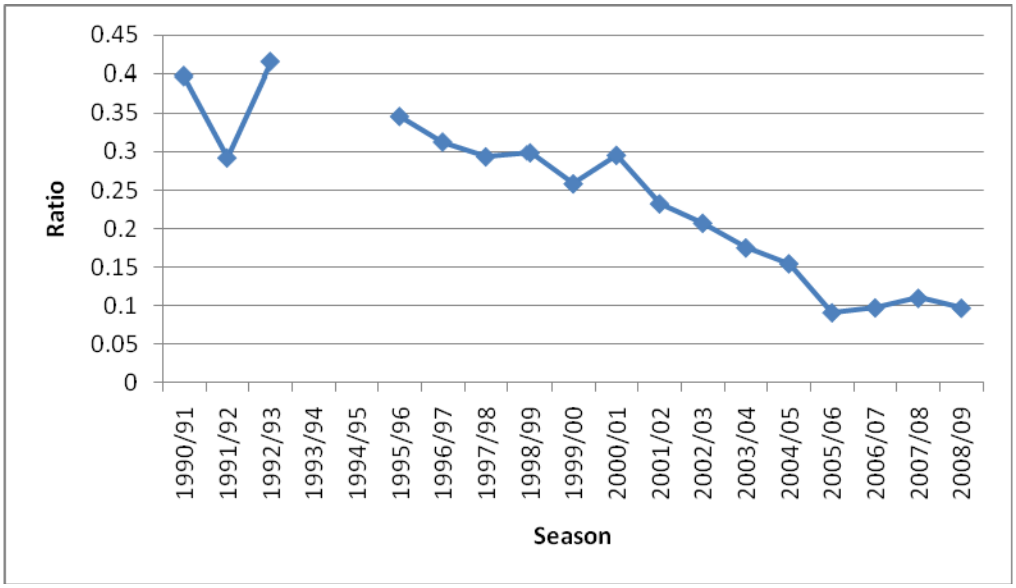

Figure 7. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Island golden king crab, 1990/91–2008/09.

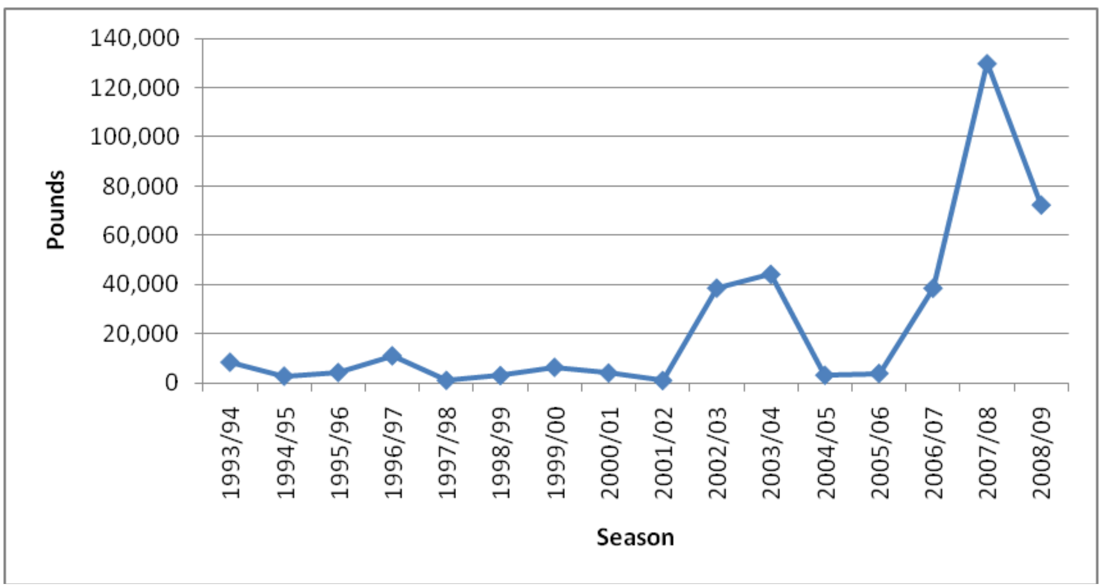

Figure 8. Estimated weight (pounds) of bycatch mortality of Aleutian Islands golden king crab due to groundfish fisheries, 1993/94–2008/09.

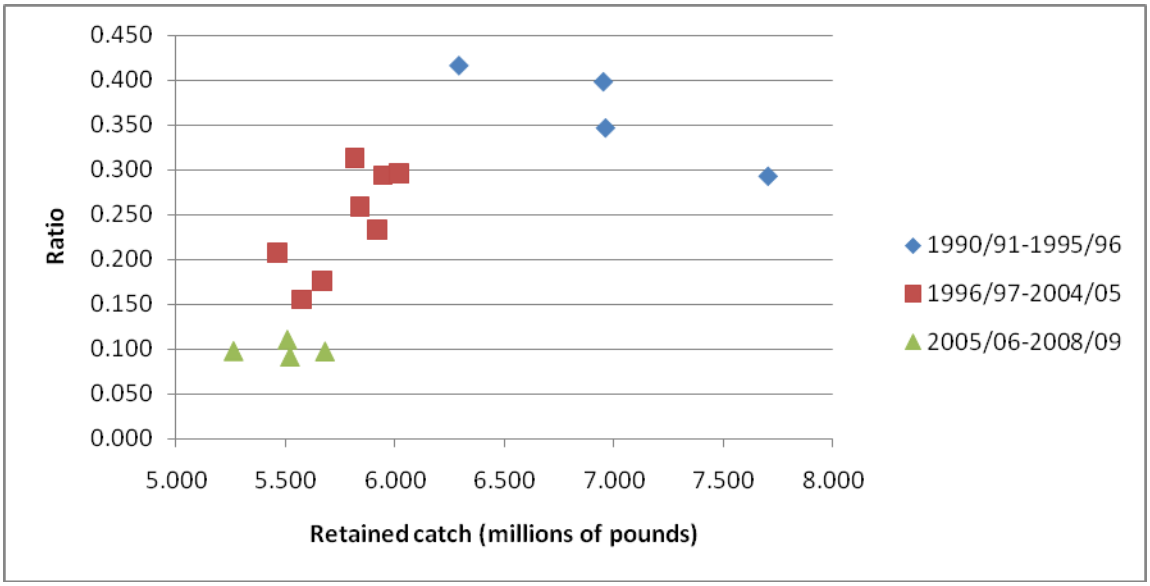

Figure 9. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Island golden king crab plotted against weight of retained catch, 1990/91–2008/09 (ratios for 1992/93–1993/94 not available).

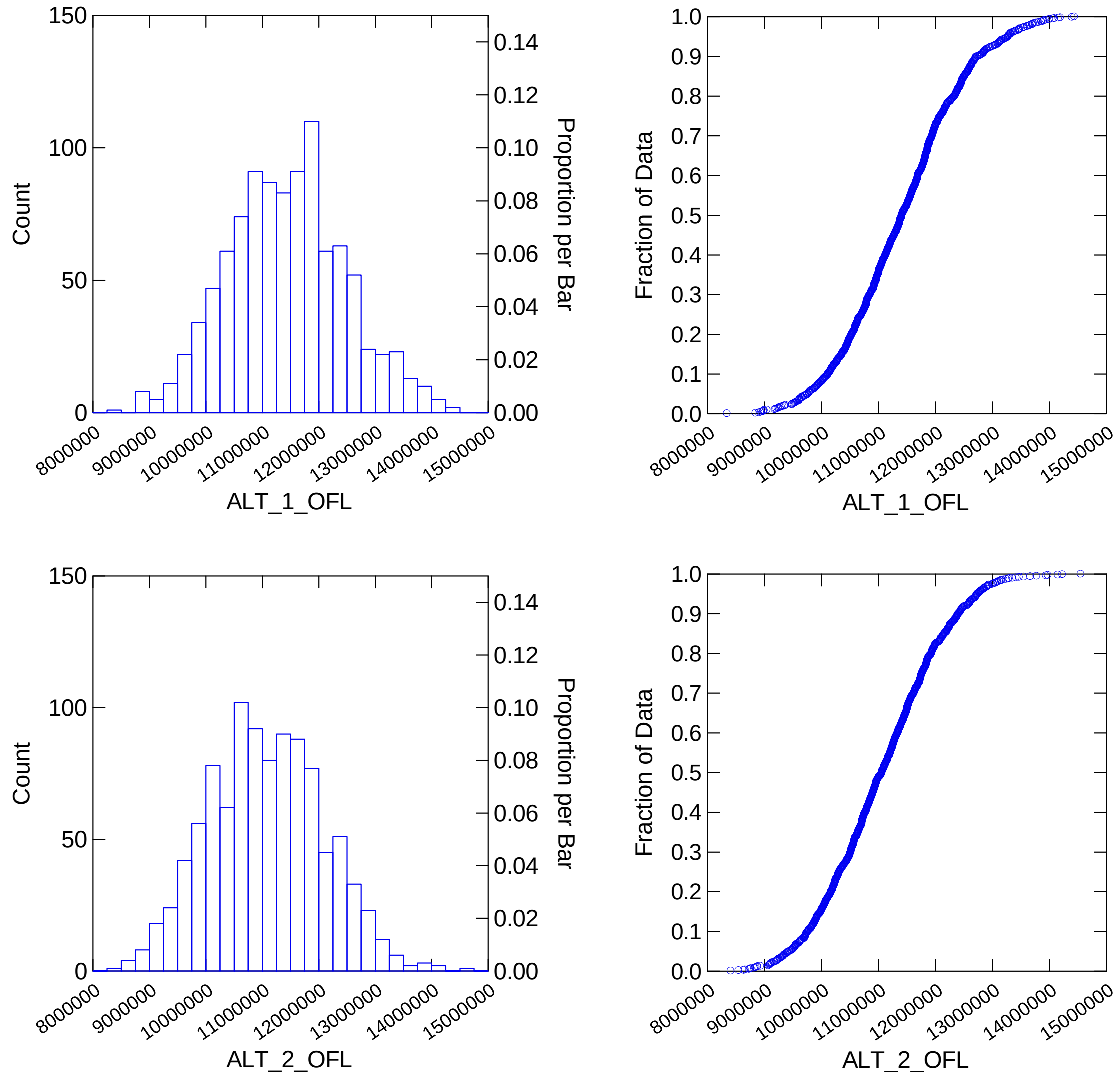

Figure 10. Bootstrapped estimates of the sampling distribution of the Alternative 1 (above) and Alternative 2 (below) 2011/2012 Tier 5 OFLs (pounds of total-catch) for the Aleutian Islands golden king crab stock; histograms in left column, quantile plots in right column.

Pribilof Islands Golden King Crab

May 2011 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak

Executive Summary

1. **Stock**: Golden king crab/Pribilof Islands (Pribilof District)

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") since 1984 (following the close of the 1983/84 season). The domestic fishery developed in the 1982/83, 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 pounds (388 t) by 50 vessels. Since then, participation in the fishery has been sporadic and annually retained catch has been variable, from 0 pounds in the nine years that no vessels participated (1984, 1986, 1990–1992, 2006–2009) up to a maximum of 0.342-million pounds (155 t) in 1995, when seven vessels made landings. The fishery is not rationalized and has been managed towards a guideline harvest level (GHL) of 0.150-million pounds (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; that catch cannot be reported under the confidentiality requirements of Sec. 16.05.815 (SOA statute). Non-retained bycatch can occur in the directed fishery, the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and the Bering Sea groundfish fisheries. Estimated annual weight of non-retained bycatch in directed and non-directed crab fisheries during calendar years 2001–2010 ranges from 0 pounds to 0.049-million pounds (22 t). Using the bycatch mortality rates assumed to compute the recommended OFL for 2012, estimates of annual total fishery mortality during calendar years 2001–2010 due to crab fisheries range from 0 pounds to 0.160-million pounds (73 t), with an average of 0.078-million pounds (35 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 pounds (12 t) annually during the 1991/92–2009/10 crab fishery years. Estimates of annual fishery mortality during 1991/92–2009/10 groundfish fisheries range from <0.001-million pounds (<1 t) to 0.019-million pounds (9 t), with an average of 0.006-million pounds (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, 2004, and 2008. The estimate for the Pribilof Canyon area in 2008 was 2.026-million pounds (919 t).

4. **Recruitment**:

From data collected during the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea upper continental slope surveys biomass of golden king crabs (all sizes and both sexes) are estimated to have increased in the eastern Bering Sea. In the Pribilof Canyon area biomass has been estimated to have increased from 1.504-million pounds (682 t) in 2002 to 2.026-million pounds in 2008 (919 t).

5. **Management performance**:

No overfished determination (i.e., MSST) is possible for this stock given the limited information and analysis on stock biomass that has been presented; there are presently no estimates of mature male biomass or mature female biomass for this stock. Overfishing did not occur during 2010 (the Pribilof Island golden king crab season is based on a calendar year); the retained-catch did not exceed the retained-catch OFL of 0.17-million pounds (77 t). Retained catch and total-catch mortality in 2010 are confidential under the requirements of Sec. 16.05.815 (SOA statute). No ABC was established for the ongoing 2011 season; the 2012 will be the first season that an ABC will be established for this stock.

See tables, below; OFL and ABC values for 2012 are the author's recommendations.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c,e]	ABC[c,e]
2008	N/A	N/A	0.150	0	0.000	N/A	N/A
2009	N/A	N/A	0.150	0	0.001	0.17, R	N/A
2010	N/A	N/A	0.150	confidential[f]	confidential[f]	0.17, R	N/A
2011	N/A	N/A	0.150	TBD	TBD	0.18, T	N/A
2012	N/A	N/A	TBD	TBD	TBD	0.20, T	0.18, T

a. The Pribilof Island golden king crab season is based on a calendar year.
b. Guideline harvest level expressed in millions of pounds. The Pribilof Islands golden king crab fishery is not rationalized and a TAC is not established for the fishery.
c. Millions of pounds.
d. Total retained catch, millions of pounds, 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 1991/92–2009/10 groundfish fisheries are ≤0.019-million pounds, with an average of 0.006-million pounds.
e. Noted as "R" for retained-catch-only OFL and "T" for total-catch OFL.
f. Only one vessel participated in the 2010 season; catch statistics are confidential under the confidentiality requirements of Sec. 16.05.815 (SOA statute).

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c,e]	ABC[c,e]
2008	N/A	N/A	68	0	0.0	N/A	N/A
2009	N/A	N/A	68	0	0.5	77, R	N/A
2010	N/A	N/A	68	confidential[f]	confidential[f]	77, R	N/A
2011	N/A	N/A	68	TBD	TBD	82, T	N/A
2012	N/A	N/A	TBD	TBD	TBD	93, T	84, T

a. The Pribilof Island golden king crab season is based on a calendar year.
b. Guideline harvest level expressed in t. The Pribilof Islands golden king crab fishery is not rationalized and a TAC is not established for the fishery.
c. Metric tons.
d. Total retained catch, t, 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 1991/92–2009/10 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.
f. Only one vessel participated in the 2010 season; catch statistics are confidential under the confidentiality requirements of Sec. 16.05.815 (SOA statute).

6. **Basis for the OFL and ABC:** See table, below; values for 2012 are the author's recommendations.

Year[a]	Tier	Years to define Average catch (OFL)	Natural Mortality	Buffer
2009	5	1993-1999[b]	0.18[e]	N/A
2010	5	1993–1998[b]	0.18[e]	N/A
2011	5	1993–1998[c]	0.18[e]	N/A
2012	5	1993–1998[d]	0.18[e]	10%

a. The Pribilof Island golden king crab 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 alternative Tier 5 OFLs was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 0.48-million pounds (CV = 0.28). See section G.1.

8. **Basis for the ABC recommendation:** A 10% buffer on the OFL; 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 pounds. One vessel has initiated fishing so far in the ongoing 2011 season.

2. **Changes to the input data:**
   - Retained catch and bycatch data has been updated with the results for the 2010 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 have been updated using the data collected from crab during 2010 and from groundfish fisheries during 2009/10. Bycatch data from the non-directed crab fisheries during 1994–2000 have been added; although data on bycatch during non-directed crab fisheries were collected prior to 1994, they were not available due to an ongoing project to reconfigure the crab observer database for data collected prior to 1994. Minor errors in the time series of catch statistics or calculations due typographical errors or rounding in

computations that were presented in the May 2010 have been corrected. Although the errors were minor, those corrections would change the computed OFL for 2011 expressed to the rounded to the nearest 0.01-million pounds from 0.18-million pounds to 0.19-million pounds.

3. **Changes to the assessment methodology:** None. This assessment follows the methodology recommended by the CPT in May 2010 and the SSC in June 2010, but incorporates new data from the 2010 season.

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 pounds. 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.
   - The OFL for 2011 was established as a total-catch OFL of 0.18-million pounds and was estimated as the average retained catch (including deadloss) for the period 1993–1998 times 1.05 plus 0.006-million pounds; i.e.,

$$OFL_{tot,2011} = 1.05*OFL_{ret,1993\text{-}1998} + 0.006\text{-million pounds.}$$

     $OFL_{ret,1993\text{-}1998}$ 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 pounds 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 recommended OFL (Alternative 1) for 2012 is a total-catch OFL of 0.20-million pounds and was estimated using 1993–1998 to compute average annual retained catch, an estimate of pounds of bycatch mortality per pound of retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 1994–1998 and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{TOT(1),2012} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,1992/93\text{–}1998/99},$$

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

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 2010:
     1. *"Some assessments provided results in metric tons. The CPT recommendation to use metric tons refers only to the ACL analysis and traditional assessment currencies (lbs) should continue to be used in stock assessments."*
        - Response: That was done.
     2. *"The team requested that all assessments explain how the groundfish bycatch data are used in the assessment and that all assessment chapters should be consistent in distinguishing and separately presenting groundfish bycatch from fixed gear fisheries and trawl gear fisheries."*
        - Response: Explanations were made and statistics from fixed gear and trawl gear fisheries are distinguished and presented separately.
   - SSC, June 2010: *"In order to have greater consistency between assessments, the SSC recommends that catch statistics reported in the executive summary section contain both metric tons and pounds (million)."*
     - Response: Catch statistics in the executive summary section contain both pounds (million) and metric tons (in parenthesis, following the pounds); elsewhere, statistics are reported in millions of pounds (except for Figure 2, which was copied from another document).
   - CPT, September 2010: None pertaining to this stock.
   - SSC, October 2010: None pertaining to this stock.

2. **Responses to the most recent two sets of SSC and CPT comments specific to the assessment:**
   - CPT, May 2010: *"No additional comments – see Crab SAFE introduction for CPT recommendations on this stock."*
     - Response: The CPT recommendations for this stock in the May Crab SAFE introduction recommended that a total-catch OFL be established for this stock in 2011, as opposed to the retained-catch OFLs established for 2009 and 2010, using the approach outlined in second bullet under A.4 (above). A total-catch OFL is recommended by the author for 2012.
   - SSC, June 2010: "*The SSC supports the Crab Plan Team's recommendation to manage this stock under Tier 5. The SSC also supports the CPTs recommended use of a total-catch OFL = 0.18 M lbs [82 t] for the first time in the Pribilof District in 2011."*
     - Response: None.
   - CPT, September 2010: None.
   - SSC, October 2010: None.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:** General distribution of golden king crabs 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 Islands king crab stock boundary is defined by the boundaries of the Pribilof District of Registration Area Q (Figure 1). Bowers et al. (2011, pages 87–88) 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, and 2008 NMFS-AFSC eastern Bering Sea continental slope trawl surveys presented by Haaga et al. (2009) and of the 2004 survey presented by Hoff and Britt (2005) show that the biomass, number, and density (in number per area and in weight per area) of golden king crabs 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 crabs in the Bering Sea occur in the Pribilof Canyon (Hoff and Britt 2005, Haaga et al. 2009; Figure 2), as does most of the commercial catch of golden king crabs (Bowers et al. 2011, Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006).

Results of the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea continental slope trawl surveys presented by Haaga et al. (2009) and of the 2004 survey presented by Hoff and Britt (2005) show that majority of golden king crabs on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (see section D.2.d). Commercial fishing for golden king crabs 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); 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:** I am aware of no data for evaluating stock structure within this stock.

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 crabs is adapted from Watson et al. (2002):

Unlike red king crabs, golden king crabs 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 crabs 95–155-mm CL and female golden king crabs 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 crabs 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 crabs, 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 crabs. Data from tagging studies on female golden king crabs 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 crabs 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 crabs 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 crabs may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crabs 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 crabs 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 2009 is provided in Bowers et al. (2011, pages 90–93).

The first domestic harvest of golden king crabs 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 pounds (Table 1, Figure 3) 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 pounds to 0.342-million pounds 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 has fished in the 2010 season; catch statistics from that single vessel 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 pounds, whereas for the 2000-2010 the GHL has been 0.150-million pounds.

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 the Pribilof Islands golden king crab fishery. By State of Alaska regulation (5 AAC 34.920 (a)), the minimum legal size limit 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 crabs may be commercially fished only with king crab pots (as defined in 5 AAC 34.050). Pots used to fish for golden king crabs 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 crabs (5 AAC 34.925 (c)). There is a pot limit of 40 pots for vessels ≤125-feet LOA and of 50 pots for vessels >125-feet LOA (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 2010 directed fishery (both of which are confidential), estimated bycatch in non-directed crab fisheries during 2010, and estimated bycatch in groundfish fisheries during the 2009/10 crab fishery year have been added. Bycatch data from the non-directed crab fisheries during 1994–2000 have been added.

2. <u>Data presented as time series</u>:

a. <u>Total catch</u> and b. <u>Information on bycatch and discards</u>:

- The 1981/82–1983/84, 1984–2010 time series of retained catch (number and pounds of crabs harvested, including deadloss), effort (vessels, landings, and pot lifts), average weight of landed crabs, average carapace length of landed crabs, and CPUE (number of landed crabs captured per pot lift) is presented in Table 1.
- The 2001–2010 times series of weight of retained catch, estimated bycatch and estimated weight of fishery mortality of Pribilof Islands golden king crabs during commercial crab fisheries is given in Table 2. Bycatch of Pribilof Islands golden king crabs 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, the bycatch estimates 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 red king crabs by applying a weight-at-length estimator (see below). 2001 is the first year that observers were deployed to collect data on bycatch during the Pribilof District golden king crab fishery. Due to the limited number of observed vessels, retained catch and observer data from at least one of the fisheries are confidential for 2001, for 2003–2005, and 2010. Estimates of bycatch during non-directed crab fisheries for the periods 1994–1998, 1994-2010, and 2001–2010 are also provided in Table 2. Following Siddeek et al. (2010), the bycatch mortality rate of golden king crabs captured and discarded during Aleutian Islands golden king crab fishery was assumed to be 0.2. Following Foy (2010a, b), bycatch mortality rate 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 as provided were grouped into crab fishery years, rather than into calendar years. The 1991/92–2009/10 time series of estimated annual weight of bycatch and total fishery mortality of golden king crabs in reporting areas 513, 517, and 521 during federal groundfish fisheries by gear type (combining pot and hook-and-line gear as as single "fixed gear" category and combining non-pelagic and pelagic trawl gear as a single "trawl" category) is provided in Table 3. Following Foy (2010a, b), the bycatch mortality of king crabs captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crabs 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, biomass estimates of golden king crabs (all sizes and sexes) by area and depth zone from the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey are presented in Table 4. Details on the survey sampling effort during the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey and the biomass estimates of golden king crabs (all sizes and sexes) by area and depth zone with estimated CVs are presented in Table 5.

e. ***Survey catch at length:*** Survey catch at length data are not used in a Tier 5 assessment. However, size composition, by sex and depth zone, of the estimated golden king crab population from the 2004 eastern Bering Sea upper continental slope trawl survey is presented in Figure 3.

f. ***Other data time series:*** See section D.4 on other time-series data that is 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):

I am not aware of data on growth per molt of Pribilof Islands golden king crabs. Growth per molt of juvenile golden king crabs, 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 crabs 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 red king crabs 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 pounds by dividing by 453.6.

c. Natural mortality rate:

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18. Note, however, natural mortality was not used for OFL estimation because this stock belongs to Tier 5.

4. Information on any data sources that were available, but were excluded from the assessment:

Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea (EBS) upper continental slope have been performed in 2002, 2004, and 2008 (Hoff and Britt 2005, Haaga et al. 2009). The raw data from those surveys have not been accessed for this assessment; only summary of results and stock biomass estimates that have been published for the 2004 survey (Hoff and Britt 2005) and reported for the 2002, 2004, and 2008 surveys (Hagga et al. 2009) are presented in this assessment. Access to the raw data from those standardized surveys could allow for estimation of abundance and biomass of golden king crab in the Pribilof District by relevant size, sex, and reproductive-status classes (e.g., mature male biomass, mature female biomass, legal-sized male biomass, etc). Additionally, a pilot slope survey was also performed in 2000 and triennial surveys using a variety of nets, methods, vessels, and sampling locations were performed during 1979–1991 (Hoff and Britt 2005) and no data from those surveys were accessed for, and no results from those surveys were reported on, in this assessment. Note, however, that the "degree of comparability between the post-2000 surveys and those conducted from 1979 to 1991 has yet to be determined due to the differences in sampling gear, survey design, sampling methodology, and species identification" (Hoff and Britt 2005). The CPT in September 2010 encouraged that data from the EBS slope survey be included to the extent possible to consider whether that information may be sufficient to move this assessment up to Tier 4 in future years (2009 Crab SAFE, Executive Summary). Although published and unpublished summaries of the EBS slope survey data have been included in recent SAFEs, the author has not acquired the raw survey data, as would be necessary for considering if that data is sufficient for a Tier 4 assessment.

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. <u>Model Description</u>: *Subsections a–i are not applicable to a Tier 5 sock.*
No assessment model for the Pribilof Islands golden king crab stock exists and none is in development. Accordingly, it has been recommended by NPFMC (2007) and by the CPT and SSC in 2008 and 2009 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 2011 OFL for this stock. This assessment recommends – and only considers – use of a total-catch OFL for 2012.

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 among 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 during the 1976/77 "regime shift" and growth to legal size. 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 again recommended that approach for setting a retained-catch OFL for 2010, but using the average retained catch during 1993–1998 for setting a retained-catch OFL. In May 2010, the CPT established a total-catch OFL computed as a function of the average retained catch during 1993–1998. Other time periods, extending into years post-1999, had been considered for computing the average retained in the establishment of the 2009, 2010, 2011 OFLs, but those time periods were rejected by the CPT and the SSC.

Because no new information has become available since the May 2010 CPT meeting (aside from the confidential catch data from the 2010 Pribilof District golden king crab fishery season and the groundfish bycatch estimates for 2009/10) and because the both the CPT and the SSC have settled on a time period of 1993–1998 for computing the average retained catch in the calculations of the 2010 and 20011 OFLs, the author sees no reason to consider any other time periods besides 1993–1998 for computing the average retained catch in the calculation of the 2012 OFL. Considerations made in choosing the 1993–1998 time period, as opposed to the alternative time periods of 1993–1999 and 1993–2002, were reviewed in the Pribilof Islands golden king crab chapter of the 2010 SAFE and will not be repeated verbatim here. Briefly, the 1993–1998 time period was chosen as the best period for computing the 2010 and 2011 OFLs because, although it the shortest (6 years) of the periods of consecutive years considered, it provided the only period of consecutive during which the harvest was not constrained by a GHL and during which the fishery landings occurred (see Table 1).

With regard to the alternative approaches for estimating the non-retained component of the total catch mortality, an obvious issue exists in the fact that there are no data on bycatch in the directed fishery during 1993–1998, so that choices must be made on how to best estimate the bycatch mortality during that period.

3. Model Selection and Evaluation:

a. *Description of alternative model configurations*

Three alternatives are presented. Alternative 1 is the author's recommended alternative. Alternative 2 is the status quo approach (i.e., the approach used to establish the 2011 total-catch OFL) except that it uses updated bycatch data from crab fisheries in 2010 and groundfish fisheries in 2009/10. Alternative 3 is the status quo (i.e., it is the same as the total-catch OFL established for 2011).

Alternative 1 (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 pounds of bycatch mortality per pound of retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 1994–1998 and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{TOT(1),2012} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93\text{–}98/99},$$

where,

- $R_{2001\text{–}2010}$ is the average of the estimated average annual ratio of pounds of bycatch mortality to pounds of retained catch in the directed fishery during 2001–2010
- $RET_{1993\text{-}1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998
- $BM_{GF,92/93\text{–}98/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

The average of the estimated annual ratio of pounds of bycatch mortality to pounds 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 6; the column means in Table 6 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 $BM_{GF,93/94\text{-}98/99}$, $OFL_{TOT(1),2012}$ is,

$$OFL_{TOT(1),2012} = (1+0.52)*173{,}722 + 13{,}418 + 8{,}353 = 0.20\text{-million pounds.}$$

<u>Alternative 2</u>. Alternative 2 follows the approach used to set the total-catch OFL for 2011, but updates the time series of bycatch estimates using the data collected in 2010 (from crab fisheries) and 2009/10 (from groundfish fisheries). Alternative 2 sets the OFL as a total-catch OFL using 1993–1998 to compute average annual retained catch, an estimate of pounds of bycatch mortality per pound of retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 2001–2010 and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1991/92–2009/10; i.e.,

$$OFL_{TOT(2),2012} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,2001\text{-}2010} + BM_{GF,91/92\text{–}09/10},$$

where,

- $R_{2001\text{–}2010}$ 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
- $BM_{NC,2001\text{-}2010}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 2001–2010
- $BM_{GF,91/92\text{–}09/10}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1991/92–2009/10.

Statistics on the data and estimates used to calculate, $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,2001\text{–}2010}$, and $BM_{GF,91/92\text{-}09/10}$ are provided in Table 7; the column means in Table 7 are the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,2001\text{–}2010}$, and $BM_{GF,91/92\text{-}09/10}$. Using those calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,2001\text{–}2010}$, and $BM_{GF,91/92\text{-}09/10}$, $OFL_{TOT(2),2012}$ is,

$$OFL_{TOT(2),2012} = (1+0.052)*173{,}722 + 548 + 6{,}051 = 0.19\text{-million pounds.}$$

<u>Alternative 3</u>. Alternative 3 is the same used to set the total-catch OFL for 2011. Alternative 3 sets the OFL as a total-catch OFL using 1993–1998 to compute average annual retained catch, an estimate of pounds of bycatch mortality per pound of retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 2001–2009 and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1991/92–2008/09; i.e.,

$$OFL_{TOT(3),2012} = (1+R_{2001\text{–}2005})*RET_{1993\text{-}1998} + BM_{NC,2001\text{-}2009} + BM_{GF,91/92\text{–}08/09},$$

where,

- $R_{2001–2005}$ is the average of the estimated average annual ratio of pounds of bycatch mortality to pounds of retained in the directed fishery during 2001–2005
- $RET_{1993-1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,2001-2009}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 2001–2009
- $BM_{GF,91/92–08/09}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1991/92–2008/09.

Statistics on the data and estimates used to calculate, $RET_{1993-1998}$, $R_{2001-2005}$, $BM_{NC,2001–2009}$, and $BM_{GF,91/92-08/09}$ are provided in Table 8; the column means in Table 8 are the calculated values of $RET_{1993-1998}$, $R_{2001-2005}$, $BM_{NC,2001–2009}$, and $BM_{GF,91/92-08/09}$. Using those calculated values of $RET_{1993-1998}$, $R_{2001-2005}$, $BM_{NC,2001–2009}$, and $BM_{GF,91/92-08/09}$, $OFL_{TOT(3), 2012}$ is,

$OFL_{TOT(3),2012}$= (1+0.054)*173,722 +608 + 5,489 = 0.19-million pounds.

