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

2010 Draft Crab SAFE

Compiled by

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

With Contributions by

D. Barnard, B. Bechtol, F. Bowers, W. Donaldson, G. Eckert,
R.J. Foy, B. Garber-Yonts, R.K. Gish, H. Hamazaki,
G. Harrington, E. Munk, D. Pengilly, A. Punt, L. Rugolo, M.S.M. Siddeek, J. Soong,
D. Stram, B. J. Turnock, S. Van Sant, L. Watson , and J. Zheng

May 2010

North Pacific Fishery Management Council
605 W. 4th Avenue, #306
Anchorage, AK 99501

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

Table of Contents

Introduction 1
Stock Status definitions 1
Status Determination Criteria 2
Crab Plan Team Recommendations 7
Stock Status Summaries 8

Stock Assessment Section

1. EBS snow crab 27
2. Bristol Bay red king crab 135
3. EBS Tanner crab 247
4. Pribilof Islands red king crab 309
5. Pribilof District blue king crab 335
6. Saint Matthew blue king crab 359
7. Norton Sound red king crab 415

8a. Aleutian Islands golden king crab assessment 461

8b. Aleutian Islands golden king crab model.. 508

9. Pribilof Islands golden king crab 517
10. Adak red king crab 549

2010 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands

Introduction

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

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

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF&G and the National Marine Fisheries Service (NMFS). This SAFE report is presented to the North Pacific Fishery Management Council (NPFMC) and is available to the public on the NPFMC web page at: http://fakr.noaa.gov/npfmc/membership/plan_teams/CRAB_team.htm. Under a process approved in 2008 for revised overfishing level (OFL) determinations, the Crab Plan Team reviews draft assessments in May to provide recommendations in a draft SAFE report for review by the Council's Science and Statistical Committee (SSC) in June. In September, the CPT reviews final assessments and provides final OFL recommendations and stock status determinations. Additional information on the new OFL determination process is contained in this report.

The Crab Plan Team met from May 10-14, 2010 in Girdwood, Alaska to review the draft stock assessments as well as Annual Catch Limits analysis and related issues, in order to provide the recommendations contained in this draft SAFE report. The Team will review revised assessments in September 2010 for 7 stocks and will revise this report accordingly at that time to form the final 2010 Crab SAFE report. The final 2010 Crab 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: Forrest Bowers (Chair), Ginny Eckert (Vice-Chair), André Punt, Jack Turnock, Shareef Siddeek, Bill Bechtol, Karla Bush, Brian Garber-Yonts, Gretchen Harrington, Doug Pengilly, Bob Foy, Lou Rugolo, Wayne Donaldson, Josh Greenberg, and Diana Stram. The final SAFE report in September 2010 will build upon recommendations contained in this report.

Stock Status Definitions

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

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

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

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

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

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

Overfished is determined by comparing annual biomass estimates to the established MSST. For stocks where MSST (or proxies) are defined, if the biomass drops below the MSST (or proxy thereof) then the stock is considered to be overfished.

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

Status Determination Criteria

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

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 criterion are annually formulated and assessed to determine the status of the crab stocks and whether (1) overfishing is occurring or the rate or level of fishing mortality for a stock or stock complex is approaching overfishing, and (2) a stock or stock complex is overfished or a stock or stock complex is approaching an overfished condition.

Overfishing is determined by comparing the overfishing level (OFL), as calculated in the five-tier system for the crab fishing year, 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. This 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 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.

Annually, the Council, Scientific and Statistical Committee, and Crab Plan Team will review (1) the stock assessment documents, (2) the OFLs and total allowable catches or guideline harvest levels for the upcoming crab fishing year, (3) NMFS's determination of whether overfishing occurred in the previous crab fishing year, and (4) NMFS's determination of whether any stocks are overfished.

Five-Tier System

The OFL for each stock is 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 will recommend tier assignments, stock assessment and model structure, and parameter choices, including whether information is "reliable," for the assessment authors to use for calculating the OFLs based on the five-tier system.

For Tiers 1 through 4, once a stock is assigned to a tier, the stock status level is determined 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).

Lastly, in stock status level "c," current biomass is below β * (B_{MSY} or a proxy for B_{MSY}). 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.

OFLs will be calculated by applying the F_{OFL} and using the most recent abundance estimates. The Crab Plan Team will review stock assessment documents, the most recent abundance estimates, and the proposed OFLs. The Alaska Fisheries Science Center will set the OFLs consistent with this FMP and forward OFLs for each stock to the State of Alaska prior to its setting the total allowable catch or guideline harvest level for that stock's upcoming crab fishing season.

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) per recruit equal to X% of the equilibrium level in the absence of any fishing.

The OFL calculation accounts for all losses to the stock not attributable to natural mortality. The OFL is the total catch limit 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 lacking. 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 is not available for a Tier 4 stock, then the OFL is 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 from this approach, therefore, would be the total catch OFL.

Tier 5

Tier 5 stocks have no reliable estimates of biomass or M and only historical data of retained catch is available. For Tier 5 stocks, the historical performance of the fishery is used to set OFLs in terms of retained catch. The OFL represents the average retained catch from a time period determined to be representative of the production potential of the stock. The time period selected for computing the average catch, hence the OFL, would be based on the best scientific information available and provide the appropriate risk aversion for stock conservation and utilization goals. In Tier 5, the OFL is specified in terms of an average catch value over 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.

For most Tier 5 stocks, only retained catch information is available so the OFL will be estimated for the retained catch portion only, with the corresponding overfishing comparison on the retained catch only. In the future, as information improves, the OFL calculation could include discard losses, at which point the OFL 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.

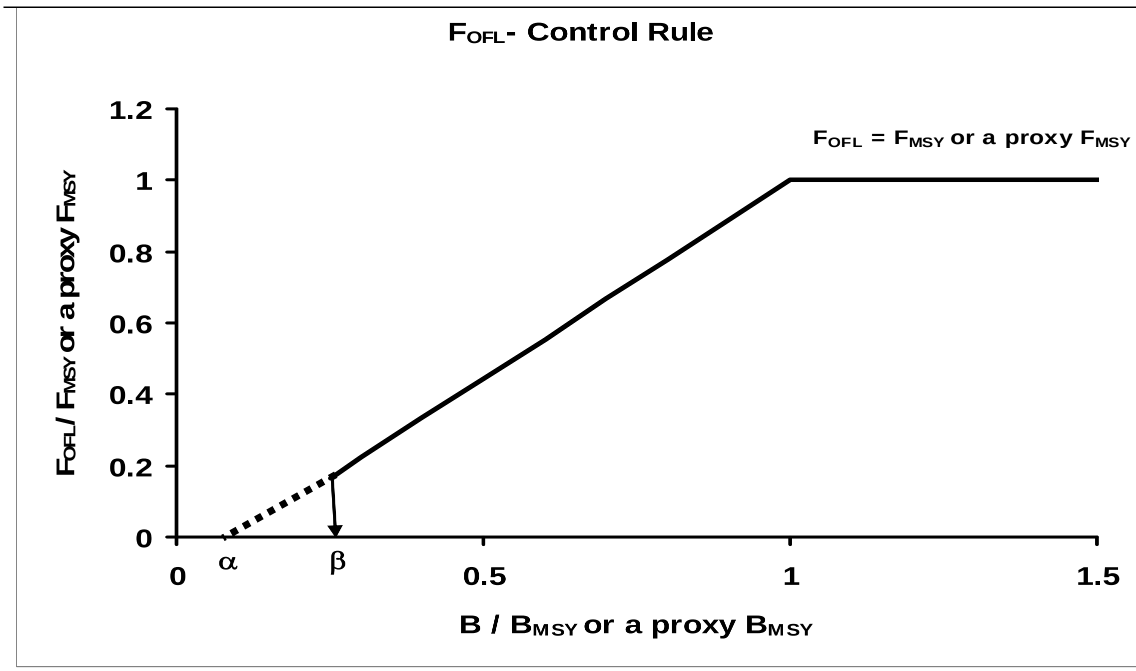


Table 1 Five-Tier System for setting overfishing limits for crab stocks. The tiers are listed in descending order of information availability. Table 6-2 contains a guide for understanding the five-tier system.

Information available	**Tier**	**Stock status level**	$\boldsymbol{F_{OFL}}$
B, B_{MSY}, F_{MSY}, and pdf of F_{MSY}	**1**	a. $\frac{B}{B_{msy}} > 1$	$F_{OFL} = \mu_A$ =arithmetic mean of the pdf
		b. $\beta < \frac{B}{B_{msy}} \leq 1$	$F_{OFL} = \mu_A \frac{B/B_{msy} - \alpha}{1-\alpha}$
		c. $\frac{B}{B_{msy}} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†
B, B_{MSY}, F_{MSY}	**2**	a. $\frac{B}{B_{msy}} > 1$	$F_{OFL} = F_{msy}$
		b. $\beta < \frac{B}{B_{msy}} \leq 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy} - \alpha}{1-\alpha}$
		c. $\frac{B}{B_{msy}} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†
B, $F_{35\%}$*, $B_{35\%}$*	**3**	a. $\frac{B}{B_{35\%*}} > 1$	$F_{OFL} = F_{35\%}*$
		b. $\beta < \frac{B}{B_{35\%}*} \leq 1$	$F_{OFL} = F^{*}_{35\%} \frac{\frac{B}{B^{*}_{35\%}} - \alpha}{1-\alpha}$
		c. $\frac{B}{B_{35\%}*} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†
B, M, $B_{msy^{prox}}$	**4**	a. $\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = \gamma M$
		b. $\beta < \frac{B}{B_{msy^{prox}}} \leq 1$	$F_{OFL} = \gamma M \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$
		c. $\frac{B}{B_{msy^{prox}}} \leq \beta$	*Directed fishery F = 0* $F_{OFL} \leq F_{MSY}$†
Stocks with no reliable estimates of biomass or M.	**5**		OFL = average catch from a time period to be determined, unless the SSC recommends an alternative value based on the best available scientific information.

*35% is the default value unless the SSC recommends a different value based on the best available scientific information.

† An $F_{OFL} \leq F_{MSY}$ will be determined in the development of the rebuilding plan for that 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 $\beta\cdot B_{MSY} < B \le B_{MSY}$.

Crab Plan Team Recommendations

Table 3 lists the team's recommendations for 2010/2011 on Tier assignments, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs (for four stocks), and whether an OFL is applied to retained catch only or to all catch. 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).

Stock status in relation to status determination criteria are evaluated in the September 2010 report. The team has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2010 assessment cycle unless indicated otherwise. 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 (May 2010 CPT Reports).

General recommendations for all assessments

The CPT is aiming to provide total catch OFLs. The male component of OFLs is based on the OFL control rule and relate directly to the sustainability of harvest relative to management benchmarks, i.e. B_{MSY}. The measure of what produces MSY on a continuing basis is mature male biomass (B_{MSY} defined in terms of MMB). There is an inherent mis-match when considering female catch. When female catch is additive to mature male catch it represents what is expected from current fishing practices rather than a catch that would jeopardize the ability of the stock to achieve MSY on a continuing basis. This can lead to potentially undesirable outcomes. For example if a total catch OFL such as Tanner crab in 2010 is computed as the sum of males and female estimated losses at 2.0 metric tons with the breakout estimated at 1.76 tons of males and 0.24 of females, overfishing would not be designated to occur if more than the estimated fraction of males or females were caught such that the sum did not exceed 2.0 tons. This could allow for more males being extracted than have been estimated as sustainable based on the assessment without being considered overfishing and does not seem responsive to the intent of the overfishing definition.

The team discussed that each assessment should explain how the groundfish bycatch data is used in the assessment and that all assessment chapters should be consistent in how the groundfish bycatch data is used and which handling mortality rate is applied.

Each assessment should highlight the last three years in the harvest control rule plots

All ecosystem considerations sections should be removed from the assessments and transferred to the authors of the new ecosystem considerations chapter as they are all going to be folded into this chapter.

Stock Status Summaries

1 Eastern Bering Sea Snow Crab

Fishery information relative to OFL setting.

The snow crab fishery has been opened, and harvest reported, every year since the 1960s. Prior to 2000, the GHL was 58% of abundance of male crab over 101 mm CW, estimated from the survey. The target harvest rate was reduced to 20% following the declaration of the stock as overfished in 1999, and the GHL/TAC since 2000 has been based on a rebuilding plan that aimed to allow recovery to a proxy for B_{MSY}. The stock remained below the proxy for B_{MSY} ($B_{35\%}$) during the 2008/09 fishing year. Consequently, the current rebuilding plan failed to recover the snow crab stock within the required 10-year time period. A new rebuilding plan for EBS snow crab is currently under development.

Data and assessment methodology

The assessment is based on a size-structured population dynamics model in which crabs are categorized into mature, immature, new shell and old shell crabs by sex. The model is fitted to data on historical catches (landed and discard), survey estimates of biomass, and fishery, discard and survey size-composition data. It covers the 1978-2009 seasons and estimates abundance from 25-29mm to 130-135mm using 5mm size bins. The results of the annual Bering Sea bottom trawl survey are analyzed in three periods: before 1982, 1982-88, and 1989 onwards, with different selectivity and catchability parameters for each period. The model is based on the assumption of a terminal molt at maturity. The 2010 assessment differs from the 2009 assessment by including the revised EBS bottom trawl survey time-series, eliminating the over-weighting of the NMFS survey data, estimating the probability of maturing as a function of size, and estimating separate survey selectivity curves for males and females. The 2010 assessment included the BSFRF survey data (estimates of abundance and size-composition) in order to inform survey selectivity and catchability.

Seven models were presented in the assessment report. The CPT could not reach consensus on which model should form the basis for the September 2010 assessment of EBS snow crab (see CPT minutes for arguments for and against the two models considered viable alternatives). However, the bulk of the CPT recommends that the 2010 assessment be based on “Model 5” in which the parameters which determine growth and natural mortality are estimated within the model, but are subject to penalties based on auxiliary information. The remaining members recommended that the 2010 assessment be based on “Model 1” in which the parameters which determine growth and natural mortality are set to the values used in the 2009 assessment.

Stock biomass and recruitment trends

Mature male biomass (MMB at the time of mating) peaked between the late-1980s and mid-1990s, declined to a minimum in 2006 and has increased thereafter. The increase in mature male biomass has been greater than in mature female biomass. Recruitment has varied considerably over the period 1979-2009, with the recruitment (at 25mm) in 1991 the highest on record. Recent recruitment has been near or below average. The most recent assessment indicates that MMB never declined below the new definition of MSST.

Tier determination/Plan Team discussion and resulting OFL determination

The CPT recommends that EBS snow crab is a Tier 3 stock so the OFL will be based on the $F_{35\%}$ control rule. The team recommends that the proxy for B_{MSY} ($B_{35\%}$) be the mature male biomass at mating, computed as the average recruitment from 1979 to the last year of the assessment multiplied by the mature male biomass-per-recruit corresponding to $F_{35\%}$, less the mature male catch under an $F_{35\%}$ harvest strategy. The MSST is defined as half of the proxy for B_{MSY}. The assessment presented to the CPT will be updated by incorporating 2010 survey and fishery data into the base model to calculate the 2010/11 OFL and MSST.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		N/A	36.2	36.4	44.9	
2007/08	158.9	218	63.0	63.0	77.1	
2008/09	163.4	241	58.6	58.5	69.5	77.3
2009/10	TBD	TBD	48.0	TBD	TBD	73.0
2010/11	TBD	TBD	TBD	TBD	TBD	TBD

Stock status determination relative to overfishing and overfished criteria will be made following review of an updated assessment that incorporates the 2010 survey data.

Additional Plan Team recommendations

The September 2010 assessment should (a) include the predictions from the May 2010 version of the model (models 1 and 5) to evaluate how well the model forecasts biomass, (b) document the basis for the standard deviations assumed for the penalties on the growth parameters, and (c) update the references.

The next assessment in May 2011 should: (a) include the model number in the table and figure captions if multiple models are presented, (b) further justify the values chosen for the weighting factors (the lambdas) and explore sensitivity to alternative weights, as outlined in the report of the 13-14 May 2009 stock assessment workshop, (c) explore whether it is possible to improve the residual patterns for the length-frequency data by modifying how maturity, growth and natural mortality are modeled and the implications of the change in distribution of the population over time, (d) consider reducing the number of size classes for females, (e) consider fitting to the discard length-frequency data for males rather than to the total length-frequency data for males (to avoid fitting to the retained length-frequency data twice), (f) explore the implications of not placing penalties on the growth and mortality parameters to determine what values for these parameters are preferred by the data, and (g) identify what changes need to be made to the model so that the model is able to fit all of the data adequately if survey selectivity is set to the “Somerton selectivity curve”.

The CPT continues to support development of a spatially-structured stock assessment model so that the implications of differences in where the catch is taken and where the survey finds snow crab can be evaluated.

Ecosystem Considerations summary
No additional ecosystem considerations were included in the assessment at this time.

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, but harvests dropped sharply in the early 1980s, and population abundance has remained at relatively low levels over the last two decades compared to that 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, 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 lbs of effective spawning biomass (ESB), and a minimum GHL of 4.0 million lbs to prosecute a fishery. The TAC increased from 15.5 million lbs for the 2006/07 season to 20.4 million lbs for the 2007/08 and 2008/09 seasons, then declined to 16.0 million lbs for 2009/2010. Catch of legal males per pot lift was relatively high in the 1970s, low in the 1980s to mid-1990's. Following implementation of the crab rationalization program in 2005, CPUE increased to 31.0 crab/pot in 2006, but fell to 21.0 crab/pot in 2009. Annual non-retained catch of female and sublegal male RKC during the fishery averaged less than 3.9 million lbs since data collection began in 1990. Estimated fishing mortality ranged from 0.28 to 0.38yr^{-1} following implementation of crab rationalization. Total catch (retained and bycatch mortality) increased from 17.2 million lbs in 2006/07 to 23.2 million lbs in 2007/08 and 23.1 million lbs in 2008/09.