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 pounds)**
Alt. 3 – status quo	Total-catch	1993–1998	0.19
Alt. 2	Total-catch	1993–1998	0.19
Alt. 1 – recommended	Total-catch	1993–1998	0.20

Alternative 1 is recommended because it comes as close as possible to meeting the specifications of a Tier 5 OFL (**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."

Alternative 2 is not recommended by the author because bycatch data from 2001–2010 from the non-directed crab fisheries and bycatch data over the period 1991/92–2009/10 would be expected to provide poorer estimates of the bycatch during 1993–1998 than the more contemporaneous data used for Alternative 1. The approach was used to establish the 2011 total-catch OFL because bycatch data from crab fisheries prior to 2001 were not available at the May 2010 CPT meeting. Now that the data prior to 2001 are available, the author believes those data should be used to meet the specifications of a Tier 5 OFL (**Federal Register** / Vol. 73, No. 116, page 33926; quoted above) to the extent possible.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:***

All alternatives have the same number of parameters. Alternative 1 is more realistic and less complex than alternative 2 because it uses the most contemporaneous data available to estimate bycatch mortality during 1993–1998, whereas Alternative 2 does not and the total-catch OFL established for 2011 did not.

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 (pounds) during a season are from fish tickets landings recorded at 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 2010), 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 6-8.

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.
- The bycatch mortality rates used in estimation of total catch.

See also Tables 6–8 and Figure 4.

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 and 2011 seasons. The time period 1993–1998 provides the longest continuous time period through 2010 during which vessels participated in the fishery, retained-catch data can be retrieved that is not confidential, and the retained catch was not constrained by a GHL. Data on bycatch mortality contemporaneous with 1993-1998 to the extent possible is 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.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c,e]	ABC[c,e]
2008	N/A	N/A	0.150	0	0.000	N/A	N/A
2009	N/A	N/A	0.150	0	0.001	0.17, R	N/A
2010	N/A	N/A	0.150	confidential[f]	confidential[f]	0.17, R	N/A
2011	N/A	N/A	0.150	TBD	TBD	0.18, T	N/A
2012	N/A	N/A	TBD	TBD	TBD	0.20, T	0.18, T

a. The Pribilof Island golden king crab season is based on a calendar year.
b. Guideline harvest level expressed in millions of pounds. The Pribilof Islands golden king crab fishery is not rationalized and a TAC is not established for the fishery.
c. Millions of pounds.
d. Total retained catch, millions of pounds, 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 1991/92–2009/10 groundfish fisheries are ≤0.019-million pounds, with an average of 0.006-million pounds.
e. Noted as "R" for retained-catch-only OFL and "T" for total-catch OFL.
f. Only one vessel participated in the 2010 season; catch statistics are confidential under the confidentiality requirements of Sec. 16.05.815 (SOA statute).

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 pounds (0.17-million pounds).

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 estimates of the sampling distributions (assuming no error in estimation of bycatch) of the Alternatives 1–3 OFLs are shown in Figure 4 (1,000 samples drawn with replacement independently from each of the four columns of values in Table 6 to calculate $R_{2001\text{-}2010}$, $RET_{1993\text{-}1998}$, $BM_{NC,1994\text{-}1998}$, $BM_{GF,92/93\text{-}98/99}$ and $OFL_{TOT(1),2012}$; 1,000 samples drawn with replacement independently from each of the four columns of values in Table 7 to calculate $R_{2001\text{-}2010}$, $RET_{1993\text{-}1998}$, $BM_{NC,2001\text{-}2010}$, $BM_{GF,91/92\text{-}09/10}$ and $OFL_{TOT(2),2012}$; and 1,000 samples drawn with replacement independently from each of the four columns of values in Table 8 to calculate $R_{2001\text{-}2005}$, $RET_{1993\text{-}1998}$, $BM_{NC,2001\text{-}2009}$, $BM_{GF,91/92\text{-}08/09}$ and $OFL_{TOT(3),2012}$). Table 9 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 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. (1-0.1)·(204,612 pounds) = 0.18-million pounds.

H. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

The available data from the NMFS-AFSC eastern Bering Sea upper continental shelf trawl surveys that have been performed (see Hoff and Britt 2005 for review through the 2004 survey) should be examined for their utility in providing reliable estimates of biomass and abundance of golden king crabs by size, sex, and reproductive status within the Pribilof District. As well as the need to determine the comparability of results from the standardized survey that has been performed since 2002 with the results of the surveys performed during 1979–1991 (see section D.4 and Hoff and Britt 2005), there is also a need to estimate the catchability of golden king crabs, by sex and size, by the currently-used survey gear.

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Table 1. Harvest history for the Pribilof Islands golden king crab fishery from the 1981/82 season through 2010 (from Table 2-14 in Bowers et al. 2011, updated with 2010 data provided by H. Fitch, ADF&G, Dutch Harbor via 8 April 2011 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

Note: CF = confidential, less than three vessels or processors participated in fishery

[a] Deadloss included.

[b] Guideline harvest level in pounds.

[c] In pounds.

[d] Number of legal crabs per pot lift.

[e] Carapace length in millimeters.

Table 2. Weight (in pounds) of retained catch, estimated non-retained bycatch, and estimated total fishery mortality of Pribilof Islands golden king crabs during crab fisheries, 2001–2010 (assumes a bycatch mortality rate of 0.2 for the directed fishery and a bycatch mortality rate of 0.5 for non-directed fisheries; from 2010 Crab SAFE, with update for 2010).

		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	not avail.	not avail.	—
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

a. Value is likely an over-estimate. Only 5 golden king crabs (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, but none of those were measured to provide an estimate of weight. An average weight of 4.3 pounds per crab was used to estimate the total bycatch weight; 4.3 pounds is average weight of landed golden king crabs during the 2002 Pribilof District golden king crab fishery.

Table 3. Estimated annual weight (pounds) of discarded bycatch and total bycatch mortality of golden king crabs (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 513, 517, and 521, 1991/92–2009/10 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries; updated from 2010 SAFE with 2009/10 provided by R. Foy AFSC, Kodiak Laboratory via 13 August 2010 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

Table 4. Biomass estimates (metric tons) of golden king crabs (all sizes, both sexes) from results of the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey, by survey subarea and depth zone (from Haaga et al. 2009 and J. Haaga, NMFS-AFSC, Kodiak, 26 August 2009).

Year	Depth (m)	Bering Canyon[a]	Pribilof Canyon[b]	Inter-canyon Pribilof-Zhemchug[b]	Zhemchug Canyon[b]	Inter-canyon Zhemchug-Navarin[a]	Perenets /Zhemchug Canyons[c]
2004	200-400	53	289	49	52	16	29
	400-600	78	253	32	1	3	14
	600-800	0	121	1	0	0	0
	800-1000	1	0	0	0	0	0
	1000-1200	0	19	0	0	0	0
	Total	131	682	81	53	19	44
2004	200-400	4	526	25	121	13	2
	400-600	45	220	13	0	13	22
	600-800	14	67	10	0	0	0
	800-1000	1	4	3	0	0	0
	1000-1200	0	0	0	0	0	0
	Total	65	817	51	121	25	24
2008	200-400	67	258	65	173	0	38
	400-600	78	584	19	0	2	29
	600-800	2	76	8	32	0	0
	800-1000	0	0	0	0	0	0
	1000-1200	0	2	0	0	0	0
	Total	146	919	91	206	2	66

a. Partially in Pribilof District.
b. Entirely in Pribilof District.
c. Not in Pribilof District.

Table 5. Survey effort (hauls), surveyed area, biomass estimates (metric tons) of golden king crabs (all sizes, both sexes), estimated variances of biomass estimates, and estimated CVs of biomass estimates from results of the 2004NMFS-AFSC eastern Bering Sea upper continental slope trawl survey, by survey subarea and depth zone (from Tables 1 and 47 *in* Hoff and Britt 2005).

Area	Depth (m)	Hauls	Area (km^2)	Biomass	Variance of Biomass	CV
Bering Canyon[a]	200-400	33	4,012.41	4.21E+00	1.77E+01	100%
	400-600	37	4,062.77	4.52E+01	1.32E+02	25%
	600-800	14	1,741.66	1.43E+01	5.02E+01	50%
	800-1000	8	1,354.74	1.27E+00	1.62E+00	100%
	1,000-1,200	9	1,106.89	5.69E-02	3.24E-03	100%
	Total	101	12,278.47	7.65E+01	2.02E+02	19%
Pribilof Canyon[b]	200-400	10	1,157.64	5.26E+02	8.61E+04	56%
	400-600	5	705.08	2.20E+02	1.04E+04	46%
	600-800	5	591.27	6.69E+01	1.53E+03	58%
	800-1000	3	552.73	3.99E+00	1.59E+01	100%
	1,000-1,200	5	535.67	0.00E+00	0.00E+00	-
	Total	28	3,542.39	8.17E+02	9.80E+04	38%
Pribilof-Zhemchug inter-canyon[b]	200-400	7	903.78	2.54E+01	2.69E+02	65%
	400-600	6	886.11	1.27E+01	7.60E+01	69%
	600-800	6	910.26	9.91E+00	8.07E+01	91%
	800-1000	4	732.35	2.80E+00	7.83E+00	100%
	1,000-1,200	2	675.52	0.00E+00	0.00E+00	
	Total	25	4,108.02	5.08E+01	4.34E+02	41%
Zhemchug Canyon[b]	200-400	9	1,236.27	1.21E+02	1.94E+03	36%
	400-600	5	730.35	0.00E+00	0.00E+00	-
	600-800	4	693.95	0.00E+00	0.00E+00	-
	800-1000	4	707.59	0.00E+00	0.00E+00	-
	1,000-1,200	3	662.42	0.00E+00	0.00E+00	-
	Total	25	4,030.58	1.21E+02	1.94E+03	36%
Zhemchug-Navarin inter-canyon[a]	200-400	3	423.71	1.25E+01	1.56E+02	100%
	400-600	3	426.73	7.50E+00	5.62E+01	100%
	600-800	4	431.83	0.00E+00	0.00E+00	-
	800-1000	3	551.99	0.00E+00	0.00E+00	-
	1,000-1,200	2	570.14	0.00E+00	0.00E+00	-
	Total	15	2,404.40	2.00E+01	2.12E+02	73%
Perenets/Zhemchug Canyons[c]	200-400	15	2,595.79	2.02E+00	4.06E+00	100%
	400-600	10	1,705.76	2.21E+01	3.00E+02	78%
	600-800	5	917.49	0.00E+00	0.00E+00	-
	800-1000	5	645.17	0.00E+00	0.00E+00	-
	1,000-1,200	2	496.42	0.00E+00	0.00E+00	-
	Total	37	6,360.63	2.41E+01	3.04E+02	72%

a. Partially in Pribilof District.
b. Entirely in Pribilof District.
c. Not in Pribilof District.

Table 6. 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 2012 total-catch OFL; values under $RET_{1993\text{-}1998}$ are from Table 1, values under $R_{2001\text{-}2010}$ were computed from the retained catch data and the directed fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,1994\text{-}1998}$ were computed from the non-directed crab fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,96/97\text{-}08/09}$ are from Table 3.

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 7. Data for calculation of $RET_{1993\text{-}1998}$ and estimates used in calculation of $R_{2001\text{-}2010}$, $BM_{NC,2001–2010}$, and $BM_{GF,91/92\text{-}09/10}$ for calculation of the Alternative 2 (updated status quo) Pribilof Islands golden king crab Tier 5 2012 total-catch OFL; values under $RET_{1993\text{-}1998}$ are from Table 1, values under $R_{2001\text{-}2010}$ were computed from the retained catch data and the directed fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,2001–2010}$ were computed from the non-directed crab fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,91/92\text{-}09/10}$ are from Table 3.

Season[a]	Season[b]	$RET_{1993\text{-}1998}$	$R_{2001\text{-}2010}$	$BM_{NC,2001\text{-}2010}$	$BM_{GF,91/92\text{-}09/10}$
1992	1991/92				10,826
1993	1992/93	67,458			19,480
1994	1993/94	88,985			17,556
1995	1994/95	341,908			5,962
1996	1995/96	329,009			3,797
1997	1996/97	179,249			1,561
1998	1997/98	35,722			2,335
1999	1998/99				7,781
2000	1999/00				6,419
2001	2000/01		0.054	conf.	5,101
2002	2001/02		0.056	1,168	2,276
2003	2002/03		conf.	conf.	987
2004	2003/04		conf.	conf.	572
2005	2004/05		conf.	conf.	859
2006	2005/06			0	200
2007	2006/07			0	1,660
2008	2007/08			0	9,619
2009	2008/09			1,061	7,145
2010	2009/10		conf.	0	10,826
	N	6	6	10	18
	Mean	173,722	0.052	548	5,785
	S.E.M	54,756	0.004	184	1,330
	CV	0.32	0.07	0.34	0.23

a. Season convention corresponding with values under $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, and $BM_{NC,2001\text{-}2010}$.
b. Season convention corresponding with values under $BM_{GF,91/92\text{-}09/10}$.

Table 8. Data for calculation of $RET_{1993\text{-}1998}$ and estimates used in calculation of $R_{2001\text{-}2005}$, $BM_{NC,2001\text{–}2009}$, and $BM_{GF,91/92\text{-}09/09}$ for calculation of the Alternative 3 (status quo) Pribilof Islands golden king crab Tier 5 2012 total-catch OFL; values under $RET_{1993\text{-}1998}$ are from Table 1, values under $R_{2001\text{-}2005}$ were computed from the retained catch data and the directed fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,2001\text{–}2010}$ were computed from the non-directed crab fishery bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,91/92\text{-}09/10}$ are from Table 3.

Season[a]	Season[b]	$RET_{1993\text{-}1998}$	$R_{2001\text{-}2005}$	$BM_{NC,2001\text{-}2009}$	$BM_{GF,91/92\text{-}08/09}$
1992	1991/92				10,826
1993	1992/93	67,458			19,480
1994	1993/94	88,985			17,556
1995	1994/95	341,908			5,962
1996	1995/96	329,009			3,797
1997	1996/97	179,249			1,561
1998	1997/98	35,722			2,335
1999	1998/99				7,781
2000	1999/00				6,419
2001	2000/01		0.054	conf.	5,101
2002	2001/02		0.056	1,168	2,276
2003	2002/03		conf.	conf.	987
2004	2003/04		conf.	conf.	572
2005	2004/05		conf.	conf.	859
2006	2005/06			0	200
2007	2006/07			0	1,660
2008	2007/08			0	9,619
2009	2008/09			1,061	7,145
2010	2009/10				
	N	6	5	9	17
	Mean	173,722	0.054	608	5,489
	S.E.M	54,756	0.004	194	1,376
	CV	0.32	0.08	0.32	0.25

a. Season convention corresponding with values under $RET_{1993\text{-}1998}$, $R_{2001\text{-}2005}$, and $BM_{NC,2001\text{-}2009}$.
b. Season convention corresponding with values under $BM_{GF,91/92\text{-}08/09}$.

Table 9. Statistics for 1,000 bootstrap OFLs calculated according to Alternatives 1, 2, and 3, with the computed OFLs for comparison.

	Alternative 1	Alternative 2	Alternative 3
Computed OFL	204,611	189,174	189,164
Mean of 1,000 bootstrapped OFLs	203,870	188,949	189,023
Std. dev. of 1,000 bootstrapped OFLs	51,030	47,375	51,468
CV = (std. dev.)/(Mean)	0.25	0.25	0.27

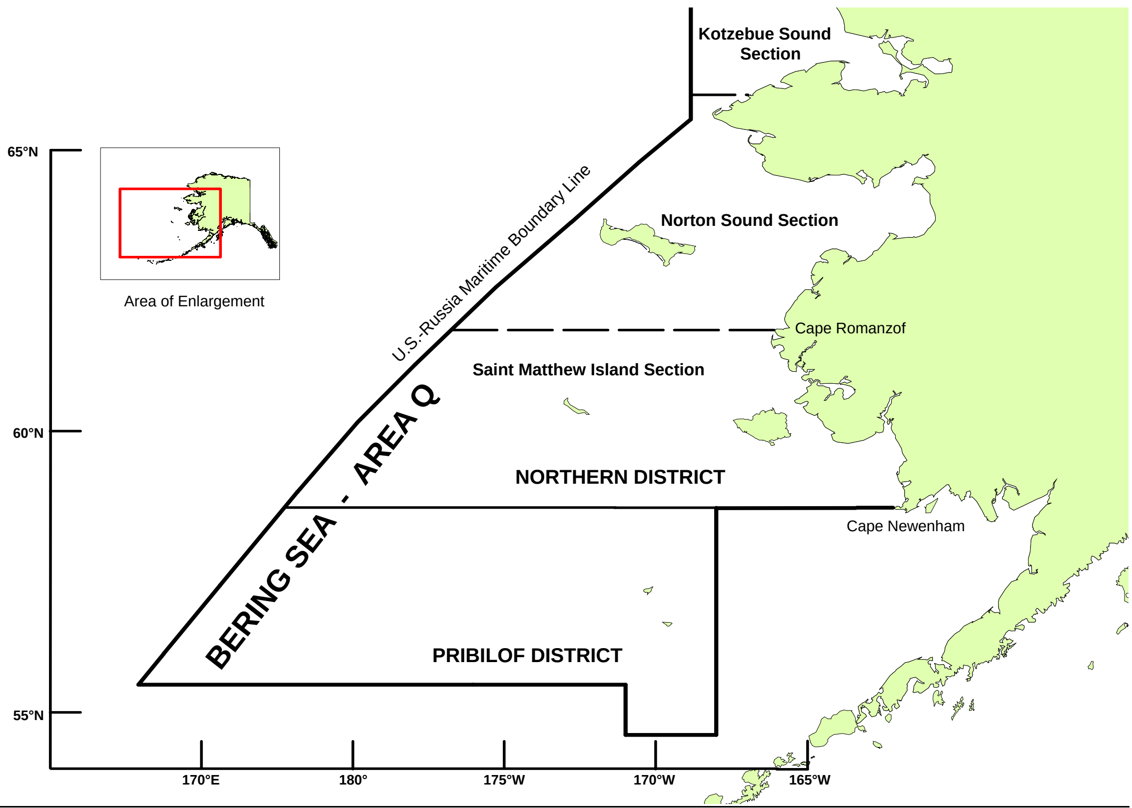

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Bowers et al. 2011).

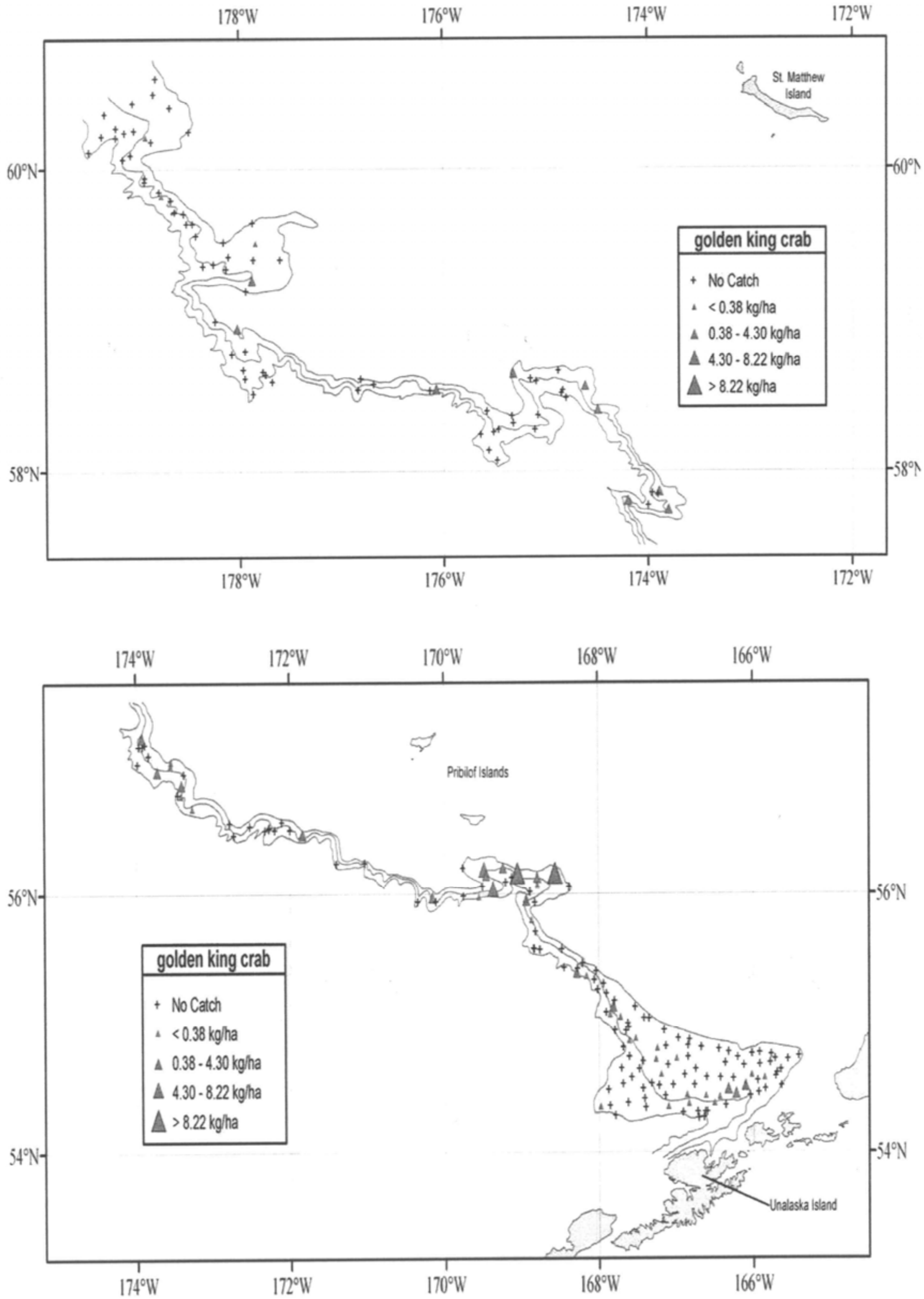

Figure 2. Distribution and relative abundance of golden king crabs from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey. Relative abundance is categorized by no catch, sample CPUE less than the mean CPUE, between the mean CPUE and two standard deviations above the mean CPUE, between two and four standard deviations above the mean CPUE, and greater than four standard deviations above the mean CPUE (from Figure 79 *in* Hoff and Britt 2005).

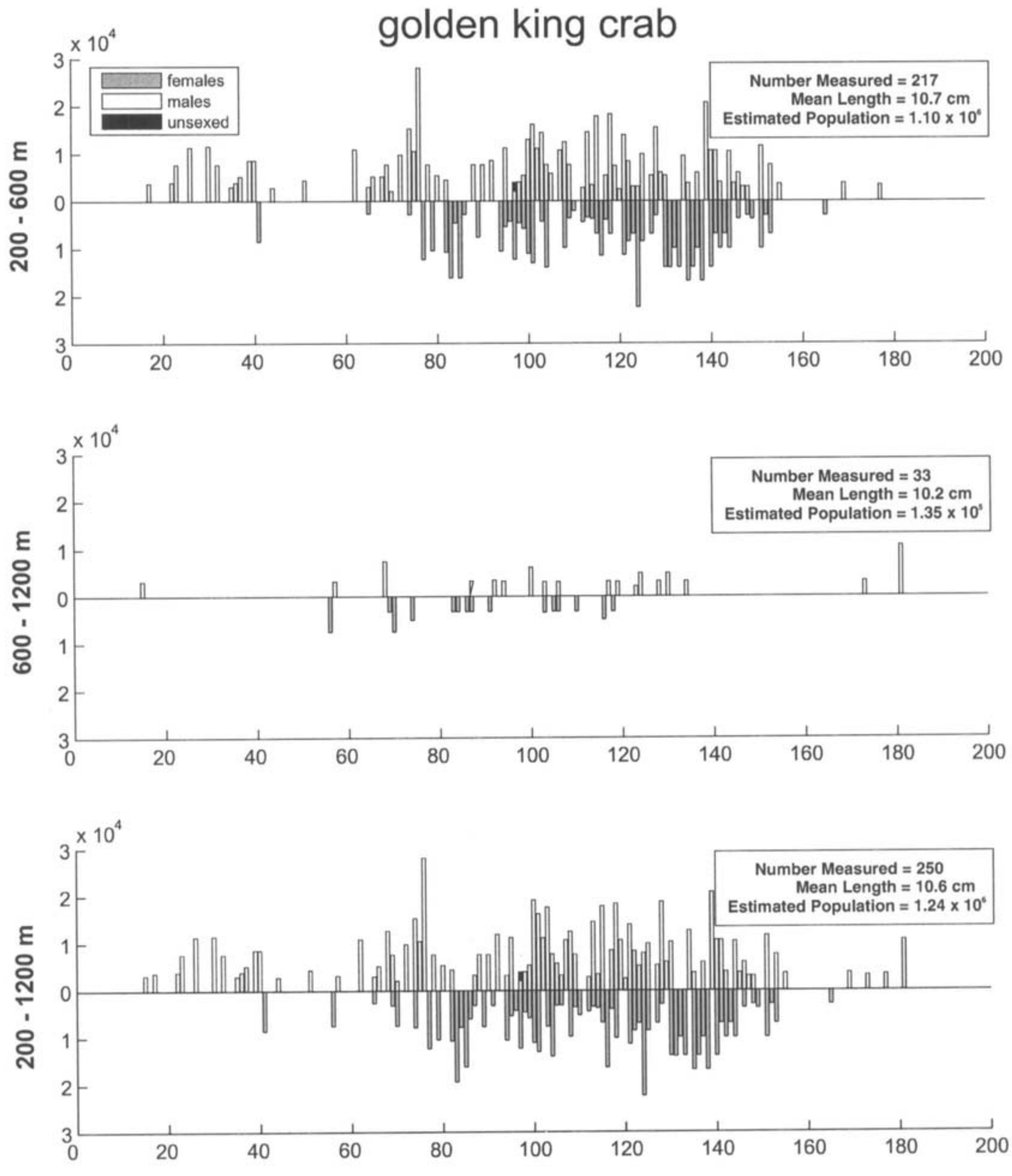

Figure 3. Size composition of the estimated golden king crab population from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey (all areas) by depth zone. The abscissa is scaled as total carapace length in millimetres and the ordinate represents the estimated total population.

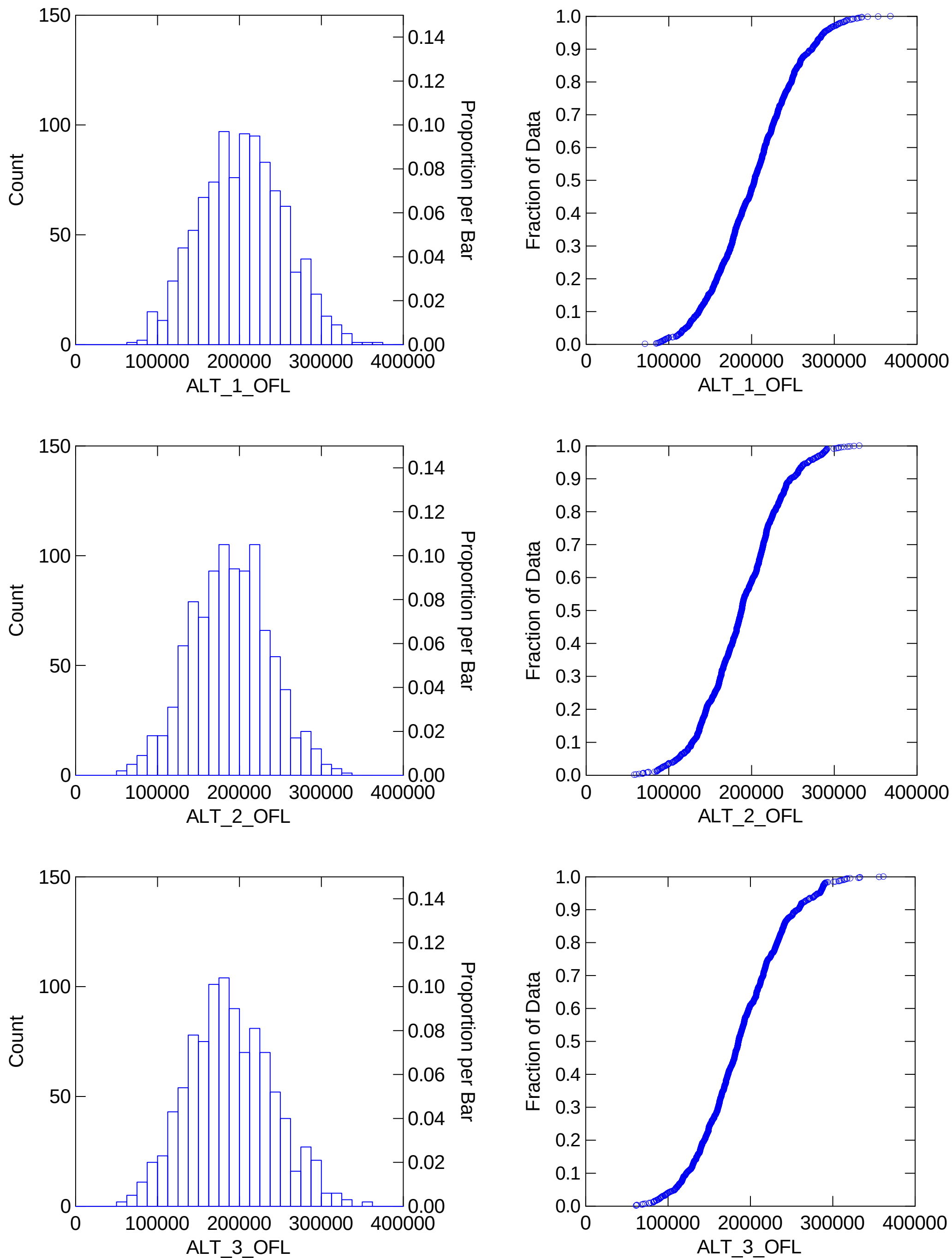

Figure 4. Bootstrapped estimates of the sampling distribution of the Alternative 1 (above), Alternative 2 (middle), and Alternative 3 (bottom) 2012 Tier 5 OFLs (pounds of total catch) for the Pribilof Islands golden king crab stock; histograms in left column, quantile plots in right column.

Adak Red King Crab

May 2011 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak

Executive Summary

1. **Stock:** Red king crab (*Paralithodes camtschaticus*)/Adak (the Aleutian Islands, west of 171° W longitude)

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 pounds (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 pounds (428 t), but the retained catch during the 1995/96 season was only 0.039-million pounds (18 t). During the 1995/96 through 2009/10 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 pounds (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 pounds (230 t) in 2002/03 and 0.479-milliion pounds (217 t) in 2003/04. The fishery has been closed through the 2010/11 season since the end of the 2003/04 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 the groundfish fisheries. Estimated annual weight of bycatch mortality during the 1995/96–2009/10 seasons averaged 0.003-million pounds (1 t) in crab fisheries and 0.022-million pounds (10 t) during groundfish fisheries. Estimated weight of annual total fishery mortality during 1995/96–2009/10 averaged 0.109-million pounds (49 t); the average annual retained catch during that period was 0.084-million pounds (38 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 Adak Area.