Data and assessment methodology

The stock assessment model is based on a length-structured population dynamics model incorporating data from the eastern Bering Sea trawl survey, commercial catch, and at-sea observer data program. Stock abundance is estimated for male and female crabs ≥ 65-mm carapace length during 1968-2009, an extension from the previous assessment that considered the years 1985-2008. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date from the fishery which targets males ≥ 165.1mm (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 to May 2010. Several other changes to the assessment, included re-analysis of the trawl survey data based on revised estimates of the area-swept from 1975 to 2009, and allowances for changes over time in the size at maturity for females, and mortality. The author evaluated nine model scenarios, including a model similar to the base model from the 2009 assessment. Additional model scenarios included variations in: (1) additional mortality for males and females in either 1980-84, 1976-79 and 1985-93, or additional bycatch mortality in 1980-84; (2) inclusion of the Bering Sea Fisheries Research Foundation (BSFRF) survey data for 2007 and 2008; and (3) estimation of male molting probabilities. A natural mortality of 0.18yr^{-1} was assumed, with additional "unexplained" mortality for males and females in specific scenarios.

Stock biomass and recruitment trends

Model estimates of total survey biomass increased from 177.2 million lbs in 1968 to 721.1 million lbs in 1978, fell to 66.3 million lbs in 1985, generally increased to 202.6 million lbs in 2008, and declined to 196.5 million lbs in 2009. Mature male biomass at mating increased from 63.3 million lbs in 2004 to 95.2 million lbs in 2009. Estimated recruitment was high during the 1970s and early 1980s and has been generally low since 1985. During 1985-2009, estimated recruitment was higher than the historical average in 1995, 2002, and 2005. Estimated recruitment was extremely low during the last 3 years.

Tier determination/Plan Team discussion and resulting OFL determination

This assessment showed improvement in exploring the use of the data that are available, and model sensitivity to inclusion of various data. In the absence of additional diagnostics, the CPT supports the use of scenario 3 [constant natural mortality (0.18), estimation of additional natural mortality for males during 1980-1984 for females during 1976-1993, BSFRF data], and recommends that the variance for the BSFRF data be selected to ensure that the estimates and model predictions are consistent.

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 1995 to the last year of the assessment multiplied by the mature male biomass-per-recruit corresponding to $F_{35\%}$ less the mature male catch under an $F_{35\%}$ harvest strategy. Estimated $B_{35\%}$ is 68.5 million lbs. Total catch includes retained male catch and all other bycatch sources.

Status and catch specifications (millions lbs.) of Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		NA	15.53	15.75	17.22	
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	95.2[A]	16.0	16.0	TBD	22.56
2010/11	TBD	TBD	TBD	TBD	TBD	TBD

A- Model forecast based on the 2009 assessment under the assumption that the 2009/10 catch equals to the OFL. This value will be updated during the September 2010 assessment when the 2010 survey data and the 2009/10 catch data become available.

Stock status determination relative to overfishing and overfished criteria will be made following review of an updated assessment that incorporates the 2010 survey data.

Additional Plan Team recommendations

The CPT noted some inconsistencies in data trends (e.g., BSFRF fit in Fig. 12c of mature male abundance), although the apparent magnitude of these differences may also represent different scaling in the presentation of the results. It was also cautioned that improved model fit attributed to additional mortality factors could be readily attributed to mortality sources other than the bycatch discard that are assumed in some model scenarios. The team noted that detailed results for many of the scenarios (e.g., molting probabilities for scenarios 6 and 7) were not presented in the document. Additional diagnostics, such as bubble plots, would facilitate evaluation of the different scenarios. The lack of detailed results limits the ability of the CPT to evaluate the scenarios.

CPT looks forward to a revision in May 2011 that addresses previous CPT and SSC comments that were not addressed in this assessment (likelihood profiles, Bayesian approach, effective sample sizes, CIE comments).

The CPT will review alternative definitions for B_{MSY} time frames. The assessment author should provide alternatives and comment on the appropriateness of each.

Ecosystem Considerations summary

Ecosystem considerations for this stock were not discussed by the CPT.

3 Eastern Bering Sea Tanner crab

Fishery information relative to OFL setting.

Two fisheries, one east and one west of 166˚ W. longitude, harvest eastern Bering Sea (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 EBS Tanner crab. Both fisheries were closed from 1997 to 2005 due to low abundance. 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˚ W. longitude. ADF&G opened both fisheries for the 2006/07 to 2008/09 crab fishing years, but only the area east of 166˚ W. longitude opened in 2009/10. In 2007, NMFS determined the stock was rebuilt because spawning biomass was above B_{MSY} for two consecutive years. However, annual harvests have declined steadily since 2007 as subsequent TACs have been reduced in response to declining stock biomass.

Tanner crab are caught as bycatch in the directed Tanner crab fishery (principally as non-retained females and sublegal males), in other crab fisheries (notably, eastern Bering Sea snow crab and Bristol Bay red king crab), in the groundfish fisheries, and in the scallop fishery.

Data and assessment methodology

This stock is surveyed annually by the NMFS EBS trawl survey. The current stock assessment model includes the entire EBS stock area. Area-swept estimates of mature male biomass (MMB), legal male biomass (LMB), and female biomass are derived from the EBS trawl survey data, revised for survey net width. Fish ticket data are used to compute retained catch, and observer data from the crab and groundfish fisheries are used to estimate the non-retained catch; assumed handling mortality rates for fishery components are used to estimate the discard mortality.

A length-based Tanner crab stock assessment model (TCSAM) is being developed; model updates were presented to the CPT in March 2010 and the SSC in April 2010, but not in May 2010. The new model will likely play a significant role in the development of a rebuilding plan; rebuilding plan timing was discussed. The CPT would potentially be reviewing a preliminary rebuilding plan next May. Because a new assessment model should be one of the alternatives in that plan, and a new model will likely need some adjustments, it will be important to have some assessment model review in September 2010.

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 623.9 million pounds in 1975, and a second peak of 255.7 million pounds in 1991. From late-1990s through 2007, MMB increased at a moderate rate from 25.1 million lbs in 1997. After 1997, MMB at the time of survey increased to 185.2 million pounds in 2007 and subsequently decreased to 77.1 million pounds in 2009. Survey estimated biomass of legal males declined 51% from 2008 to 2009.

Tier determination/Plan Team discussion and resulting OFL determination

The team recommends the OFL for this stock be based on the Tier 4 control rule because an assessment model to move the entire EBS stock into a Tier-3 is still being developed. The team recommends that B_{MSY} is based on the average MMB for the years 1969-1980, 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 because it encompasses periods of both high and low stock status. The team recommends that gamma be set to 1.0.

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

Year	MSST	Biomass (MMB)	TAC (east + west)	Retained Catch	Total Catch	OFL
2006/07		130.46	2.97	2.12	6.95	
2007/08		151.58	5.62	2.11	8.00	
2008/09	94.88	118.20	4.30	1.94	4.96	15.52
2009/10	94.88	62.28[A]	1.85[B/]	TBD	TBD	5.57
2010/11	92.37[C]	TBD	TBD	TBD	TBD	TBD

A- Projected 2009/10 MMB at time of mating after extraction of the estimated total catch OFL.
B- Only the area east of 166 deg. W opened in 2009/10; TAC was 1.85 million lbs.
C- Now based on the revised historical bottom trawl survey data.

Total catch for 2009/10 (TBD) was less than/more than the 2009/10 OFL (5.57 million lbs), so overfishing did/did not occur during 2009/10. It is estimated that the Tanner crab stock will be in an overfished condition after final accounting for losses from the 2009/2010 fisheries and M from the survey to mating. The May 2010 assessment estimates a likely upper limit on MMB at time of mating; it is apparent that the stock was below the MSST during the 2009 survey, the 2009/10 fishery, and at 2010 mating, although a formal determination of the stock being overfished will occur with the Fall 2010 assessment.

Ecosystem Considerations summary

Ecosystem considerations for this stock have been moved to the ecosystem chapter and were not discussed by the CPT.

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

There is no harvest strategy for this fishery in State regulation. The fishery began as bycatch in 1973 during the blue king crab fishery. A red king crab fishery opened with a specified GHL for the first time in September 1993. The 1993/94 fishery yielded1,179 t under a 1,542 t GHL, with the highest catches occurred east of St. Paul Island, but harvests also south, southwest, west, and northeast of St.Paul Island. The 1994 fishery was also prosecuted with a specified red king crab GHL. Since 1995, a combined GHL for red and blue king crabs was set and ranged from 567 to 1,134 t. The fishery has remained closed since 1999 because of uncertainty with estimated red king crab survey abundance and concerns for incidental catch and mortality of blue king crab, an overfished and very depressed stock. Prior to the closure, the CDQ harvest (3.5%) in 1998/99 was 16 t. The non-retained catches (without application of bycatch mortality rate) from pot and groundfish bycatch estimates of red king crab ranged from 50 to 86 t during 1991/92 – 2008/09.

Data and assessment methodology

Although a catch survey analysis has been used for assessing the stock in the past, which incorporated data from the eastern Bering Sea trawl survey, commercial catch, pot survey, and at-sea observer data; for this assessment, trends in MMB at mating are based on NMFS annual trawl survey estimates for 1980-2010 and incorporated commercial catch and observer data. The revised NMFS trawl survey historical abundance estimates were used in this assessment. The 2009/2010 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. For 2010 reference points' estimation, an F_{OFL} is determined using a mean mature male biomass (MMB) at the time of mating (projected to mating time), the default γ value of 1, and an M value of $0.18 yr^{-1}$. The stock assessment analyzes two time period options for estimating mean MMB as a proxy B_{MSY}, 1991-2009, the recommended period, and 1980-2009, for comparison purposes. This F_{OFL} is applied to the projected legal male biomass at the time of the fishery to determine the catch OFL. Total crab removal (retained, and directed and non-directed bycatch losses) with legal male biomass and MMB are used to estimate the exploitation rates on legal male and mature male biomasses, respectively, at the time of the fishery.

Stock biomass and recruitment trends

The stock exhibited widely varying mature male and female abundances during 1980-2009. The estimate of MMB from the 09 survey was 2,023 t; the estimate from the 2010 survey was not available.. Recruitment indices are not well understood for Pribilof red king crab. Pre-recruitment have remained relatively consistent in the past 10 years, although may not be well assessed with the survey. Stock biomass in recent years has decreased since the 2007 survey with a substantial decrease in all size classes in 2009 and this will be updated for 2010. Red king crabs have been historically harvested with blue king crabs and are currently the dominant of the two species in this area.

Tier determination/Plan Team discussion and resulting OFL determination

This stock is recommended to be in Tier 4. The CPT recommends that γ be set to 1.0.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		13.87	Closed	0	0.024	
2007/08	4.33	14.70[A]	Closed	0	0.008	
2008/09	4.39	11.06[B]	Closed	0	0.021	3.32
2009/10	TBD	TBD[C]	Closed	0	TBD	0.50
2010/11	TBD	TBD[D]	TBD	TBD	TBD	TBD

A – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
B – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
C – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
D – Based on survey data available to the Crab Plan Team in September 2010

Stock status determination relative to overfishing and overfished criteria will be made following review of an updated assessment that incorporates the 2010 survey data.

Additional plan team recommendations

The plan team looks forward to the presentation of the CSA model in September.

Ecosystem Considerations summary
This section was removed from the assessment and will be incorporated into the crab ecosystem considerations chapter for September 2010 distribution.

5 Pribilof District blue king crab

Fishery information relative to OFL setting.

The Pribilof blue king crab fishery began in 1973, with peak landing of 11.0 million lbs in the 1980/81 season. A steep decline in landings occurred after the 1980/81 season. Directed fishery harvest from 1983 until 1987 was annually less than 1.0 million lbs with low CPUE. The fishery was closed in 1988 until 1995. The fishery reopened from 1995 to 1998. Fishery harvests during this period ranged from 1.3 to 0.5 million lbs. The fishery closed again in 1999 due to declining stock abundance and has remained closed through the 2009/10 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. In 2009 NMFS updated the trawl survey time series resulting in a minor adjustment in current and historical survey biomass and a minor adjustment in the B_{MSY} calculation. This assessment uses the new survey data series with measured net widths. 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

Based on 2009 NMFS bottom-trawl survey, the estimated total mature-male biomass increased to 1.28 million lbs from 0.29 million lbs in 2008. However, the 2009/10 MMB at mating is projected to be 1.13 million lbs which is about 12% of B_{MSY}. The Pribilof blue king crab stock biomass continues to be low. From recent surveys there is no indication of recruitment.

Tier determination/Plan Team discussion and resulting OFL determination

This stock is recommended for placement into Tier 4. The time period for B_{MSY} is 1980/81-1984/85 plus 1990/1991-1997/1998, 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 as 8.99 million pounds.

The CPT recommended $\gamma = 1$, given the absence of information presented to establish an alternate value at this time. Natural mortality was M=0.18yr^{-1}.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		0.33	closed	0	0.0004	
2007/08		0.66	closed	0	0.005	
2008/09	4.64	0.25	closed	0	0.001	0.004
2009/10	4.64	TBD	closed	0	TBD	0.004
2010/11	TBD	TBD	TBD	TBD	TBD	TBD

Stock status determination relative to overfishing and overfished criteria will be made following review of an updated assessment that incorporates the 2010 survey data.

Additional Plan Team recommendations

A revised rebuilding plan is under development. Initial review of this analysis will occur at the October 2010 Council meeting. The team's comments on the preliminary review draft are contained in the Crab Plan Team report from March 2010.

Ecosystem Considerations summary

This section was removed from the assessment and will be incorporated into the crab ecosystem considerations chapter for September 2010 distribution.

6 St. Matthew blue king crab

Fishery information relative to OFL setting

The St. Matthew Island fishery developed when 10 U.S. vessels harvested 1.202 million pounds in 1977/78. Harvests peaked in 1983/84 when 9.454-million pounds were landed. From 1986/87 to 1990/91 the fishery was fairly stable, with a mean annual harvest of 1.252-million pounds. The mean catch increased to 3.297-million pounds during 1991-1998. This fishery was declared overfished and closed in 1999 when the stock size 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 1998). 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 St. Matthew Island blue king crab stock. The rebuilding plan included a harvest strategy established in regulation by the Alaska Board of Fisheries and area closures to control bycatch as well as gear modifications and an area closure for habitat protection. Since 1999, the abundance estimates calculated from the National Marine Fisheries Service (NMFS) annual eastern Bering Sea shelf survey data have not met the rebuilding plan's harvest strategy threshold or minimum TAC, although 2006 and 2007 abundance estimates, 11.2-and 15.6-million pounds respectively, were above MSST and the stock is considered rebuilding (Bowers et al. 2008). The fishery was closed during 1999/00-2008/09 and re-opened in 2009/10 with a TAC of 1.167-million pounds and 0.461-million pounds of retained catch were harvested. 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.

Data and assessment methodology

Assessment data are from three sources: 1) fishery effort and catch data; 2) trawl survey data; and pot survey data. 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 the 1978–2009 NMFS annual summer trawl survey for stations within the St. Matthew Section. Survey design within that area changed between 1982 and 1983 in the number and density of tows; since 1983 the tows in that area are divided into a low-density strata and a high-density strata. Trawl gear used in the NMFS survey changed between 1980 and 1981. 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 newshell ≥134 mm CL) males. Pot survey data are from the July–August 1995, 1998, 2001, 2004 and 2007 ADF&G triennial pot surveys for Saint Matthew Island blue king crab, which sample from areas of important habitat for blue king crab, particularly females, that the NMFS trawl survey cannot sample from. Data used are from only the 96 stations fished in common in 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.

A four-stage catch-survey analysis (CSA) is used to assess abundance. Annual abundance of male crabs in the four size and shell-condition categories listed above (representing prerecruit-2s, prerecruit-1s, recruits, and postrecruits, respectively) is modeled by the CSA. The CSA model links the crab abundances in four stages in year t+1 to the abundances and catch in the previous year through natural mortality, fishing mortality, molting probability, and a growth matrix. Five scenarios of the CSA model were developed for the assessment, differing in whether parameters for natural mortality or trawl survey selectivity are fixed (estimated independently) or conditionally and whether natural mortality is constant or variable with time.

Stock biomass and recruitment trends

Based on data through 2009/10 and modeled by the "Scenario 1" assessment model, the stock is estimated to have been above BMSY during 2008/09 and 2009/10. Numbers of legal males, post-recruit-sized legal males, and mature male biomass and abundance (numbers of crabs) are estimated to have increased since 1999/00 and, especially, since 2005/06 through 2009/10. Numbers of recruit-sized legal males and pre-recruit-1-sized sublegal males are estimated to have increased during 2005/06–2009/10. Numbers of pre-recruit-2-sized sublegal males and recruits to the modeled male size class are estimated to have increased during 2004/05–2008/09, but their numbers, especially those of the recruits to the modeled male size class, are estimated to have decreased in 2009/10.

Tier determination/Plan Team discussion and resulting OFL determination

The CPT recommends that the stock be in Tier 4 with gamma =1 used for calculating F_{OFL}. The author recommended using the Scenario 1 model (i.e., same as used for 2009/10, with M fixed at 0.18 for 1978–1998, 2000–2009 and estimated for 1999 and Q fixed at 1.0). The CPT agrees and recommends using the Scenario 1 model, updated with the 2010 survey data and 2009/10 bycatch data for computing the OFL for 2010/11.

Status and catch specifications (millions lbs.)

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		7.1[A]	closed	closed	0.66	
2007/08		9.7[B]	closed	closed	0.35	
2008/09	4.0	10.74[C]	closed	closed	0.20	1.63 (retained)
2009/10	4.0	TBD	1.167	0.461	TBD	1.72 total male catch
2010/11	TBD	TBD	TBD	TBD	TBD	TBD total male catch

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2007
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2008
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2009

Stock status determination relative to overfishing and overfished criteria will be made following review of an updated assessment that incorporates the 2010 survey data.

Additional Plan Team recommendations

For the September assessment, the author should: (1) on page 19, that says "the mean bycatch", clarify that the calculation of OFL uses the mean fishing mortality of bycatch; (2) clarify the subcomponents of bycatch mortality (i.e., to fixed gear versus trawl gear for groundfish fishery bycatch); (3) add a table that shows the annual trawl and fixed-gear bycatch, and (4) up-date the text to include most recent year and current status of the stock.

For the September assessment, the author should: (1) justify weights used in log likelihood computation (e.g., lambda = 100 for retained catch); (2) report CVs in table on pot survey data; and (3)report whether any model parameter estimates are hitting parameter bounds (e.g., trawl fishery mortality), possibly by widening the bounds.