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 for legal males, 0.2 for sublegal males, and 0.2 for 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 high 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 CPUE of red king crab in those "niche fishing" pots in 2006 was 15.6 for legal males, 4.1 for sublegal males, and 3.1 for females. Ninety-two (92) 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 for legal males, 2.5 for sublegal males, and 2.1 for females; during the November 2001 ADF&G-Industry survey the CPUEs for the 121 pots fished at those locations were 85.5 for legal males, 5.5 for sublegal males, and 9.7 for 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 for legal males, <0.1 for sublegal males, and 0.1 for 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).

5. <u>Management performance</u>:

No overfished determination (i.e., MSST) is possible for this stock given the lack of biomass information. Overfishing did not occur during the 2009/10 fishing year. No ABC was established for the 2010/11 season.

See tables, below; OFL and ABC values for 2011/12 are the author's recommendations.

Year	**MSST**	**Biomass (MMB)**	**TAC**	**Retained Catch[a]**	**Total Catch[a,b]**	**OFL[a,c]**	**ABC[a,c]**
2007/08	N/A	N/A	Closed	0	0.011	N/A	N/A
2008/09	N/A	N/A	Closed	0	0.014	0.46, R	N/A
2009/10	N/A	N/A	Closed	0	0.012	0.50, R	N/A
2010/11	N/A	N/A	Closed	0	TBD	0.12, T	N/A
2011/12	N/A	N/A	TBD	TBD	TBD	0.12, T	0.11, T

a. Millions of pounds.
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]
2007/08	N/A	N/A	Closed	0	<1	N/A	N/A
2008/09	N/A	N/A	Closed	0	<1	209, R	N/A
2009/10	N/A	N/A	Closed	0	<1	227, R	N/A
2010/11	N/A	N/A	Closed	0	TBD	56, T	N/A
2011/12	N/A	N/A	TBD	TBD	TBD	56, T	51, T

a. Metric tons.
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 2011/12 are the author's recommendations

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]	10%

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>** A 10% buffer on the OFL; i.e., ABC = (1-0.1)·OFL.

9. **<u>A summary of the results of any rebuilding analyses</u>:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **<u>Changes to the management of the fishery</u>:** None.

2. **<u>Changes to the input data</u>:**
   - Data on non-retained bycatch and estimates of bycatch mortality in crab and groundfish fisheries during 2009/10 have been added to judge if overfishing occurred in 2009/10, but is not put into the calculation of the recommended 2011/12 total-catch OFL.

3. **<u>Changes to the assessment methodology</u>:** None.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:** None.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general</u>:**
   - <u>CPT, May 2010</u>:
     1. *"Some assessments provided results in metric tons. The CPT recommendation to use metric tons refers only to the ACL analysis and traditional assessment currencies (lbs) should continue to be used in stock assessments."*
        - <u>Response:</u> That was done.
     2. *"The team requested that all assessments explain how the groundfish bycatch data are used in the assessment and that all assessment chapters should be consistent in distinguishing and separately presenting groundfish bycatch from fixed gear fisheries and trawl gear fisheries."*
        - <u>Response:</u> Explanations were made and statistics from fixed gear and trawl gear fisheries are distinguished and presented separately.
   - <u>SSC, June 2010</u>: *"In order to have greater consistency between assessments, the SSC recommends that catch statistics reported in the executive summary section contain both metric tons and pounds (millions)."*
     - <u>Response</u>: That was done.
   - <u>CPT, September 2010</u>: [*None*.]
   - <u>SSC, October 2010</u>: [*None*.]

2. **<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:**
   - <u>CPT, May 2010</u>: *"No additional comments – see Crab SAFE introduction for CPT recommendations on this stock."*
     - <u>Response</u>: The CPT recommendations for this stock in the May Crab SAFE introduction recommended that a total-catch OFL be established for this stock in 2010/11, as opposed to the retained-catch OFLs established for 2008/09 and 2009/10, using the estimated annual total catch for the period 1995/96–2007/08. The same total-catch OFL is recommended by the author for 2011/12.
   - <u>SSC, June 2010</u>:

     1)"The SSC requests that the 2006 and 2009 description of the survey be expanded to include CPUE or biomass estimates for the regions surveyed."
     - <u>Response</u>: The CPUE from the 2006 and 2009 surveys are reported in the Executive Summary, item 4.

     2) "The CPT recommended and the SSC agrees, that the base time period for estimation of the OFL should be changed to 1995/96-2007/08 (this time period will then be fixed) to allow the estimation of a total catch OFL. Based on these considerations, the SSC recommends a 2010/11 OFL for Adak red king crab of 0.12 million pounds (total catch OFL)."
     - Response: The author recommends a total-catch OFL based on the fixed time period of 1995/96–2007/08. Given the SSC statement that the time period be fixed, the author offers no alternative OFLs.

- CPT, September 2010: [*None.*]
- .SSC, October 2010: *"...the SSC has no additional comments..."*

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 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. 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; ADF&G observer database, Dutch Harbor, April 2008).

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 Bowers et al (2011, page 8) 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.

Little data is 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."

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 is provided in Bowers et al. (2011, pages 8–12). 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 pounds during the 1960/61–1975/76 seasons, with a peak harvest of 21.193-million pounds 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 pounds; the peak harvest during that period was 1.982-million pounds 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 2004/05–2009/10 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 pounds, which occurred in the 2002/03 season.

Season	Change in management measure
1996/97–1997/98	• Fishery closed
1998/99	• GHL of 15,000 pounds (for exploratory fishing) with fishery closed in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude)
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
2001/02	• Fishery closed • Catch retained ADF&G-Industry survey of Petrel Bank area conducted as commissioner's permit fishery, November 2001
2002/03	• Fishery opened with GHL of 500,000 pounds restricted to Petrel Bank area • ADF&G-Industry survey of the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery (4 legal males captured in 1,085 pot lifts)
2003/04	• Fishery opened with GHL of 500,000 pounds restricted to Petrel Bank area
2004/05–2010/11	• Fishery closed

A summary of relevant fishery regulations and management actions pertaining to the Adak red king crab fishery is provided below.

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)).

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 (Bowers et al 2011). Fishing for red king crab in the area between 172° W longitude and 179° W longitude in the Aleutian Islands is limited to vessels 90 feet or less in overall length (5 AAC 34.610 (d)). Additionally, 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 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 pounds and west of 179° E longitude with a GHL of 0.010-million pounds, 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 2011, Bowers et al. 2002). 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; Bowers et al 2011) with a GHL of 0.500-million pounds. 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"; Bowers et al 2008). The remaining area in the Adak Area was closed to commercial red king crab fishing during the 2003/04 season.

D. Data

1. <u>Summary of new information</u>:

- Retained catch data from the closed 2010/11 directed fishery season has been added; the retained catch was 0 pounds.
- Data on non-retained bycatch in crab and groundfish fisheries has been updated with data from the 2009/10 Aleutian Islands golden king crab fishery and the 2009/10 groundfish fisheries in reporting areas 541, 542, and 543.

2. <u>Data presented as time series</u>:

a. Total catch and b. Information on bycatch and discards:

- The 1960/61–2009/10 time series of retained catch (number and pounds 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; Table 1 does not include data for the closed (0 retained catch, 0 effort) 2010/11 season.
- The 1960/61–2009/10 time series of retained catch (pounds of landed crab) is presented graphically in Figure 2.
- The 1995/96–2009/10 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 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 by a vessel while an observer was on board during the 2001/02–2002/03 and 2004/05–2008/09 seasons were counted and recorded for capture location and biological data.
- The 1993/94–2009/10 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) during federal groundfish fisheries by gear type (fixed or trawl) is provided in Table 3. Bycatch estimates for 1992/93 are available, but appear to be suspect because they are extremely low. Following Foy (2010 a, b), 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.

- The 1995/96–2008/09 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 4. Following Siddeek et al. (2010), 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 4 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 4 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 1972/73–2009/10 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 pounds 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 continue to be managed as a Tier 5 stock and that the 2010/11 OFL be specified as a total-catch OFL, that 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 that 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 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 has been shown, the recommended approach for establishing the 2011/12 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 2011/12 is

$$OFL_{TOT,\ 2011/12} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

   where,

- $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Given the June 2010 SSC recommendations, items ***E.2 a–i*** are not applicable.

3. **Model Selection and Evaluation:** Not applicable; see section ***E.2***.

4. **Results (best model(s)):**

a. ***List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties:*** Not applicable.

b. ***Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):*** See Table 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 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.
- The bycatch mortality rates used in estimation of total catch.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5: total-catch OFL specified as the estimated average annual total-catch during the period 1995/96–2007/08; i.e.,

$$OFL_{TOT,\ 2011/12} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

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.

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 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; OFL and ABC values for 2011/12 are the author's recommendations.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a,c]	ABC[a,c]
2007/08	N/A	N/A	Closed	0	0.011	N/A	N/A
2008/09	N/A	N/A	Closed	0	0.014	0.46, R	N/A
2009/10	N/A	N/A	Closed	0	0.012	0.50, R	N/A
2010/11	N/A	N/A	Closed	0	TBD	0.12, T	N/A
2011/12	N/A	N/A	TBD	TBD	TBD	0.12, T	0.11, T

a. Millions of pounds.
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 pounds (0.97-million pounds).

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 4 (the sample means of 1,000 samples drawn with replacement from the 1995/96–2007/08 estimates of total fishery mortality in Table 4). 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 4.

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 for 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. (1-0.1)·(123,867 pounds) = 0.111-million pounds.

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 has 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, but only produced a catch of one red king crab (J. Alas, ADF&G, 7 May 2010 ADF&G Memorandum).

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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Table 1. Aleutian Islands, Area O, red king crab commercial fishery data, 1960/61–2009/10, 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 Bowers et al. 2011); though not included in this table, note that the fishery was closed for the 2010/11 season.

		Number of					Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1960/61	East of 172° W	NA	NA	NA	NA	NA	NA	NA	NA	NA
	West of 172° W	4	41	NA	NA	2,074,000	NA	NA	NA	NA
	TOTAL									
1961/62	East of 172° W	4	69	NA	NA	533,000	NA	NA	NA	NA
	West of 172° W	8	218	NA	NA	6,114,000	NA	NA	NA	NA
	TOTAL		**287**			**6,647,000**				
1962/63	East of 172° W	6	102	NA	NA	1,536,000	NA	NA	NA	NA
	West of 172° W	9	248	NA	NA	8,006,000	NA	NA	NA	NA
	TOTAL		**350**			**9,542,000**				
1963/64	East of 172° W	4	242	NA	NA	3,893,000	NA	NA	NA	NA
	West of 172° W	11	527	NA	NA	17,904,000	NA	NA	NA	NA
	TOTAL		**769**			**21,797,000**				
1964/65	East of 172° W	12	336	NA	NA	13,761,000	NA	NA	NA	NA
	West of 172° W	18	442	NA	NA	21,193,000	NA	NA	NA	NA
	TOTAL		**778**			**34,954,000**				
1965/66	East of 172° W	21	555	NA	NA	19,196,000	NA	NA	NA	NA
	West of 172° W	10	431	NA	NA	12,915,000	NA	NA	NA	NA
	TOTAL		**986**			**32,111,000**				
1966/67	East of 172° W	27	893	NA	NA	32,852,000	NA	NA	NA	NA
	West of 172° W	10	90	NA	NA	5,883,000	NA	NA	NA	NA
	TOTAL		**983**			**38,735,000**				
1967/68	East of 172° W	34	747	NA	NA	22,709,000	NA	NA	NA	NA
	West of 172° W	22	505	NA	NA	14,131,000	NA	NA	NA	NA
	TOTAL		**1,252**			**36,840,000**				
1968/69	East of 172° W	NA	NA	NA	NA	11,300,000	NA	NA	NA	NA
	West of 172° W	30	NA	NA	NA	16,100,000	NA	NA	NA	NA
	TOTAL					**27,400,000**				
1969/70	East of 172° W	41	375	NA	72,683	8,950,000	NA	NA	NA	NA
	West of 172° W	33	435	NA	115,929	18,016,000	6.5	NA	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	7	46	NA	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	5.4	43	NA	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	12,722,660	7.1	43	NA	NA
	West of 172° W	41	239	1,844,974	70,059	9,741,464	5.3	26	148.6	NA
	TOTAL		**529**	**3,625,647**	**111,899**	**22,464,124**	**6.2**	**32**		

(Continued)

Table 1. page 2 of 3.

Season	Locale	Number of Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Average Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1974/75	East of 172° W	87	372	1,812,647	71,821	13,991,190	7.7	25		
	West of 172° W	36	97	532,298	32,620	2,774,963	5.2	16	148.6	NA
	TOTAL		**469**	**2,344,945**	**104,441**	**16,766,153**	**7.1**	**22**		
1975/76	East of 172° W	79	369	2,147,350	86,874	15,906,660	7.4	25		
	West of 172° W	20	25	79,977	8,331	411,583	5.2	10	147.2	NA
	TOTAL		**394**	**2,227,327**	**95,205**	**16,318,243**	**7.3**	**23**		
1976/77	East of 172° W	72	226	1,273,298	65,796	9,367,965 [f]	7.4	19		
	East of 172° W	38	61	86,619	17,298	830,458 [g]	9.6	5	NA	NA
	West of 172° W	F I S H E R Y	C L O S E D							
	TOTAL		**287**	**1,359,917**	**83,094**	**10,198,423**	**7.5**	**16**		
1977/78	East of 172° W	33	227	539,656	46,617	3,658,860 [f]	6.8	12		
	East of 172° W	6	7	3,096	812	25,557 [h]	8.3	4	NA	NA
	West of 172° W	12	18	160,343	7,269	905,527	5.7	22	152.2	NA
	TOTAL		**252**	**703,095**	**54,698**	**4,589,944**	**6.5**	**13**		
1978/79	East of 172° W	60	300	1,233,758	51,783	6,824,793	5.5	24	NA	NA
	West of 172° W	13	27	149,491	13,948	807,195	5.4	11	NA	1,170
	TOTAL		**327**	**1,383,249**	**65,731**	**7,631,988**	**5.5**	**21**		
1979/80	East of 172° W	104	542	2,551,116	120,554	15,010,840	5.9	21	NA	NA
	West of 172° W	18	23	82,250	9,757	467,229	5.7	8	152	24,850
	TOTAL		**565**	**2,633,366**	**130,311**	**15,478,069**	**5.9**	**20**		
1980/81	East of 172° W	114	830	2,772,287	231,607	17,660,620 [f]	6.4	12	NA	NA
	East of 172° W	54	120	182,349	30,000	1,392,923 [h]	7.6	6		
	West of 172° W	17	52	254,390	20,914	1,419,513	5.6	12	149	54,360
	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	5,155,345	6.9	3	NA	NA
	West of 172° W	46	106	291,311	40,697	1,648,926	5.7	7	148.3	8,759
	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	431,179	6.7	1		
	West of 172° W	72	191	284,787	66,893	1,701,818	6.0	4	150.8	7,855
	TOTAL		**469**	**349,167**	**139,817**	**2,132,997**	**6.1**	**3**		
1983/84	East of 172° W	F I S H E R Y	C L O S E D							
	West of 172° W	106	248	298,958	60,840	1,981,579	6.6	5	157.3	3,833
1984/85	East of 171° W	F I S H E R Y	C L O S E D							
	West of 171° W	64	106	196,276	48,642	1,296,385	6.6	4	155.1	0
1985/86	East of 171° W				F I S H E R Y	C L O S E D				
	West of 171° W	35	82	156,097	29,095	868,828	5.6	5	152.2	0
1986/87	East of 171° W	F I S H E R Y	C L O S E D							
	West of 171° W	33	69	126,204	29,189	712,543	5.7	4	NA	800
1987/88	East of 171° W	F I S H E R Y	C L O S E D							
	West of 171° W	71	103	211,692	43,433	1,213,892	5.7	5	148.5	6,900

(Continued)

Table 1. page 3 of 3.

		Number of						Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted		Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1988/89	East of 171° W	FISHERY CLOSED									
	West of 171° W	73	156	266,053	64,334		1,567,314	5.9	4	153.1	557
1989/90	East of 171° W	FISHERY CLOSED									
	West of 171° W	56	123	193,177	54,213		1,105,971	5.7	4	151.5	759
1990/91	East of 171° W	FISHERY CLOSED									
	West of 171° W	7	34	146,903	10,674		828,105	5.6	14	148.1	0
1991/92	East of 171° W	FISHERY CLOSED									
	West of 171° W	10	35	165,356	16,636		951,278	5.8	10	149.8	0
1992/93	East of 171° W	FISHERY CLOSED									
	West of 171° W	12	30	218,049	16,129		1,286,424	6.0	14	151.5	5,000
1993/94	East of 171° W	FISHERY CLOSED									
	West of 171° W	12	21	119,330	13,575		698,077	5.9	9	154.6	7,402
1994/95	East of 171° W	FISHERY CLOSED									
	West of 171° W	20	31	30,337	18,146		196,967	6.5	2	157.5	1,430
1995/96	East of 171° W	FISHERY CLOSED									
	West of 171° W	4	12	6,880	1,986		38,941	5.7	3	153.6	235
1996/97		FISHERY CLOSED									
1997/98		FISHERY CLOSED									
1998/99	West of 174° W	1	CF	CF	CF	0.015	CF	CF	CF	CF	CF
1999/2000		FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
2000/01[k]	Petrel Bank[l]	1	3	11,299	496	FC	76,562	6.8	23	161.0	0
2001/02[m]	Petrel Bank[l]	4	5	22,080	564	FC	153,961	7.0	39	159.5	82
2002/03	Petrel Bank[l]	33	35	68,300	3,786	0.5	505,642	7.4	18	162.4	1,311
2003/04	Petrel Bank[l]	30	31	59,828	5,774	0.5	479,113	8.0	10	167.9	2,617
2004/05 - 2009/10		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 pounds.

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).

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).

m November Petrel Bank survey (fish ticket harvest code 15, exploratory shellfish harvest).

Table 2. Weight (in pounds) 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 by season for the 1995/96–2009/10 seasons (from Pengilly 2010, updated with estimates for 2009/10 by D. Pengilly with data from the ADF&G crab observer database 28 April 2011).

	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
Average	84,008	176	2,903	4,412	3,998	996	656	13,467

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 (pounds) of discarded bycatch of red king crab (all sizes, males and females) and bycatch mortality during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1993/94–2009/10 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries; updated from Pengilly 2010 with addition of 2009/10 estimates provided by R. Foy, AFSC, Kodiak Laboratory via 13 August 2010 email and with removal of 1992/93 estimates which are suspect).

Season	Fixed Gear	Trawl Gear	Mortality
1993/94	1,312	88,384	71,363
1994/95	2,993	22,792	19,730
1995/96	5,804	15,289	15,133
1996/97	2,874	44,662	37,167
1997/98	3,819	11,717	11,283
1998/99	10,143	45,532	41,497
1999/00	37,765	27,973	41,261
2000/01	2,697	13,879	12,452
2001/02	5,340	59,552	50,312
2002/03	11,295	73,027	64,069
2003/04	3,577	9,151	9,109
2004/05	791	12,930	10,740
2005/06	3,546	2,359	3,660
2006/07	6,781	617	3,884
2007/08	16,971	2,630	10,590
2008/09	10,778	10,290	13,621
2009/10	315	14,104	11,440
Average	7,459	26,758	25,136

Table 4. Estimates of total fishery mortality (pounds) for red king crab in the Adak Area, 1995/96–2009/10, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries (from Table 2 with assumed bycatch mortality rate of 0.2 applied to total non-retained bycatch and Table 3).

Season	Retained Catch	Bycatch mortality: Crab Fisheries	Bycatch mortality: Groundfish Fisheries	Total
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[c]	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	693	11,440	12,133
Mean, 1995/96–2007/08	96,932	3,000	23,935	123,867
CV of mean	52%	37%	23%	43%
Mean, 1995/96–2009/10	84,008	2,651	22,415	109,073
CV of mean	53%	37%	22%	43%

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.

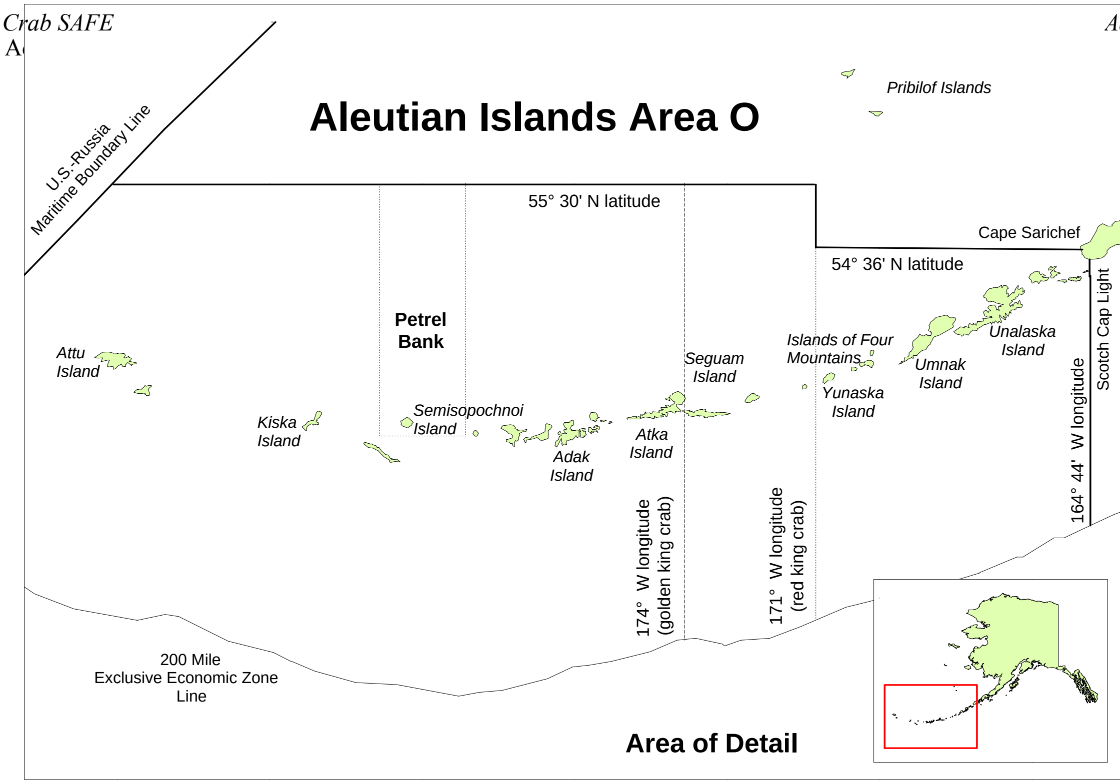

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Bowers et al 2008).

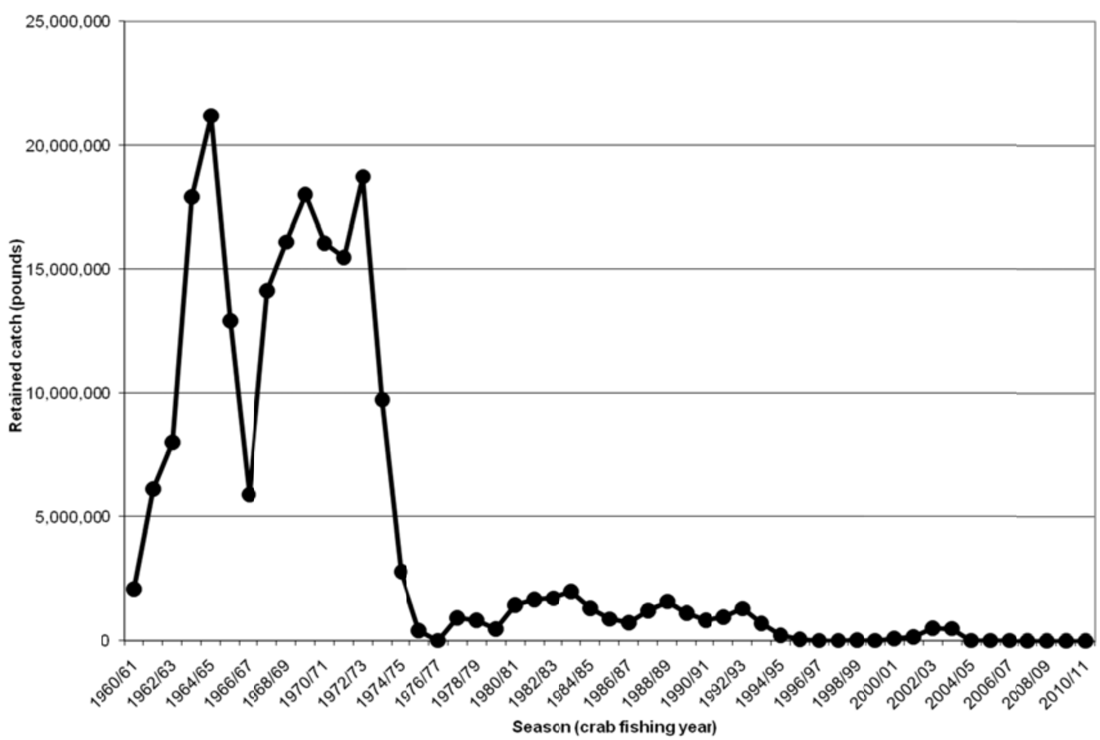

Figure 2. Retained catch in the Adak red king crab fishery, 1960/61–2010/11 (catch is for the area west of 172º W longitude during 1960/61–1983/84 and for the area west of 171º W longitude during 1984/85–2010/11; see Table 1).

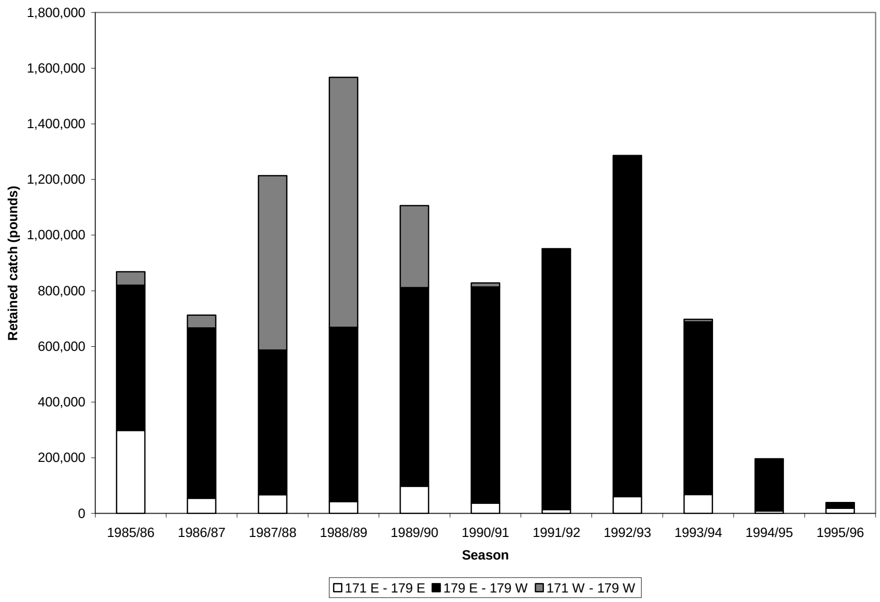

Figure 3. Retained catch (pounds) in the Adak red king crab fishery for the 1984/85–1995/96 seasons, partitioned into three longitudinal zones (171º W longitude to 179º W longitude, 179º W longitude to 179º E longitude, and 179º E longitude to 171º E longitude; from ADF&G fish ticket summary provided by F. Bowers, ADF&G).

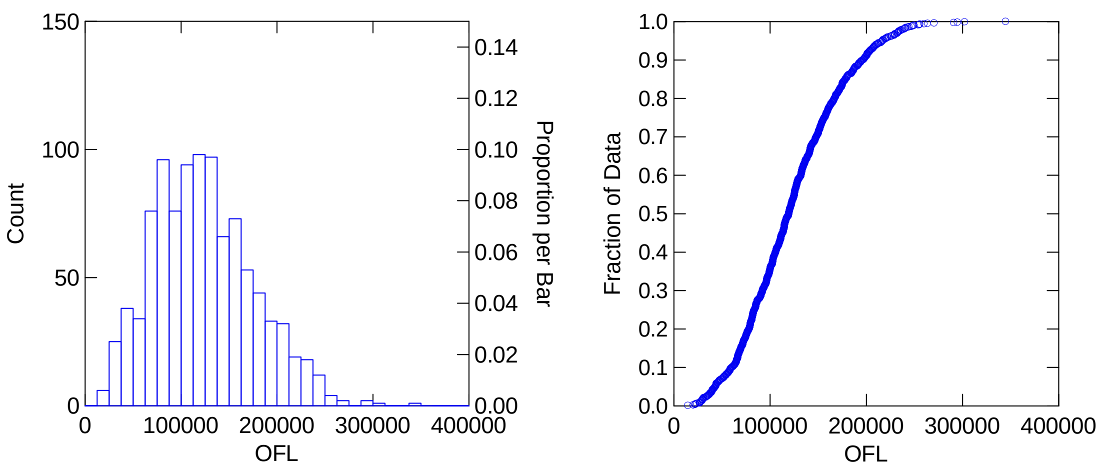

Figure 4. Bootstrapped estimate of the sampling distribution of the recommended 2011/2012 Tier 5 OFL (pounds of total catch) for the Adak red king crab stock; histogram in left column, quantile plot in right column.

ECOSYSTEM CONSIDERATION INDICATORS FOR BERING SEA AND ALEUTIAN ISLANDS KING AND TANNER CRAB SPECIES

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Summary of updates from the May 2011 SAFE

Although the presentation of the final draft ecosystem chapter to the Crab Plan Team (CPT) is scheduled for May, the CPT asked for an update to this chapter before the final BSAI crab SAFE report is submitted to the Council in the fall.

> *The CPT team discussed how ecosystem indicators would be useful in stock assessments and that it would be useful to compile information on how (if any) these indicators relate to crab stocks. The team recommends the author compile proposed ecosystem indicators and conduct a literature search on reference information to evaluate these in relation to crab stocks for September to facilitate team discussion of appropriate indicators*.

Two physical and two biological environmental indicators have been proposed as ecosystem indicators in the *Current Status of Ecosystem Indicators on 2010/2011* section of this document with supporting literature for BSAI crab stocks.

Summary of updates from the September 2010 SAFE

The timing of the ecosystem chapter presentation to the Crab Plan Team (CPT) has been changed from September to May in order to include the most current environmental data as well as annual survey data from the previous summer. The *Current Status of Ecosystem Indicators in 2010/2011*has been updated with the 2010 summer survey data as well as the most recent environmental data available (winter 2011).

- Variability in benthic production in the EBS was examined and compared to male mature biomass of commercial crab stocks.

- An overview of the temporal changes in flatfish and other crab predators in the EBS along with mature male crab biomass is provided.

- Ecosystem indicators were selected in the *Current Status of Ecosystem Indicators in 2010/2011* section as they appear to correlate with patterns in crab abundance.

- The effects of bottom trawling on the benthic substrate are discussed in *Effects of Fishing Gear on Seafloor Habitat* section.

- Current ecosystem related research with resepct to commercial crab stock in the the BSAI is listed in the *Current Status of Ecosystem Indicators in 2010/201* section along with future research suggestions.

Responses to Comments from the Science and Statistical Committee (SSC)

October 2010 SSC Comments

1. *The SSC commends the authors on advancing this section and has some recommendations for future consideration. The current section includes data through 2008-2009. It would be useful to add more current data, to the extent practicable.*

We agree with the SSC suggestion and have changed the timing of the ecosystem chapter presentation to the CPT from September to May in order to include the most current environmental data as well as annual survey data from the previous summer. The final Ecosystem chapter will be submitted to the NPFMC and the SSC after the September CPT meeting.