The team also requests that ADF&G review the pot survey data, particularly for overestimation of recruit class (possible misclassification of recruit class).

Ecosystem Considerations summary

The stock assessment contains a comprehensive ecosystem considerations section. This section should be folded into the new ecosystem considerations chapter.

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 fisheries. 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 two 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, Zheng et al. (1998) developed a length-based stock synthesis model of male crab abundance 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. We updated the model with data from 1976 to 2010 and estimated population abundance in 2010. Estimated abundance and biomass in 2010 are dependent on the choice of natural mortality (M).

Stock biomass and recruitment trends

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. 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 infrequent trawl surveys (every 3 to 5 years).

Tier determination/Plan Team discussion and resulting OFL determination

The team recommended Tier 4 stock status for Norton Sound red king crab. The team reviewed 7 different models. The Team recommended model 6 for OFL determination in 2010. This model included an estimation of bycatch mortality in the directed fishery, changed the weight on the fishing effort data, increased M to 0.288 for the largest length bin, and assumed flat selectivity for the summer fishery. The estimated abundance and biomass in 2010 are:

Legal males: 1.6940 million crabs with a standard deviation of 0.1892 million crabs.
Mature male biomass: 5.4410 million lbs with a standard deviation of 0.6284 million lbs.
Average of mature male biomasses during 1983-2010 was used as the *BMSY* proxy and the CPT chose gamma =1.0 to derive the *FMSY* proxy.
Estimated *BMSY* proxy, *FMSY* proxy and retained catch limit in 2010 are:
BMSY proxy = 3.1173 million lbs,
FMSY proxy = 0.18,
Retained catch limit: 0.2791 million crabs or 0.7335 million lbs.

Status and catch specifications (millions lbs.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL
2006		3.62	0.45	0.45	0.48	
2007		4.40	0.32	0.31		
2008	1.78	5.24[A]	0.41	0.39		0.68 [A]
2009	1.54	5.83[B]	0.37	0.40	TBD	0.71 [B]
2010	1.56	5.44[C]	TBD	TBD	TBD	0.73 [C]

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

Stock status determination relative to overfishing in 2009 will be made in September with total catches tabulated for the 2009 season. Stock biomass is above MSST thus the stock is not overfished.

Additional Plan Team recommendations

While the CPT recommended Model 6 (given that no operational differences between Model 2/Model 6), in future iterations, the team recommends improved rationale for model specifications. Other requested changes and modification for the next assessment include:
Figure 3: include CVs for final version, and noted that apparent CV is .16, which is better than for other stocks;
Figure 7: (Applies to all chapters) Use different symbols for last two years to make visible;
Figure 11: Recommend showing CPUE trend and add XY plot of observed and predicted CPUE.
Figure 5, (residuals of length compositions in the winter pot survey and summer fishery): authors should consider time-varying selectivity and investigate reasons for break points in time series.
The authors should also provide a clearer explanation for OFL result and apportionment of OFL between directed catch, bycatch, and discard, noting that although observer data in directed fishery not available, fixed gear bycatch data is available. It would be useful to plot time series trajectories from each model. Authors should explore higher weight on fit to fishery effort and perform and present sensitivity analysis of alternative weighting of survey sources

Ecosystem Considerations summary
No additional ecosystem considerations were included in the assessment at this time.

8 Aleutian Islands golden king crab

Fishery information relative to OFL setting

The directed fishery has been prosecuted annually since the 1981/82 season. Retained catch peaked during the 1985/86–1989/90 seasons (average catch of 11.9 million lbs), but average harvests dropped sharply from the 1989/90 to 1990/91 season to an average harvest of 6.9 million lbs. 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 lbs beginning with the 1998/99 season. The GHL (or TAC, since the 2005/06 season) remained at 5.7 million lbs through the 2007/08 season. In March 2008 the Alaska Board of Fisheries set the TAC for this stock in regulation at 5.985 million pounds. Average retained catch for the period 1996/97–2008/09 was 5.6 million lbs, including 5.68 million lbs in the 2008/09 season. 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-frequency data from samples of landed crabs, at-sea observer data from pot lifts sampled during the fishery (date, location, soak time, catch composition, size, sex, and reproductive condition of crabs, etc), data from a triennial pot survey in the Yunaska-Amukta Island area of the Aleutian Islands (approximately 171° W longitude), recovery data from tagged crabs released during the triennial pot surveys and bycatch data from the groundfish fisheries. These data are available through the 2008/09 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

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. However, there is good evidence that the sharp increase in CPUE of retained legal males during recent fishery seasons was not due to a sharp increase in recruitment of legal-size males, but rather to changes in fishing practices (i.e. longer soak times).

Tier determination/Plan Team discussion and resulting OFL determination

AIGKC is recommended for Tier 5 stock in 2010/11. B_{MSY} and MSST are not estimated for this stock. Observer data on bycatch from the directed fishery and groundfish fisheries can provide estimates of total bycatch mortality for years after the 1996/97 season. 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.

During the May 2010 CPT meeting, the CPT recommended that a total-catch OFL be established for the 2010/11 Aleutian Islands golden king crab season. The CPT requested that the total-catch OFL be computed according to three different alternatives for consideration:

1. $OFL_{TOT(1)} = (1+RATE_{05/06\text{-}08/09})\cdot OFL_{RET(85/86–95/96)} + MGF_{96/97–08/09}$
2. $OFL_{TOT(2)} = (1+RATE_{96/97\text{-}04/05})\cdot OFL_{RET(85/86–95/96)} + MGF_{96/97–08/09}$
3. $OFL_{TOT(3)}$ = Average of total catch for all components in Table 4 in assessment.

where:

$(RATE_{05/06\text{-}08/09})$ = mean of annual Rate = (bycatch mortality in crab fisheries)/(retained catch) over the period 2005/06–2008/09,

$(RATE_{96/97\text{-}04/05})$ = mean of annual Rate = (bycatch mortality in crab fisheries)/(retained catch) over the period 1996/97–2004/04,

$OFL_{RET(85/86–95/96)}$ = mean of annual retained catch over the period 1985/86–1995/96, and

$MGF_{96/97–08/09}$ = mean of annual bycatch mortality in groundfish fisheries over the period 1996/97–2008/09.

Note that $OFL_{RET(85/86–95/96)}$ is the retained-catch OFL that was established for the 2008/09 and 2009/10 Aleutian Islands golden king crab seasons, 9.18-million pounds.

Should the SSC chose to employ a methodology such as proposed under alternatives 1, 2 or 3 to establish a total catch OFL for the 2010/11 season more detailed information and resulting total catch OFLs under each scenario have been provided in the Crab Plan Team Report. The options above result in the following total catch OFLs in millions of pounds:

$OFL_{TOT(1)}$	$OFL_{TOT(2)}$	$OFL_{TOT(3)}$
10.1-million pounds	11.5-million pounds	6.8-million pounds

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL (retained)
2005/06	NA	NA	5.70	5.52	6.0	
2006/07	NA	NA	5.70	5.22	5.8	
2007/08	NA	NA	5.70	5.51	6.2	
2008/09	NA	NA	5.99	5.68	6.3	9.18 [retained]
2009/10	NA	NA	5.99	TBD	TBD	9.18 [retained]
2010/11	NA	NA	TBD	TBD	TBD	TBD [total catch]

No overfished determination is possible for this stock given the lack of biomass information. Stock status determination relative to overfishing for 2009/10 will be made in September when total catches for the 2009/10 season are tabulated..

Additional Plan Team recommendations

In May 2010, the plan team reviewed a new stock assessment model for Aleutian Islands golden king crab (Chapter 8b, Draft May Crab SAFE report). Use of an assessment model could allow for this stock to be moved to Tier 4 and would provide focus for establishing research and data collection priorities. The team believes that the model has been improved greatly from the 2009 iteration. The team recommends incorporation of plan team comments into the model for the September 2010 plan team meeting but did not recommend adopting the model for OFL determination in this year. Specific comments on model suggestions are contained in the May Crab Plan Team report.

Ecosystem Considerations summary

An ecosystem discussion is included in the assessment and is focused on fishery effects on the ecosystem.

9 Pribilof Islands 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 pounds during the 1983/84 season. Historical fishery participation has been sporadic and retained catches variable. The current fishing season is a calendar year. Since 2000, the fishery was managed for a guideline harvest level (GHL) of 0.15 million pounds. 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 68-thousand pounds (2002-2009). Crab mortality in groundfish fisheries (July 1–June 30, 1991/92–2008/09) averages 3-thousand pounds. There has been no participation in the directed fishery from 2006 through 2009. Pribilof District golden king crab was 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 at-sea observer data from 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 is 919 mt, an increase from 692 mt in 2002. There is no recent directed fishery participation (2006-2009).

Tier determination/Plan Team discussion and resulting OFL determination

The Team recommends this stock be assigned to Tier 5. Biomass information was provided for Pribilof Canyon, but not specific to mature males.

The assessment author presented a retained-catch OFL based on data from 1993-98, and two alternative retained-catch OFLs based on 1993-1999 and 1993-2002 time periods. The assessment author also presented a total-catch OFL.

The Team recommends a total-catch OFL. The total-catch OFL is derived based on the following relationship to the retained-catch OFL (1993-98 seasons) adopted for 2010 fishing season:

$OFL_{tot} = 1.05 * OFL_{ret} + 0.006$ million

This relationship accounts for groundfish and non-directed crab bycatch mortality at a background level that is independent of the Pribilof District golden king crab stock size and directed catch, however, the bycatch mortality in the directed fishery is assumed to be proportional to retained catch. Bycatch data from crab fisheries was often confidential and only available from 2001 – 2009. The groundfish bycatch data was available from 1991/92 – 2008/09 in federal reporting areas 513, 517 & 521. The 1.05 multiplier accounts for crab bycatch mortality in the directed crab fishery and 6-thousand pounds is the average “background level” groundfish and non-directed crab bycatch mortality. The Team recommends a total catch OFL of 0.18 million pounds for the 2011 Pribilof District golden king crab fishing year.

Historical status and catch specifications (millions lbs.) of Pribilof Islands golden king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL (retained)
2007	NA	NA	0.15	0		
2008	NA	NA	0.15	0	0.00	
2009	NA	NA	0.15	0	0.001	0.17 (retained)
2010	NA	NA	0.15	0	TBD	0.17 (retained)
2011	NA	NA	TBD	TBD	TBD	0.18

No overfished determination is possible for this stock given the lack of biomass information. Overfishing will be assessed in September for the 2010 fishery.

Additional Plan Team recommendations

None

Ecosystem Considerations summary

The fishery is concentrated in the Pribilof Canyon at depths of 100 – 300 fathoms. Fishery effects on the ecosystem are not determined at this time.

10 Adak red king crab, Aleutian Islands

Fishery information relative to OFL 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 occasionally, 1998/99, 2000/01-2003/04. Peak harvest occurred during the 1964/65 season with a retained catch of 21 million pounds. 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 through 1994/95, averaged 0.943 million pounds, but the retained catch during the 1995/96 season was low, only 0.039 million pounds. 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 pounds 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 pounds (2002/03) and 0.479 million pounds (2003/04). The fishery has been closed through the 2009/10 season 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 1995/96-2008/09 seasons averaged 0.003 million pound in crab fisheries and 0.023 million pounds in groundfish fisheries. Estimated annual total fishing mortality (in terms of total crab removal) during 1995/96-2008/09 averaged 0.116 million pounds. The average retained catch during that period was 0.09 thousand pounds. 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 1995/96-2008/09 and from groundfish fisheries during 1992/93-2008/09 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. A pot survey conducted by ADF&G in the Petrol Bank area in 2006 provided no evidence of strong recruitment. The 2009 survey encountered smaller ageing population with the catch of legal male crabs occurred 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 determination

The CPT recommends this as a Tier 5 stock for the 2009/10 season. Author provided three model alternatives (Alt.) with different time periods (Base: 1984/85-2007/08; Alt.1: 1977/78-2007/08; Alt.2: 1960/61-2007/08) to compute the average retained catch as OFL. The team recommended a total catch OFL for the 2010/11 season because complete information on total catch is available for the period 1995/96-2007/08. The total catch OFL for this period is 0.12-million pounds. The CPT also recommends freezing the final fishing season at 2007/08.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL (retained)
2006/07	NA	NA	Closed	0	0.004	NA
2007/08	NA	NA	Closed	0	0.011	NA
2008/09	NA	NA	Closed	0	0.014	0.46[A] (retained)
2009/10	NA	NA	Closed	0	TBD	0.50[A] (retained)
2010/11	NA	NA	Closed	TBD	TBD	0.12[B]

A-based on 1984/85-07/08 mean retained catch
B-CPT recommended total catch OFL of 0.12 million pounds based on the average for 1995/96-07/08 (Table 5).

No overfished determination is possible for this stock given the lack of biomass information. Overfishing will be assessed in September for the 2009/2010 fishery.

Additional Plan Team recommendations

None

Ecosystem Considerations summary

This stock is unsurveyed, remote, and data-poor. Since the fishery is sporadic and restricted to a limited area (Petrel Bank), fishery specific effects on target size crab, discards, age at maturity, EFH non-living substrate appears minimal.

Table 3. Crab Plan Team recommendations May 2010
(Note diagonal fill indicated parameters not applicable for that tier level while shaded sections are to be filled out for the final SAFE in September 2010)

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2010[2][3] MMB	2010 MMB / MMB_{MSY}	γ	Mortality (M)	2010/11 OFL mill lbs [retained]
1	EBS snow crab	3				1979-current [recruitment]				Male- estimated Female – 0.23	
2	BB red king crab	3				1995-current [recruitment]				0.18 default , estimated otherwise[4]	
3	EBS Tanner crab	4			183.6	1969-1980 [survey]			1.0	0.23	
4	Pribilof Islands red king crab	4				1991-current [survey]			1.0	0.18	
5	Pribilof Islands blue king crab	4			9.28	1980-1984; 1990-1997 [survey]			1.0	0.18	
6	St. Matthew Island blue king crab	4				1989-current [model estimate]			1.0	0.18 (1978-98, 2000-08); 1.8 (1999)	[total male catch]
7	Norton Sound red king crab	4	a	0.18	3.12	1983-current [model estimate]	5.44	1.7	1.0	0.18	0.73
8	AI golden king crab	5				TBD [total catch]					TBD (see intro)
9	Pribilof Island golden king crab	5									0.18
10	Adak red king crab	5									0.12

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 2/15/2011 at time of mating.
3 Model mature biomass on 7/1/2010
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.

Stock Assessment of eastern Bering Sea snow crab

Benjamin J. Turnock and Louis J. Rugolo
National Marine Fisheries Service
April 29, 2010

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

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 809,600 t. The total mature biomass includes all sizes of mature females and morphometrically mature males. The stock was declared overfished in 1999 because the survey estimate of total mature biomass (149,900 t) was below the minimum stock size threshold (MSST = 208,710 t). A rebuilding plan was implemented in 2000.
Under this rebuilding plan, NMFS required that the stock should be above B_{MSY} for two consecutive years (NPFMC 2000). The currency for estimating B_{MSY} changed during the 10 year rebuilding period. Using the current definitions for estimating B_{MSY}, the snow crab stock remained below B_{MSY} in the 2008/09 fishing year. Based on this finding, the current rebuilding strategy failed to make adequate progress towards rebuilding and has failed to rebuild the snow crab stock within the required 10 year time period.

Observed survey mature male biomass increased from 121,600 t in 2008 to 141,300 t in 2009, however, the 2009 biomass is below the 2007 estimate of 147,300 t. Observed survey mature female biomass also increased from 86,400 t in 2008 to 103,800 t in 2009, however mature female biomass has a generally declining trend since 2005. The 2009 estimate of males greater than 101 mm was 125.9 million an increase from 97.7 million estimated in 2008.

Model estimates of mature male biomass at mating increased from 84,800 t in 2007/8 to 97,300 t in 2008/9 (70% of B35%).

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 the 2008/9 fishery was 26,560 t compared to 28,600 t in the 2007/08 fishery. The total catch in the 2008/09 fishery was estimated at 29,770 t, below the OFL of 35,070 t. The TAC (retained catch) for the 2009/10 fishery was set at 21,780t.

Estimated discard mortality (mostly undersized males and old shell males) in the directed pot fishery has averaged about 15.5% (with assumed 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. Discard mortality was assumed to be 50%.

Seven model scenarios are presented that follow recommendations by the Crab Plan Team and the SSC as well as profiles on survey Q and male natural mortality. All model runs contain the "new" survey data that uses measured net widths to estimate abundance instead of a 50ft fixed net width. Model scenarios represent different assumptions concerning survey selectivity. The 2009 study area data from BSFRF and NMFS was added to the assessment model as an additional survey for estimation of survey selectivity. Changes to the assessment model based on CPT and SSC recommendations are detailed below.

The retained catch (1000 t), percent MMB/B35%, full selection fishing mortality and exploitation rate projected for 2010/11 using the 75% F35% strategy for Models 1 through 6.

Model	Retained catch	Percent MMB/B35%	F	exp rate
1	18.2	72.8	0.34	0.17
2	26.9	82.6	0.43	0.20
3	67.8	113.6	0.69	0.27
4	26.2	77.6	0.54	0.23
5	29.2	77.4	0.69	0.24
6	66.0	85.9	1.68	0.38

The MMB projected for 2010/11 fishing at F35% is X t with an OFL of X 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	148.2	74.1	113.9	21.8			33.1
2010/11							

[a] Bmsy proxy for 2007/8 based Sept 2008 assessment. Bmsy proxy for 2008/09 and 2009/10 based on Sept 2009 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

Seven model scenarios are presented here with various assumption concerning survey selectivities, male natural mortality and growth (see model scenarios section for full descriptions). Changes to Model 1 from the September 2009 assessment are: 1) no extra weight on survey biomass likelihood (recommended by data weighting workshop 2009), 2) estimation of probability of maturing in the model (SSC recommendation), 3) M = 0.23 for all crab, 4) Separate survey selectivities estimated for males and females (SSC recommendation).

Changes to the Data

All model scenarios in the current assessment use the “new” survey data with estimated net widths instead of fixed 50ft net width data used in the September 2009 assessment. The 2009 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.

CPT Comments May 2009

The CPT requested that the September 2009 assessment use the survey data with the fixed 50ft net width as was used in May 2009, however, the May 2010 assessment should use the measured net width biomass estimates.

This assessment uses the survey biomass estimates with the measured net width and other corrections to data.

CPT Comments March 2010

The CPT ***agrees*** *with the general approach used to include the BSFRF survey data in the assessment but notes that the fit of the model to the length-frequency data for BSFRF survey is very poor.* ***The CPT recommends that a model configuration that is able to fit all of the data sources be created and identify five possible ways to improve the fit of the model to the BSFRF length-frequency data: (1) disaggregate the data spatially and perhaps fit the model to each of the three subsets of the survey region separately; (2) replace the logistic selectivity function with a selectivity pattern that is smooth but more flexible than the logistic curve (the selectivity pattern needs to account for both gear selectivity and availability); (3) drop the data for size-classes smaller than 40mm (or 50mm); (4) estimate natural mortality with a prior based on the results of the Canadian tagging data (consider re-analyzing the Canadian data using mark-recapture methods); and (5) estimate growth within the model. It may be necessary to combine some of items (1)-(5) to create a model which fits all of the data adequately.***

The CPT recommends that the assessment for May 2010 include at least: (a) the current base model; (b) a model that sets Q to 0.75; and (c) a model which assumes the Somerton selectivity and sets Q to 0.75. A likelihood profile for survey Q should also be reported in the assessment.

The CPT notes that considerable work remains to complete the stock assessment for EBS snow crab. Moreover, the assessment is needed for both the Rebuilding Plan and ACL environmental assessment (EA) and for status determination and Over Fishing Limit (OFL) calculation. ***The CPT suggests the following work plan: (a) the period between now and the May 2010 CPT meeting should be used primarily to explore model formulations as outlined above; (b) the final ACL/rebuilding calculations should be based on the model selected during the May 2010 CPT meeting using the data currently available; and (c) status determination and OFL calculation should be based on the model selected during the May 2010 CPT meeting and should also take account of the data from the 2009/10 fishing season and the 2010 survey.*** *The CPT notes that this may mean that, for example, the estimate of the time to recover to B_{MSY} may differ between the analyses in the final EA and those presented to the CPT in September 2009.*

Authors Response to March CPT Comments

See model descriptions for model scenarios based on CPT recommendations. Time did not permit running scenarios with smooth functions for survey selectivities and runs with disaggregating the study area data. Removing small crab from the length frequencies in the study area and using logistic functions was satisfactorily implemented without using smooth functions. Recommendations 3-5 were followed and model scenarios are presented for models a), b) and c). A likelihood profile of Q using the base model is included.

SSC Comments April 2010

The SSC requests that the methods used to estimate natural mortality (survivorship) are discussed in the assessment. To the extent possible, the SSC requests that the authors consider stage based mortality.

The SSC supports Crab Plan Team recommendations for model runs that will be presented at the May, 2010 Crab Plan Team meeting. *In an effort to more fully explore model sensitivity to alternative assumptions on growth and mortality,* ***the SSC recommends the author run a suite of models that assumes the Somerton selectivity curve and assumes a male natural mortality rate between 0.2 - 0.5 incrementing values by 0.05.*** *For these model runs, female mortality will be fixed at 0.23, growth, maturity probability and female selectivity will be re-estimated.* ***The SSC also recommends a model that assumes the Somerton selectivity curve, estimates growth, maturity probability and mortality with a prior based on Canadian tagging data.***

Authors Response to March CPT Comments

The method used to estimate natural mortality continues to be included in the stock assessment document as in past assessments as requested by the SSC.

The model scenario requested by the SSC with a fixed Somerton selectivity curve (Model 3) (as included in the presentation to the SSC in April 2010) and a profile on male natural mortality using that model have been included. A model scenario with survey selectivity fixed at the curve estimated by Somerton with estimation of growth, probability of maturing and natural mortality for male crab with a prior is included (Model 6).

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 328 million lbs in 1991, declined to 65 million lbs in 1996, increased to 243 million lbs in 1998 then declined to 33.5 million lbs in the 1999/2000 fishery (Table 1, Figure 1). Due to low abundance and a reduced harvest rate, retained catches remained low from about 24 to 37 million lbs from 2000/01 to 2006/07 fisheries. The retained catch for the 2007/08 fishery increased to 63 million lbs and was 58.5 million lbs in 2008/09 due to increasing biomass. The OFL (total catch) for the 2008/9 fishery was 77.3 million lbs using the F35% control rule. The total catch for the 2008/09 fishery was estimated at 69.0 million lbs. The TAC was set at 48.0 million lbs for the 2009/2010 fishery.

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 4 million lbs, increased to about 7.8 million lbs in 1995, then declined to about 2 to 3 million lbs until 1999. Trawl bycatch in 2007 and 2008 was 0.97 and 0.66 million lbs 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 1.1 lbs (1983-1984) and 1.6 lbs(1979), and 1.3 lbs 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 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) 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). 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 2008/09 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 2008/09. Total discarded catch was estimated from observer data from 1992 to 2008/09 (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 2008/09. 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	1978/79-2008/09
Discarded male and female crab pot fishery size frequency	1992/3-2008/09
Trawl fishery bycatch size frequencies by sex	1991-2008
Survey size frequencies by sex and shell condition ("new" survey data)	1978-2009
Retained catch estimates	1978/79-2008/09, TAC used for 2009/10 retained catch.
Discard catch estimates from snow crab pot	1992/93-2008/09 from observer data

fishery	
Trawl bycatch estimates	1973-2008/09
Total survey biomass estimates and coefficients of variation ("new" survey data)	1978-2009
2009 study area biomass estimates and coefficients of variation and length frequencies for BSFRF and NMFS tows	2009

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 (Figure 4, Figure 5, female mature biomass).

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 6). The mature biomass increased in 2000 and 2001, mainly due to a few large catches of mature females. Survey estimates of total mature biomass increased to 268,700 t in 2007, decreased in 2008 to 208,000 t, then increased in 2009 to 245,000 t.
Survey mature male biomass increased to 147,300 t in 2007, decreased to 121,600 t in 2008, then increased to 141,300 t in 2009.

The observed survey estimate of males greater than 101 mm increased to124.1 million in 2007, then declined to 97.7 million in 2008, then increased to 125.9 million in 2009 (Table 2).

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 8 through 10). In 2009 small crab(<50mm) increased in abundance and may be an indication of future recruitment, however, more years of data are needed. High numbers of small crab in the late 1970's survey data did not follow through the population to the mid-1980's. The high numbers of small crab in the late 1980's resulted in the high biomass levels of the early 1990's and subsequent high catches. Moderate increase in numbers can also be seen in the mid 1990's.

Spatial distribution of catch and survey abundance

The majority of the fishery catch occurs south of 58.5 ^{o} N., even in years when ice cover did not restrict the fishery moving farther north. In past years, most of the fishery catch occurred in the southern portion of the snow crab range possibly due to ice cover and proximity to port and practical constraints of meeting delivery schedules. In 2004 78% of the catch was south of 58.5 ^{o} N. (Figure 11). In 2003 and 2004 the ice edge was farther north than past years, allowing some fishing to occur as far north as 60-61 ^{o} N. Catch in the 2006/07 fishery was similar to recent years (Figure 12) with most catch south of 58 ^{o} N. and west of the Pribilof Islands between about 171 ^{o} W and 173 ^{o} W. The pattern of catch was similar to previous years for the 2008/09 fishery however, about 3,580 t of retained catch was taken east and south of the Pribilof Islands at 168 to 167 ^{o} longitude and 55.5 to 56.6 ^{o} latitude which has not occurred in recent years (Figure 13). About 93% of the retained catch came from south of 58.5 ^{o} N.

Summer survey data from 2003 to 2007 show approximately 75% of the mature male snow crab population resides in a region outside of the fishery zone (north of 58.5 ^{o} N Latitude). The 2003 survey estimated about 24% of the male snow crab >101mm were south of 58.5 ^{o} N. About 48% of those males were estimated to be new shell (which are preferred by the fishery). In 2004 and 2005, about 26 % of the survey abundance of male snow crab > 101 mm and the mature male biomass were south of 58.5 ^{o} N. latitude (Figures 14 through 18). About 53% of those males south of 58.5 ^{o} N. were estimated to be new shell. The 2004 fishery retained about 19 million crab of which about 14.8 million were caught south of 58.5 ^{o} south (about 78%). Although these new shell males are morphometrically mature (i.e., large clawed), at the time of the fishery, they are subject to exploitation prior to recruiting to the reproductive stock. The 2003 survey estimate of new shell male crab > 101 mm was about 7.6 million south of 58.5 ^{o} N. which would have been fished on in the 2004 fishery. In the 2004 survey about 9.5 million new shell males >101mm were estimated south of 58.5 ^{o} N.

The spatial distribution of large male snow crab in the 2007 survey was similar to 2005 (Figures 18 and 19), however, 2007 had fewer crab in the area to the south and west of St. Matthew Island. Female crab > 49 mm occurred in higher concentration in generally three areas, just north of the Pribilof Islands, just south and west of St. Matthew Island, and to the north and west of St. Matthew Island. Males > 78 mm were distributed in similar areas to females, except the highest concentrations were between the Pribilof Islands and St. Matthew Island.

The spatial distribution of large male snow crab in the 2008 survey was farther south and east than in 2007 (Figures 19 and 20). The distribution of males and females in 2009 are shown in Figures 21a to 21g. Males > 77 mm (approximately mature males) are mostly distributed between the Pribilof Islands and St. Matthew Island (Figure 21a). The distribution of large male crab (>101 mm) in 2009 was similar to 2008, however, the top three tows accounted for 36% of the total abundance (Figure 21c). Small males (<78 mm) and immature females were distributed mainly north of St. Matthew Island (Figures 21a and 21c). Mature old shell females with no eggs comprised 8% of old shell mature females, primarily from only one tow (Figure 21f). Mature females with less than or equal to a half clutch were 28% of old shell and 20% of new shell mature females, and were distributed between 58 ^{o} and 60 ^{o} N in the area south of St. Mathew Island(Figure 21e). Mature females with eggs (any clutch size) were distributed from 62 ^{o} N to about 57 ^{o} N, however, the higher CPUE was in the area 58 ^{o} N to 60 ^{o} N and between about 172 ^{o} and 174 ^{o} W (Figure 21g).

The difference between the summer survey distribution of large males and the fishery catch distribution indicates that survey catchability may be less than 1.0 and/or some movement occurs between the summer survey and the winter fishery. However, the exploitation rate on males south of 58.5 ^{o} N latitude may exceed the target rate, possibly resulting in a 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. Lower egg production in the south from lower clutch fullness and higher percent barren females possibly due to insufficient males for mating may drive a change in distribution to the north. The northward shift in mature females is particularly problematic in terms of annual reproductive output due to lowered productivity from the shift to biennial spawning of animals in waters < 1.5 ^{o} C in the north. The lack of males in the southern areas at mating time (after the fishery occurs) may result in insufficient males for mating.

Ernst, et al. (2005) found the centroids of survey summer distributions have moved to the north over time (Figures 22 and 23). In the early 1980's the centroids of mature female distribution were near 58.5 ^{o} N, in the 1990's the centroids were about 59.5 ^{o} N. The centroids of old shell male distribution was south of 58 ^{o} N in the early 1980's, moved north in the late 1980's and early 1990's then shifted back to the south in the late 1990's. The distribution of males>101 mm was about at 58 ^{o}o N in the early 1980's, then was farther north (58.5 to 59 ^{o} N) in the late 1980's and early 1990's, went back south in 1996 and 1997 then has moved north with the centroid of the distribution in 2001 just north of 59 ^{o} N.. The centroids of the catch are generally south of 58 ^{o} N, except in 1987. The centroids of catch also moved north in the late 1980's and most of the 1990's. The centroids of the catch were about at 56.5 ^{o} N in 1997 and 1998, then moved north to above 58.5 ^{o} in 2002.

2009 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 24, 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 25). 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 25). 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 26). 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 crab in the entire Bering Sea area were north of the study area near St. Matthew Island (Figure 21a). Some higher tows for large males (>=100mm) and for mature females occurred in the study area as well as outside the study areas (Figures 21d through 21g). 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.

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 28).

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 29). 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 29). The probability of maturing for male crab was about 15% to 20% at 60 mm to 90mm, then 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 99th percentile of the distribution of ages in an unexploited population if observable. Under negative exponential depletion, the 99th percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method an M=0.23 corresponds to a maximum age of 18 years (Table 6). M=0.23 was used for all crab in Model 1.

Model scenarios with male natural mortality estimated use 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 30 and 31). 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 32 and 33). 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 34). 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,

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

where,

R_0 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 are distributed to length bins based on a premolt to postmolt length transition matrix. For immature crab in year t-1 that remain immature in year t,

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

$G^s_{l',l}$ Growth transition matrix by sex, premolt and postmolt length bins. Defines the fraction of crab of sex s and premolt length bin l', that move to length bin l after molting.

$N^s_{t,l}$ Abundance of immature crab in year t, sex s and length bin l.

$N^s_{t-1,l'}$ Abundance of immature crab in year t-1, sex s and length bin l'.

$Z_{l'}^{s}$ Natural and fishing mortality by sex s and length bin l'

PM_{l}^{s} Fraction of immature crab that become mature for sex s and length bin l

l' Premolt length bin

l Postmolt 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, 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 35). 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 36),

$$\text{Width}_{t+1} = a + b^{*}\ \text{width}_{t}$$

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.

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),

$$G_{l',l}^{s} = \int_{l-2.5}^{l+2.5} gamma(x / \alpha_{s,l'}, \beta_{s})$$

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

$G^{s}_{l',l}$ is the growth transition matrix for sex, s and length bin l' (premolt size), and postmolt size l.

The Gamma distribution is,

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

Where x is length, 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 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 ($NMN^{s}_{t,l}$),

$$NMN^{s}_{t,l} = PM^{s}_{l} \sum_{L=l_1}^{l'} G^{s}_{l',l} \; e^{-Z^{s}_{l'}} N^{s}_{t-1,l'}$$

Crab that are new shell mature in year t-1, no longer molt, and move to old shell mature crab in year t ($NMO^{s}_{t,l}$). Crab that are old shell mature in year t-1 remain old shell mature for the rest of their lifespan.

$$NMO^{s}_{t,l} = e^{-Z^{s,old}_{l}} NMO^{s}_{t-1,l} + e^{-Z^{s,new}_{l}} NMN^{s}_{t-1,l}$$

Fishing occurs before growth (molting) takes place. Crab that molted in year t-1 are defined as new shell until after the spring molting season, which occurs after the fishery. Crab that molted to maturity (the terminal molt) in year t-1 are new shell mature until the next molting season when they become old shell mature.

Mature male biomass is the sum of all mature males at the time of mating multiplied by the weight at length for male crab.

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

Where,

tm is time of mating, which is after the fishery occurs, and before molting,

l Length bin,

Lbins number of length bins in the model,

$NMO_{tm,l}^{males}$ abundance of mature old shell males at time of mating in length bin l,

$NMN_{tm,l}^{males}$ abundance of mature new shell males at the time of mating in length bin l,

W_l weight of a male crab for 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 37).

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

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 38).

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

Separate survey selectivities were estimated for the period 1978 to 1981, 1982 to 1988, and 1989 to the present. Survey selectivities were estimated separately for males and females in the 1989 to present period. The maximum selectivity(Q) for each time period was estimated in the model for the Base model (Model 1) 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 10.

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.

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

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

Where, T is year, L is length bin and p is the proportion by length bin.

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,

$$\lambda \sum_{t=1}^{ts} \left[\frac{\log\left[\dfrac{SB_{obs,t}}{SB_{pred,t}}\right]}{sqrt(2) * s.d.(\log(SB_{obs,t}))} \right]^2$$

$$s.d.(\log(SB_{obs,t})) = sqrt(\log((cv(SB_{obs,t}))^2 + 1))$$

Recruitment deviations likelihood equation is,

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

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.

$$\sum_{t=1}^{tf} \left[\frac{\log\left[\dfrac{CPUE_{obs,t}}{CPUE_{pred,t}}\right]}{sqrt(2) * s.d.(\log(CPUE_{obs,t}))} \right]^2$$

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,

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

Female bycatch fishing mortality penalty.

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

Trawl bycatch fishing mortality penalty

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

If male natural mortality was estimated in the model then a penalty was added assuming a normal distribution. A 95% CI of +/- 1.7 yrs translates to a 95% CI in M of about +-0.025 using an exponential model, which is a CV= 0.054.

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

If growth was estimated in the model then a penalty was added assuming a normal distribution,

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

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

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

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

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

There were a total of 272 parameters estimated in the Base model (Model 1) (Table 9) for the 32 years of data (1978-2009). The 93 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 32 recruitment parameters estimated in the model, one for the mean recruitment, 31 for each year from 1979 to 2009 (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 3 parameters for females estimated. There were 12 survey selectivity parameters estimated for the study area BSFRF and NMFS male and female selectivity curves. One parameter was estimated to fit the pot fishery CPUE time series.

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 fixed in the model using parameters estimated from growth measurements for Bering Sea snow crab (4 parameters, Table 9). 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 CPT, SSC and NPFMC all requested a review of the implications of incorporating the results of the 2009 Bering Sea Fisheries Research Foundation (BSFRF) trawl survey into the snow crab assessment. In addition, the SSC requested that the author explore the implications of separate selectivity curves for males and females and the implications of different assumptions regarding natural mortality. A sensitivity analysis was presented to the SSC at the February and April 2010 Council meetings (Turnock 2010) and also at the March 2010 Crab Plan Team meeting. In this analysis likelihood profiles were examined for different assumptions regarding survey catchability and natural mortality.

The analysis presented here builds on earlier analyses by addressing key recommendations from the CPT and SSC. The CPT recommended in September 2009 to use the BSFRF survey data as an alternative survey in the assessment model to inform estimates of survey selectivity.