2. *The SSC also continues to encourage crab stock assessment authors to use the information within their individual stock assessments.*

This request is the intended outcome of this chapter. We will continue to work with the stock assessment authors to develop appropriate ecosystem indicators and information which may be useful to the stock assessment authors.

3. *There would be value in re-examining the prey used at all age classes of crab.*

We agree with making this important distinction in crab prey identification. Specific prey species consumed by EBS crabs are not well known and must be established before prey availability and trends can be determined. Some recent work at AFSC has begun on identifying prey items in adult Tanner crab stomachs. It is often difficult to identify masticated and semi-digested remains in crab stomachs; therefore genetic ID of Tanner crab stomach content is being pursued by the Kodiak Laboratory in collaboration with the AFSC Pathology Program.

4. *In the vicinity of the Pribilof Islands, there should be a concentrated effort to determine prey use by potential predators of crab, in particular PIBKC, to see if predation might be a contributor to the failure of this stock to meet rebuilding targets, particularly given the spatial changes in flatfish predators that may have occurred.*

Pacific cod have been identified as a primary king crab predator, especially after molting when the crab carapaces are soft and malleable while larval crab have been found in flatfish diets. Time series analysis of BKC year classes compared with Pacific cod and yellowfin sole year classes have not revealed any significant correlation between groundfish predation or competition and the decline in BKC stocks (Zheng and Kruse 2006). Given the recent change in flatfish distribution, future investigation would be beneficial and is listed as a future research priority in this document.

5. *In discussing recent trends in crab and the Bering Sea ecosystem, authors should recognize that the period 2000-2010 is comprised of two very different pentades: a warm one from 2001-2005 and a cold one from 2007-2010, with 2006 intermediate in conditions. Averaging over 2000-2010 for many aspects of the marine environment may prove misleading.*

We agree with your suggestions and apologize for any confusion that may have occurred by the impression of combining the two temperature pentades in the last decade. A majority of the trends discussed in this chapter recognize the two separate time periods with the different temperatures schemes.

Responses to Comments from the Crab Plan Team

September 2010 CPT Comments

1. *The CPT acknowledged the hard work in putting together this document by Liz and her colleagues. Suggestions were made from the CPT as to how to focus the chapter for future versions. One major recommendation was to remove crab stock assessment information and to focus on ecosystem issues.*

Thank you for the feedback, although the authors would like to acknowledge much of the initial ecosystem summary was developed by the CPT in their individual stock assessments. The overarching theme from the CPT at the September 2010 meeting was to focus this chapter on ecosystem issues common to crab stocks in the Bering Sea/Aleutian Islands and prevent duplication of information addressed in the individual stock assessment chapters. Under that direction, we have removed specific details or data relating to the individual crab stocks such as population assessments or bycatch mortality unless these data relate to an ecosystem trend or highlight a relationship with other ecosystem indicators.

2. *With regards to research priorities, which were taken from last year's Crab Plan Team minutes, the suggestion was to focus research priorities within this document on ecosystem issues.*

From this point forward, the section *Current crab ecosystem research and future priorities* will list the most current ecosystem oriented crab research as well as provide an opportunity for the CPT to describe future research priorities on crab ecosystem issues.

Ecosystem SAFE overview

The objectives of this chapter are to assess the BSAI ecosystem trends, identify and provide annual updates of ecosystem status indicators and research priorities for BSAI crab stocks, and to update management status indicators. A summary of the most recent ecosystem trends affecting BSAI crab is summarized below with additional information detailed in the ecosystem considerations chapter.

Recent trends in the 2010 ecosystem indicators (physical & biological)

- The 2010/ 2011 winter in the Bering Sea was not as cold as expected from La Niña
- Sea ice coverage was not as extensive in January through March of 2011 compared to the previous five years although the sea ice edge advanced in April 2011
- Benthic invertebrate biomass has remained stable relative for the last five years, dominated by purple-orange sea star (*Asterias amurensis*) and other echinoderms.
- Groundfish biomass is increasing in the EBS, especially as Pacific cod biomass doubled from 0.42 t in 2009 to 0.86 t in 2010.

Introduction

The purpose of the Crab Ecosystem Consideration Indicators (CECI) report is to consolidate ecosystem information specific to the crab stocks in the Bering Sea and Aleutian Islands (BSAI) Fishery Management Plan. The BSAI Fishery Management Plan covers 10 stocks of crab representing five species: red king crab (*Paralithodes camtschaticus*; RKC), blue king crab (*Paralithodes platypus*; BKC), golden king crab (*Lithodes aequispinus*; GKC), southern Tanner crab (*Chionoecetes bairdi*), and snow crab (*Chionoecetes opilio*). The CECI report will serve as an appendix to the BSAI King and Tanner Crab Stock Assessment and Fisheries Evaluation (SAFE) document.

The objectives of this chapter are to assess the BSAI ecosystem trends, identify and provide annual updates of ecosystem status indicators and research priorities for BSAI crab stocks, and to update management status indicators. The format and organization of the CECI chapter are adapted from the Ecosystem Considerations Appendix to the BSAI and Gulf of Alaska Groundfish SAFE documents and the North Pacific Marine Science Organization (PICES) workshop on integrating ecological indicators of the North Pacific (Kruse et al. 2006). In order to avoid duplication of effort, sections in this document may occasionally refer to detailed reports from the Groundfish Ecosystem Considerations Appendix on topics specifically impacting crab ecology.

Beamish and Mahnken (1999) addressed incorporating the dynamics of an ecosystem, i.e. multispecies interactions and environmental variations, into stock assessments and resource management by discussing the need to understand natural influences which regulate a species as well as the influence from humans. Ecosystem-based management in the BSAI crab fisheries involves accounting for other influences on the target species beyond directed fishing. To address these influences, the CECI is composed of three main sections. First, the **Ecosystem Assessment** portion of the document provides a historical overview of the physical and biological environment of the BSAI ecosystem utilized by crab species as well as aspects of crab life history such as survival, recruitment, growth, maturity and natural mortality which are known to be impacted by changes in the BSAI ecosystem. The second section of the CECI, **Current Status of Ecosystem Indicators**, provides current information and updates on the status of the physical and biological components of the BSAI ecosystem. Physical components include pelagic and benthic habitat variables while biological components include prey availability and their abundance as well as distribution and abundance of competitors and predators. This section updates current research and identifies future research priorities for BSAI crab stocks with respect to ecosystem interactions. The final section, the **Ecosystem-based Management Indicators**, provides trends which could indicate early warning signals of direct fishery effects on crab-oriented BSAI ecosystem components, warranting management intervention or providing evidence of the efficacy of previous management actions. Specific indicators include the magnitude of directed fishery effects on BSAI habitat and resulting management efforts, and spatial and temporal removals of the target catch affecting other biological predators. In this section, we also review potential fishery effects on crab biology such as changes in age and size at maturity, and reproduction.

Ecosystem Assessment

Purpose

This section provides a historic overview of the physical and biological components in the BSAI ecosystem that are utilized by crab species at specific life stages. Three major crab life history stages, larval, juvenile and adult, utilize distinct components of the physical environment, both pelagic and benthic, as well as exhibit unique species interactions within the biological environment as prey, competitors and predators. The duration of the major life history stages are specific to each crab species (Fig. 1).

Crab Life History

Larval stages are distributed according to vertical swimming abilities, the oceanographic currents, and mixing or stratification of the water column. Generally, the larval stages occupy the mixed layer near the sea surface except golden king crab larvae, which are fully lecithotrophic (yolk-nourishing) and are considered demersal (Shirley and Zhou 1997). Egg extrusion and hatching in RKC and BKC are relatively synchronous, although alternate year hatching has been observed in BKC (Somerton and MacIntosh 1985). Larval hatching in GKC is asynchronous with no apparent seasonal mating period in mature adults (Shirley 2006). After molting through multiple larval stages, crab settle on the seafloor. Settlement on habitat with suitable shelter, food, and temperature is imperative for survival of settling crab. Young of the year RKC and BKC require nearshore shallow habitat with significant cover that offers protection (e.g., sea stars, anemones, macroalgae, shell hash, cobble, and shale). Early juvenile stage Tanner and snow crab also occupy shallow waters and are found on mud habitat. Juvenile GKC have been observed on structure-forming sessile invertebrates growing on the sea floor, such as corals, sponges and sea-whips, which provide protection (Stone 2006).

King crab reproduction occurs between a soft-shelled female and hard-shelled male while Tanner and snow crab females exhibit a terminal molt and can store sperm to fertilize subsequent clutches or mate while hard-shelled. Tanner and snow crab mate in the middle shelf of the EBS while RKC and BKC mate in relatively shallow (< 50 m) nearshore areas (Somerton and MacIntosh 1985; Loher and Armstrong 2005; Orensanz et al. 2007). Golden king crab mate in deepwater canyons, along the slope of the EBS and on isolated seamounts (Shirley 2006). All crab species are highly vulnerable to predation and damage during molting. The benthic environment or habitat occupied by molting and mating crab differs from that occupied by mature crab during the remainder of the year.

Physical Environment of the BSAI Ecosystem

The Bering Sea is semi-enclosed with a total area of 2.3 million km^2, of which 44% is continental shelf, 13% is continental slope, and 43% is deep-water basin. The Aleutian Islands (AI) lie in an arc that forms a partial geographic barrier to the exchange of northern Pacific marine waters with EBS waters. The AI continental shelf is narrow compared with the EBS shelf, ranging in width on the north and south sides of the islands from about 4 km or less to 46 km; the shelf broadens in the eastern portion of the AI arc. The AI archipelago comprises approximately 150 islands and extends about 2,260 km in length (Johnson 2003) (Fig. 2).

North Pacific Climate Historic Overview

Variation in climate and ocean dynamics have been implicated as important factors influencing crab recruitment in Alaska, with cold periods partially explaining strong recruitment events (Zheng and Kruse 2000). Air temperature anomalies over the last four decades in the EBS are characterized by a 1971-1976 cold period, a 1977-1988 warm period, a weaker cold period from 1989-1998, followed by warm years in 2000-2005 with a transitional year in 2006 to the cold period from 2007 to the present (Schumacher et al. 2003, NPFMC 2008). Overland et al. (1999) found three shifts of wintertime climate forcing patterns identified as: 1) 1967-1976 a positive Aleutian Low and mixed Arctic Oscillation, 2) 1977-1988 a negative Aleutian Low and negative Arctic Oscillation, and 3) 1989-1998 a mixed Aleutian Low and positive Arctic Oscillation. The negative Aleutian Low and negative Arctic Oscillation period from1977-1988 is coincident with the warm period in the EBS while the mixed Aleutian Low and positive Arctic Oscillation in 1989-1998 is coincident with a colder period (Hare and Mantua 2000).

Bering Sea air temperatures have been warmer on average in the past decade (2000-2010) compared to the pre-1977 air temperatures. During this period, however, fluctuations included cooler air temperatures in the winter and spring 2007. (Wang et al. 2008). The last five years, 2006-2010, have been the coldest average surface air temperatures on St. Paul Island since pre-1978 conditions. Moderate El Niño conditions developed in the fall and winter of 2009/2010, resulting in a slight warming of the water temperatures in the Bering Sea (Overland et al. 2009).

A low Aleutian Low Pressure Index (ALPI) and relatively cool sea surface temperatures (SST) in the fall of 2008 contributed to a cold winter in the Bering Sea and extensive sea ice conditions persisted into the spring of 2009 with a prominent cold pool (< 2°C) residing on the middle shelf well into the summer (Bond and Overland 2009). The SST in the Aleutian Islands in the fall of 2008 was relatively warm compared to seasonal norms, then cooled to near normal temperatures by the summer of 2009. Southern wind anomalies prevailed throughout much of the winter of 2008/2009 in the western Aleutians followed by northern wind anomalies in the summer of 2009 compared to southeastern wind anomalies occurring for most of the winter and spring of 2009 in the eastern Aleutians. This difference in prevailing wind direction resulted in suppressed storm activity in the eastern Aleutians and along the Alaska Peninsula (Bond and Overland 2009).

It is generally acknowledged that the global climate is changing and those changes are driving marine ecosystems toward conditions not seen in historic times. The effects on BSAI crab stocks will be both direct and indirect due to changes in temperatures, winds, storm intensity, salinity, stratification, pH, and abundance of suitable physical habitat. There is, however, considerable uncertainty over the spatial and temporal distribution of the effects of changing climate on marine ecosystems (Brander 2010, Hoegh-Guldberg and Bruno 2010). In the EBS, increases in air temperature, storm intensity, storm frequency, southerly wind, humidity, and precipitation are anticipated. The increased precipitation, plus snow and ice melt, leads to an increase in freshwater runoff (Barange and Perry 2009). The only atmospheric change showing a decrease is sea level pressure, which is associated with the northward shift in the storm track. Ocean circulation decreases are likely to occur in the major current systems: the Alaska Stream, Near Strait Inflow, Bering Slope Current, and Kamchatka Current. Competing effects make changes in the Unimak Pass inflow, the shelf coastal current, and the Bering Strait outflow unknown. Changes in hydrography should include increases in sea level, sea surface temperature, shelf bottom temperature, and basin stratification. Decreases should occur in mixing energy and shelf break nutrient supply, while competing effects make changes in shelf stratification and eddy activity unknown. Ice extent, thickness, and brine rejection are all expected to decrease (Barange and Perry 2009).

When considering the effect of climate change on BSAI crab stocks, differing time scales will have different management implications (Brander 2010). At short time scales (i.e., 1-5 years), the effects of long-term climate change can be relatively unimportant but the frequency of extreme conditions such as abnormally warm winters with minimal ice cover in the Bering Sea or a regime shift can have major consequences on the recruitment of a particular year class of crab. At medium-term time scales (~ 5-25 years) which span several generations of crab, changes in climate affect the basic productivity of the marine ecosystem (King 2005) and consequently crab rebuilding plans and biological reference points used in the assessment process. The long term impact of climate change on crab stocks will undoubtedly be very large, but the uncertainty associated with that change is also very large. Responses may be nonlinear and have greater impact on populations that may be less resilient (Brander 2007).

Sea Ice Trends in the Eastern Bering Sea

The extent and timing of the retreat of sea ice in the Bering Sea determines the strength and fate of the spring phytoplankton bloom which in turn can have a major impact on the survival of larval crab and the whole food web structure (Hare et al. 2007). The extent of sea ice coverage is variable and related to the location of the Aleutian Low and Siberian High which typically produce northeast winds in the winter that freeze the seawater and push the ice southwestward (Stabeno et al. 2001). During 1971-1976, extensive ice coverage on the Bering Sea shelf extended south and west, beyond the slope, and remained around St. Paul Island for more than a month in the spring. During the next cold phase from 1989-1998, 2-4 more weeks of ice were observed at the 59°N parallel than during the previous decade (Schumacher et al. 2003).

The Ice Retreat Index, defined by Overland et al. (2008) as the number of days with sea ice coverage after March 15th within the vicinity of king crab mooring 2A (KC-2A, Fig. 2), increased in 2006-2010 compared to the previous five years. This increase drives the recent trend in colder water temperatures and high ice coverage, if the ice cover is not extensive or retreats early in the spring, a shift occurs from ice-edge blooms to later open-water blooms (Hunt et al. 2010). The Ice Cover Index represents the average ice concentration from Jan 1 to May 31st in a 2° x 2° box (56-58°N, 163-165°W) for 1978-2008 relative to the 1981-2000 mean index of 7.15 (SD = 4.01) (Overland 2008). The presence of sea ice in 2007 (Fig. 3) along with below normal ocean temperatures likely resulted in the first ice-edge bloom since 1999 (Wang et al. 2008).

The seasonal melt and retreat of the sea ice edge leaves low saline and less dense water at the surface and the increased warming creates a stratified water mass of cold, dense seawater at the bottom of the seafloor. This cold pool (< 2°C) extends over a large portion of the EBS and has extended into Bristol Bay during the summer months, particularly in 1999-2000 and again in 2007-2010 as shown by bottom temperatures recorded at KC-2A (Fig. 4). As a response to changing water temperatures, the ecosystem in the Bering Sea is shifting northward (Overland and Stabeno 2004). Changes in the location of the cold pool alter the composition of the arctic and subarctic marine communities, but the response among taxa is variable and difficult to predict (Aydin and Mueter 2007; Mueter and Litzow 2008).

Wang et al. (2010) predict an approximately 40% reduction in Bering Sea sea ice coverage by 2050. Long-term changes in sea ice cover may affect benthic communities because much of the production from retreating ice edge spring blooms sink to the bottom, but if these blooms do not occur there may not be sufficient phytoplankton falling to the benthos to support abundant communities (Lovvorn et al. 2005).

Pelagic Habitat

During their larval stages, crab utilize the pelagic habitat of the Bering Sea and Aleutian Islands (Fig. 1, except Golden King Crab-see *Crab Life History* above). The pelagic habitat is vast and dynamic but many aspects of this habitat affecting larval survival are poorly understood. Kinney et al. (2009) presented an updated description of the general circulation of the Bering Sea and Aleutian Islands based upon recent modeling. The Alaskan Stream is the strongest current in the region and brings water from the North Pacific through Unimak Pass and Amukta Pass northward into the Bering Sea. The Alaska Coastal Current also supplies water from the North Pacific to the Bering Sea through Unimak Pass. The shelf break region is characterized by the Bering Slope Current which extends from the eastern Aleutian Islands along the shelf break toward the coast of Siberia near Cape Navarin and flows to the northwest (Fig. 2).

The shelf of the Bering Sea is divided into three depth domains each with distinct circulation patterns and hydrographic (temperature and salinity) characteristics. The coastal shelf domain (0-50 m) is characterized by one well mixed layer. In the middle shelf domain (50 to 100 m), a two-layer temperature and salinity structure exists because of wind which mixes the upper water column and tidal currents which mix the lower layer. In the outer shelf domain (100 to 180 m), a three-layer temperature and salinity structure exists due to wind mixing the upper water column, tidal currents mixing the lower layer and a middle layer that is not well mixed (Stabeno et al. 2001). The majority of the Norton Sound bathymetry is dominated by shallow depths, between 0 and 50 m, with one well mixed layer influenced by the freshwater driven Alaska Coastal Current as it flows north to the Bering Strait (Fig. 2).

Snow crab and RKC larvae have been shown to have strict survival tolerances to extremes in salinity (Shirley and Shirley 1989, Charmantier and Charmantier-Daures

1995) but the effects on survival due to variable salinity in the BSAI have not been demonstrated. Along the edge of the EBS shelf in the Alaska Stream, a low salinity tongue-like feature (less than 32.0) protrudes westward towards the EBS slope. On the south side of the central AI, nearshore surface salinities can reach as high as 33.3, as the higher salinity EBS surface water occasionally mixes southward through the AI passes. Proceeding south and west, a minimum of approximately 32.2 is usually present over the slope in the Alaska Stream and values rise to above 32.6 in the oceanic water offshore with salinity increasing towards the west as the influence of fresh water from the land decreases (Ladd et al. 2005).

High primary productivity along the shelf edge is maintained by vertical nutrient supply to the subsurface layer and shelf to slope exchange occurring with an increase in the Bering Slope Current transport and eddy fluctuations (Mizobata and Saitoh 2004). Vertical mixing of nutrient-rich deep Bering Sea water can enhance productivity in regions of the Bering Sea including around St. Lawrence Island and the Pribilof Islands (Stabeno et al. 2008, Kinney et al. 2009). Eddies along the southern edge of the Aleutian Islands influence the advection of both nutrients and water temperatures into the Bering Sea (Maslowski et al. 2008; Okkonen 1996). Cold, deep-water, high in nutrients, moves through the Aleutian Island passes and mixes with surface water in the Bering Sea. Water within these deep gullies and passes is highly mixed, resulting in low productivity, but as this water moves northward and becomes stratified, high-nutrient water is brought to the surface of the Bering Sea (Ladd et al. 2005).

Benthic Habitat

McConnaughey and Smith (2000) and Smith and McConnaughey (1999) synthesized the available sediment data for the EBS shelf. These data were used to describe four habitat types (Fig. 5). The first, situated around the shallow eastern and southern perimeter and near the Pribilof Islands, has primarily sand substrates with a little gravel. The second, across the central shelf out to the 100 m contour, has mixtures of sand and mud. A third, west of a line between St. Matthew and St. Lawrence Islands, has primarily mud (silt) substrates, with some mixing with sand. Finally, the areas north and east of St. Lawrence Island, including Norton Sound, have a complex mixture of substrates. The AI region has complicated mixes of substrates, including a significant proportion of hard substrates (pebbles, cobbles, boulders, and rock), but data are not available to describe the spatial distribution of these substrates.

Juvenile BKC have a mottled color pattern that blends into the background epifauna and, specifically, shell hash habitat may be important to juvenile BKC as a refuge from predators. Juvenile BKC likely require cover afforded by shell hash due to a lack of long spines and the lightly mottled carapace blends in with shell hash (Armstrong et al. 1985; Palacios et al. 1985). Survival in juvenile BKC is linked to the abundance of shells of certain mollusk species, including mussels *(Modiolus modiolus),* scallops *(Chlamys sp.),* rock oysters *(Pododesmus macrochisma),* and hairy tritons *(Fusitriton oregonensis)* (Palacios et al. 1985). This type of epifauna is scarce in offshore, sandy environments. Habitat of adult BKC is primarily composed of hard substrate such as cobble, gravel and rock found in the shallow (< 50 m) waters surrounding St. Matthew and the Pribilof Islands (Zheng et al. 1997).

Juvenile RKC have been shown to prefer nearshore habitats of high complexity (Dew 1990; Loher and Armstrong 2000) which includes a well-developed community of living substrate, such as hydroids, bryozoans and sponges. Juvenile RKC at the early post-settlement stage (< 10 mm CL) have strong preferences for structurally complex habitat with biogenic structure that provide foraging opportunities as well as protection from predation (Pirtle and Stoner 2010). Adult RKC move to soft bottom substrates further offshore (Rodin 1989). Tanner and snow crab juveniles are reported to prefer homogenous mud substrate (Dionne et al. 2003) or mud, silt, and sand (Rosenkranz et al. 1998). Adults prefer a similar habitat, with Tanner crab found primarily in a sand-mud substrate (Zhou and Shirley 1998) and snow crab generally occurring in the northwestern area of the Bering Sea although their ranges overlap (Slizkin 1989). Juvenile GKC have been seen associated with hexactinellid sponges *Aphrocallistes vastus* and *Heterochone calyx* (Stone 2006), while adults are associated with cold-water corals including *Primnoa* (Krieger and Wing 2002).

Changes in bottom water temperatures impact the amount of benthic habitat available to crab species. Over the last three decades, distribution of mature female snow crab in the EBS shifted in relation to changing water temperatures. Increased water temperatures in the mid-1980s resulted in a shift of mature female snow crab to the northwest EBS shelf while the more recent temperature decrease in the last decade did not result in a return of mature females to their historical distribution (Orensanz et al. 2004). See *Recruitment of King and Tanner Crab* section below for more details.

The Bristol Bay mean bottom water temperature collected over the last decade in early June on the NMFS Alaska Fisheries Science Center (AFSC) EBS bottom trawl survey ranged from lows of 1.8°C (SD = 1.6) in 2010 to 2.2°C (SD = 0.7) in 2006 compared to warmer temperatures ranging from 3.5°C (SD = 0.3) in 2001 to 4.3°C (SD = 0.5) in 2005. These cold temperatures in the summer reflect the extent of the sea ice coverage from 2006 to 2010 compared to the warmer bottom water temperatures from 2001 to 2005.

Based on data collected during the biennial AI bottom trawl survey from 1994 to 2006 and standardized to a median date of July 10^{th}, water temperatures both at the surface and in deeper depths were warmest in 1997, followed by 2004 compared to the other years (Martin 2010). Average bottom water temperatures collected on the Norton Sound trawl survey in late summer have fluctuated between 9.0 °C to 5.6 °C over the last two decades, with an average of 7.1°C bottom water temperature from the most recent Norton Sound triennial bottom trawl survey in 2008 (Hamazaki et al. 2005; Soong 2008).

Ocean Acidification

Since the start of the industrial revolution in the late 18^{th} century, anthropogenic activities, including the burning of fossil fuels and the production of cement have released CO_2 into the atmosphere and the world's oceans have taken up approximately 30% of this CO_2 (Feely et al. 2004; Sabine et al. 2004). When CO_2 dissolves in seawater, the pH is lowered and is known as ocean acidification. The pH of the world's ocean have lowered by approximately 0.1 units since the industrial revolution and is predicted to drop by 0.7 units over the next two and a half centuries (Caldeira and Wickett 2003). In the North Pacific Ocean the saturation depth is relatively shallow due to the cold temperature and age of advected deep water masses. This combination of factors means that these waters may become constantly undersaturated for aragonite by mid-century and for calcite by the end of the century (Fabry et al. 2009; Feely et al. 2009). This rapid decline in ocean pH will likely have strong effects on marine species and substantially alter marine ecosystems (Doney et al. 2009; Raven et al. 2006)

Biological Environment of the BSAI Ecosystem

Crab Prey

Information on BSAI crab food habits is limited; however, it is known that crab diets vary with life stage and in general crab are opportunistic omnivorous feeders, eating a wide variety of microscopic and macroscopic plants and animals. Red king crab, BKC, Tanner and snow crab larvae are planktonic feeders and consume both phytoplankton and zooplankton including diatoms, algae and copepods (Bright 1967, Paul et al. 1979, Abrunhosa and Kittaka 1997). Golden king crab larvae are considered lecithotrophic which are non-feeding and survive on yolk reserves (Shirley and Zhou 1997). The glaucothoe stage of RKC and BKC, their last larval stage, is non-feeding (Epelbaum et al. 2006).

Increased primary production could result in increased phytoplankton and zooplankton prey items for crab larvae. Nutrient supply and productivity in the Bering Sea is related to ice coverage, currents and eddies (see above, *Sea Ice Trends in the Eastern Bering Sea)*. When sea ice coverage over the southeast Bering Sea shelf occurs in March/April, a strong phytoplankton bloom occurs. In the absence of sea ice, the bloom does not occur until May/June and is typically weaker (Stabeno et al. 2001). For example, timing of the expansion and contraction of EBS sea ice coverage in 1997 was favorable for a phytoplankton bloom but not in 1998 or 1999 (Rho et al. 2005). The premature contraction of the sea ice coverage in 1998 and 1999, combined with strong mixing due to high winds, may have prevented the development of density-driven stratification, and resulted in higher nitrate concentrations with a lack of an obvious spring bloom (Rho et al. 2005).

Changes in the zooplankton community in the eastern Bering Sea may have an effect on RKC, BKC, Tanner and snow crab larvae which consume both phytoplankton and zooplankton. A decline of the euphausiid *Thysanoessa raschii* throughout the middle domain of the EBS shelf as well as coastal areas was discovered in the diet of short-tailed shearwaters during the late 1990s (Hunt et al. 2002). More recently, declines in summer zooplankton biomass have been linked to the warm years of 2001-2005 in the eastern Bering Sea (Renner et al. 2008). Part of the decrease in biomass over the middle shelf was most likely due to decreases in the abundance of *Calanus marshallae*, the only "large" copepod found in that area, and euphausiids (Renner et al. 2008). After a six year period of relatively low biomass, the EBS zooplankton began increasing on the middle shelf during the cold period of 2006-2008 (Napp and Yamaguchi 2008) and more recently, the biomass of *Calanus* spp. increased 10 fold by 2009 compared to the pervious warm years. Unfortunately, due to a reduction in ship time, no samples were collected on the EBS shelf in 2010.

Juvenile and adult crabs are opportunistic omnivorous scavengers. Juveniles consume benthic prey such as diatoms, foraminifera, copepods, algae, sponge, bryozoans, hydroids, polychaetes, small bivalves, snails, seastars, ophiuroids, echinoids, barnacles, crab, and sediment; detritus may also be a major component of their diet (Feder et al. 1980, Feder and Jewett 1981, Paul 1982). Cannibalism has been documented for juvenile RKC held in laboratory settings while examining early post-settlement juveniles and habitat preference (Stevens and Swiney, 2005; Stoner et al. 2010). The predominant prey of adult red king crab are bivalves, barnacles, polychaetes, hydroids, gastropods, amphipods, crabs, brittle stars, sand dollars and sea urchins (reviewed in Jewett and Onuf 1988). The predominant prey of adult Pribilof Islands blue king crab are fish, barnacles, hydroids, brittle stars, bivalves, crabs, polychaetes, sea stars, and amphipods (ADFG unpublished data). Stomach contents of Tanner crab near Kodiak Island had predominantly arthropods by weight (primarily juvenile Tanner crab); followed by fish and mollusks (Jewett and Feder 1983).

Adult snow crab in the EBS eat polychaetes, bivalves, detritus and other benthic prey (Aydin et al. 2007), which is similar to the most frequently occurring prey of adult snow crab from the Newfoundland shelf of polychaetes, shrimp, crab, small crustaceans, infaunal clams, and fishes (Squires and Dawe 2003). The diet of snow crab in the northern Bering Sea includes the most dominate prey available and changes ontogenetically, with smaller snow crab (< 50mm CW) eating amphipods and thin shelled bivalves while larger prey were found in the larger snow crab diets, such as bivalves, gastropods, polychaetes, brittle stars, and decapod crustaceans, (Lovvorn 2010). Additionally, cannibalism was found to provide a major food source for adult snow crab in the Gulf of the St. Lawrence (Lovrich and Sainte-Marie 1997).

A small number of BKC (28) and RKC (32) stomachs were collected by Alaska Department of Fish and Game (ADF&G) on the 2003 Pribilof Islands pot survey with prey analysis conducted by a marine taxonomist at the University of Alaska Fairbanks (unpublished data). Information on the distribution of the most frequently observed prey items from this study such as teleost tissue, barnacles, hydroids, Ophiuroidea (brittle stars), gastropod fragments, and polychaetes around the Pribilof Islands is limited.

The most complete description of benthic infaunal prey distribution in the EBS, such as polychaetes, other worms, and bivalves, comes from grab samples collected in 1975 and 1976 (Halflinger 1981), followed by a description of polychaete assemblages collected from a small section of the south-eastern portion of the Bering Sea in 2006 (Yeung et al. 2010). Polychaete families were associated with sediment type or benthic substrate based on their functional ecology such as burrowers in mud and sand or mobile species distributed on hard substrate. Coyle et al. (2007) compared late 1950s to mid 1970s benthic infaunal data from the southeastern Bering Sea shelf and found a trend toward higher overall infaunal biomass during the mid 1970s among carnivores, omnivores, and surface detritivores. The 1970s data was collected during a cold period which suggests a link between temperature and infaunal biomass. During cold periods, infaunal biomass is predicted to increase due to elevated carbon flux to the benthos and a reduction in groundfish predators due to cold bottom water (Coyle et al. 2007).

On the annual EBS bottom trawl survey, the catchability of most epibenthic crab prey is low but still accounted for 23% of the total demersal animal biomass (15.4 million t) in 2007, 24% (14.3 million t) in 2008 and 13% (0.70 million t) in 2009 (Acuna and Lauth 2008; Lauth and Acuna 2009; Lauth 2010). The majority of the invertebrates in 2009 were asteroid seastars, brittle stars, and sea urchins at 1.5 million t followed by crustaceans at 0.71 million t (Lauth 2010).