This report describes seven model scenarios for the Bering Sea snow crab stock assessment that all represent changes from the September 2009 assessment model (Turnock and Rugolo 2009). Several model scenarios are included for sensitivity analyses recommended by the Crab Plan Team as well as the SSC. Model scenarios are described in Tables 12 and 13. Model 1 (referred to as the base model) was recommended by the Crab Plan Team at it’s March 2010 meeting. Model 1 uses the “new” survey data, no extra weight on survey biomass likelihood, separate survey selectivities for males and females, probability of maturing estimated in the model and incorporates the BSFRF 2009 survey data and NMFS survey data in the study area into the model to inform survey selectivities. 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 the 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 removes the problem of lack of fit of 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 to inform survey selectivity of mature and larger crab. Model 2 is the same as Model 1 with survey Q for male crab fixed at 0.75. Model 3 is the same as Model 1 with male survey selectivity for 1989-2009 fixed at the Somerton(2010) estimate of the selectivity curve from analysis of the study area data. Model 4 is the same as Model 1 with male M estimate with a penalty. Model 5 is the same as Model 4 with growth per molt parameters (intercept and slope of the linear growth function) estimated with a penalty. Model 6 is the same as Model 3 (Somerton selectivity curve) with male M estimated and growth parameters estimated as in Model 5. Model 7 is the same as Model 1 except the study area data has been removed and penalties put on the three parameters of the male survey selectivity to fit the Somerton curve (CV of parameters = 0.13 from Somerton (2010)). Model 7 was run to compare the results of using the study area data directly in the model to using a penalty on selectivity parameters. The 95% CI on the maximum survey selectivity estimated by Somerton (2010) was 0.55 to 0.95 (Q = 0.76).

Following the recommendation of the CPT (September 2009), 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, the BSFRF tows in the study area and the NMFS tows in the study area. 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 maximum selectivity 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. A separate parameter for females was estimated and multiplied by the male Q to estimate female Q for the NMFS survey in the entire Bering Sea and for the NMFS survey in the study area. 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 similarities and differences between models are provided in Tables 12 and 13. Male survey selectivity curves were estimated as follows:

a) 2009 BSFRF survey selectivity = Q (availability) * logistic selectivity

b) 2009 NMFS survey selectivity in study area = Q(availability)* Q (entire Bering Sea) * logistic selectivity

c) NMFS survey entire Bering sea 1989 to 2009 period =
Q (entire Bering Sea) * logistic selectivity

Separate female survey selectivity was estimated for BSFRF study area, NMFS study area and NMFS entire Bering sea as follows:

(a) For the 1978 – 1981, and the 1982 to 1988 periods,
Female survey selectivity = female mult. * Q male * male logistic selectivity

(b) For 1989 to 2009,

i)Female selectivity = female mult.* Q(male) * female logistic selectivity curve

ii)Female logistic selectivity curve has two estimated parameters separate from male selectivity.

iii)2009 NMFS female survey selectivity in study area =
female mult. * Q(availability) * Q (entire Bering Sea) * NMFS study area female logistic selectivity

iv) 2009 BSFRF female survey selectivity in the study area =
Q for females = female mult. * Q (availability)* BSFRF female logistic selectivity.

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, set at 1.0 billion,
σ_R^2	variance for recruitment deviations, estimated at 0.74 from the assessment model.

The temporal autocorrelation error (ε_t) was estimated as,

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

ρ_R	temporal autocorrelation coefficient for recruitment, set at 0.6.

Recruitment variability, autocorrelation and R_0 were estimated using recruitment estimates from the stock assessment model. R_0 was estimated at 1.0 billion which is approximately the 75% percentile of the cumulative distribution of the recruitment from the assessment model.
Implementation error was modeled as a lognormal autocorrelated error on the mature male biomass used to determine the fishing mortality rate in the harvest control rule,

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

$B_t^{'}$	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, set at 0.15.

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

Following the CPT recommendations, Model 1 is termed the Base model. Results in tables and figures are from Model 1 except where noted otherwise.

The total mature biomass increased from about 324,100 t in 1978 to the peak biomass of 670,700 t in 1990. Biomass declined sharply after 1997 to about 209,700 t in 2002. Total mature biomass remained at about 206,000 t to 207,000 t until 2006, then increased slightly in 2008 to 234,100 t then declined to 226,100 t in 2009 (Table 3 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%) (Table 1 and Figure 39). Parameter estimates for Model 1 are in Table 9. During the last three years (2006/7 to 2008/9 fishery seasons) under rationalization observed estimates of discard mortality averaged 15% of the retained catch compared to the average model estimates of discard mortality of 19%. Estimates of observed discard mortality ranged from 6% of the retained catch to 32% of the retained catch (assuming 50% discard mortality). In the 2008/9 observed fishery discard mortality was 13%, lower than the average values for either the last three years or the complete time series.

The model fit to the total directed male catch, groundfish bycatch, male discard catch and female discard catch are shown in Figures 39, 40, 41 and 42 respectively.

Mature male and female biomass show similar trends (Table 3, Figures 43 and 45). Model estimates of mature male biomass increased from 111,700 t in 2006 to 143,500 t in 2009. Observed survey mature male biomass declined from 147,300 t in 2007 to 121,600 t in 2008, then increased to 141,300 t in 2009. Model estimates of mature female biomass show a declining trend from 96,300 t in 2007 to 82,600 t in 2009. Mature female biomass observed from the survey decreased from 121,400 t in 2007 to 86,400 t in 2008, then increased to 103,800 t in 2009.

Estimated female mature biomass for Model 1 with "new" survey data and other changes was higher than from the September 2009 assessment (Figure 44) although has a declining trend in the last few years in contrast to the previous assessment.
Estimated male biomass is lower and shows less of an increase since 2006 than estimated from the September 2009 assessment (Figure 46).

Fishery selectivities and retention curves were estimated using ascending logistic curves (Figures 37 and 47). Selectivities for trawl bycatch were estimated as ascending logistic curves (Figure 48). Plots of model fits to the survey size frequency data are presented in Figures 49 and 51 by sex for shell conditions combined with residual plots in Figures 50 and 52. A summary of the fit across all years for male and female length frequency data indicates a very good fit overall (Figure 53). 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.

Survey selectivities for the period 1978 to 1981 were estimated at 50% at 37.5mm and 95% at 56.7 mm and maximum selectivity of 1.0 (Figure 38 and Table 9). Survey selectivities for the period 1982 to 1988 were estimated at 50% of the maximum (Q = 0.89) at about 39 mm and 95% at 62 mm. The maximum survey selectivity for the 1989 to present period with Model 1 (which includes the 2009 study area data) was estimated at 0.90, which is lower than Q=1.2 estimated using the September 2009 assessment model (Turnock 2010). Survey selectivities for the period 1989 to the present were estimated at 50% of Q at about 32 mm and 95% at about 45 mm. An underbag experiment estimated survey selectivity of 50% at 78 mm and a maximum of about 89% at 135 mm (Somerton and Otto 1998) with the survey net in use since 1982. The survey selectivity curve estimated using the 2009 study area by Somerton (2010) was 0.75 at 135mm (Figure 38).

The estimated number of males > 101mm generally follows the observed survey abundance estimates (Figure 54). The observed survey estimate of males greater than 101 mm decreased from about 124.1 million in 2007 to 97.7 million in 2008, then increased to 125.9 million in 2009. The estimated 95% confidence interval for the observed survey large males in 2009 was +/-29% of the estimate. Model estimates of large males were 114.5 million crab in 2007, 133.7 million crab in 2008 and 136.1 million crab in 2009.

Two main periods of above average recruitment were estimated by the model, in 1979-1981, 1983 (fertilization year) and in 1987-1988 (Figure 55). Recruits are 25mm to about 40 mm and may be about 4 years from hatching, 5 years from fertilization (Figure 56, although age is approximated). Lower than average recruitments were estimated from 1989 to 1997 and in 2000 to 2004. The 1998-1999 and 2001 year classes appear to be about average recruitment that has resulted in an increase in biomass in recent years. The 2004 year class is also estimated to be near average recruitment, however, the last few years recruitments have higher uncertainty. 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 57 and 58). 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 57 through 61. Fits to the trawl fishery bycatch size frequency data are in Figures 62 through 64.

Fishing mortality rates ranged from 0.14 to 2.80 (Figure 65 and Table 4). Fishing mortality rates ranged from 0.75 to 2.80, for the 1986/87 to 1998/99 fishery seasons. For the period after the snow crab stock was declared overfished (1999/2000 to 2008/09), full selection fishing mortality ranged from 0.26 to 0.73, with an average of 0.43.
Mature male biomass at mating in 2008/09 estimated from Model 1 was at 65% (90,700 t) of B35% (139,200 t) (Figure 66).

Model Scenario Results with 2009 Study Area and Survey Selectivity Sensitivity

Likelihood values for Models 1 through 6 show that model 5 (Base model with male M estimated at 0.29 and growth estimated with priors) has the best fit even when the additional parameters are accounted for (Table 14). Survey selectivities estimated for Model 1 are shown in Figure 69, while male survey selectivity for 1989 to present for models 1 through 6 are shown in Figure 85. Model 4 (Base model with male M estimated at 0.29, growth fixed) had the second best fit followed by Model 1 (Base model). The worst fitting model was Model 3 with male survey selectivity fixed at the Somerton estimate. The estimation of male M (0.35) and growth improved the fit with the Somerton selectivity curve (Model 6),

however, Model 6 ranked 4th in fit. Model 2 (Base model with male Q fixed at 0.75) ranked 5th in fit. Model 7 likelihood values are not comparable to the other models as the fits to the study area data were removed. Model 7 was run to compare the use of priors on the parameters of the Somerton selectivity curve to using the study area data as an alternative survey (Model 1). The male Q for Model 7 was estimated at 0.95 compared to Model 1 male Q = 0.90. The 95% CI for maximum selectivity from Somerton (2010) was 0.55 to 0.95. The use of the study are data in the model in this case resulted in a lower Q value than using a prior.
Most of the differences in likelihood values by model were due to fit to the Bering sea survey length frequency data and the Bering sea survey biomass. Model 3 fit to Bering sea survey mature biomass was low for both male and female crab, except for male mature biomass from 2005 to 2009 where estimates were higher than other models and higher than the observed survey in 2008 and 2009 (Figures 70 and 71). Growth was estimated slightly lower for male and female crab in models 5 and 6 compared to models 1 through 4 where growth was fixed (Figures 86 and 87).

Model fits to the length frequency data in the study area were similar for all models. Fits for Models 1, 3 and 6 are shown in Figures 72, 73 and 74. The fit to mature biomass estimates in the study area by sex and model were best for models 5 and 6, however, fits were similar across models (Figure 75).

The CPT in March 2010 requested a likelihood profile on Q for Model 1. Male maximum survey selectivity was fixed at values from 0.5 to 1.0. The best total likelihood occurred at 0.90, with a slight increase in likelihood at 1.0 (Table 15 and Figure 76). Previous model sensitivity (without the 2009 study area data and other changes to the model) identified the best fit at Q=1.2. The increase in likelihood at Q=0.5 was 80 points, and at Q=0.75 about 12 points. Most of the change in fit with change in Q was due to changes in the likelihood for Bering sea survey length and biomass fits (Figure 69 and 70).

The SSC at its April 2010 meeting requested a likelihood profile on male natural mortality using Model 3 with M for females fixed at 0.23. Models were run for M = 0.2 to 0.5 by 0.05 increments (Table 16 and Figure 77). The best fit for Model 3 occurred at M=0.4. The change in likelihood from the best fit M=0.4 and M=0.23 with Model 3 was 221 in total likelihood. Most of the improvement in likelihood from lower to higher M is due to a better fit to the Bering sea survey length and biomass data. The use of the Somerton selectivity curve estimates more small crab relative to large crab than the survey data indicate with M=0.23. With a higher M the population has more small crab relative to large crab, resulting in a similar survey length frequency with lower selectivity for small crab. In general, models can obtain similar fits to survey data with various combinations of survey Q and M due to the interaction with the relative abundance by length or age of the population.

Future projections for Models 1 through 6 are presented later in the section on rebuilding analyses for comparison among models. Other rebuilding scenarios are included in the draft EA on ACL analysis.

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 and was applied to survey biomass estimates to calculate the 2008/09 fishery season retained catch of 26,560 t. 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 (230.4 million lbs of total mature biomass (TMB), 0.25*Bmsy), a minimum GHL of 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.

$$E = \begin{cases} \text{Bycatch only, Directed } E = 0, & \text{if } \dfrac{TMB}{averageTMB} < 0.25 \\[2ex] \dfrac{0.225 * \left[\dfrac{TMB}{averageTMB} - \alpha \right]}{(1-\alpha)} & \text{if } 0.25 < \dfrac{TMB}{averageTMB} < 1 \\[2ex] 0.225 & \text{if } TMB \geq averageTMB \end{cases} \quad (13)$$

Where, α = -0.35 and averageTMB = 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 legal males >=4.0-in (102 mm) CW plus a percentage of the estimated abundance of old shell legal males >=4.0-in 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 54).

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

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.

Biomass and catch projections based on $F_{REF} = F_{35\%}$ and Bref = $B_{35\%}$ were used to estimate the catch OFL. Projections at other harvest strategies were used to evaluate rebuilding probabilities and to provide catch projections with a buffer below the OFL to reduce the probability of overfishing, given uncertainty in current biomass and reference points. F35% for Model 1 was estimated at 0.68, lower than in 2009 (0.703). B35% was estimated at 139,200 t, lower than in 2009 (148,200 t).

B35% was estimated using average recruitment from1978 to 2009 and mature male biomass per recruit fishing at F35%.

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 2009 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 2009 mature male biomass projected forward to the time of mating time (Feb. 2010), 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 23).

Rebuilding Analyses

The Eastern Bering Sea snow crab stock has failed to make adequate progress toward rebuilding in the required 10 year time period established in the rebuilding plan. The mature male biomass at mating (MMB) would have needed to be above the B35% level in 2008/09 and again in 2009/10 to be declared rebuilt within the 10 year limit (Figure 67). MMB in 2008/09 (97,300 t) was below B35% (149,200 t) and the projected MMB in 2009/10 taking the estimated total catch resulting from a TAC of 21,780 t is currently projected to be below B35% at 102,170 t (73.4% of B35%) (Table 8a and Figure 80).

NMFS' National Standard One Guidelines (NSG1), adopted pursuant to the Magnuson Stevens Act (MSA) state that if a stock fails to rebuild in the specified time period then the default maximum fishing mortality threshold (MFMT) should be continued at the rebuilding strategy or 75% MFMT whichever is less. In the case of snow crab the 75% MFMT strategy is less than the existing rebuilding strategy and represents the highest harvest rate that can be considered. However, if an existing rebuilding plan has failed to make adequate progress to rebuild the stock within the prescribed time frame, NMFS should recommend further conservation and management measures which the Council should consider to achieve adequate progress.

When a stock is declared overfished, MSA (Section 304(e)(4)) states that the rebuilding plan must "(A) specify a time period for ending overfishing and rebuilding the fishery that shall—
(i) be as short as possible, taking into account the status and biology of any overfished
stocks of fish, the needs of fishing communities, recommendations by international organizations in which the United States participates, and the interaction of the
overfished stock of fish within the marine ecosystem;"

Analysts will work with the NPFMC, NMFS Alaska Region and the State to revise the rebuilding plan for snow crab. In the interim period, the authors recommend that the NPFMC and ADF&G apply conservative harvest strategies. History shows that crab stocks are vulnerable to sustained periods of low production. Tanner and king crab stocks in the GOA have not recovered even after more than 25 years of no directed fishing. This failure to rebuild implies some level of depensation where low biomass levels result in the inability of the stock to produce recruitment at precollapse levels. Orensanz, et al. 1998 hypothesized that GOA crab stocks may have experienced serial depletion from fishing at unsustainable levels. The historical performance of the collapsed GOA crab stocks reveals persistently poor recruitment and an inability to rebuild even under fishing moratoria in instances where stock biomass declines to critical biomass levels. King, Tanner and snow crab stocks have relatively low reproductive output, slow growth, slow maturity, and with unique reproductive features (e.g., size dependencies for successful copulation, spatial distribution requirements and recruitment mechanisms) which could slow recovery when biomass falls below some critical level. Future recruitment may depend on current mature male biomass levels and spatial distribution of mature males relative to mature females which is effected by fishing.

Rebuilding Results by Model Scenario

A full suite of rebuilding scenarios for select models with various multipiers on F35% is presented in the Draft EA on ACLs for BSAI crab stocks. Rebuilding projections for 75% F35% control rule without the ADFG harvest strategy only for each model scenario is presented here for comparison among models. F35% increases from 0.680 for Model 1 to 2.765 for Model 6. B35% is highest for Model 3 (181,400 t) and lowest for Model 4 (126,300 t) (Table 7). Median MMB at mating is below B35% in 2009/10 for all models except Model 3 and 6 (Tables 8a through 8f and Figures 78 through 81). MMB at mating falls below B35% in 2010/11 for Model 6 fishing at 75 % F35% control rule (Figure 80). Model 3 remains above B35% resulting in rebuilding in 2010/11. Rebuilding to above 50% probability (2 years in a row) occurs in 2016/17 (Model 1), 2015/16 (Model 2), 2015/16 (Model 4), 2015/16 (Model 5) and in 2014/15 (Model 6) (Figure 81). Retained catches were highest and quite variable for Models 3 and 6 (Figure 78). Retained catches declined from 2010/11 to 2012/13 for all model scenarios. Models 3 and 6 retained catches in 2010/11 were estimated at 66,000 to 67,800 t, while Model 1 was 18,200 t, Model 2 26,900 t, Model 4 26,200 t and Model 5 29,200 t. The TAC for 2009/10 (retained catch only) was 21,800 t.

All values presented for MMB and catch are median values from 1000 simulation runs. The September 2009 assessment presented mean values from projection runs. The mean retained catches from 75%F35% control rule rebuilding projections from the September 2009 assessment were higher than for Model 1 until after 2014/15 when Model 1 estimates higher mean retained catch. Mean MMB was lower for Model 1 than the September 2009 projected MMB. The differences in MMB and retained catches are mainly due to the change in observed survey data that indicate a future declining trend.

The following table compares retained catches, Percent MMB/B35%, full selection fishing mortality and exploitation rate on mature male biomass for 2010/11 fishing at 75% F35% control rule.

Model	Retained catch	Percent MMB/B35%	F	exp rate
1	18.2	72.8	0.34	0.17
2	26.9	82.6	0.43	0.20
3	67.8	113.6	0.69	0.27
4	26.2	77.6	0.54	0.23
5	29.2	77.4	0.69	0.24
6	66.0	85.9	1.68	0.38

In their deliberations on conservation measures for the Bering Sea walleye pollock stock, the SSC recently identified the spawning exploitation rate as a metric to consider. The exploitation rates on MMB for snow crab from the period of reduced catches for rebuilding (1999/2000 to 2008/09) ranged from 0.12 to 0.29 with an average of 0.174. Fishing mortality estimates during 1999 to 2008 ranged from 0.26 to 0.73 with an average of 0.428.

Conservation concerns

- The Bering Sea snow crab stock has failed to rebuild in the required 10 year time period. MMB was estimated at 70% of B35% in 2008/2009.

- Some years of near average recruitment have occurred during the rebuilding period, however, in general recruitment has been below average.

- 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. Additional sampling of crabs that are close to molting is needed to estimate growth for immature males and females.

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 2008-2010.

Literature Cited

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

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

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

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

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

Fu, C. H., and T. J. Quinn II, 2000. Estimability of natural mortality and other population parameters in a length-based model: *Pandalus borealis* in Kachemak Bay, Alaska. Can. J. Fish. Aquat. Sci. 57: 2420–2432.

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

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

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

McMullen, J.C. and H.T. Yoshihara. 1969. Fate of unfertilized eggs in king crabs *Paralithodes camtschatica (Tilesius)*. Department of Fish and Game. Informational Leaflet 127. INPFC document no. 1151. 14pp.

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

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

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

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

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

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

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

Paul, A.J. and J.M. Paul. 1995. Molting of functionally mature male *Chionoecetes bairdi* Rathbun (Decapoda: Majidae) and changes in carapace and chela measurements. Journal of Crustacean Biology 15:686-692.

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

Press, W.H., S.A. Teukolsky, W.T.Vetterling, B.P. Flannery. 1992. Numerical Recipes in C. Second Ed. Cambridge Univ. Press. 994 p.

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

Rugolo, L.J., R.A. MacIntosh, C.E. Armisted, J.A. Haaga and R.S. Otto. 2003. Report to industry on the 2003 Eastern Bering Sea crab survey. AFSC Processed Report 2003-11.

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

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

Schnute, J. and L. Richards. 1995. The influence of error on population estimates from catch-age models. Can. J. Fish. Aquat. Sci. 52: 2063-2077.

Shirley, T.C. 1998. Appendix D: Crab handling mortality and bycatch reduction. In: King and Tanner crab research in Alaska: Annual report for July 1, 1997 through June 30, 1998. Alaska Department of Fish and Game Regional Information Report No. 5J98-07.

Somerton, D.A. and R.S. Otto. 1999. Net effeciency of a survey trawl for snow crab, *Chionoecetes opilio*, and Tanner crab, *C. Bairdi*. Fish.Bull. 97:617-625.

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

Turnock, B.J. and L.J. Rugolo. 2007. Eastern Bering sea snow crab stock assessment. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Turnock, B.J. and L.J. Rugolo. 2008. Eastern Bering sea snow crab stock assessment. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

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

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

Zhou, S. and G.H. Kruse. 1998. Appendix C: Crab handling mortality and bycatch reduction. In: King and Tanner Crab research in Alaska: Annual Report for July 1, 1997 through June 30, 1998. Alaska Department of Fish and Game Regional Information Report No. 5J98-07.

Table 1. Catch (1,000 t) for the snow crab pot fishery and groundfish trawl bycatch. Retained catch for 1973 to 1981 contain Japanese directed fishing. Observed discarded catch is the total estimate of discards before applying mortality. Discards from 1992 to 2008/9 were estimated from observer data. Model estimates of male discard include a 50% mortality of discarded crab.

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)	Model estimate of male discard(50% mort) (1000 t)	Model estimate Discard female catch (1000 t)	Model estimate total directed catch (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	3.04						1973	13.63		
1974	2.28						1974	18.87		
1975	3.74						1975	7.30		
1976	4.56						1976	3.16		
1977	7.39						1977	2.14		
1978-79	23.72			2.11	0.07	25.90	1978	2.46		
1979-80	34.04			3.45	0.08	37.57	1979	1.98		
1980-81	30.37			6.69	0.07	37.13	1980	1.44	17.9-41.3	
1982	13.32			5.02	0.05	18.40	1981	0.60	7.3-10.0	
1983	11.85			2.53	0.06	14.45	1982	0.24	7.17	
1984	12.17			1.23	0.05	13.45	1983	0.31	22.23	
1985	29.95			2.39	0.05	32.39	1984	0.33	44.46	
1986	44.46			3.50	0.05	48.01	1985	0.29	25.86	
1987	46.24			5.24	0.08	51.56	1986	1.23	25.59	
1988	61.41			12.18	0.11	73.70	1987	0.00	50.23	
1989	67.81			16.16	0.12	84.09	1988	0.44	59.89	
1990	73.42			16.15	0.15	89.72	1989	0.51	63.43	
1991	149.11			27.65	0.16	176.92	1990	0.39	142.92	
1992	143.06	43.65	186.71	34.40	0.18	177.64	1991	1.95	151.09	
1993	104.71	56.65	161.37	28.00	0.35	133.06	1992	1.84	94.01	
1994	67.96	17.66	85.62	9.64	0.24	77.84	1993	1.81	48.00	
1995	34.14	13.36	47.50	6.97	0.18	41.30	1994	3.55	25.27	

1996	29.82	19.10	48.92	9.76	0.07	39.65	1995	1.35	23.00	
1997	54.24	24.68	78.92	10.08	0.22	64.53	1996	0.93	53.09	
1998	110.41	19.05	129.46	11.51	0.05	121.97	1997	1.50	102.50	
1999	88.02	15.50	103.52	8.06	0.05	96.14	1998	1.02	84.48	
2000	15.20	1.72	16.92	1.41	0.04	16.65	1999	0.61	12.93	
2001	11.46	2.06	13.52	1.12	0.04	12.62	2000	0.53	12.39	
2002	14.85	6.27	21.12	2.04	0.04	16.92	2001	0.39	13.97	
2003	12.84	4.51	17.35	2.02	0.04	14.91	2002	0.23	11.62	
2004	10.86	1.90	12.77	1.22	0.04	12.12	2003	0.76	9.44	
2004/2005	11.29	1.69	12.98	0.95	0.04	12.28	2004	0.96	9.48	
2005/2006	16.78	4.52	21.30	1.71	0.04	18.52	2005	0.37	16.74	
2006/2007	16.50	5.90	22.39	2.44	0.03	18.97	2006	0.84	16.42	
2007/2008	28.60	8.42	37.02	4.37	0.05	33.02	2007	0.44	28.58	
2008/2009	26.56	6.86	33.42	3.16	0.05	29.77	2008	0.30	26.59	35.07

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	Observed survey male mature biomass	Observed survey total mature biomass	Observed number of males > 101mm (millions)
1978	153.0	193.1	346.2	163.4
1979	323.7	240.3	564.1	169.1
1980	364.9	193.8	558.7	133.9
1981	195.9	107.7	303.6	40.7
1982	213.3	173.1	386.4	60.9
1983	125.4	146.0	271.5	65.2
1984	70.4	161.2	231.5	139.9
1985	12.5	69.6	82.1	71.5
1986	47.7	87.3	135.1	77.1
1987	294.7	192.1	486.8	130.5
1988	276.9	251.6	528.5	170.2
1989	427.3	299.1	726.4	162.4
1990	312.1	442.4	754.5	389.6
1991	379.2	430.5	809.6	418.8
1992	242.4	238.5	480.9	232.5
1993	237.3	178.3	415.6	124.4
1994	216.8	163.6	380.4	71.2
1995	257.0	209.5	466.5	63.0
1996	161.7	281.7	443.4	154.8
1997	157.5	319.9	477.4	280.2
1998	124.3	201.1	325.4	208.4
1999	51.4	89.5	140.9	82.1
2000	152.4	88.9	241.3	65.7
2001	131.4	129.2	260.6	67.6
2002	50.5	90.2	140.8	63.1
2003	74.2	73.0	147.3	52.3
2004	84.5	75.8	160.3	56.0
2005	158.2	119.5	277.7	61.5
2006	109.6	134.5	244.2	118.7
2007	121.4	147.3	268.7	124.1
2008	86.4	121.6	208.0	97.7
2009	103.8	141.3	245.0	125.9

Table 3. Abundance estimates of females and males by size groups for the BSFRF net in the study area, the NMFS net in the study area, and the NMFS survey of the entire Bering Sea. Mature abundance uses a maturity curve.

		Females			Males	
	>25mm	>50mm	mature	>25mm	mature	>100
BSFRFStudy	585.3	113.6	129.4	422.9	200.9	66.9
NMFS Study	150.2	121.5	120.5	119.2	76.9	36.7
NMFS Bering Sea	1773.5	828.7	1,143.9	1,225.0	463.8	147.2

Table 4. Model estimates of population biomass (1000t), population numbers, male, female and total mature biomass(1000t) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs.

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)	Recruitment (millions, 25 mm to 50 mm)	Male mature biomass at mating time(Feb of survey year+1) (1000t)	Ratio mature females to mature males at mating time	Full selection fishing mortality	Exp.rate of total male catch on mature male biomass
1978	441.9	5,850	142.3	181.8	324.1	150.1	*	123.9	3.4	0.37	0.19
1979	444.6	5,790	159.5	152.8	312.3	117.1	595.6	86.8	4.6	0.83	0.31
1980	450.0	5,605	186.9	112.9	299.8	67.4	536.8	58.6	5.7	1.83	0.39
1981	462.3	5,099	199.2	100.8	300.0	46.1	361.9	68.8	5.1	0.91	0.21
1982	487.3	4,313	189.2	151.5	340.7	110.4	153.3	113.7	3.8	0.28	0.11
1983	519.0	4,669	168.4	223.8	392.2	216.3	636.1	173.2	2.8	0.14	0.07
1984	546.8	5,583	155.9	253.4	409.3	261.0	949.3	175.6	2.6	0.30	0.16
1985	571.1	6,664	159.9	238.5	398.4	240.8	1142.9	155.3	2.9	0.51	0.25
1986	667.4	9,964	178.0	206.5	384.5	185.1	2375.1	125.5	3.2	0.75	0.31
1987	735.3	8,363	227.6	207.3	434.9	161.9	270.1	114.7	3.6	1.36	0.40
1988	874.7	11,297	248.1	237.7	485.8	177.5	2396.5	129.2	3.3	1.44	0.40
1989	940.1	9,263	282.5	296.1	578.6	231.9	230.3	178.2	3.1	1.03	0.35
1990	957.1	7,591	285.8	384.9	670.7	345.6	203.9	170.7	3.1	1.83	0.52
1991	811.3	6,072	261.9	335.7	597.7	276.2	191.7	131.1	3.2	2.80	0.56
1992	736.5	9,424	224.3	265.5	489.8	204.6	2480.3	120.4	3.2	2.44	0.51
1993	692.3	9,246	239.3	222.0	461.3	172.8	1015.6	120.6	3.4	1.48	0.40
1994	687.4	7,846	264.1	177.2	441.3	98.6	321.5	115.1	3.6	1.16	0.27
1995	717.0	6,387	262.8	199.3	462.1	105.1	121.4	142.8	3.2	0.83	0.21
1996	733.8	5,095	234.1	308.4	542.5	257.9	52.9	212.2	2.5	0.60	0.23
1997	666.1	4,059	195.7	381.4	577.1	385.1	67.4	212.3	2.3	0.94	0.37
1998	488.5	3,644	160.2	279.4	439.7	265.0	316.5	148.7	2.5	1.11	0.41
1999	353.6	3,505	136.4	167.3	303.8	130.7	385.3	128.4	2.5	0.29	0.12
2000	314.0	3,014	124.0	136.0	260.0	101.0	129.2	100.8	2.7	0.30	0.12
2001	287.6	2,566	112.4	116.2	228.6	80.7	97.4	84.3	2.8	0.50	0.18
2002	271.2	2,450	98.7	111.0	209.7	80.5	221.2	82.5	2.6	0.42	0.16
2003	275.2	2,977	87.5	119.4	206.9	101.5	528.8	91.8	2.4	0.27	0.12
2004	288.5	3,392	86.9	120.5	207.3	108.7	524.9	91.9	2.5	0.26	0.12
2005	297.2	3,112	93.6	112.8	206.4	96.3	219.5	79.8	2.7	0.46	0.19
2006	315.3	3,289	95.6	111.7	207.3	89.2	424.3	79.1	2.7	0.50	0.20
2007	324.3	2,723	96.3	131.9	228.2	114.5	72.6	84.8	2.6	0.73	0.29
2008	311.9	2,518	90.1	144.0	234.1	133.7	207.5	97.3	2.4	0.55	0.24
2009	305.3	2,966	82.6	143.5	226.1	136.1	508.9				

*** Numbers by length estimated in the first year, so recruitment estimates start in second year.**

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. Reference points and parameters used in rebuilding projections for Models 1 through 6.

Model	F35%	B35%	Steepness	R0	sigma R	cv extra	cv within
1	0.680	139.2	0.708	726,327	1.110	0.2	0.085
2	0.739	148.0	0.715	780,988	1.075	0.2	0.060
3	0.943	181.4	0.742	1,002,250	1.098	0.2	0.056
4	0.983	126.3	0.726	1,090,710	1.088	0.2	0.056
5	1.278	128.8	0.744	1,196,960	1.110	0.2	0.088
6	2.765	140.1	0.951	1,818,180	1.060	0.2	0.059

Tables 8a-f. Projections using Models 1 through 6 with 75% F35% control rule for 2010/11 to 2018/19 fishery seasons. Retained catch in 2009/10 was fixed at the TAC. Median ABC (total catch 1000t), median retained catch (1000 t), Percent mature male biomass at time of mating relative to B35%, probability of rebuilding in 1 year and probability of rebuilding to 2 years in a row. 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.

Table 8a. Model 1 75% F35% control rule.

				prob	prob		
	ABC	Retained	Percent MMB/Bmsy	reb 1 yr	reb 2 yr	F	Exp. rate
2009/10	24.2(24.2,24.3)	21.8(21.8,21.8)	73.4(61.1,85.8)	0	0	0.41	0.19
2010/11	20.2(11.1,34.2)	18.2(9.9,31)	72.8(61,84.7)	0	0	0.34	0.17
2011/12	18(10,30.2)	16.3(8.9,27.2)	70.2(58.3,82.3)	0	0	0.33	0.16
2012/13	16.5(8.9,29.1)	14.4(7.7,25.5)	70.7(57.7,86.2)	0.004	0	0.32	0.14
2013/14	24(12.1,40)	20.8(10.5,34.4)	81.7(62.7,113.5)	0.136	0.004	0.39	0.17
2014/15	33.6(15.8,69.4)	29.8(14.2,59.9)	95.9(65.5,166.9)	0.428	0.136	0.44	0.20
2015/16	41(14.8,95.5)	36.1(13.3,86.4)	104.2(64.3,216.5)	0.551	0.419	0.45	0.22
2016/17	42.1(12.8,102.8)	37.4(11.5,92.9)	108.1(60.3,241.4)	0.617	0.526	0.46	0.22
2017/18	42.9(11,105.9)	38.2(9.7,96.6)	111.3(57.5,249.9)	0.675	0.588	0.45	0.22
2018/19	43.7(10.4,111.5)	38.8(9.3,101.4)	116.9(54.9,264.4)	0.729	0.646	0.45	0.21

Table 8b. Model 2 75% F35% control rule.

				prob	prob		
	ABC	Retained	MMB/Bmsy	reb 1 yr	reb 2 yr	F	Exp. rate
2009/10	24.2(24.2,24.3)	21.8(21.8,21.8)	89.5(79.2,99.5)	0.039	0	0.33	0.15
2010/11	29.7(18.5,46)	26.9(16.7,41.7)	82.6(71.3,93.2)	0.039	0.002	0.43	0.20
2011/12	23.8(14.2,37.4)	21.5(12.8,33.8)	76.9(64.4,88.9)	0.04	0.002	0.4	0.17
2012/13	21(12.2,34.4)	18.2(10.5,29.8)	76.7(63.1,93.4)	0.055	0.003	0.39	0.16
2013/14	30.1(16,46.2)	25.9(13.9,38.9)	88.2(68.1,125.4)	0.257	0.02	0.46	0.19
2014/15	41.6(20.3,81.7)	36.5(18.2,69.3)	103.9(71,182.9)	0.582	0.233	0.5	0.21
2015/16	48.7(18.6,114)	42.8(16.8,100.5)	113.3(69.3,238.9)	0.674	0.552	0.51	0.23
2016/17	50.1(16.4,120.1)	44.2(14.7,108.4)	117.6(65.1,262.6)	0.719	0.638	0.51	0.22
2017/18	50.2(14.1,124.3)	44.6(12.5,112.9)	120.8(62.6,271.1)	0.766	0.684	0.5	0.22
2018/19	51.1(13.2,130.5)	45.1(11.7,116.1)	127(59,283.6)	0.805	0.729	0.5	0.21

Table 8c. Model 3 75% F35% control rule

				prob	prob		
	ABC	Retained	MMB/Bmsy	reb 1 yr	reb 2 yr	F	Exp. Rate
2009/10	24.3(24.3,24.4)	21.8(21.8,21.8)	132.8(118.7,146.5)	1	0	0.2	0.09
2010/11	74.8(52.9,94)	67.8(48,85)	114.2(100.1,128.6)	1	0.953	0.69	0.27
2011/12	58.4(38,73)	52.1(34.1,64.9)	106(91.2,123.9)	1	0.953	0.69	0.23
2012/13	51.8(33.3,66.4)	43.7(28.6,55.5)	110.2(91.6,136.4)	1	0.955	0.68	0.21
2013/14	66.8(44.5,88.8)	56.8(38.6,74)	127.4(99.7,188)	1	0.978	0.68	0.23
2014/15	78.3(49.8,146)	68.8(44.5,124.8)	141.1(97.2,248.4)	1	0.991	0.69	0.24
2015/16	79.8(37.7,187.1)	69.9(33.7,164.8)	144.8(87.2,305.2)	1	0.995	0.68	0.23
2016/17	77.1(29,192.5)	67.1(25.6,169.4)	143.5(77.7,319)	1	0.995	0.68	0.23
2017/18	74.3(23.1,188.2)	65.1(20.4,167.3)	144.5(71.7,319.2)	1	0.996	0.67	0.22
2018/19	75(20.6,193.4)	65(18,170.5)	148.5(68.8,334.7)	1	0.996	0.66	0.22