Variability in benthic production in the EBS, such as changes in epibenthic prey and benthic-foraging invertebrates, has been suggested as an important ecosystem indicator of productivity for commercial crab stocks, as crab are primarily benthic predators and crab production is likely influenced by benthic production. Invertebrates identified on the EBS bottom trawl survey from 1982 to present provide the most complete dataset available of trends in the benthic community. Asteroid seastars and brittle stars have been identified as crab prey and, excepting crab, are also the most abundant epifaunal invertebrates sampled by the AFSC EBS bottom trawl survey. The purple–orange sea star (*Asterias amurensis*) is distributed along the middle and coastal shelf domain of the EBS while the notched brittle star (*Ophiura sarsi*) is found primarily in the middle shelf domain, two areas which are also important for commercial crab stock on the EBS shelf. The mean CPUE of the purple–orange sea star caught on the EBS bottom trawl survey increased during the warm years of 2001-2005 followed by a decrease in 2006 and continuing in the cold years of 2007-2009, with a slight increase in 2010 (Fig. 6). Slight changes in the mean CPUE of the notched brittle star during the same time period does not appear to be associated with the two temperature regimes in the EBS although the mean CPUE is greatly reduced in 2009 and at the lowest level in 2010 (Fig. 6).

Competitive Interactions

Forage fish are planktonic feeders and may be competitors or predators for larval crab. Abundance trends of forage fish species for the EBS have been examined using data obtained on the AFSC EBS bottom trawl survey from 1982-2009. In general, abundance estimates of stichaeids and Pacific sand lance (*Ammodytes hexapterus*) were higher from 1982-1998 and lower from 1999-2009. Eulachon (*Thaleichthys pacificus*) abundance has been variable from 1982-2009 with the lowest years of abundance observed in 1985, 1989, 2008 and 2009 and the highest abundance years were 1984, 1991, and 1997 while capelin (*Mallotus villosus*) abundance has been low except for 1993 (Gaichas and Bolt 2009; Lauth 2009).

Abundance indices of other planktonic feeders in the EBS such as juvenile sockeye salmon (*Oncorhynchus nerka*), age-0 walleye pollock (*Theragra chalcogramma*), and age-0 Pacific cod (*Gadus macrocephalus*) were estimated from surface trawl data collected in the fall of 2002-2007 on the Bering-Aleutian Salmon International survey (BASIS). In warm water years, 2002-2005, juvenile sockeye salmon and age-0 pollock abundance increased and were widely distributed throughout the EBS shelf compared to decreased abundances in cold water years, 2006 and 2007, when juvenile sockeye salmon were primarily found in the inner Bristol Bay waters and age-0 pollock were restricted to the middle domain of the EBS. The abundance of age-0 Pacific cod fluctuated throughout the six year period with a relatively high number caught in 2005 and again in 2006 (Farley et al. 2008).

The 2008-2009 age-0 pollock year classes estimated from the EBS bottom trawl survey at 440 and 701 million fish respectively, decreased significantly compared to the 2007 estimate of 1,665 million fish (SAFE: Ianelli et al. 2009). The 2008-2009 year class of age-0 Pacific cod has been estimated to be a large year class by the Pacific cod stock assessment model, although the year class has only been observed once and the estimate is bounded by large confidence intervals (SAFE: Grant et al. 2009).

Benthic-foraging epibenthic invertebrates are likely competitors with juvenile and adult king, Tanner and snow crab for food. Examination of epibenthic invertebrate catches from the AFSC EBS bottom trawl survey 1982-2002 found distinct inshore and offshore communities that are separated by an oceanographic front occurring at the 50 m isobath. The biomass of the inshore community is dominated by seastars and the offshore community is dominated by snails, hermit crabs and snow crab (Yeung and McConnaughey 2006). Variations in this inshore and offshore community structure occur with a reduction in the spatial extent of the inshore community when mean bottom temperatures in the survey area were higher than normal the preceding summer. During these events, epibenthic invertebrates such as red king crab in Bristol Bay shifted from inshore communities to either offshore or undefined communities (Yeung and McConnaughey 2006). Yeung and McConnaughey (2006) concluded that epibenthic communities in the EBS may be rearranged by mobile epibenthic invertebrates, primarily crab, migrating offshore toward cooler water in warm years.

Marine benthic snails from the genus *Neptunea* are ubiquitously distributed throughout the EBS shelf and represent a significant element of the motile benthic epifauna in the EBS benthic ecology (Smith and Armistead *in review*). As a carnivorous benthic forager (Shimek 1984), *Neptunea* species are a good candidate for reflecting changes in benthic productivity. While some *Neptunea* have been identified to species on the EBS trawl survey over the last thirty years, analysis of confidence in the consistent identification of *Neptunea* to the species level resulted in a low confidence report while identification of *Neptunea* to the family level resulted in a high confidence report (Stevenson and Hoff 2009). Changes in the mean CPUE of *Neptunea* snails caught on the EBS bottom trawl survey were negligible during the last two pentades within 2000-2010, although higher CPUE were observed from 1987 through 1992 (Fig. 6). The motile benthic epifauna as a whole has been as assessed as a stable foraging guild in the more recent time period of 2005-2010 with mean biomass, catch and exploitation rates within ± one standard deviation of 1977-2010 levels (SAFE; Zador and Gaichas 2010).

Comparisons of two of the most abundant benthic epifaunal species, the purple–orange sea star and the notched brittle star, and Neptunea from the Buccinidae family with mature male biomass of Tanner, snow and Bristol Bay RKC from 1982 to 2010 did not elucidate any trends in benthic productivity or highlight a relationship between these benthic species (Fig. 7). Further analysis of the relationship between these epibethic organisms on a smaller spatial scale would be beneficial and is listed as a future research priority in this document.

Benthic foragers such as flatfish, skates, and other invertebrates including crab species may compete with juvenile and adult crab for food. Juvenile flatfish including rock sole

(*Lepidopsetta* spp*.)*, yellowfin sole *(Limanda aspera*), Pacific halibut (*Hippoglossus stenolepis)* and flathead sole (*Hippoglossoides elassodon*) consume polychaetes, bivalves, snails, and crustaceans (Holladay and Norcross 1995). Adult flatfish and skates consume benthic prey such as snails, clams, shrimp, crabs, fish, brittlestars, and polychaetes (Yang 2003). Refer to the *Predation by Groundfish, Marine Mammals and Seabirds* section for population trends as these species are both competitors and predators of crab.

Predation by Groundfish, Marine Mammals and Seabirds

During each life history stage, from the pelagic larvae to benthic adults, crab are consumed by different predators contributing in part to the natural mortality of these species. Other factors contributing to natural mortality in crab are discussed in the *Physical and Biological Environmental Impacts on Crab Biology* below. For king crab, numerous planktivorous fishes prey on Paralithodid larvae (Livingston et al. 1993; Wespestad et al. 1994). The size of Paralithodid prey in yellowfin sole and walleye pollock stomachs indicates they feed on larval and very early juvenile king crab (Livingston et al. 1993). Juvenile king crab may fall prey to Arrowtooth flounder (*Atheresthes stomias*), Irish lords (*Hemilepidotus* sp), snailfish (*Liparis* sp.), and octopus (*Enteroctopus dofleini*) (Livingston and Goiney 1983) but as the crab grow larger, they begin to exceed the mouth gape of many of these predators. Juvenile RKC experienced mortality due to cannibalism by older RKC in laboratory experiments (Stevens and Swiney 2005). However, juvenile king crab are usually found in shallow, nearshore waters (RKC, and BKC) or deepwater canyons (GKC) and outside of the annual bottom trawl survey area where a majority of the stomach samples are collected for food habits analysis, thus the potential of juvenile king crab as prey in these collections is greatly reduced.

A high number of early juvenile Tanner and snow crab age 0 to age 1 are consumed by Pacific cod in the eastern Bering Sea (Lang et al. 2005). It was estimated that cod removed up to 94% of age 1 Tanner crab and up to 57% of snow crab in the Bering Sea in a single year (Livingston 1989). A seasonal study in the Gulf of Alaska showed the primary prey item of Pacific cod were early juvenile Tanner crab (≤ 45 mm CW), both by weight and number (Urban 2010). Over the last thirty years, an increase in Tanner and snow crab mature male biomass from the EBS trawl survey is evident with a decrease in the Pacific cod biomass. When the Pacific cod biomass is time lagged three years to represent the juvenile crab predation, a more prominent trend reflects the impact these predators have on the smaller size classes which results in an increase or decrease in recruitment to maturity (Fig. 8). A similar trend of declining Bristol Bay RKC recruitment was found with increasing Pacific cod and yellowfin sole biomass (Zheng and Kruse 2000, 2006). The affect of yellowfin sole as a predator of juvenile Tanner and snow crab is not evident in this time series using a three-year lag on the predator, although yellowfin sole could be competing with adult Tanner and snow crab for the same prey (Fig. 9).

Other groundfish species such as; Alaska plaice (*Pleuronectes quadrituberculatus*), Arrowtooth flounder, flathead sole, northern rock sole (*Lepidopsetta polyxystra*), Pacific halibut, and yellowfin sole, also consume juvenile snow and Tanner crab, based on stomach contents data (Lang et al. 2003). Tanner crab were observed as a small percentage in the diet of Big skates (*Raja binoculata*), Aleutian skates (*Bathyraja aleutica*), Bering skate (*Bathyraja interrupta*) and Alaska skates (*Bathyraja parmifera*) collected on the AFSC Aleutian Island bottom trawl survey in 1994, 1997, 2000 and 2002 (Yang 2007). These predators may have an impact on the recruitment of juvenile Tanner and snow crab.

Pacific cod and large sculpins prey on adult king, Tanner and snow crab (NPFMC 2003, Aydin et al. 2007) but adult crab are relatively invulnerable to predation except after molting when they are in a soft shell state (Blau 1986, Livingston 1989, Loher et al. 1998). Because molting typically occurs in the spring and stomach samples are collected during the summer EBS and AI surveys, records of predation on adult crab occur infrequently in the AFSC food habits database.

Records of predation on golden and blue king crab are rare. The Resource Ecology and Ecosystem Modeling Program at AFSC collected stomachs on the EBS bottom trawl survey from over 100 species, yet BKC were found only in Pacific cod, walleye pollock and yellowfin sole stomachs. From 1981 to 2005, 5 Pacific cod, 27 walleye pollock and 8 yellowfin sole contained BKC prey from a total of 13,831 stomach samples with Pacific cod having the largest amount of BKC by weight (AFSC, REEM food habits database). One golden king crab was found in a white-blotched skate (*Bathyraja maculata*) stomach from the 612 samples collected from along the Kuril Islands and southeast Kamchatka during 1996 (Orlov 1998). Simenstad et al. (1977) assessed the AI marine food web in the vicinity of Amchitka Island and reported 6 instances of GKC and RKC in 69 halibut stomachs examined from inshore areas.

Coincident with the decline of Pribilof Islands blue king crab in the early 1980s, the abundance of Pacific cod and flatfish species increased dramatically in the late 1970s and early 1980s and has generally been high ever since; the influx of rock sole in the Pribilof Islands area has been particularly high (NPFMC 2003). A cause and effect relationship between the decline in BKC stock and the increase in the stocks of groundfish that are predators of and competitors with king crab remains speculative. Time series analysis of BKC year classes compared with Pacific cod, yellowfin sole, and rockfish (*Sebastes* spp.) year classes have not revealed any correlation between groundfish predation or competition and the decline in BKC stocks. Increases in Pacific cod and yellowfin sole biomass was associated with lower RKC recruitment (Zheng and Kruse 2000; Zheng and Kruse 2006). Correlations between Pacific cod biomass and Bristol Bay RKC recruitment with recruitment time lags from ages 0 to 3 and yellowfin sole biomass with recruitment time lags from ages 0 to 2 were statistically significant (Zheng and Kruse 2006). The spatial distribution of yellowfin sole and Bristol Bay RKC overlap in the southeastern section of Bristol Bay and this area of overlap has not changed substantially over time. This research is discussed in more detail in *Recruitment of King and Tanner Crab* section.

As benthic foragers, Arctic ice seals, such as bearded seals (*Erignathus barbatus*) and ribbon seals (*Phoca fasciata*), could be both competitors as well as predators of snow crab. Bearded seals are primarily found on ice floes in circumpolar arctic and subarctic waters migrating as far south as 57°N with the advancing ice edge in the spring. Ribbon seals stayed in the ice-free waters out towards the shelf break in the late spring and summer, after the ice edge begins to retreat (Cameron and Boveng 2009; Cameron et al. 2009). Bearded seals feed at depths less than 200 m with a diet composed of shrimp, crabs, clams and gastropods such as whelks while ribbon seals primarily eat groundfish, shrimp and some crustacean species (Lowry et al. 1980; Cameron et al. 2009).

The short-tailed shearwater (*Puffinus tenuirostris*) represents a major portion of the marine bird biomass in the southeastern Bering Sea. In the late 1990s the bird's diet was examined after a rapid decline of the species in the southeastern Bering Sea. The expected prey species, euphausiids (*Thysanoessa raschii),* was not predominant after 1997. The birds were feeding primarily on Pacific sandlance in the summer as well as crab zoea and copepods in the inner domain of the EBS (Hunt et al. 2002).

Predator Population Trends

Estimates from EBS bottom trawl surveys show a steady increase in Pacific cod biomass from the late 1970s through the mid 1980s, fluctuating from 1988 through 1994 (peak observed) then steadily declining with the 2008 estimate of 403,125 metric tons being the lowest on record (Thompson et al. 2009). Although recent biomass estimates of Pacific cod have been declining, there has been an increase in the number of smaller sized fish, suggesting the emergence of a strong year class (Acuna and Lauth 2008). Yellowfin sole biomass was at low levels during most of the 1960s and early 1970s after a period of high exploitation then increased and peaked in 1984. Although the biomass has been in slow decline, it has remained stable in recent years (SAFE: Wilderbuer et al. 2009). The abundance of EBS pollock remained at a fairly high level from 1982 through 1988. The stock is characterized by peaks in the mid 1980s and mid 1990s with a substantial decline by 1991 and the lowest point occurring at present. The stock has continued to decline substantially since 2003 due to apparently poor recruitment between 2000 and 2005 although the 2006 and 2008 year classes showed positive signs of recruitment (SAFE: Ianelli et al. 2009). Biomass estimates of EBS skate species have not been reported with the exception of Alaska skate, which is the dominant skate on the EBS shelf between the 50 and 200 m isobaths (Stevenson 2004). Alaska skate biomass fluctuated from 1982 through 1986, increased from 1986 through 1990 (peak), decreased from 1991 through 1999, and demonstrated an increasing trend from 353 thousand t in 1999 to 480 thousand t in 2007, followed by a dramatic decrease to 362 and 351 thousand t in 2008 and 2009, respectively (SAFE: Ormseth et al. 2010) (Fig. 10). Other skate species found in the EBS have no reliable estimates of biomass due to lack of survey data and are managed using average catch data.

Abundance trends of Pacific halibut showed an increase in biomass from 1982 through 1988 with a decrease in 1989. An upward trend with some fluctuation was observed through 2001 followed by a decrease in 2002. Low commercial and survey catch rates from the International Pacific Halibut Commission support a general decline in abundance estimates of Pacific halibut in the eastern Bering Sea (Clarke and Hare 2008). In 2006-2007, the under-40 cm halibut size class dominated the overall catch, but in 2008, the 40-79 cm size class regained that position (Sadorus and Lauth 2009). This indicates an increase in recruitment of Pacific halibut, although a majority of the 2009 biomass estimate of 130 million t in the eastern Bering Sea was dominated by smaller age classes (Hare 2010).

Early biomass estimates of bearded seal in the EBS and Chukchi Sea ranged from 250,000 to 300,000 animals. Surveys flown from Shishmaref to Barrow, Alaska, during May-June 1999 and 2000 provided preliminary results indicating densities up to 0.652 seals km^2. These densities cannot be converted into an abundance estimate, however, without information on the proportion of the population hauled out during the survey (Cameron and Boveng 2009). Surveys conducted in the 1970s estimated the Bering Sea population of ribbon seals between 60,000 to 100,000 animals. More recent population estimates are not currently available.

Physical and Biological Environmental Impacts on Crab Biology

Recruitment of King and Tanner Crab

Recruitment trends for RKC in Alaska are correlated with decadal shifts in climate and physical oceanography. Strong year classes for eastern Bering Sea RKC were observed when temperatures were low, and weak year classes occurred when temperatures were high, but temperature alone cannot explain year class strength trends for RKC (Zheng and Kruse 2000). In Bristol Bay, there is a relationship between RKC brood strength and the intensity of the Aleutian Low atmospheric pressure systems; during low pressure the brood strength is reduced (Tyler and Kruse 1996; Zheng and Kruse 2000). Gish (2006) suggested that the lack of king crab recruitment in the Pribilof Islands area may be the result of a large-scale environmental event affecting abundance and distribution.

The spatial distribution of mature females prior to larval release and locations of crab larvae settlement appear to be important for the recruitment success of crab in the EBS (Zheng and Kruse 2006). Both of these life history stages are affected by changes in the pelagic and benthic environment of the BSAI ecosystem. Bottom water temperatures may be important in structuring the distribution of ovigerous RKC (Loher and Armstrong 2005; Chilton et al. 2010). Female RKC were found primarily in central Bristol Bay during 1980-1987 and 1992-2006 (Zheng and Kruse 2006). The distribution centers of mature females moved south slightly during 1988-1991 but did not reach the southern locations previously occupied in the 1970s. Distribution of ovigerous RKC in the southeastern Bering Sea shifted from the eastern edge of Bristol Bay to the northeast, central shelf area during the late 1970s and early 1980s and this distribution change coincided with increased early summer bottom temperatures (Loher and Armstrong 2005). When the cold pool extended onto the Bristol Bay shelf area in 2006-2009, the summer distribution of ovigerous RKC had moved from the central area of Bristol Bay to the nearshore areas along the Alaska Peninsula (Chilton et al. 2010).

Snow crab recruitment in the EBS is also affected by temperature and ice cover, as well as spawning locations, settlement location and cod predation. Parada et al. (2010) developed a larval trajectory model based on female snow crab reproductive index, a ROMS oceanographic model, bottom temperatures collected during NMFS surveys, ice cover, chlorophyll-a, a cod predation index and larval recruitment patterns data from 1978-2003. In cold years, retention occurs in areas off the Pribilofs and St. Matthew Islands, whereas transport is generally north in warm years. Larval settlement occurs over a larger area in cold years than in warm years, and is always focused in the northwest section of the EBS.

Strong year classes of Bristol Bay Tanner crab are associated with warm seawater temperatures during gonadal development and embryo incubation along with northeast winds during the larval stages (Rosenkranz et al. 2001). Northeast winds may promote upwelling and provide Tanner crab larvae with food while advecting larvae to regions of preferred settling habitat (Rosenkranz et al. 1998; Rosenkranz et al. 2001).
Recruitment of king, Tanner and snow crab may be affected by ocean acidification because acidified waters can impact the development (Findlay et al. 2009, Parker et al. 2009), development time (Findlay et al. 2009), viability (Kurihara et al. 2004a), and even behavior (Ellis et al. 2009) of the embryos of marine invertebrates (though see Arnold et al. 2009). Further, acidified waters can reduce fertilization success (Parker et al. 2009), the hatching success of embryos (Kurihara et al. 2004a), and the fecundity of females (Kurihara et al. 2004b). No experiments examining the effects of ocean acidification specifically on crab reproduction or recruitment have been published to date; however, research on RKC is progressing at the Kodiak Laboratory, see Current Crab Ecosystem Research and Future Priorities section.

Ocean acidification and Bristol Bay red king crab recruitment-current modeling work

Contributed by Dusanka Poljak, University of Washington

Zheng and Kruse (2006) noted that the abundances of eastern Bering Sea (EBS) crab stocks, including red king crab in Bristol Bay (BBRKC), are driven greatly by recruitment variability. When recruitment is density-dependent, spawning biomass can explain some of the variation in recruitment through the stock recruitment relationship (Ricker, 1954; Beverton and Holt, 1957), with the remaining variation due to environmental factors such as temperature, wind, barometric pressure, or perhaps eventually ocean acidification (OA). Zheng and Kruse (2003) also found a high correlation among year classes, which implies environmental effects on recruitment. Environmental factors may affect food availability, larval timing and transport, growth, survival and consequently recruitment strength (Shepherd et al., 1984).

Given OA, North Pacific waters may become constantly undersaturated for aragonite and for calcite ions by the mid-century (Fabry et al. 2009, Feely et al. 2009). In addition, with increasing acidity, concentration of hydrogen ions will increase. Calcifying organisms need more energy to create their shells when the concentration of hydrogen ions increases because hydrogen ions are released when carbon shells are created. OA may slow down or stop process of shell construction in molting crab, which may reduce larval growth and fitness (Walther et al, 2010).

Survival of pre-recruitment stages of Bristol Bay red king crab (BBRKC) is being modeled under two OA scenarios to construct scenarios regarding trends in recruitment to the first size-classes in the stock assessment model. The implications of these trends for management will then be evaluated. The recruitment model considers all juvenile RKC life stages, with the final stage being the recruitment to the first size-class in the stock assessment model. It is assumed that individual animals in a stage, given that they survive, have to spend a certain amount of time in that stage before then can move to the next stage. Survival rates per stage are modeled using fecundity and recruitment data. Probabilities to stay in or progress to the next stage are a function of pH, hence, OA. The changes over time in pH were calculated by fitting a linear relationship to predictions of ocean pH for 2000 (pH_{2000}=8.069) and 2100 (pH_{2100}=7.824) (Caldiera and Wickett, 2003; Orr et al., 2005). Uncertainty in the model is accounted for by conducting a large number (1,000) of simulations where the reference values for annual survival and stage duration are drawn independently from beta and uniform distributions respectively.

The simulations estimate time-trajectories of recruitment for two scenarios: (a) pH is decreasing linearly over time, and (b) pH is constant over time. The first scenario identifies potential thresholds in response to changing pH. The second scenario shows likely trends in recruitment given no changes to pH values in the future. The two scenarios bound likely recruitment trends in the future for use in the later modeling, i.e., simulating catches of BBRKC based on a population model which mimics that used for stock assessment purposes.

Growth

Changes in both the physical and biological environment of the BSAI ecosystem utilized by crab species may have an effect on the individual growth of commercial crab species. Several studies have examined the direct effect of changing temperatures on the length of intermolt periods in juvenile Tanner crab and GKC (Paul and Paul 1996; Paul and Paul 2001a; Paul and Paul 2001b). Growth of juvenile RKC from Bristol Bay was found to be slower than that of juvenile RKC collected from Unalaska and Kodiak Island in the Gulf of Alaska (Loher and Armstrong 2000). One hypothesis for the protracted juvenile phase in Bristol Bay was related to water temperatures differences. Colder bottom temperatures in Norton Sound have been associated with the smaller size at maturity observed in RKC when compared to the Pribilof Islands and Bristol Bay RKC stocks (Blau 1990; Otto et al. 1990). The affects of temperature on juvenile blue king crab growth and intermolt period is currently being examined at the Kodiak Laboratory see *Current Crab Ecosystem Research and Future Priorities* section.

Ocean acidification has highly variable and species-specific effects on marine species (Kroeker et al. 2010). Calcification rates in marine calcifiers frequently decrease with decreasing pH (e.g. Gao et al. 2009, Comeau et al. 2010a, Comeau et al. 2010b, Rodolfo-Metalpa et al. 2010a), although the response is not always linear or negative (e.g. Rodolfo-Metalpa et al. 2010b). Crustaceans, in particular, may increase calcification rates under reduced pH conditions (Egilsdottir et al. 2009, Ries et al. 2009); however, increasing calcification rates may come at a high energetic cost (Wood et al. 2008). Embryos and larvae may be particularly vulnerable, although, again, the effects are variable. Acidification can increase development time (Findlay et al. 2009), decrease survival (Dupont et al. 2008, Parker et al. 2009, Watson et al. 2009), decrease growth (Talmage & Gobler 2009, Gazeau et al. 2010, Walther et al. 2010), cause malformations

(Comeau et al. 2010a, Parker et al. 2010), alter behavior (Ellis et al. 2009), and reduce settlement (Cigliano et al. 2010) in the embryos and larvae of marine species, although some species are unaffected (Arnold et al. 2009). The Kodiak Laboratory is currently investigating the affects of ocean acidification on growth and calcification rates of juvenile red king crab, blue king crab and Tanner crab as well and calcification of adult Tanner crab and red king crab, see *Current Crab Ecosystem Research and Future Priorities* section.

Maturity

Causes for differences in size of maturity have not been well studied for EBS crab species, but are often attributed to temperature or oceanographic processes. Female snow crab in the EBS can reach maturity at four different instars and reach maturity at smaller sizes at high latitudes in colder water and larger sizes at warmer low latitudes (Orensanz et al. 2007). Otto et al. (1990) found that among red king crab stocks, female size of maturity was lowest for Norton Sound, the northernmost stock studied, which may suggest that size of maturity is inversely correlated with latitude and temperature. However, the Pribilof Islands and Bristol Bay are located at approximately the same latitude, and while the Pribilof Islands are slightly colder, the size of maturity in females is lower for Bristol Bay red king crab than Pribilof Islands crab (Otto et al. 1990). Furthermore, size of maturity among red king crab females is nearly identical for Bristol Bay and Adak stocks, but Adak is south of Bristol Bay and is warmer. Size at maturity for male and female EBS golden king crab decreases with increasing latitude which may be due to temperature differences resulting in a decrease in growth rate in colder water (Somerton and Otto 1986). Size at maturity of male and female golden king crab is lower at Bowers Ridge than Seguam Pass, two areas that occur over a narrow range of latitude with similar temperatures (Otto and Cummiskey 1985). Oceanographic processes may account for differences in maturity between these areas. Seguam Pass is characterized by strong currents and turbulent mixing of North Pacific and Bering Sea waters and may be more productive than Bowers Ridge which is characterized by gentle currents (Otto and Cummiskey 1985).

Natural Mortality

Several factors may influence the natural mortality of commercial crab stocks other than senescence. Predation on commercial crab stocks or mortality due to disease should also be considered, particularly when those factors are also influenced by the same physical and biological environment of the BSAI ecosystem utilized by crab species. Crab predation is addressed in the *Predation by Groundfish, Marine Mammals, and Seabirds* section of this document while the effects of disease and parasitism on crab mortality are discussed here.

Mortalities are an obvious end-point of disease and parasitism, but these factors may affect individuals by less obvious means. Disease and parasitism may reduce growth rates and/or fecundity. Reproductive capability may be affected at several levels; failure of the ovary to develop or mature completely, and loss or failure of embryos to develop to hatching. Currently, several diseases and/or parasites are known to affect North Pacific crabs at all levels.

Potentially fatal diseases that may affect *Paralithodes* spp. *and Lithodes aequispinus* populations include a herpes-like viral disease of the bladder and antennal gland (Sparks and Morado 1986a, Bower et al. 1994), a pansporoblastic microsporidian (*Thelohania* sp.) which infects the hepatopancreas, ovary and muscle tissue, and produces a cottage cheese appearance in the abdominal cavity (Morado 2010), and a parasitic barnacle or rhizocephalan (*Briarosaccus* sp.) (Sparks and Morado 1986b; Hawkes et al. 1985). Symbiotic snailfish, *Careproctus* spp., deposit eggs into golden king crab gill chambers which interferes with respiration by compressing the gills, causing necrosis, and may lead to mortality (Somerton and Donaldson 1998). Otto et al. (1990) found three of 243 Bristol Bay RKC egg clutches containing nemertian worms, which are known predators of embryos. Although the amphipod *Ischyrocerus* sp. feeds on the eggs of king crab and could have a significant impact on fecundity they are usually never abundant enough to be a major predator (Kuris et al. 1991).

Bitter crab syndrome (BCS) in Tanner and snow crab is a fatal disease caused by a parasitic dinoflagellate of the genus *Hematodinium*, which infects the hemolymph (Meyers et al. 1990) and is widely distributed throughout the North Pacific (Meyers et al. 1996). The meat of crab infected with *Hematodinium* is not a public health concern but has a chalky texture and bitter taste, and is not marketable (Taylor and Khan 1995). Heavily infected crab may be identified by the opaque, white appearance of the ventral side of the abdomen and legs, and the milky white color of the hemolymph. The AFSC Fisheries Resources Pathobiology group has been monitoring BCS since 1988, detecting BCS in EBS Tanner and snow crab for more than 20 years with no clear trends in prevalence. The overall occurrence of BCS in snow crab has been about 3.5% with a low of < 1% to a high > 20% in 2003 since monitoring began (pers. comm. F. Morado, NOAA Fisheries). Tanner and snow crab stock recruitment may be affected as BCS is more common in crab less than 50 mm and is present throughout much of their distribution range. Some recent collections and analysis suggest that only one species of *Hematodinium* infects both North Pacific snow and Tanner crabs although other research indicates there may be more than one species of *Hematodinium* based on the frequency and distribution of occurrence in Tanner crab (Jensen et al. 2010). The long-term effect of this syndrome on affected crab populations is only now being investigated. The disease is more prevalent in the western Bering Sea Tanner crab stock than in the eastern stock (Tanner crab stocks divide by longitude 166°W). Siddeek et al. (2010) determined recovery of the western stock would be delayed by 2-3 years because of BCS when compared to the eastern stock. However, this delay was negligible when compared to the impact of the disease on the Stephens Passage, southeast Alaska Tanner crab stock which under any scenario would not recover under either a medium and long-term recovery plan.

Another disease detected in EBS Tanner crab is black mat syndrome, a systemic fungal infection caused by *Trichomaris invadens*, which penetrates the carapace and affects the epidermis and muscle (Sparks and Hibbits 1979). It has only been observed in *C. bairdi* and seldom encountered in the Bering Sea, thus it is not considered an issue of concern in the EBS (pers. comm. F. Morado, NOAA Fisheries).

Current Status of Ecosystem Indicators in 2010/2011

Purpose

The purpose of this section is to present current physical and biological environmental data within the BSAI ecosystem utilized by crab species and examine the trophodynamic interactions between crab and lower/upper trophic levels using information from the most recent publications or survey and research data. Current ecosystem oriented research projects and future research priorities for BSAI crab stocks are also presented here. One objective of the CECI is to identify key ecosystem status indicators relating to variability in BSAI crab stocks. Two physical and two biological environmental indicators have been proposed in this document as ecosystem stocks indicators with supporting literature for BSAI crab stocks.

Physical Environment of the BSAI Ecosystem in 2010/2011

North Pacific Climate

Despite the appearance of the 2009/2010 El Niño, the North Pacific experienced cooler than normal ocean temperatures in the northern and eastern sections mainly due to the cooler pre-existing state of the North Pacific. A relatively weak Aleutian Low occurred based on the arrival of La Nina in the spring/summer of 2010 which created a negative Pacific Decadal Oscillation for the North Pacific (Bond and Guy 2010).

Sea Ice Cover and EBS Climate

The Bering Sea climate conditions are driven by local and North Pacific processes throughout the winter into spring, which are uncoupled from the warming trends and sea ice loss observed in the Arctic. Both air and water temperatures in 2009/2010 contributed to extensive sea ice coverage in 2010 persisting into late spring which resulted in one of the largest summer cold pools encountered in the EBS. Reversing the trend of the relatively cold years of 2006-2010, the winter of 2010-2011 returned to warmer temperatures, especially the late winter months. The maximum air temperatures recorded at St. Paul Island were above the long-term average of 1947-2011, during three out of four days in January to March of 2011 (Fig. 11). The extent of the sea ice coverage was reduced in January to March of 2011 compared to the previous five years although the ice edge did extend further south in April 2011.