Table 8d. Model 4 75% F35% control rule

				prob	prob		
	ABC	Retained	MMB/Bmsy	reb 1 yr	reb 2 yr	F	Exp. Rate
2009/10	24.2(24.2,24.3)	21.8(21.8,21.8)	88.5(73,104.3)	0.111	0	0.4	0.18
2010/11	29(16.4,46.8)	26.2(14.7,42.4)	77.6(63.9,91.8)	0.111	0.004	0.54	0.23
2011/12	21.5(12.5,34.4)	19.3(11.2,30.9)	71.4(57.9,85.8)	0.112	0.004	0.49	0.19
2012/13	19.6(10.9,33.1)	16.8(9.3,27.8)	73.9(58.4,95.3)	0.139	0.005	0.49	0.17
2013/14	31.1(15.3,50)	26.2(13.3,40.4)	88.6(64.9,143.5)	0.348	0.037	0.62	0.22
2014/15	45.6(20.3,98.2)	39.4(18,82.1)	107.8(67.9,208.8)	0.63	0.288	0.67	0.25
2015/16	54.3(19.1,137.1)	47.4(17.2,119.8)	119.4(66.8,274.2)	0.713	0.579	0.67	0.26
2016/17	55.3(16.7,143.5)	48.6(15,127.6)	123.1(63.4,289.3)	0.759	0.658	0.68	0.26
2017/18	54.4(14.4,138.9)	47.3(12.9,124.2)	126(59.1,291.4)	0.801	0.707	0.66	0.25
2018/19	54.9(13.1,144.6)	48.5(11.5,128.8)	129.7(57.4,305.8)	0.831	0.754	0.67	0.25

Table 8e. Model 5 75% F35% control rule

				prob	prob		
	ABC	Retained	MMB/Bmsy	reb 1 yr	reb 2 yr	F	exp rate
2009/10	24.1(24.1,24.1)	21.8(21.8,21.8)	91.2(76,106.7)	0.181	0	0.45	0.17
2010/11	32.1(18.5,50.5)	29.2(16.7,45.9)	77.4(63.9,91)	0.181	0.002	0.69	0.24
2011/12	22.8(13.6,35.6)	20.6(12.2,31.8)	70.5(57.6,84.6)	0.182	0.002	0.63	0.20
2012/13	19.5(11,32.5)	16.7(9.4,26.9)	72.3(57.4,95.2)	0.207	0.003	0.63	0.17
2013/14	28.9(14.5,46.4)	24(12.4,36.8)	85.8(62.9,140.6)	0.377	0.035	0.78	0.21
2014/15	45.1(20.8,95.5)	38.4(18.3,78.3)	105.7(67.3,206.5)	0.643	0.257	0.86	0.25
2015/16	57.9(21.5,145)	49.9(19.2,128.1)	119.9(67.3,277.4)	0.739	0.567	0.87	0.27
2016/17	60.8(19.2,159.2)	53.2(17.1,141.2)	126.2(64.2,298)	0.784	0.659	0.89	0.27
2017/18	59.6(16.7,158.1)	51.8(14.6,141)	128.6(60.8,297.3)	0.814	0.71	0.87	0.26
2018/19	59.5(14.4,158.1)	52(13.1,140.5)	133.1(58.9,312.4)	0.839	0.754	0.87	0.26

Table 8f. Model 6 75% F35% control rule

				prob	prob		
	ABC	Retained	MMB/Bmsy	reb 1 yr	reb 2 yr	F	exp rate
2009/10	24.2(24.1,24.2)	21.8(21.8,21.8)	124.6(111,137.8)	1	0	0.37	0.12
2010/11	73.4(51.8,96.8)	66(46.8,86)	85.9(71.8,100.3)	1	0.056	1.68	0.38
2011/12	41(27.6,56.1)	35.2(23.6,47.8)	80.4(66.8,99.9)	1	0.056	1.59	0.27
2012/13	37.2(23.4,50.4)	28.4(18.8,38)	91.7(70.5,145.1)	1	0.089	1.77	0.22
2013/14	57(33.1,86.6)	42.9(26.9,59.8)	115.1(77.7,227.4)	1	0.369	1.95	0.26
2014/15	85.2(43,198.7)	68(36.5,151.4)	140.6(80.7,314.5)	1	0.701	1.97	0.30
2015/16	105.9(42.7,281.6)	87.4(36.5,232)	153.2(77.9,368.9)	1	0.801	1.97	0.33
2016/17	104.3(36,279.8)	86.7(30.3,239.9)	154.5(72.6,366.7)	1	0.84	1.98	0.33
2017/18	96.5(29.1,249.4)	79.2(25.2,210)	156(68.3,357.7)	1	0.871	1.95	0.31
2018/19	92.6(25.5,245.5)	75.5(21.3,206.2)	156.7(67.7,359.3)	1	0.884	1.94	0.30

Table 9. Parameters values for the base model (Model 1), excluding recruitments, probability of maturing and fishing mortality parameters.

Parameter	Value	Estimated(Y/N)
Natural Mortality immature both sexes and mature males	0.23	N
Female intercept (a) growth	6.773	N
Male intercept(a) growth	6.773	N
Female slope(b) growth	1.05	N
Male slope (b) growth	1.16	N
Alpha for gamma distribution of recruits	11.5	N
Beta for gamma distribution of recruits	4.0	N
Beta for gamma distribution female growth	0.75	N
Beta for gamma distribution male growth	0.75	N
Fishery selectivity total males slope	0.162	Y
Fishery selectivity total males length at 50%	103.29	Y
Fishery selectivity retention curve males slope	0.33	Y
Fishery selectivity retention curve males length at 50%	96.27	Y
Pot Fishery discard selectivity female slope	0.216	Y
Pot Fishery discard selectivity female length at 50%	83.69	Y
Trawl Fishery selectivity slope	0.072	Y
Trawl Fishery selectivity length at 50%	115.0	Y
Survey Q 1978-1981 male (female)	1.0 (0.996)	Y
Survey 1978-1981 length at 95% of Q	56.7	Y
Survey 1978-1981 length at 50% of Q	37.5	Y
Survey Q 1982-1988 male (female)	0.886 (0.873)	Y
Survey 1982-1988 length at 95% of Q	62.1	Y
Survey 1982-1988 length at 50% of Q	39.36	Y
Survey Q 1989-present	0.90	Y
Survey 1989-present, length at 95% of Q	45.4	Y
Survey 1989-present length at 50% of Q	31.62	Y
Female Survey Q 1989-present	0.889	Y
Female Survey 1989-present, length at 95% of Q	50.25	Y
Female Survey 1989-present length at 50% of Q	32.09	Y
Male BSFRF Study area Q (availability)	0.439	Y
Male BSFRF Study area length at 95% of Q	72.16	Y
Male BSFRF Study are length at 50% of Q	61.69	Y

Table 9 cont.. Parameters values for the base model (Model 1), excluding recruitments, probability of maturing and fishing mortality parameters.

Male NMFS Study area Q	0.39	Y
Male NMFS Study area length at 95% of Q	115.0	Y
Male NMFS Study are length at 50% of Q	84.87	Y
Female BSFRF Study area Q (availability)	0.351	Y
Female BSFRF Study area length at 95% of Q	69.4	Y
Female BSFRF Study are length at 50% of Q	57.87	Y
NMFS Study area female Q	0.216	Y
Female NMFS Study area length at 95% of Q	58.12	Y
Female NMFS Study are length at 50% of Q	51.15	Y
Fishery cpue q	0.00104	Y

Table 10. 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 11. Model estimated recruitment deviations and mature male biomass at survey time with standard deviations.

Survey year	Recruit (male,millions)	S.D.	MMB at survey (1000 tons)	S.D.
1978	595.6	113.3	123.9	8.1
1979	536.8	105.7	86.8	5.7
1980	361.9	90.4	58.6	4.5
1981	153.3	65.7	68.8	5.2
1982	636.1	102.9	113.7	8.1
1983	949.3	140.7	173.3	11.5
1984	1142.9	170.4	175.6	12.2
1985	2375.1	177.4	155.3	11.9
1986	270.1	104.7	125.6	10.0
1987	2396.5	82.0	114.7	8.5
1988	230.3	56.3	129.2	8.6
1989	203.9	41.0	178.2	9.7
1990	191.7	38.1	170.7	7.7
1991	2480.3	115.4	131.1	6.0
1992	1015.6	92.2	120.4	5.8
1993	321.5	48.3	120.6	6.0
1994	121.4	29.8	115.1	6.1
1995	52.9	17.4	142.8	7.7
1996	67.4	22.7	212.2	10.7
1997	316.5	46.6	212.3	11.2
1998	385.3	47.8	148.7	9.6
1999	129.2	30.1	128.4	8.3
2000	97.4	27.3	100.8	6.8
2001	221.2	41.2	84.3	6.2
2002	528.8	62.6	82.5	6.1
2003	524.9	66.8	91.8	6.2
2004	219.5	55.6	91.9	6.0
2005	424.3	66.0	79.8	5.5
2006	72.6	27.3	79.1	5.6
2007	207.5	47.8	84.8	6.7
2008	508.9	104.5	97.3	8.6

Table 12. Model scenarios with changes from the September 2009 assessment model. All models contain “new” survey data.

Model Scenario	Description
1	New survey data, no extra weight on survey biomass, BSFRF 2009 survey data added (small crab <40 mm removed from length freqencies), logistic curves used for survey selectivity, separate survey selectivities males and females, probability of maturing estimated, all M=0.23,
2	Male survey Q fixed at 0.75, else same as Model 1.
3	Male survey selectivity for 1989-2009 fixed at the Somerton curve. Else same as Model 1.
4	Male M estimated with prior, else same as Model 1
5	Male M estimated with prior, Growth per molt parameters estimated with prior, else same as Model 1
6	Male M estimated with prior, Growth per molt parameters estimated with prior, else same as Model 3.
7	Model 1 except BSFRF 2009 survey data likelihoods removed and priors on 3 survey selectivity parameters from Somerton added.

Table 13. Model scenarios showing changes from September 2009 assessment model.

Model	new survey data	no extra weight survey biomass	BSFRF survey	Separate survey select. female	Prob. Mature estimated	Male M estimated	Growth per molt parameters estimated	Q fixed 0.75	male sel. Fixed Somerton
1	X	X	X	X	X				
2	X	X	X	X	X			X	
3	X	X	X	X	X			X	X
4	X	X	X	X	X	X			
5	X	X	X	X	X	X	X		
6	X	X	X	X	X	X	X	X	X
7	X	X		X	X				

Table 14. Likelihood values and selected parameter values for 7 model scenarios. AIC was calculated for Models 1 through 6. Model 7 has the 2009 study area data removed from the likelihood so is not comparable to other models.

Model No.	1	2	3	4	5	6	7
params	272	271	269	273	276	273	272
male Q	0.90	0.75	0.75	0.77	0.73	0.75	0.95
female Q	0.89	0.78	0.68	0.62	0.58	0.62	0.92
Male M	0.23	0.23	0.23	0.29	0.29	0.35	0.23
Growth a	6.773	6.773	6.773	6.773	7.93	7.95	6.773
female b	1.05	1.05	1.05	1.05	1.019	1.004	1.05
male b	1.16	1.16	1.16	1.16	1.122	1.118	1.16
Likelihood Component							
Recruitment	30.9	30.0	28.7	30.4	32.6	30.9	30.9
init numbers	3.0	3.1	2.8	2.9	2.8	2.6	3.1
	-	-	-	-	-	-	-
ret fishery length	1904.0	1896.7	1910.6	1910.2	1918.0	1925.1	1904.4
total fish length	688.5	689.7	692.6	687.0	682.6	685.0	687.9
female fish length	160.3	163.3	174.7	172.2	167.5	183.1	160.1
survey length	3375.9	3393.4	3544.4	3329.5	3316.4	3359.0	3377.7
trawl length	223.3	215.8	207.6	228.9	219.8	218.5	225.6
BSFRF length	-96.3	-96.4	-95.9	-96.9	-98.3	-98.1	0.0
NMFS study area length	-80.2	-81.2	-81.7	-80.7	-81.0	-81.2	0.0
M prior	0.0	0.0	0.0	13.2	13.6	47.5	0.0
maturity smooth	23.0	22.0	31.7	23.8	25.0	33.3	24.6
growth a	0.0	0.0	0.0	0.0	7.5	7.7	0.0
growth b	0.0	0.0	0.0	0.0	0.1	0.1	0.0
BSFRF biomass	1.9	0.7	0.6	0.7	0.5	0.3	0.0
NMFS study area biomass	3.5	1.5	1.3	1.3	0.7	0.5	0.0
fishery cpue	0.2	0.1	0.1	0.2	0.2	0.1	0.2
retained catch	3.6	3.7	4.1	3.7	2.9	3.0	3.5
discard catch	125.3	132.8	149.2	134.8	99.3	105.2	121.3
trawl catch	8.1	8.9	15.4	8.0	7.9	9.8	8.3
female discard catch	5.7	5.6	6.3	5.3	4.7	5.2	5.7
survey biomass	157.8	177.3	215.3	147.6	144.5	149.3	156.2
F penalty	50.8	51.0	56.0	51.4	53.4	55.7	50.2
init smooth	55.1	57.7	51.9	52.4	50.9	47.9	55.7
Smooth survey sel study area	0.0	0.0	0.0	0.0	0.0	0.0	0.0
init extra length like	536.7	539.3	534.4	536.3	537.3	537.3	537.0
prior on Somerton survey sel parameters	0.0	0.0	0.0	0.0	0.0	0.0	23.8
Total likelihood	3373.1	3421.7	3628.8	3341.7	3272.8	3377.5	3567.3
AIC (2k+2 Total Likelihood)	7290.2	7385.4	7795.7	7229.3	7097.6	7301.0	

Table 15. Likelihood values for the Base Model (Model 1) with Q for male survey selectivity fixed at 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0.

				Q			
Likelihood Component		0.5	0.6	0.7	0.8	0.9	1
Recruitment		28.3	29.1	29.7	30.4	30.9	31.3
init numbers		2.9	2.9	3.0	3.0	3.0	3.1
ret fishery length		-1910.8	-1909.0	-1907.3	-1905.5	-1904.0	-1902.2
total fish length		692.1	690.8	689.8	689.1	688.5	688.1
female fish length		168.2	165.6	163.4	161.7	160.3	159.2
survey length		3402.4	3391.3	3383.8	3379.0	3375.9	3375.2
trawl length		201.8	207.9	213.5	218.6	223.3	227.3
BSFRF length		-96.3	-96.2	-96.1	-96.4	-96.3	-96.3
NMFS study area length		-82.8	-82.9	-82.3	-80.5	-80.2	-79.8
M prior	0.0	0.0	0.0	0.0	0.0	0.0	0
maturity smooth		24.3	22.9	22.4	22.5	23.0	23.8
growth a	0.0	0.0	0.0	0.0	0.0	0.0	0
growth b	0.0	0.0	0.0	0.0	0.0	0.0	0
BSFRF biomass		0.19	0.16	0.67	0.90	1.89	3.05
NMFS study area biomass		0.06	0.34	1.36	1.83	3.50	5.36
fishery cpue		0.1	0.1	0.1	0.1	0.2	0.2
retained catch		3.8	3.7	3.7	3.6	3.6	3.6
discard catch		147.6	140.4	134.5	129.7	125.3	121.7
trawl catch		12.5	11.0	9.9	8.9	8.1	7.5
female discard catch		5.6	5.7	5.7	5.7	5.7	5.8
survey biomass		208.7	186.2	171.7	162.9	157.8	156.8
F penalty	56.6	54.1	52.3	51.3	50.8	50.7	50.7081
init smooth		52.1	53.0	53.8	54.5	55.1	55.9
smooth survey sel study area		0.0	0.0	0.0	0.0	0.0	0.0
init extra length like		536.0	536.2	536.4	536.6	536.7	536.9
prior on Somerton survey sel parameters		0.0	0.0	0.0	0.0	0.0	0.0
Total Likelihood	3453.3	3413.2	3390.1	3378.0	3373.1	3377.1	3377.144

Table 16. Likelihood values for the Model 3 (Male survey selectivity fixed at Somerton curve) with M for males fixed at 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5.