2010 Summer Bottom and Surface Temperatures in the eastern Bering Sea

Bottom temperatures measured during the 2010 EBS standard trawl survey ranged from -1.6° to 6.4°C (Fig. 12a) while sea surface temperatures ranged from 0.5°C to 9.7°C (Fig. 12b). These temperatures were collected at 20 nmi intervals as the survey progressed from east to west, beginning on 7 June 2010 in the northeast corner of Bristol Bay and moving westward towards the shelf edge finishing on 4 August 2010. A cold pool of water < 2°C was prevalent between the 50 m and 100 m isobaths in the middle shelf and southwestern portion of Bristol Bay area with cool temperatures persisting at the nearshore stations along the Alaska Peninsula. Bottom temperatures ranging from 2.5° to

3.9°C were evident between the 100 m and 200 m isobaths in the southwestern section of the survey area of the EBS, while cooler water temperatures ranging from 1.3° to 2.7°C persisted in the northwestern area between the 100 m and 200 m isobaths and the waters surrounding St. Matthew Island. Sea surface temperatures followed a similar pattern although colder temperatures were seen in Bristol Bay and the inner shelf of the EBS. Sea surface temperatures increased with increasing depths on the shelf but could be an artifact of the sample design where outer shelf stations were sampled later in the summer.

2010 Summer Bottom and Surface Temperatures in Norton Sound and Aleutian Islands

The mean bottom temperature per tow in the NBS area ranged from -1.6° to 12.3°C (Fig. 13a). These temperatures were collected at 20 nmi intervals as the survey progressed from southeast to northwest, beginning on 23 July just north of Nunivak Island and finishing just south of the Bering Straits on 9 August 2010. A cold pool of water < 2°C was prevalent west and south of St. Lawrence Island with cooler temperatures persisting at stations along 50 m isobath and deeper. Warmer bottom temperatures were evident in Norton Sound and in shallow waters along the Alaskan coastline, south of Norton Sound. Surface water temperatures followed a similar pattern in Norton Sound and along the Alaskan coastline with a cooler band of surface water east of St. Lawrence Island (Fig. 13b). Water temperatures collected on the 2010 AI bottom trawl survey were similar to data collected in 2006, with warmer surface water temperatures in the eastern and western ends of the AI trawl survey (Unimak Island and Adak Island) while cooler water temperatures were observed in the central area of the trawl survey near Seguam Island (Martin 2010).

Biological Environment of the BSAI Ecosystem

Status of BSAI Epifaunal Prey and Competitors in 2010

The 2010 total demersal biomass of the eastern Bering Sea estimated from the annual EBS bottom trawl survey was 15.6 million t, with benthic invertebrates representing 25% (3.9 million t) and composed primarily of echinoderms such as sea stars, sea urchins, and sea cucumbers at 1.7 million t (Lauth *in review*). The biomass of benthic invertebrates increased compared to 2009 levels.

Status of Crab Predators in 2010

The current biomass and abundance estimates for a group of likely crab predators common on the eastern Bering Sea shelf are reported by Lauth (*in review*) for the 2010 EBS bottom trawl survey, and are summarized in the next paragraph. The overall trend in crab predator abundance in the EBS appears to be increasing in comparison to previous years, especially with an increase in the biomass of Pacific cod which are know predators on juvenile Tanner crab (Urban 2010). The distribution of both Pacific cod and walleye pollock on the 2010 EBS bottom trawl survey was associated with areas outside of the cold pool and in water temperatures warmer than 0°C (Lauth *in review*).

The 2010 biomass estimate of 0.86 million t for Pacific cod has increased by 100% compared to 2009 estimate of 0.42 million t, most likely due to growth of the highly abundant younger year classes observed in the 2009 survey. The total biomass of walleye pollock for the entire survey area in 2010 was 3.75 million t, which was 63% higher than the 2009 biomass estimate of 2.28 million t. Yellowfin sole biomass increased to 2.37 million t in 2010 from 1.7 million t in 2009 while the estimated biomass of northern and southern rock sole (*L. bilineata*) increased by 18% to 2.06 million t in 2010 compared to 1.74 million t in 2009. Estimates of biomass for Arrowtooth flounder increased to 0.53 million t in 2010 compared to 0.41 million t in 2009, while the biomass estimate for Pacific halibut in the eastern Bering Sea was 0.198 million t in 2010 compared to 0.178 million t in 2009 (Lauth *in review*). Pacific halibut is one of the few crab predators with a decreasing abundance, but is still well above the values seen in the past 20 years although there has been a recent increase in the number of small halibut suggesting a strong year class (Hare 2010).

The estimated biomass of Alaska skate increased slightly to 367 thousand t in 2010 from 351 thousand t in 2009 and biomass estimates for other individual skate species in the BSAI region are not available. The total biomass estimate for the aggregated skate complex in the EBS for 2010 is 385 thousand t (SAFE: Ormseth et al 2010).

Current Crab Ecosystem Research and Future Priorities

This section of the CECI provides an opportunity to highlight current ecosystem oriented crab research such as funded proposals without published results or recent presentations at scientific meetings as well as identify gaps in the data and future research priorities.

The Crab Plan Team creates a list of crab specific research priorities on an annual basis that is forwarded to the North Pacific Fishery Management Council (NPFMC) for inclusion into a larger document. Several of these priorities have evolved into research projects funded by various entities including but not limited to AFSC and NMFS, the North Pacific Research Board (NPRB), the University of Alaska and other Universities. Crab specific research priorities are also developed at the annual December Interagency Crab Meeting held in Anchorage where a diverse number of research biologists from ADF&G, University of Alaska Fairbanks, University of Alaska Southeast, and AFSC present data from current projects and discuss potential collaborations (Webb and Woodby 2008). Currently, a number of crab ecosystem projects are being pursued which have developed from the research priorities discussed at these meetings.

Current crab ecosystem research includes

- Assessing inter-annual and seasonal variability in Bristol Bay red king crab fecundity in warm and cold years

- Investigating snow crab population genetic structure with respect to the changing environmental factors in the EBS

- Variability in reproductive potential of EBS snow crab with respect to spawning stock demography and temperature

- Recruitment of larval and juvenile Tanner crab affected by predation from groundfish, biomass of mature female Tanner crab, and environmental variables
- Diet and reproductive status of snow crab in the northern Bering Sea prior to commercial removals
- Sperm reserves of EBS snow crab
- Affects of habitat, predator density and predator size on the cannibalistic predator functional response in red king crab
- Juvenile red king crab habitat choice and habitat specific survival and growth
- Affects of ocean acidification on juvenile red king crab, blue king crab and Tanner crab growth, survival and calcification
- Affects of ocean acidification on maternal condition and reproductive success and larval condition and survival of Tanner crab
- Affects of ocean acidification on red king crab embryology and larval condition and survival
- Affects of temperature on juvenile blue king crab growth and intermolt period
- Assessing discard mortality of Tanner crab in the Alaskan bottom trawl fishery
- Investigating the impact of cold temperatures on snow crab survival using reflex assessment model predictor in a simulated environment

Proposed crab ecosystem research

- Affects of ocean acidification on red and blue king crab larval development
- Determine the functional response of one year old red king crab predators using young of year red king crab and alternative prey
- Identify as well as assess spatial and temporal productivity trends which may impact crab stock recruitment
- Identify the spatial distribution of potential competitors/predators of Pribilof Island BKC
- Genetic identification of EBS Tanner crab diet

The following ecosystem indicators were selected for their relationship to variability in BSAI crab stock abundances in the eastern Bering Sea:

Changes in north Pacific climate effecting sea ice coverage in the EBS.

> The north Pacific Climate is the primary driving force behind the extent and duration of sea ice coverage (Hunt, Jr. et al. 2010; Grebmeier et al. 2006). The extent of sea ice coverage is variable and related to the location of the Aleutian Low and Siberian High which typically produce northeast winds in the winter that freeze the seawater and push the ice southwestward (Stabeno et al. 2001). The extent and timing of the retreat of sea ice in the Bering Sea determines the strength and fate of the spring phytoplankton bloom and subsequent zooplankton production (Wang et al. 2008). When sea ice coverage over the southeast Bering Sea shelf occurs in March/April, a strong phytoplankton bloom occurs. In the absence of sea ice, the bloom does not occur until May/June and is typically weaker (Stabeno et al. 2001). Variability in the extent and timing of sea ice coverage in the EBS can have a major impact on the survival of larval crab and the whole food web structure (Hare et al. 2007).
>
> The effects of variability in the north Pacific climate on BSAI crab stocks will be both direct and indirect due to changes in temperatures, winds, storm intensity, salinity, stratification, pH, and abundance of suitable physical habitat. There is, however, considerable uncertainty over the spatial and temporal distribution of the effects of changing climate on marine ecosystems (Brander 2010, Hoegh-Guldberg and Bruno 2010). When considering the effect of climate change on BSAI crab stocks, differing time scales will have different management implications (Brander 2010). On a time scale of 5 to 25 years, spanning several generations of crab, changes in climate affect the basic productivity of the marine ecosystem (King 2005). Long-term changes in sea ice cover may affect benthic communities because much of the production from retreating ice edge spring blooms sink to the bottom, but if these blooms do not occur there may not be sufficient phytoplankton falling to the benthos to support abundant communities (Lovvorn et al. 2005).

Summer bottom water temperatures impacting distribution of benthic crab, competitors and predators.

> As a response to changing water temperatures, the ecosystem in the Bering Sea is shifting northward (Overland and Stabeno 2004). Changes in the location of the cold pool alter the composition of the arctic and subarctic marine communities, but the response among taxa is variable and difficult to predict (Aydin and Mueter 2007). Increased water temperatures in the mid-1980s resulted in a shift of mature female snow crab to the northwest EBS shelf (Zheng et al. 2001) while the more recent temperature decrease in the last decade did not result in a return of mature

females to their historical distribution (Orensanz et al. 2004). Other planktivorous feeders and potential crab competitors, such as juvenile sockeye salmon and age-0 pollock, increased in abundance and were widely distributed throughout the EBS during the warm years of 2002-2005. In the cold years of 2006-2008, juvenile sockeye salmon were primarily found in the inner Bristol Bay waters and age-0 pollock were restricted to the middle domain of the EBS with abundance decreasing for both species (Farley et al. 2008).

Major groundfish predators are intolerant of the low temperatures of ice-associated bottom water so a natural refugia for crabs is formed (Mueter and Litzow 2008). The distribution of Pacific cod in the EBS has been associated with areas outside of the cold pool and in water temperatures warmer than 0°C (Ciannelli and Bailey 2005; Lauth *in review*). Temperature has been shown to have opposing effects upon snow crab and their main predator, Atlantic cod (*G. morhua*). Snow crab abundance was negatively correlated with temperature while cod and temperature were positively correlated (Boudreau et al. 2011).

Changes in the abundance of Pleuronectidae and Gadidae biomass in the EBS

Groundfish predators have been shown to have a major impact on crab stocks (Livingston 1989, Aydin et al. 2007). Changes in the abundance of these predators would likely affect the variability of crab stocks, specifically at the larval and juvenile stages as adult crab are relatively invulnerable to predation except after molting when they are in a soft shell state (Blau 1986, Livingston 1989, Loher et al. 1998).

For king crab, numerous planktivorous fishes prey on Paralithodid larvae (Livingston et al. 1993; Wespestad et al. 1994). The size of Paralithodid prey in yellowfin sole and walleye pollock stomachs indicates they feed on larval and very early juvenile king crab (Livingston et al. 1993). Juvenile king crab may also fall prey to other flatfish species (Livingston and Goiney 1983), but crab begin to exceed the mouth gape of many of these predators as they grow. Suitably lagged models of predator abundance such as Pacific cod and yellowfin sole, could be used to predict future king crab abundance although the relationships need further analysis (Zheng and Kruse 2000, 2006).

A high number of early juvenile Tanner and snow crab age 0 to age 1 are consumed by Pacific cod in the eastern Bering Sea (Lang et al. 2005). It was estimated that Pacific cod removed up to 94% of age 1 Tanner crab and up to 57% of snow crab in the Bering Sea in a single year (Livingston 1989). A seasonal study in the Gulf of Alaska showed the primary prey item of Pacific cod were early juvenile Tanner crab (≤ 45 mm CW), both by weight and number (Urban 2010).

Ecosystem-based Management Indicators

Purpose

This section of the CECI provides early signals of direct human effects on BSAI crab ecosystem components via directed fishery affects on the ecosystem and summarizes current management actions such as; management efforts in response to directed fishery effects on BSAI habitat, and spatial and temporal removals of the target catch affecting other biological predators. In this section, we also review potential fishery effects on crab life history stages such as removal of legal sized males, age at maturity and reproduction.

Fishery-Specific Impacts on the Physical Environment

Effects of Crab Fishing Gear on Seafloor Habitat

In the BSAI crab fisheries Final Environmental Impact Statement (EIS), the impact of pot gear on benthic EBS species is discussed (NMFS 2004). Benthic species examined included fish, gastropods, coral, echinoderms (sea stars and sea urchins), non-target crab, and invertebrates (sponges, octopuses, anemones, tunicates, bryozoans, and hydroids). It is likely that habitat is affected during both setting and retrieval of pots, but little research has been done. Physical damage to the habitat by pot gear depends on habitat type. Sand and soft sediments where the majority of EBS crab pot fishing occurs are less likely to be impacted, whereas coral, sponge, and gorgonian habitats are more likely to be damaged by commercial crab pots in the AI GKC fishery (Quandt 1999, NMFS 2004). The total portion of the EBS impacted by commercial pot fishing may be less than 1% of the shelf area (NMFS 2004). The report concludes that BSAI crab fisheries have an insignificant effect on benthic habitat.

Management Enacted Efforts

Habitat protection areas, prohibited species caps (PSC) and crab bycatch limits are in place to protect important benthic habitat for crab and other resources and reduce crab bycatch in the trawl and fixed gear fisheries. Beginning in 1995, the Pribilof Islands Conservation Area was closed to all trawling and dredging year-round to protect BKC habitat (NPFMC 1994). Also beginning in 1995, the Red King Crab Savings Area was established as a year-round bottom trawl and dredge closure area (NPFMC 1995). This area was known to have high densities of adult red king crab, and closure of the area greatly reduced bycatch of this species. The Red King Crab Savings Subarea is a portion of the Red King Crab Savings Area between 56° 00’ and 56° 10’ N lat. Within this Subarea, non-pelagic trawl gear may be used if GHLs were established for a Bristol Bay RKC fishery the previous year. The RKC bycatch limit is established by NMFS after consultation with the Council and the limit does not exceed an amount equivalent to 25 percent of the RKC PSC allowance (Federal Register 679.21 Prohibited Species Bycatch Management). To protect juvenile RKC and critical rearing habitat (stalked ascidians and other living substrate), another year-round closure to all trawling was implemented in 1996 for the nearshore waters of Bristol Bay. Specifically, the area east of 162° W (i.e., all of Bristol Bay) is closed to trawling and dredging, with the exception of an area bounded by 159° to 160° W and 58° to 58°43' N that remains open to trawling during the period April 1 to June 15 each year (NPFMC 2008, Fig. 14).

The Bering Sea Habitat Conservation Area, Northern Bering Sea Research Area, Nunivak Island, Etolin Strait, and Kuskokwim Bay Habitat Conservation Area, St. Lawrence Island Habitat Conservation Area, and St. Matthew Island Habitat Conservation Area were closed to non-pelagic gear in 2008. These areas include BKC habitat, locations that have not been fished with non-pelagic gear, nearshore bottom habitat that support subsistence marine resources and a research area (Federal Register Vol. 73, No 144, July 25, 2008, Rules and Regulations). A scientific research plan is currently being developed for the Northern Bering Sea Research Area and will be reviewed by the North Pacific Fishery Management Council in 2011. The major objectives of the plan are to study the effects of bottom trawling on benthic species and habitat with the goal of providing information to assist in the development of future protection measures for crab and other species as well as subsistence needs of western Alaska communities (Fig. 15).

PSC limits are in place for RKC, Tanner and snow crab. If PSC limits are reached in predetermined bottom trawl fisheries executed in specific areas (Fig. 14), those fisheries are closed. Snow crab taken within the "Snow Crab Bycatch Limitation Zone" (COBLZ) accrue towards the PSC limits established for individual trawl fisheries. Upon attainment of a snow crab PSC limit apportioned to a particular trawl target fishery, that fishery is prohibited from fishing within the COBLZ. A recent review of the PSC limits for commercial crab species in groundfish fisheries is detailed in *Crab Bycatch in the Bering Sea/Aleutian Island Fisheries* (NPFMC 2010). Annual crab bycatch limits (CBLs) are specified for RKC, Tanner and snow crab in the scallop fishery in the Bering Sea, Registration Area Q, and are calculated as a percentage of the most recent abundance estimate of RKC, Tanner and snow crab in Registration Area Q.

Effects of groundfish Fishing Gear on Seafloor Habitat

McConnaughey et al. (2000) examined the impact of trawl gear on the EBS seafloor by comparing an area closed to trawling adjacent to an area that has experienced intensive fishing for yellowfin sole. There were significantly detectable differences in macrofaunal populations between the two areas, with greater diversity and niche breadth of sedentary macrofauna in the unfished area. The biomass of stalked, attached and encrusted epifaunal organisms (sponges, anemones, soft corals, and tunicates) was greater in the unfished area. These organisms provide substrate complexity and are vulnerable to bottom trawl gear. A larger number of marine snail and bivalve shells also added to the complexity of the substrate in the unfished area. Overall, the complexity of the benthic substrate as well as the epifaunal diversity is affected by bottom trawl gear and reduces the heterogeneity of the benthic communities (McConnaughey et al. 2000). Recent research by Rose et al. (2010) examined the adaption of rubber cookie discs and different lengths of bottom trawl bridle cables to improve fishing efficiency of flatfish as well as reduce the impact of these bottom trawls to the seafloor.

The CPT presented a discussion paper to the NPFMC in March 2011 evaluating the effects of groundfish fishing on essential fish habitat for RKC. The discussion paper highlighted the interaction between trawl fishing and ovigerous female RKC in the southwest area of Bristol Bay, an area with potentially higher survival rates for larval and juvenile RKC. The NPFMC requested further analysis on the effectiveness of the RKC Savings Area and the Nearshore Bristol Bay Trawl Closure with respect to the impact of fishing gear on seafloor habitat (Fig. 14).

Fishery-Specific Impacts on Biological Environment

Directed Fishery Contribution to Competitor and Predator Mortality

The EBS crab fisheries catch a small amount of other species as bycatch. A limited number of groundfish, such as Pacific cod, Pacific halibut, yellowfin sole, and sculpin (*Myoxocephalus* spp.), are caught in the directed pot fishery (Barnard and Burt 2007; Barnard and Burt 2008; Gaeuman 2010). The invertebrate component of bycatch includes echinoderms (stars and sea urchin), snails, non-FMP crab (hermit crabs and lyre crabs), and other invertebrates (sponges, octopus, anemone, and jellyfish). Typically, low levels of bycatch of these species do not impact their abundance (NMFS 2004).

Mortality to fish and non-target invertebrates from ghost fishing of lost crab and groundfish pots in the EBS has not been evaluated. The term ghost fishing describes continued fishing by lost or derelict gear. Crab caught in lost pots may die of starvation; however, the impact of ghost fishing on crab stocks remains unknown. To reduce starvation mortality in lost pots, crab pots have been required to be fitted with degradable escape mechanisms such as cotton thread or twine since 1977. Pots without escape mechanisms could continue to catch and kill crab for many years. High and Worlund (1979) estimated an effective fishing life of 15 years for king crab pots. The ADFG requires the use of a biodegradable twine panel in each crab pot intended to disable ghost fishing in lost pots after approximately 30 days. Recent work indicates that even biodegradable twine may remain intact for up to 89 days in lost pots (Barnard 2008), or 3 times the length of time (30 days) found to cause irreversible starvation in crab (Paul et al. 1994). Testimony from crabbers and pot manufacturers indicate that all pots currently fished in Bering Sea crab fisheries contain escape mechanisms (NPFMC 2007).

NMFS conducted Endangered Species Act (ESA) Section 7 Consultations-Biological Assessments on the impact of the Bering Sea and Aleutian Island FMP crab fisheries on marine mammals (NMFS 2000) and on seabirds (NMFS 2002). As noted in the Endangered Species Act EIS report, crab fisheries do not adversely affect ESA listed species, destroy or modify their habitat, or comprise a measurable portion of their diet (NMFS 2004). Although the possibility of strikes of listed seabirds with crab fishing vessels does exist (NMFS 2000), NMFS concluded that available evidence is not sufficient to suggest that these interactions occur in today's fisheries or limit the recovery of seabirds. Of non-listed marine mammals, bearded seals (*Erignathus barbatus*) are the only marine mammal potentially impacted by crab fisheries insofar as crab are a measurable portion of their diet (Lowry et al. 1980; NMFS 2004). For non-listed seabirds, the Alaska Groundfish Fisheries Final Programmatic SEIS (NMFS 2004) provides life history, population biology and foraging ecology for marine birds. The SEIS concluded that crab stocks under the NPFMC fishery management plan (NPFMC 1998) have very limited interaction with non-listed seabirds.

Directed Fishery Contribution to Discards and Offal Production

The EIS for the BSAI crab fisheries summarizes some of the effects of discards and offal production (NMFS 2004). Returning discards, process waste, and the contents of used bait containers to the sea provides energy to scavenging birds and animals that may not otherwise have access to those energy resources. The total offal and discard production as a percentage of the unused detritus already going to the bottom has not been estimated.

Groundfish and Scallop Fisheries By-Catch of Commercial Crab

RKC, Tanner and snow crab, regardless of sex or size, are considered prohibited species in the groundfish and scallop fisheries with an estimated handling mortality of 50% in fixed gear, 80% in trawl gear and 40% dredge gear fisheries. Bottom trawl fisheries in specific areas are closed when PSC limits of RKC, Tanner and snow crab are reached (see *Management Enacted Efforts* section).

Bycatch data of commercial crab species caught in the groundfish fisheries is provided by NMFS, Alaska Regional Office from 1991 through 2010 and incorporated into the individual species stock assessments when appropriate to their tier level.

The scallop fishery in the Bering Sea (Registration Area Q,) is executed from July 1st through the end of February and closes if harvest guidelines or CBLs are reached. Since 1993, 100% observer coverage has been required on all vessels participating in the scallop fishery. Scallop observers collect biological data from the targeted catch as well as bycatch species. The Bering Sea fishery within Area Q targets scallop beds in 90 to 106 m of water in a small area (13 nmi^2) north of Unimak Island (Rosenkranz 2010). Scallop fishery closures in Area Q resulting from CBLs have decreased in recent years mainly due to lower crab abundances in the EBS (Barnhart and Rosenkranz 2003, Table 2).

Fishery-Specific Impacts on Crab Biology

Directed Fishery Effects of the Target Catch Relative to Predators

The spatial and temporal removal of the target catch, legal sized male crab (Table 1), is dependent on the size of the vessel quota, weather conditions, advancing ice edge, processor demand, and Community Development Quotas (CDQ) deliveries distributed between St. Paul Island and Dutch Harbor, Alaska. Historically, Bristol Bay RKC is fished from late October through early December, and EBS Tanner and snow crab January through April. The St. Matthew Island BKC fishery opened in November of 2009 after a ten year rebuilding plan, although this fishery was historically executed in September and October just prior to the red king fishery. The Norton Sound RKC and Aleutian Islands GKC fisheries are conducted in the summer and fall.

There are few species identified as predators of legal sized male crab and specific information is limited due to the difficulty of identifying prey items to the species level with only partial carapace or dactyl pieces. Based on food habits data collected in the summer months during the annual EBS bottom trawl survey, Pacific cod, Pacific halibut and skates are the primary predators of large or legal size crab although legal sized crab are a minimal component of these predators diets.

Directed Fishery Effects on Target Crab, Age-At-Maturity and Reproduction

In the BSAI, minimum size limits for male crab are established based upon the estimated average size-at-maturity with the intent of allowing males to mate at least once before becoming harvestable. Females are not harvested and fishing seasons are timed to protect the crab when they are molting and mating (NPFMC 2008). It is possible that male-only fisheries with minimum size limits reduce the abundance of large crab; however this has not been examined for Bering Sea crab stocks. In Glacier Bay National Park and Preserve, located at the northern end of the southeastern Alaska panhandle, the number and size of legal-sized male Dungeness crab increased significantly after the closure of the park to commercial fishing. Females and sub-legal males were not targeted by the commercial fishery and these crab did not increase in size or abundance following the closure of the fishery (Taggart et al. 2004). Commercial fishing in Glacier Bay National Park and Preserve appeared to have altered the size structure of male Dungeness crab which may also be occurring within EBS crab stocks.

Over time, size-at-maturity may be reduced due to fishing-induced mating selection in male-only fisheries (Zheng 2008). A significant decline in size at 50% maturity of male Bristol Bay Tanner crab may be the result of genetic responses to the fishery. Fast-growing males may not have an opportunity to mate prior to being harvested in the fishery, whereas slow-growing males may undergo their terminal molt to maturity before reaching the legal size limit and therefore mate (Zheng 2008). Recent analysis of the economic and biological impact of reducing the legal size of Tanner crab in the EBS concluded that a reduction would result in decreased handling mortality in the directed fishery of the terminally molted sublegal males due to the increased CPUE from the smaller legal males but handling mortality would not be reduced in other fisheries (Bechtol et al. 2010). A reduction in the size of legal caught Tanner crab may also reduce potential risk of genetic effects from removing only the larger males (Zheng and Pengilly 2011).

A reduction in the abundance of large males may result in the mating of less fecund males, reduced female mate choice and an increased chance of sperm limitation (Smith and Jamieson 1991; Sato et al. 2005a; Sato et al. 2006; Sato and Goshima 2006; Sainte-Marie et al. 2008). Male size and mating frequency affects reproductive success of many crab species. In general larger males are more successful at mating (production of a fertilized egg clutch) and can successfully mate with multiple females (Paul and Paul 1990; Paul and Paul 1997; Sato et al. 2005b; Sato and Goshima 2006). Based upon manipulation population studies of *Hapalogaster dentate*, a decrease in male size and sex ratio would result in sperm limitation (Sato and Goshima 2006). Laboratory research and field studies in eastern Hokkaido, Japan suggest that sperm limitation could occur in fished populations of *Paralithodes brevipes* (Sato et al. 2005b). Large male snow crab from heavily harvested stocks in the Gulf of St. Lawrence, Canada have small amounts of spermatophores in their vas deferens which is in contrast to higher levels observed in lightly or not fished stocks (Conan and Comeau 1986; Sainte-Marie et al. 1995). In heavily exploited snow crab stocks, a high percenteage of males may be harvested upon reaching morphometric maturity resulting in an inability of mature males to accumulate a sufficient number of spermatophores necessary to successful mate (Conan and Comeau 1986; Sainte-Marie et al. 1995). In the EBS, female snow crab sperm reserves increase with female size and appear to generally be lower than other snow crab stocks (Slater et al. 2010). Limited sperm reserve data from EBS snow and Tanner crab suggest that in 2005 less than one half of primiparous females sampled had sufficient sperm reserves to fertilize a full second clutch of eggs (Gravel and Pengilly 2007). Alternately, in northern California, nearly all molting female Dungeness crab mate regardless of size despite intense fishing on males (Hankin et al. 1997). The short and long term effects of removing large male crab from a population is not well understood and may vary by species and population.

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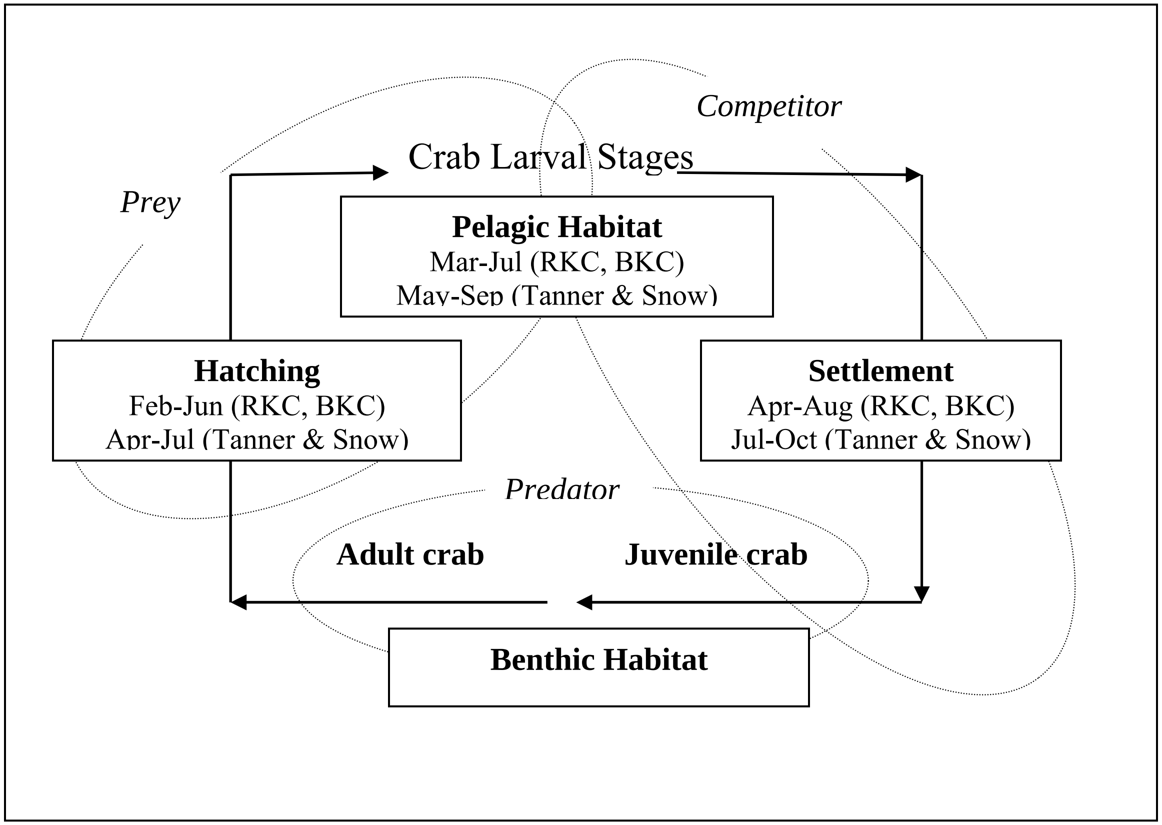

Figure 1. Seasonal timing and duration of crab life history stages in relation to the physical and biological components of the Bering Sea/Aleutian Island ecosystem, red king crab (RKC) and blue king crab (BKC).

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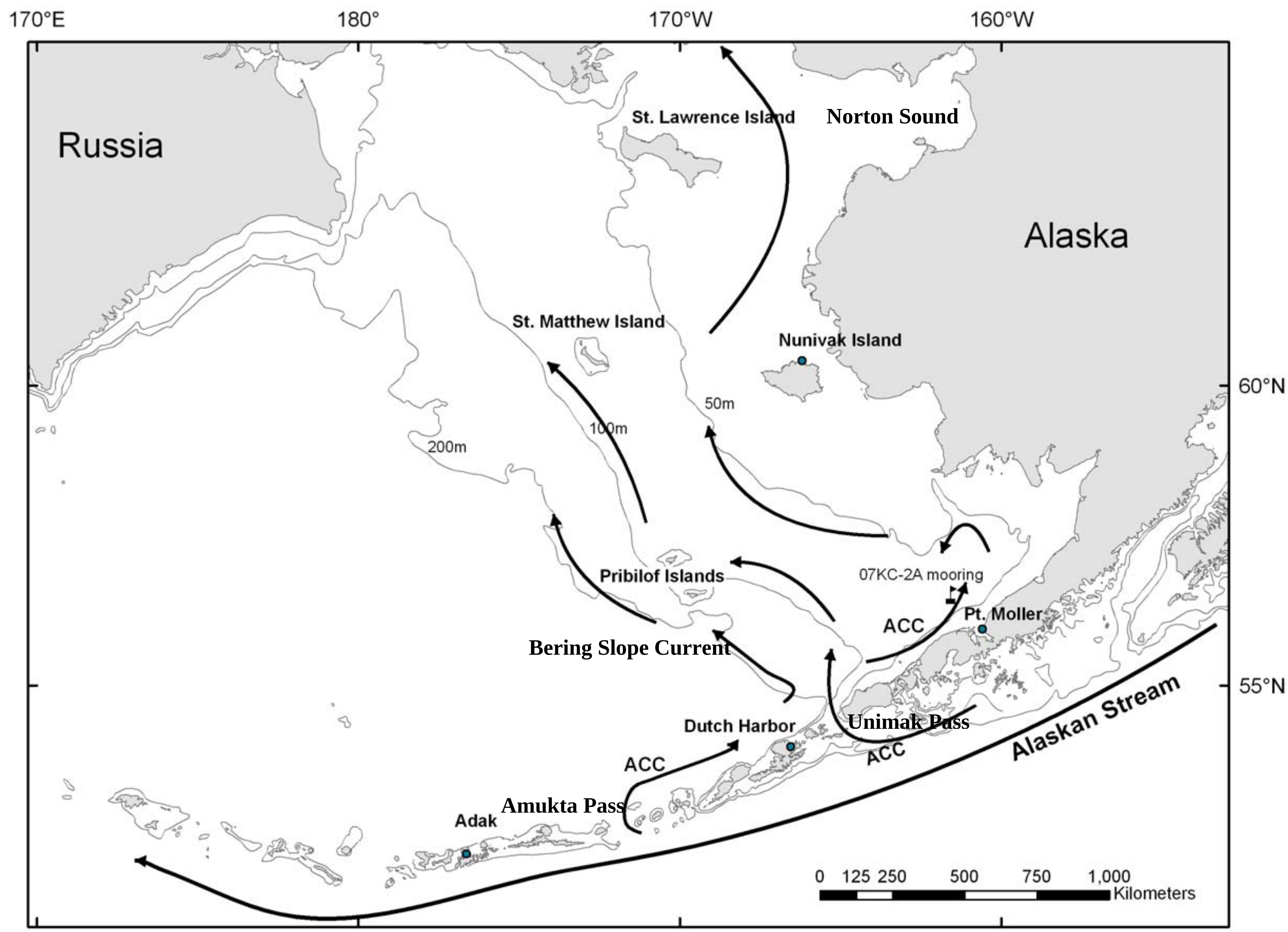

Figure 2. Inner, Middle, and Outer domains on the eastern Bering Sea shelf with King Crab mooring 2A (KC-2A) and major current flow depicted, including the Alaska Coastal Current (ACC) entering through Unimak Pass (Current flow from Stabeno et al. 2001).

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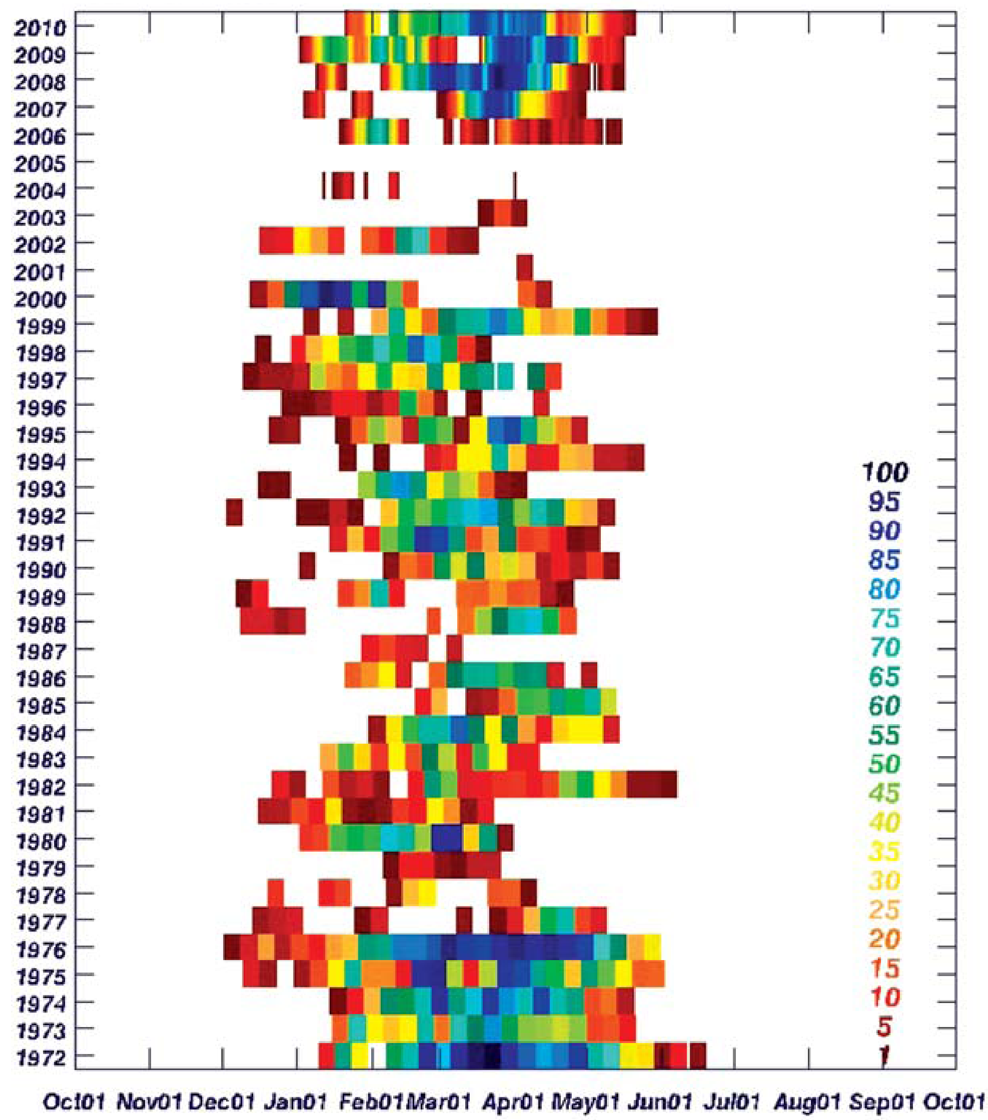

Figure 3. The percentage of sea ice coverage in the eastern Bering Sea as the average ice concentration in a 2° x 2°box at 56-58°N, 163-165°W from 1972-2010. The numeric color scale on the right corresponds with the percentage of ice coverage (Source: Hunt et al. 2011).

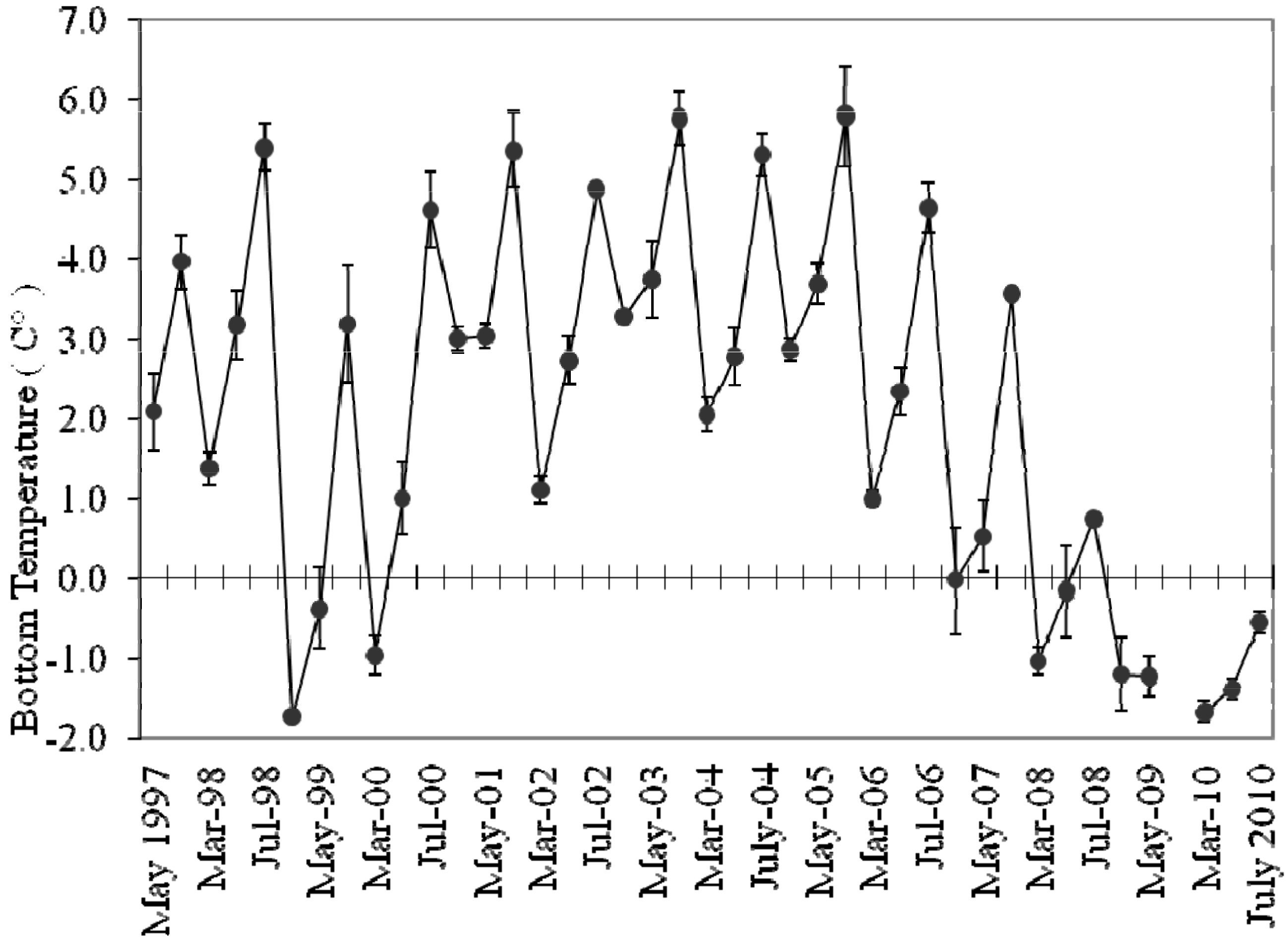

Figure 4. Monthly averaged water temperatures (°C ± SD) at the Bristol Bay mooring M2 in eastern Bering Sea from May 1997 to July 2010. Data in July 2009 was not available.

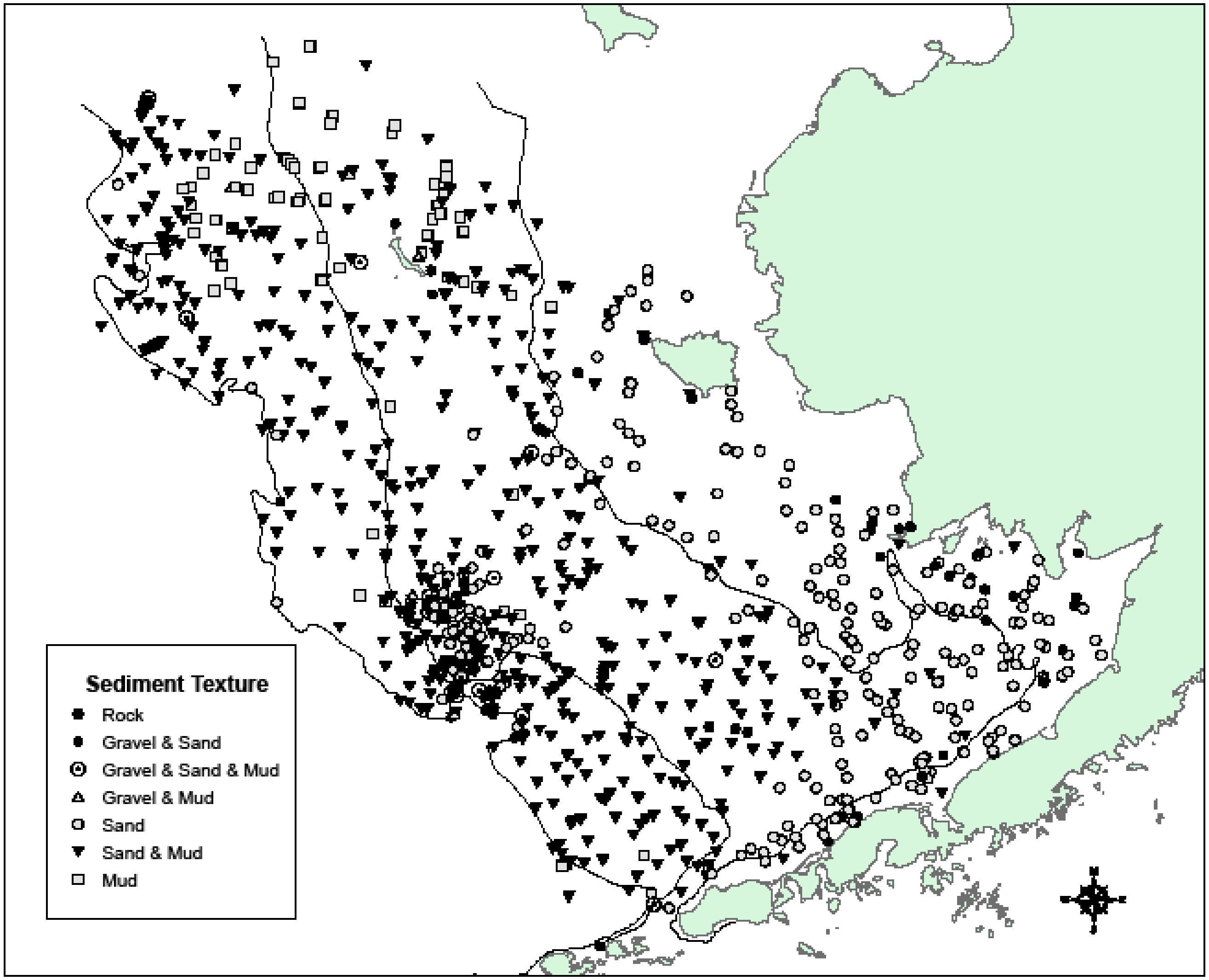

Figure 5. Distribution of benthic sediment types in the eastern Bering Sea (Source: Smith and McConnaughey 1999).

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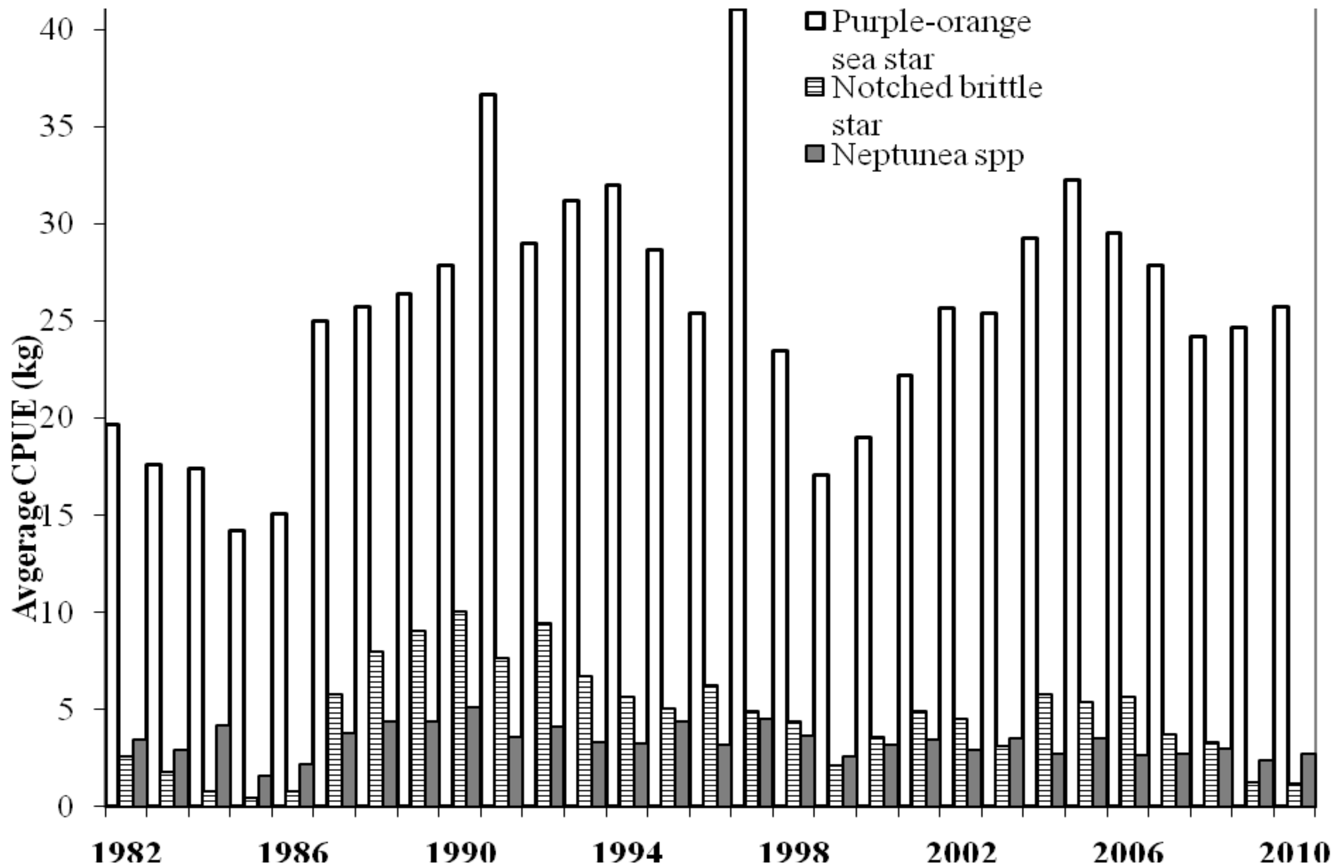

Figure 6. Average Catch Per Unit Effort (CPUE) by weight (kg) of the most prevalent benthic invertebrates caught on the eastern Bering Sea bottom trawl survey from 1982-2010.

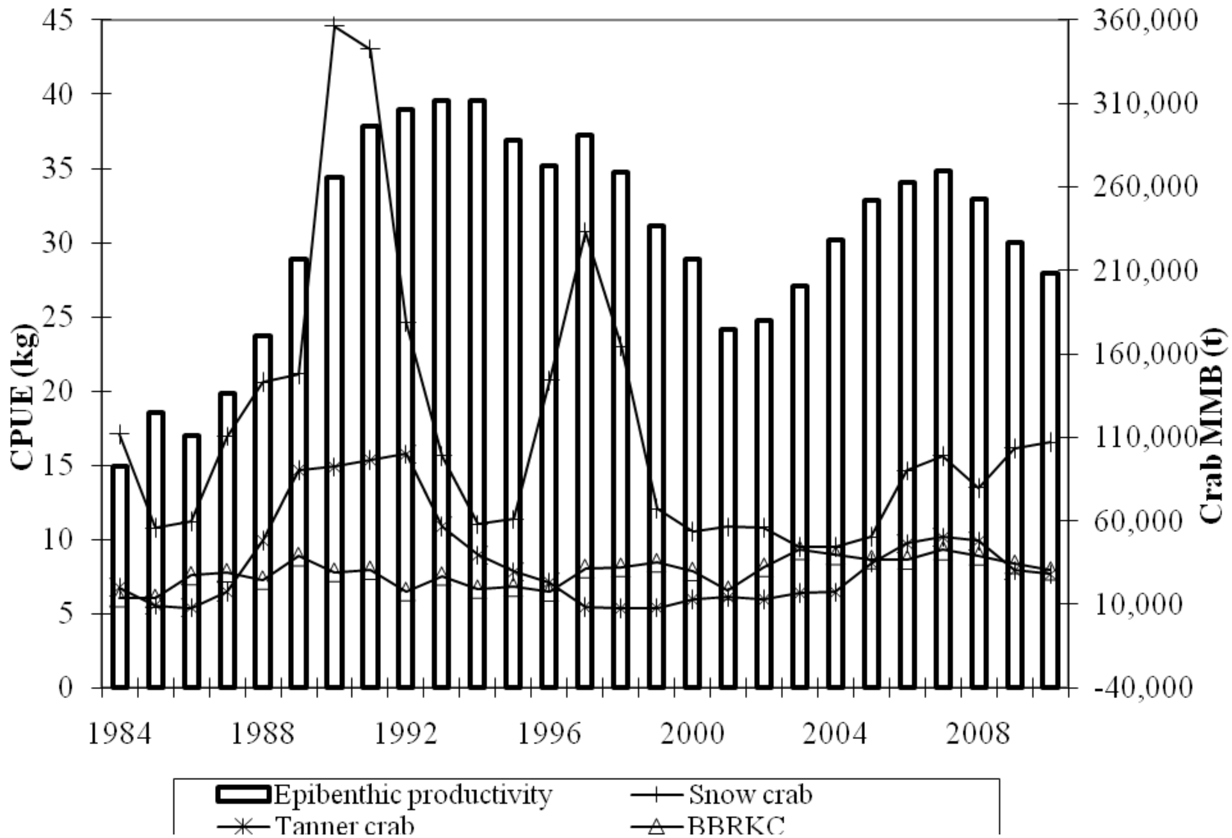

Figure 7. Epibethic productivity (four year average of the most prevalent benthic invertebrates CPUE from the eastern Bering Sea bottom trawl survey) and mature male biomass of three commercial crab stocks in the eastern Bering Sea from 1984-2010 (BBRKC = Bristol Bay red king crab).

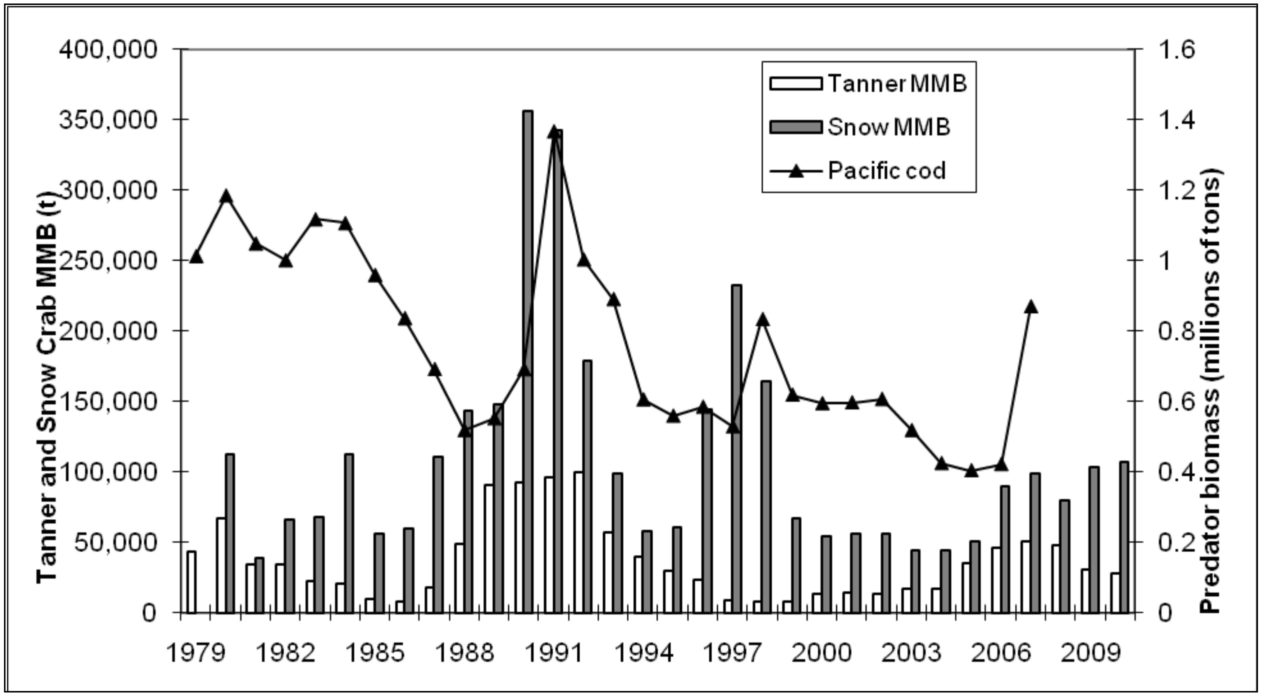

Figure 8. Trends in mature male biomass of Tanner and snow crab from the National Marine Fisheries Service annual eastern Being Sea bottom trawl survey, 1979 to 2010, in contrast to Pacific Cod biomass (time lag of three years).

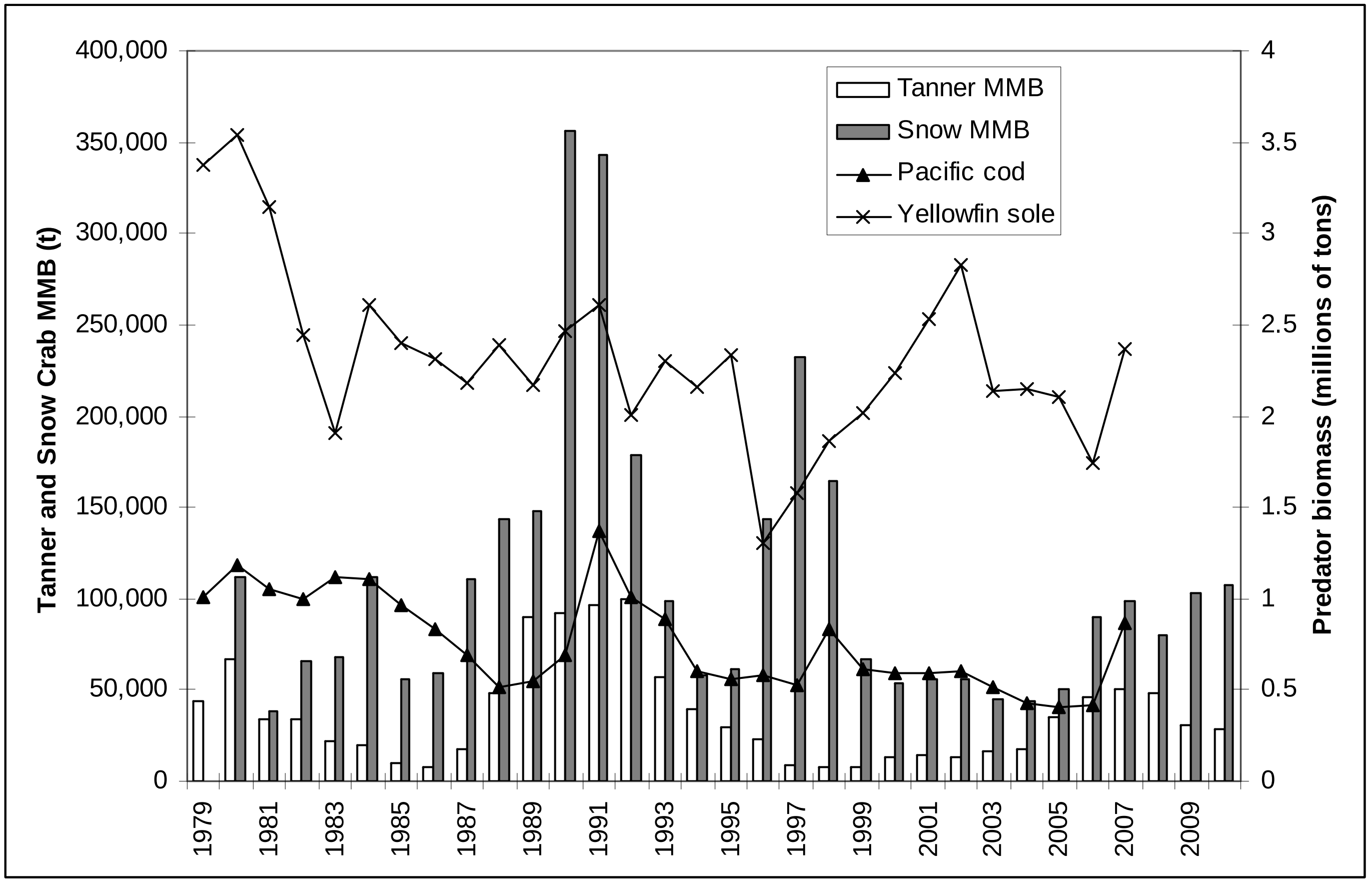

Figure 9. Trends in mature male biomass of Tanner and snow crab from the National Marine Fisheries Service annual eastern Being Sea bottom trawl survey in contrast to Pacific cod and yellowfin sole biomass (time lag of three years).

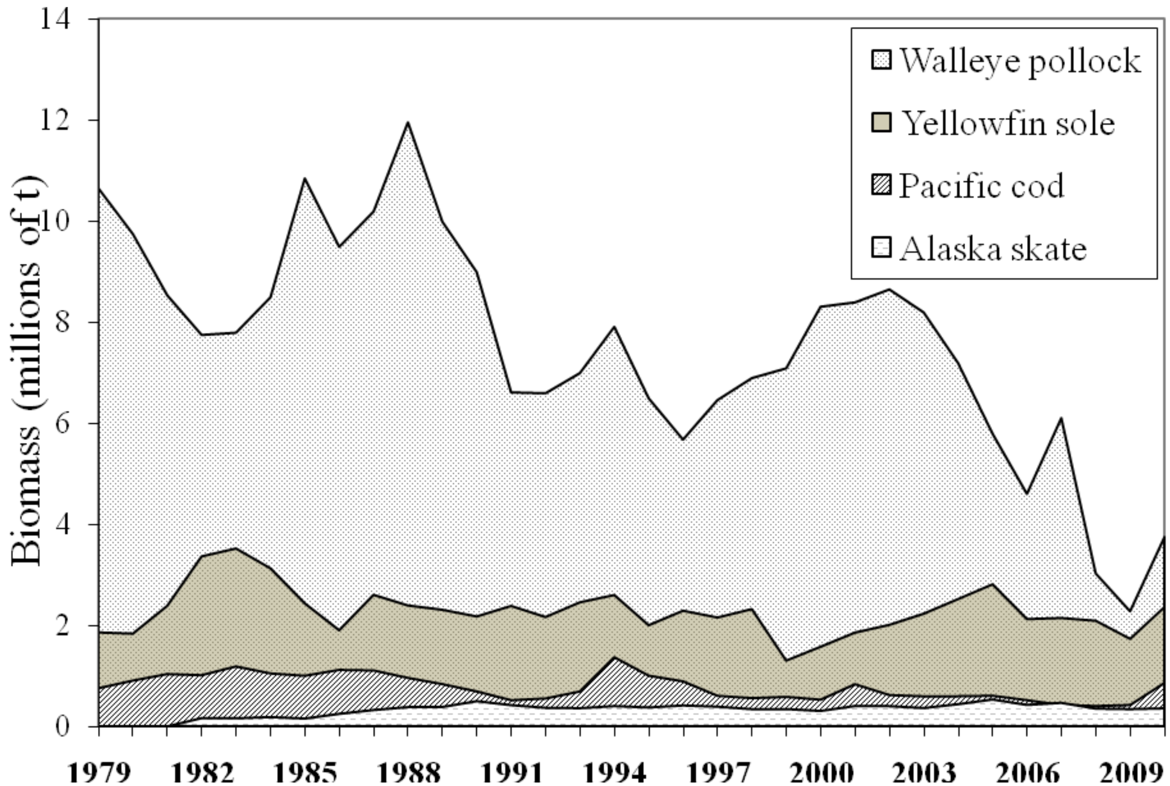

Figure 10. Trends in total biomass estimates of four major crab predators derived from the National Marine Fisheries Service eastern Bering Sea bottom trawl survey, 1979 to 2010.

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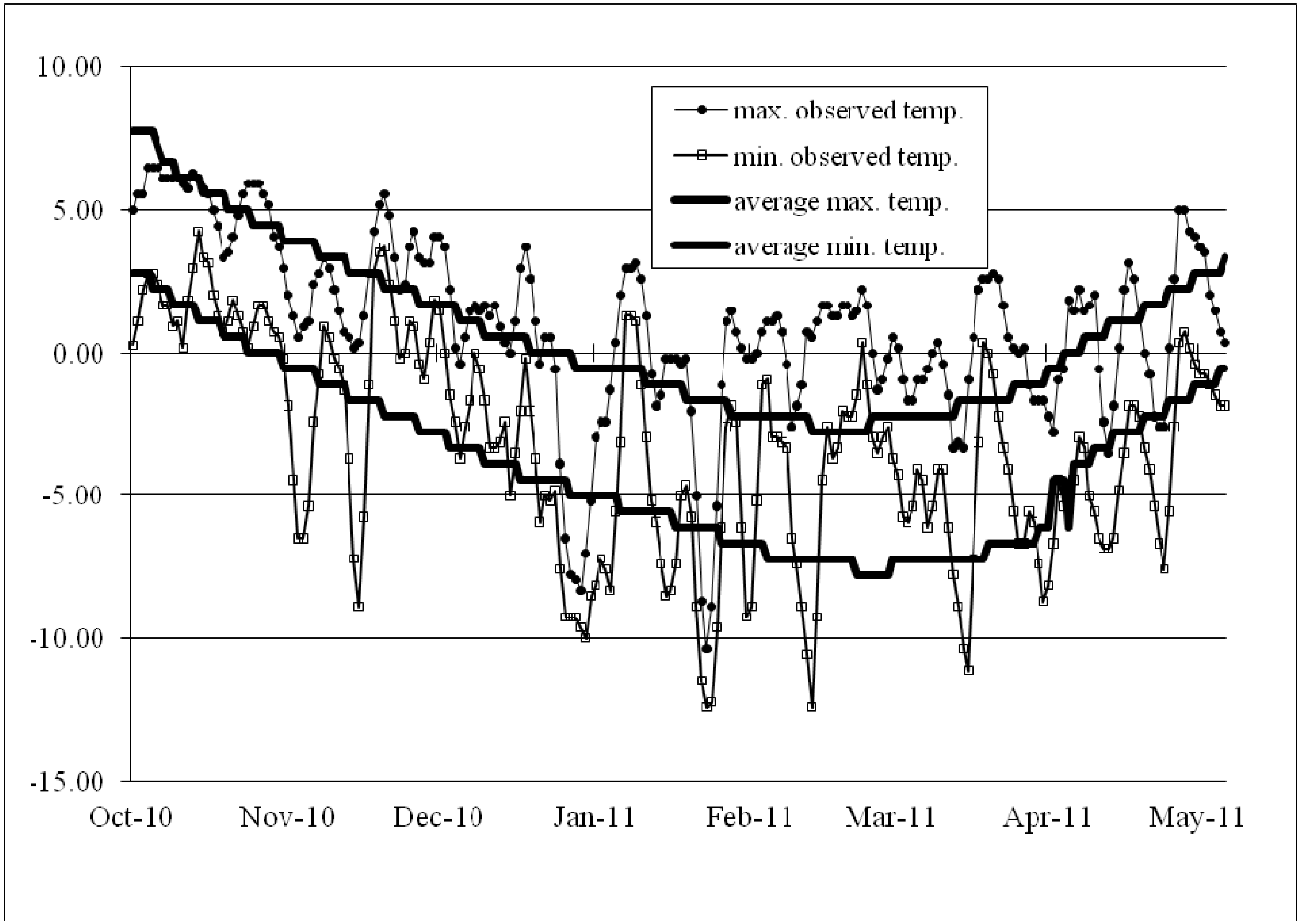

Figure 11. Three day running average of maximum and minimum temperatures (°C) from the St. Paul, Alaska weather station along with the long-term average maximum and minimum daily temperatures (1947-2011).

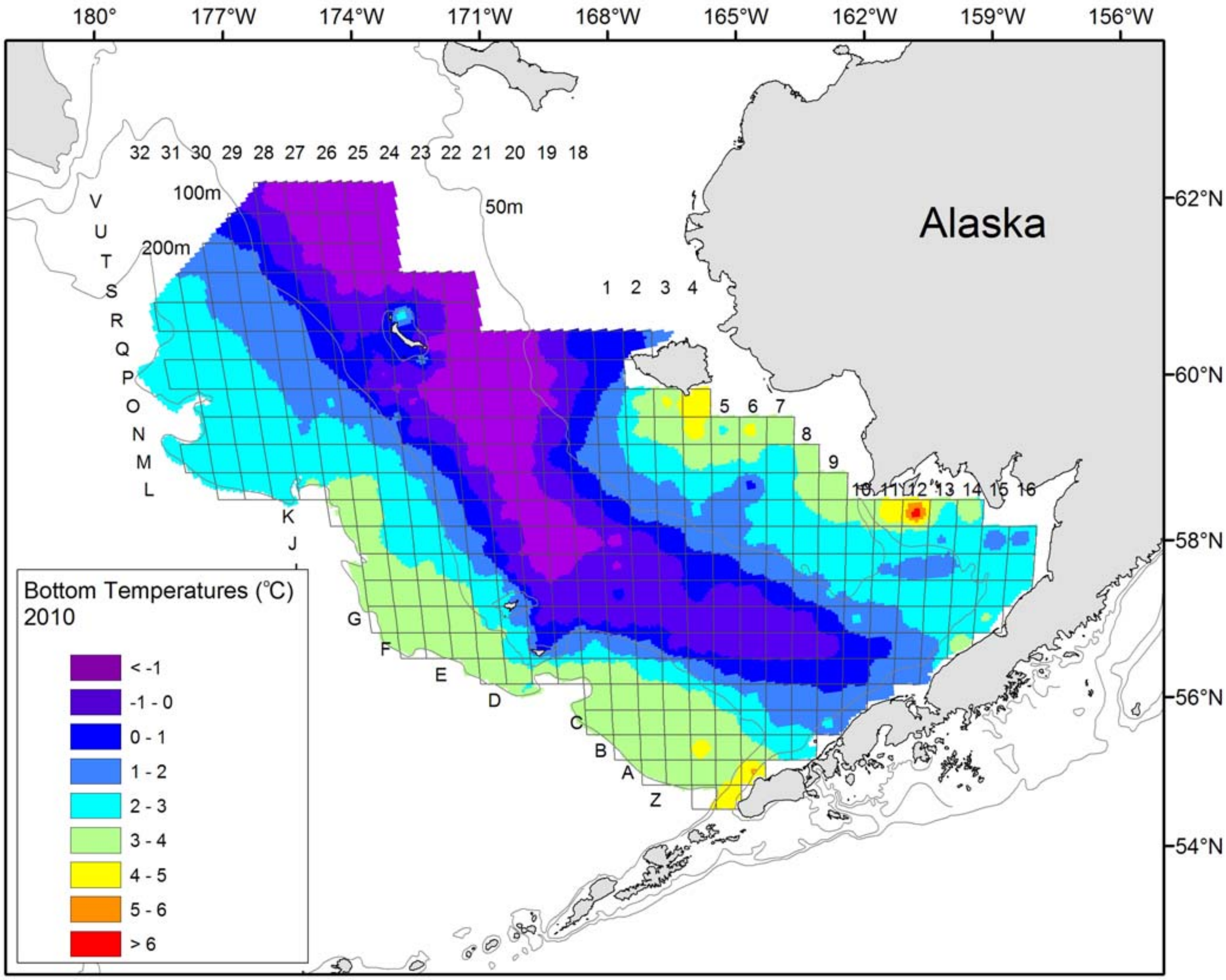

Figure 12a. Mean bottom temperatures (°C) measured at stations from the National Marine Fisheries Service eastern Bering Sea bottom trawl survey, beginning 7 June 2010 in Bristol Bay and ending on 4 August 2010 at station V27.

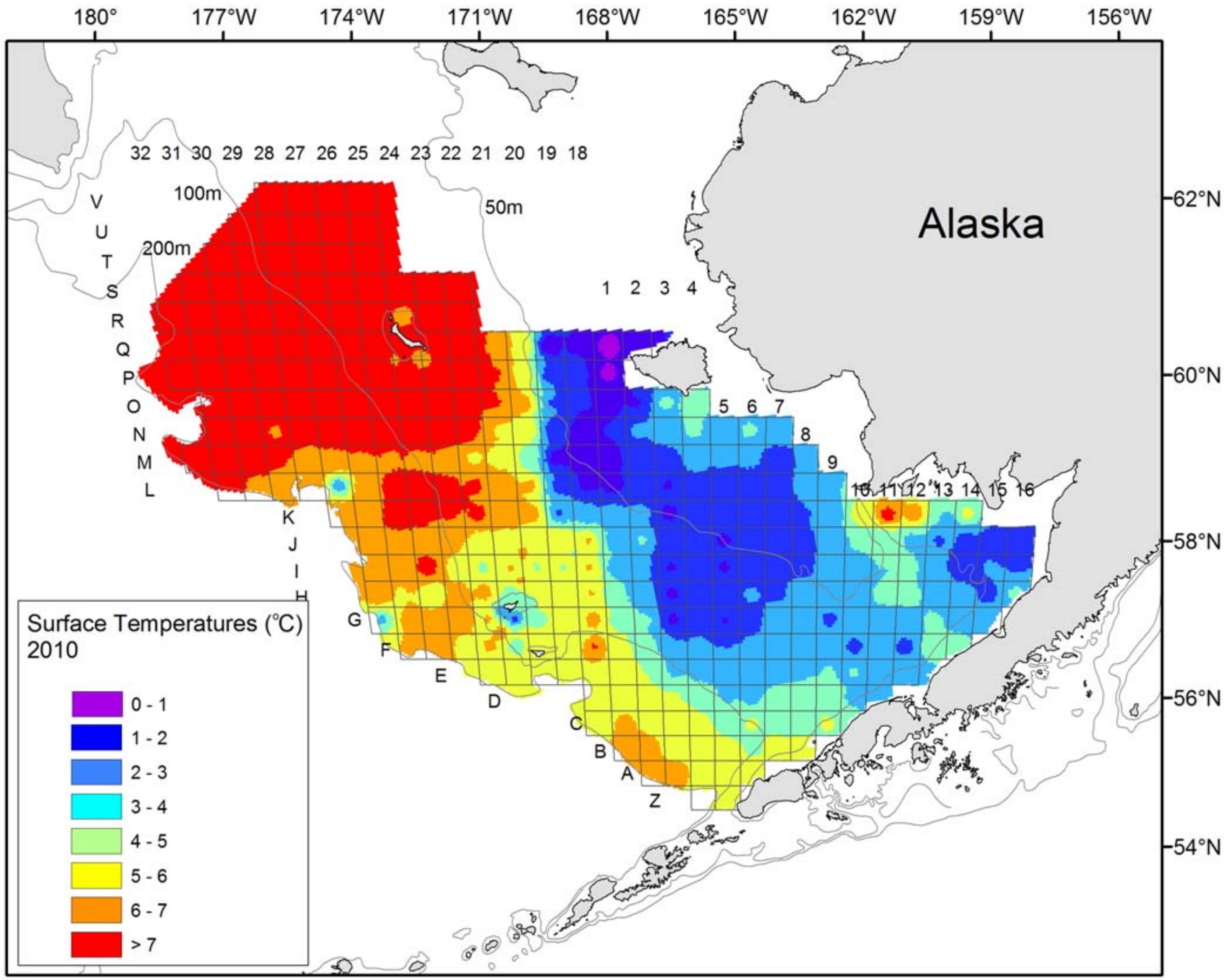

Figure 12b. Mean sea surface temperatures (°C) measured at stations from the National Marine Fisheries Service eastern Bering Sea bottom trawl survey, beginning 7 June 2010 in Bristol Bay and ending on 4 August 2010 at station V27.

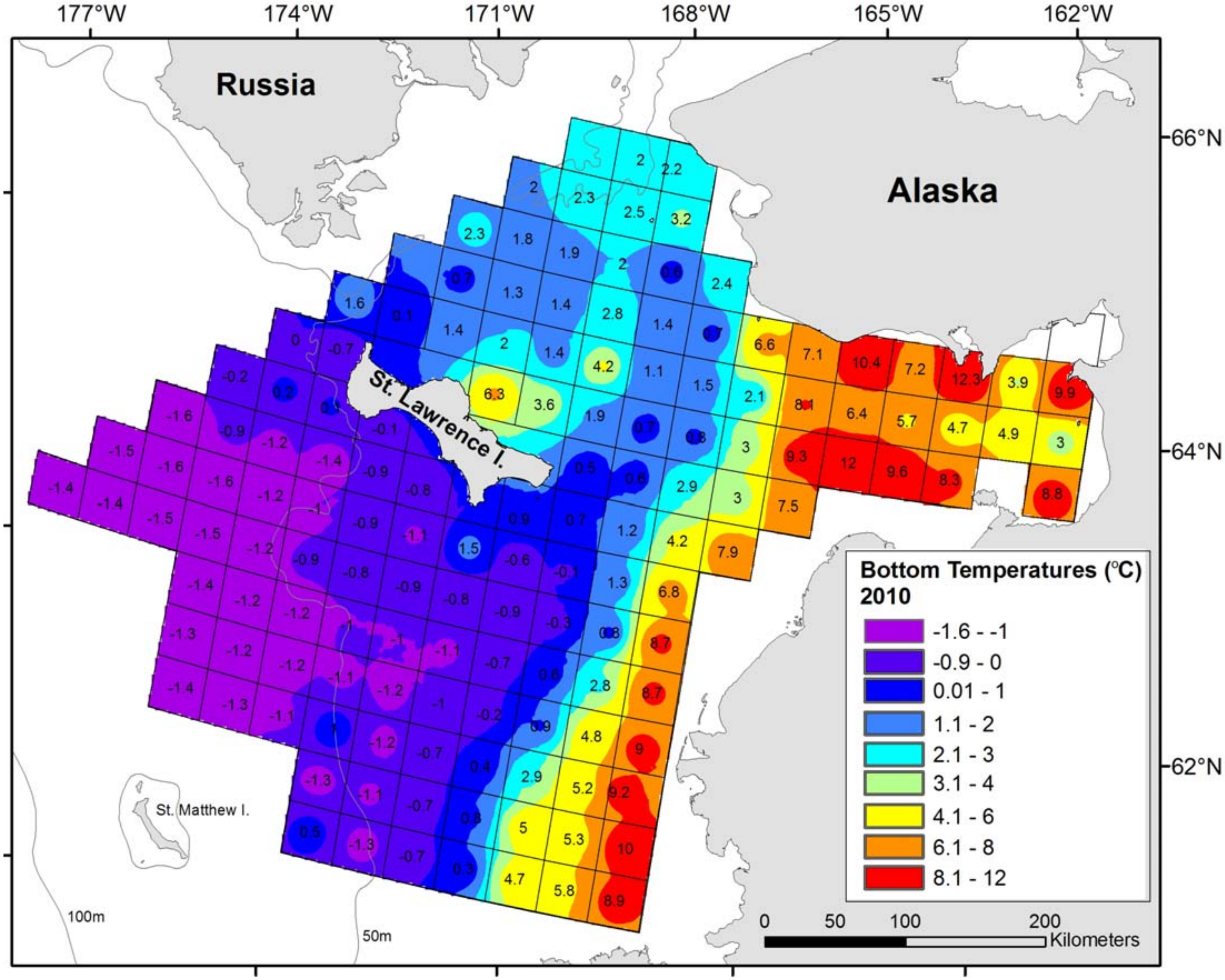

Figure 13a. Mean bottom temperatures (°C) measured at stations on the northern extension of the 2010 National Marine Fisheries Service eastern Bering Sea bottom trawl survey, conducted from 23 July to 9 August 2010.

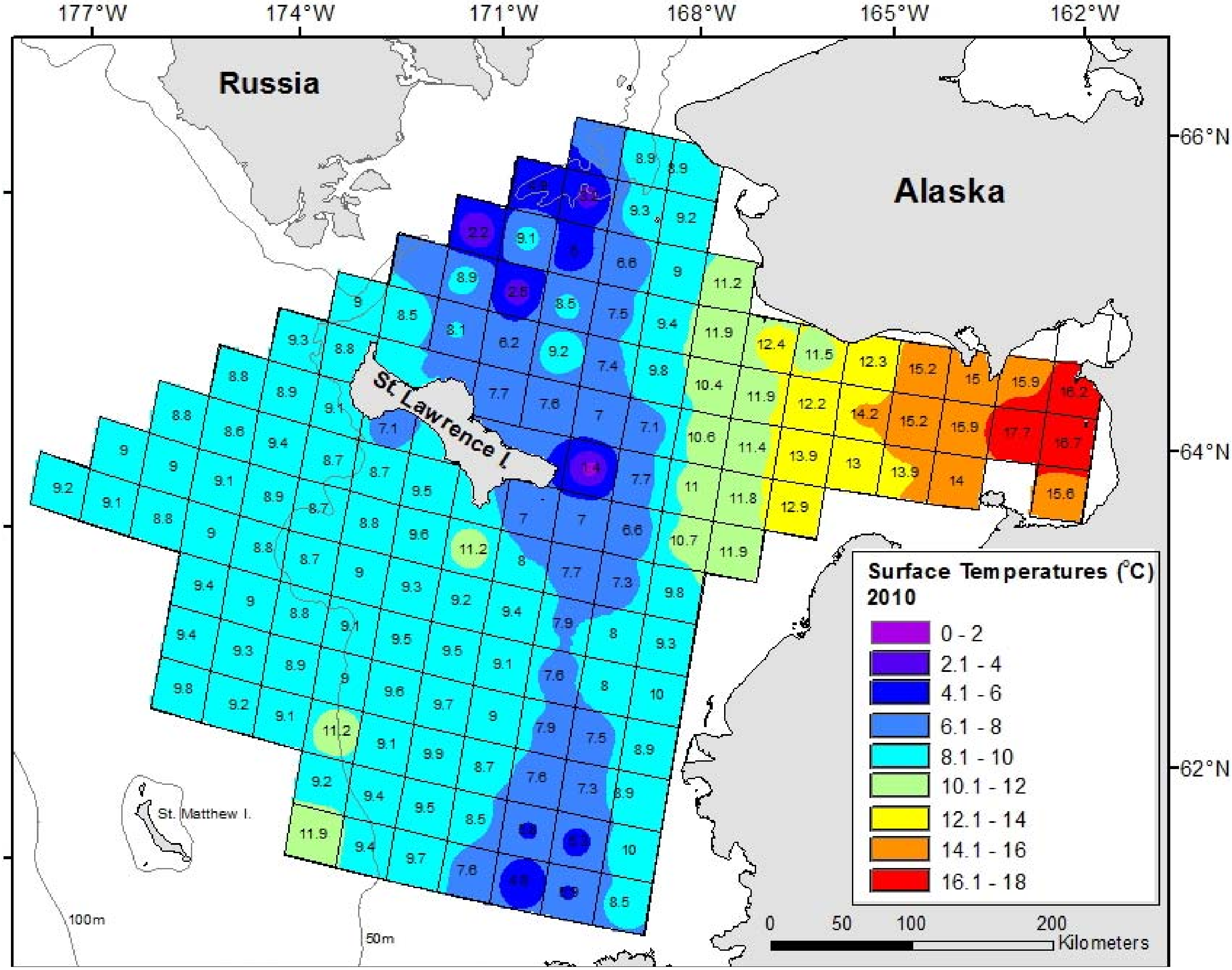

Figure 13b. Mean sea surface temperatures (°C) measured at stations on the northern extension of the 2010 National Marine Fisheries Service eastern Bering Sea bottom trawl survey, conducted from 23 July to 9 August 2010.

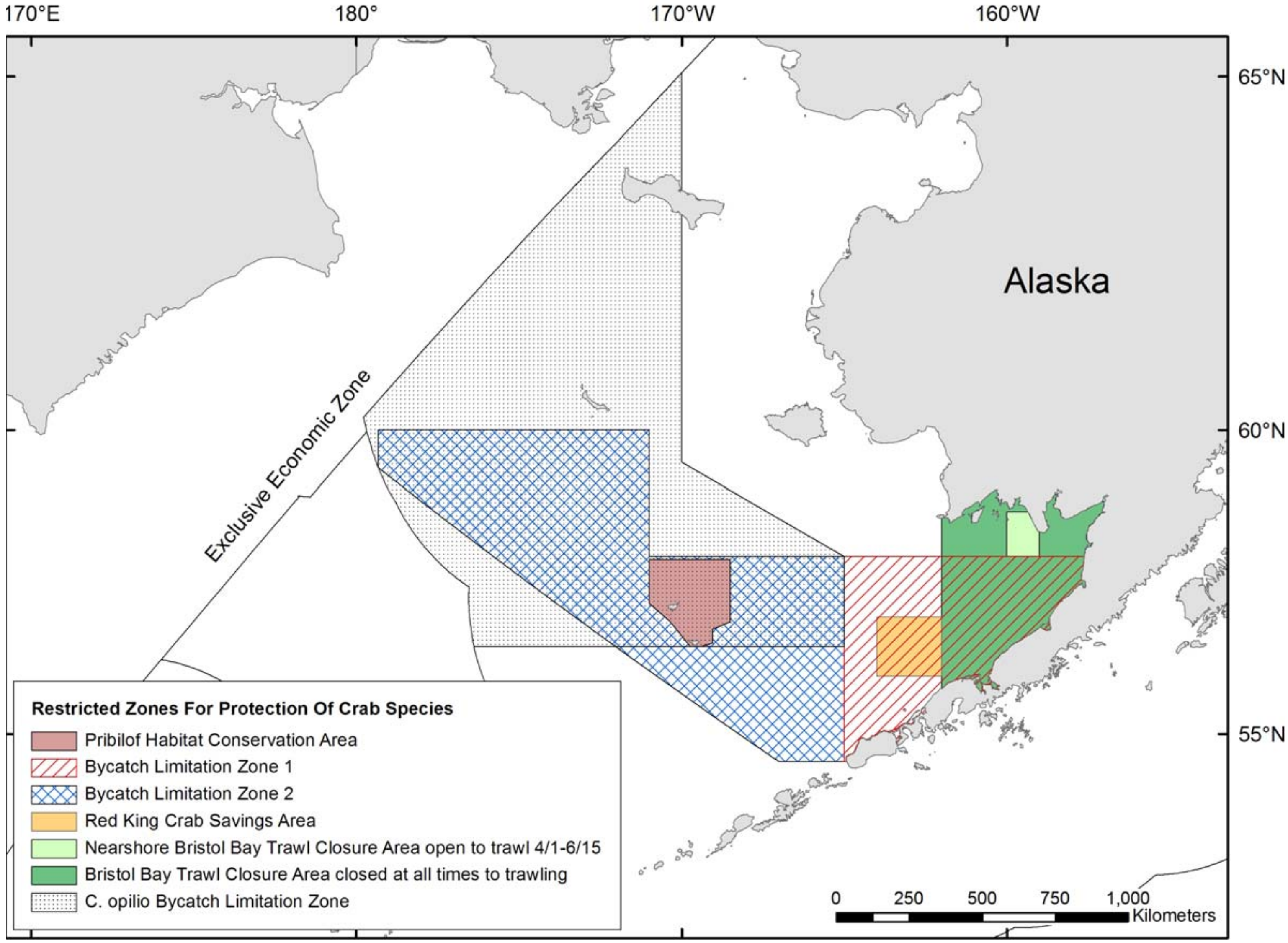

Figure 14. Restricted areas in the eastern Bering Sea enacted as protective management for commercial crab species.

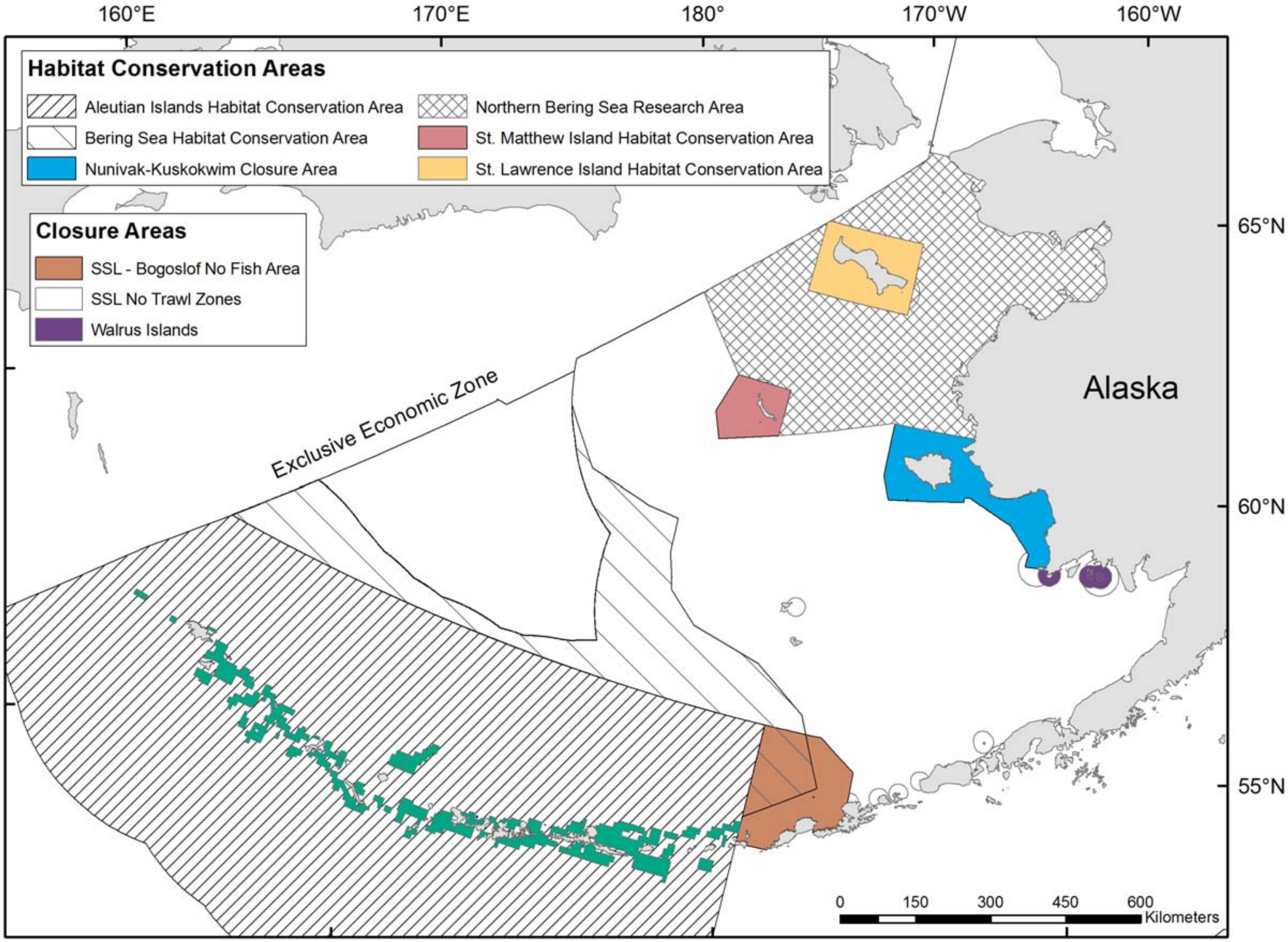

Figure 15. Habitat conservation areas and other locations closed to bottom trawling in the eastern Bering Sea and Aleutian Islands.

Table 1. Summary of ten commercial stocks managed under the Bering Sea and Aleutian Island (BSAI) king and Tanner crab Fishery Management Plan. Species listed in bold represents 2010/2011 commercial fisheries. TAC (Total Allowable Catch), GHL (Guideline Harvest Level), RKC (red king crab), BKC (blue king crab), GKC (golden king crab), CL (carapace length), CW (carapace width).

BSAI Crab Stock	TAC or GHL	Status of Fishery	Fishing season	Legal male size	Mean size retained males in 2009/2010
Bristol Bay RKC	14.84 million pounds legal males	Open in 2010	October 15, 2010-January 15, 2011	≥135 mm CL	153.2 mm CL
Pribilof Islands RKC		Closed in 1998			
Norton Sound RKC	0.40 million pounds legal males	Open in 2010	June through following August	≥121 mm CW	116 mm CW
Aleutian Islands (Adak) RKC		Closed in 2004			
Aleutian Islands GKC	5.985 million pounds legal males	Open in 2010	August through following spring	≥135 mm CL	151.6 mm CL east of 174°W, 151.2 mm CL west of 174°W
Pribilof Islands GKC	0.15 million pounds of legal males	Few vessels registered for 2009-2010	August through following spring	≥140 mm CW	No vessels registered 2006-2009
Pribilof Islands BKC		Closed in 2002			
St. Matthew Island BKC	1.60 million pounds legal males	Open 2009 after 10 yr rebuilding plan	October 15, 2010 to February 1, 2011	≥120 mm CL	N/A
EBS Tanner crab		Closed in 2010	October to March or April	≥138 mm CW	150 mm CW east of 166° W
EBS snow crab	54.28 million pounds of legal males	Open in 2010/2011	October 15, 2010 to May 2011	≥78 mm CW legal, ≥102mm CW preferred	110 mm CW

Table 2. Historical bycatch statistics from the Bering Sea (Registration Area Q) scallop fishery. Fishing was not opened during the 1995/96 season (Source: Rosenkranz and Spafard 2010).

	Crab bycatch limits			Estimated bycatch (number animals)				Lbs meat per
Season	Tanner	King (red)	Snow	Tanner	King (red)	Snow	Halibut	Tanner/snow*
1993/94	260,000	17,000	NA	290,913	207	15,000	165	<1
1994/95	260,000	17,000	NA	220,710	22	34,867	3,513	2
1996/97	257,000	500	275,000	16,642	0	106,935	124	1
1997/98	238,000	500	172,000	28,446	0	195,345	98	<1
1998/99	215,000	500	130,000	39,363	146	232,911	98	<1
1999/2000	65,000	500	300,000	62,268	2	159,656	106	<1
2000/01	65,000	500	150,000	52,505	2	103,350	50	1
2001/02	65,000	500	300,000	48,718	2	68,458	76	1
2002/03	65,000	500	300,000	48,053	2	70,795	85	<1
2003/04	65,000	500	150,000	31,316	0	16,206	61	<1
2004/05	65,000	500	150,000	15,303	0	3,843	0	<1
2005/06	65,000	500	150,000	15,529	2	5,211	53	1
2006/07	260,000	24	300,000	45,204	10	8,543	82	<1
2007/08	260,000	500	300,000	35,288	1	19,367	11	<1
2008/09	260,000	500	300,000	60,373	1	17,205	0	<1
2009/10	260,000	500	300,000	27,430	1	36,786	4	<1

*Ratio of pounds scallop meat harvested for each incidentally caught Tanner crab or snow crab × Tanner crab hybrid.