	Male M						
Likelihood Component	0.2	0.25	0.3	0.35	0.4	0.45	0.5
Recruitment	29.3	28.4	28.0	28.0	28.4	28.9	29.7
init numbers	2.8	2.8	2.7	2.6	2.6	2.6	2.5
ret fishery length	-1908.1	-1911.9	-1915.7	-1919.2	-1922.3	-1924.8	-1926.5
total fish length	693.9	691.9	690.3	689.1	688.3	687.8	687.7
female fish length	169.0	178.3	186.6	193.8	200.2	208.0	216.2
survey length	3609.9	3507.1	3431.8	3380.7	3352.1	3343.5	3353.1
trawl length	204.2	210.5	219.7	231.1	244.3	258.7	273.3
BSFRF length	-95.6	-96.1	-96.5	-96.8	-97.0	-97.2	-97.2
NMFS study area length	-81.7	-81.7	-81.8	-81.8	-81.8	-81.8	-81.7
M prior	0.0	0.0	0.0	0.0	0.0	0.0	0.0
maturity smooth	30.2	32.6	34.2	35.1	35.4	35.0	34.4
growth a	0.0	0.0	0.0	0.0	0.0	0.0	0.0
growth b	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BSFRF biomass	0.66	0.58	0.53	0.49	0.47	0.52	1.03
NMFS study area biomass	1.44	1.20	1.01	0.87	0.75	0.70	1.10
fishery cpue	0.1	0.1	0.1	0.1	0.1	0.1	0.2
retained catch	4.2	4.1	4.1	4.1	4.1	4.2	4.2
discard catch	149.6	149.1	149.4	150.3	151.8	153.6	154.4
trawl catch	17.3	14.3	12.1	10.5	9.4	8.6	8.2
female discard catch	6.6	6.2	5.7	5.2	4.7	4.4	4.1
survey biomass	238.2	202.8	178.0	159.9	146.8	137.0	132.3
F penalty	56.7	55.6	55.0	54.8	55.0	55.9	57.4
init smooth	52.7	51.5	50.3	48.9	47.4	46.2	45.3
smooth survey sel study area	0.0	0.0	0.0	0.0	0.0	0.0	0.0
init extra length like	534.4	534.5	534.6	535.3	536.7	538.7	541.2
prior on Somerton survey sel parameters	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Likelihood	3715.7	3581.9	3490.2	3433.3	3407.6	3410.8	3440.8

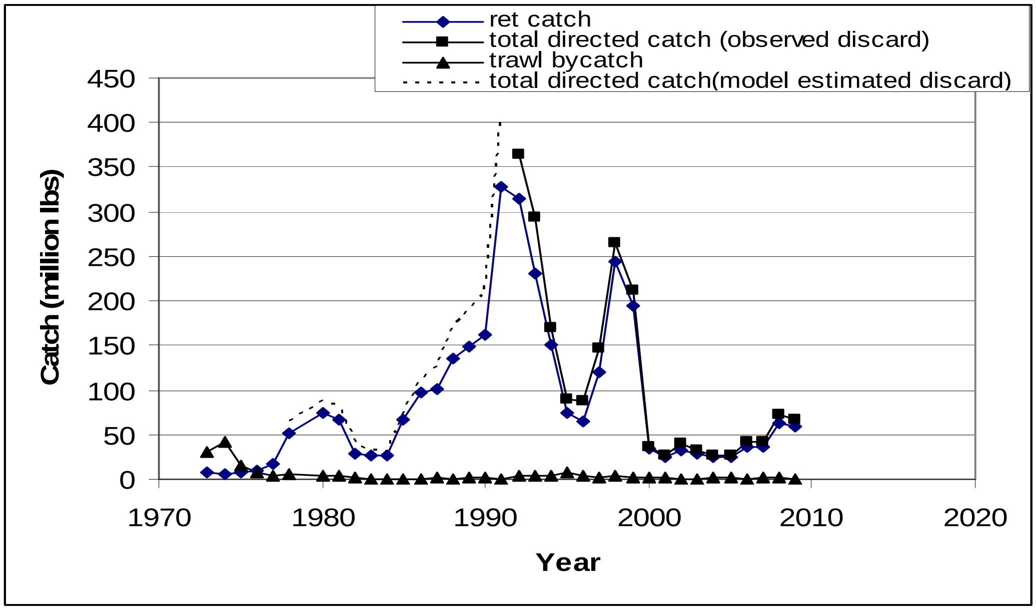


Figure 1. Catch (million lbs) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch is retained catch plus discarded catch after 50% discard mortality was applied. Discard catch was estimated from observer data 1992 to present. Discard for 1978 to 1991 was estimated from the model. Trawl bycatch is male and female bycatch from groundfish trawl fisheries with 80% mortality applied.

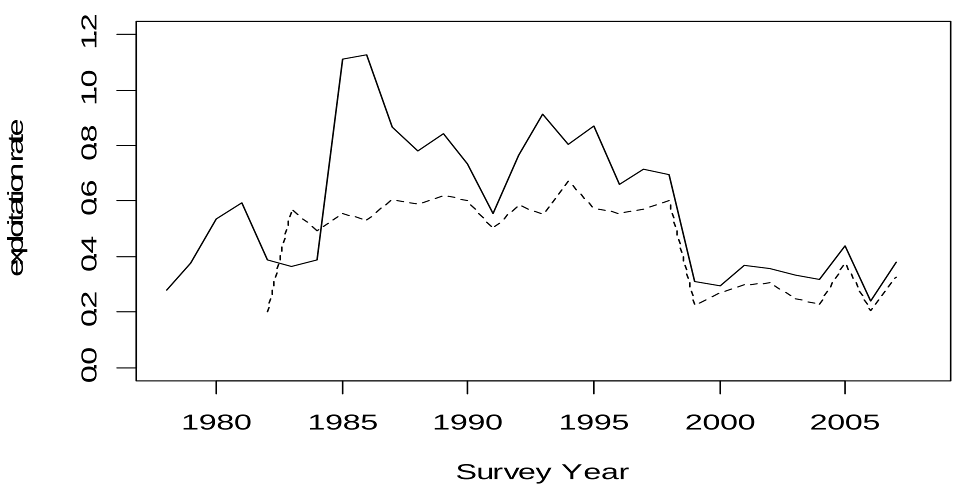


Figure 2. Exploitation rate estimated as the preseason GHL divided by the survey estimate of large male biomass (>101 mm) at the time the survey occurs (dotted line). The solid line is the retained catch divided by the survey estimate of large male biomass at the time the fishery occurs. Year is the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

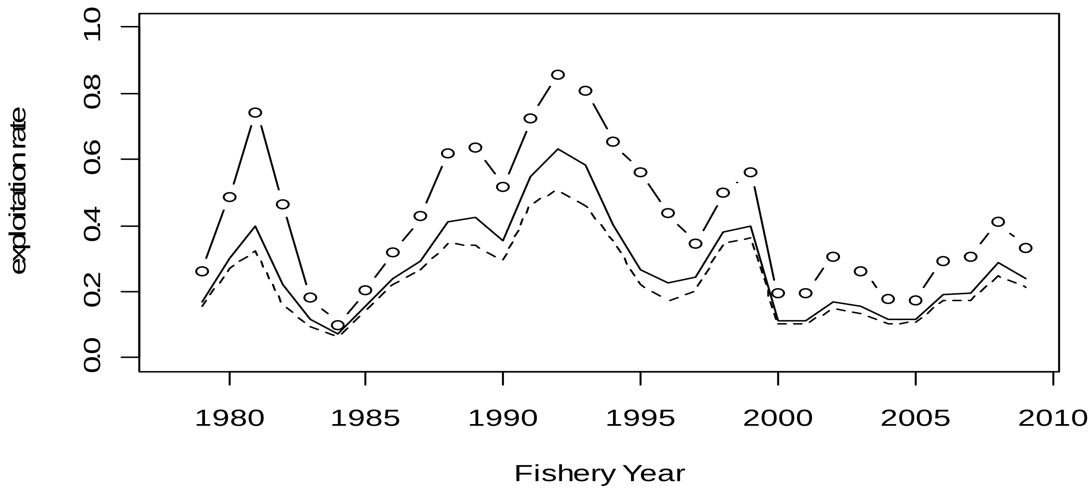


Figure 3. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line and dotted line). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the solid line with dots.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

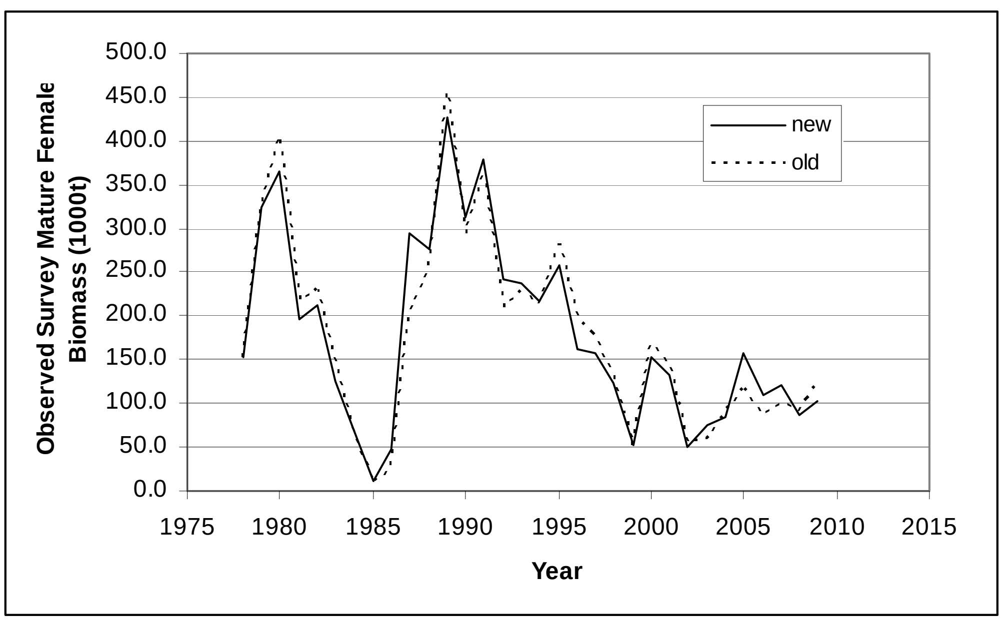


Figure 4. Observed survey mature female biomass from 1978 to 2009. New data uses actual measured net widths as well as other corrections to the database. Old data uses fixed 50 ft net width.

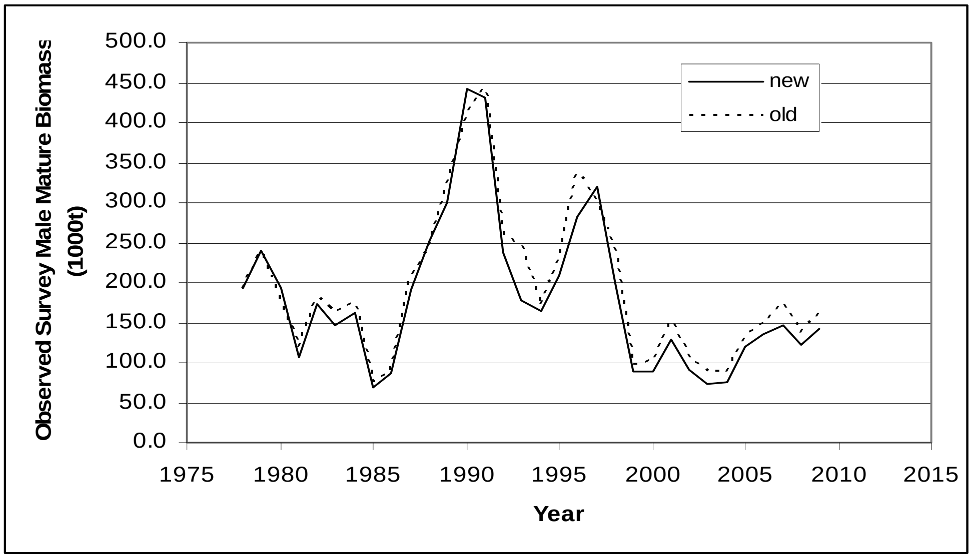


Figure 5. Observed survey mature male biomass from 1978 to 2009. New data uses actual measured net widths as well as other corrections to the database. Old data uses fixed 50 ft net width.

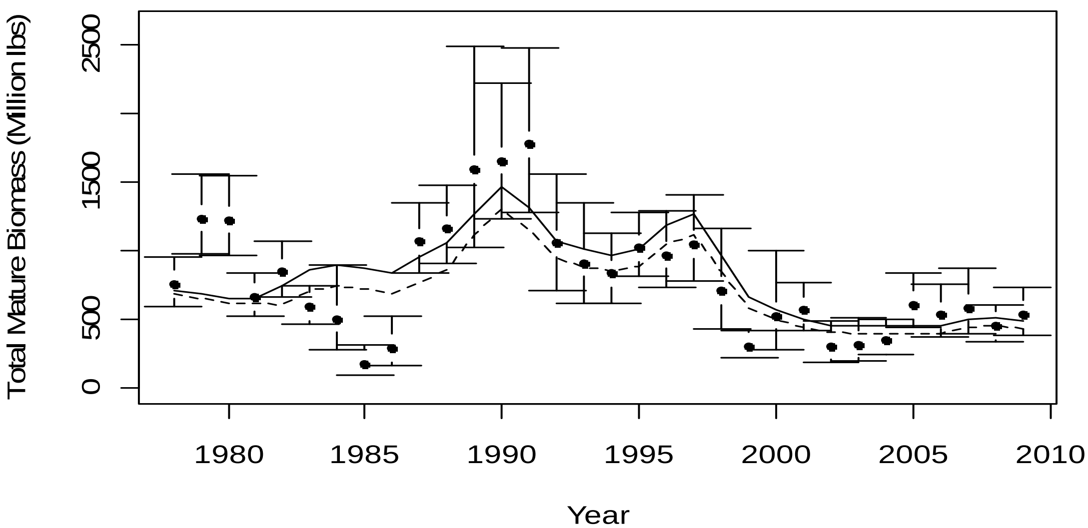


Figure 6. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

Figure 7. Standardized residuals for model fit to total mature biomass from Figure 2.

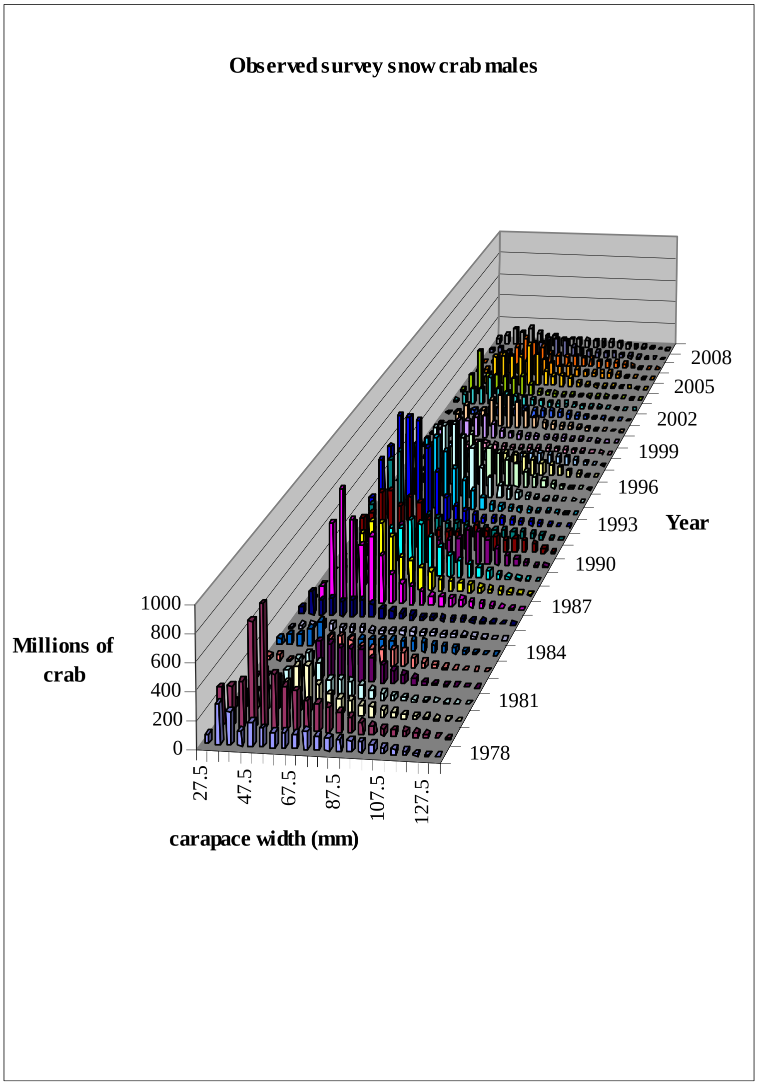


Figure 8. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

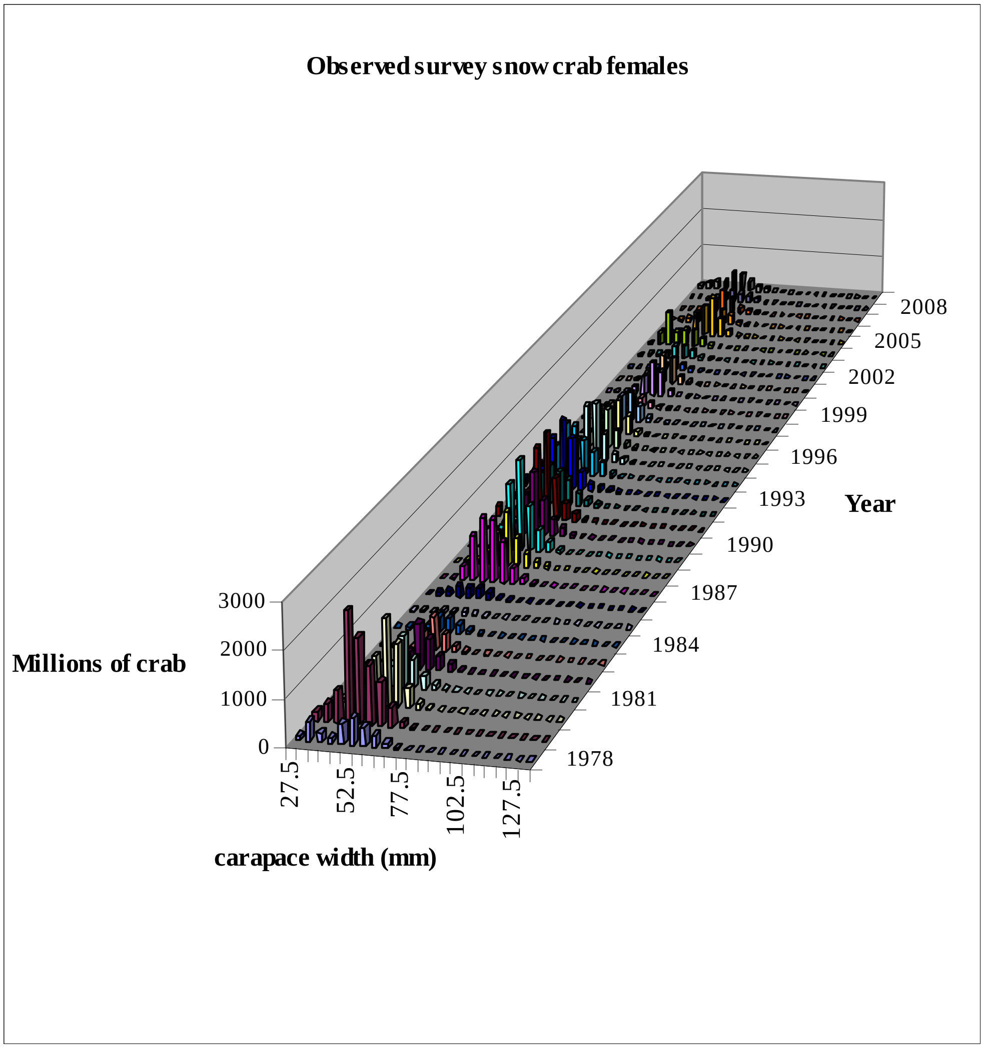


Figure 9. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

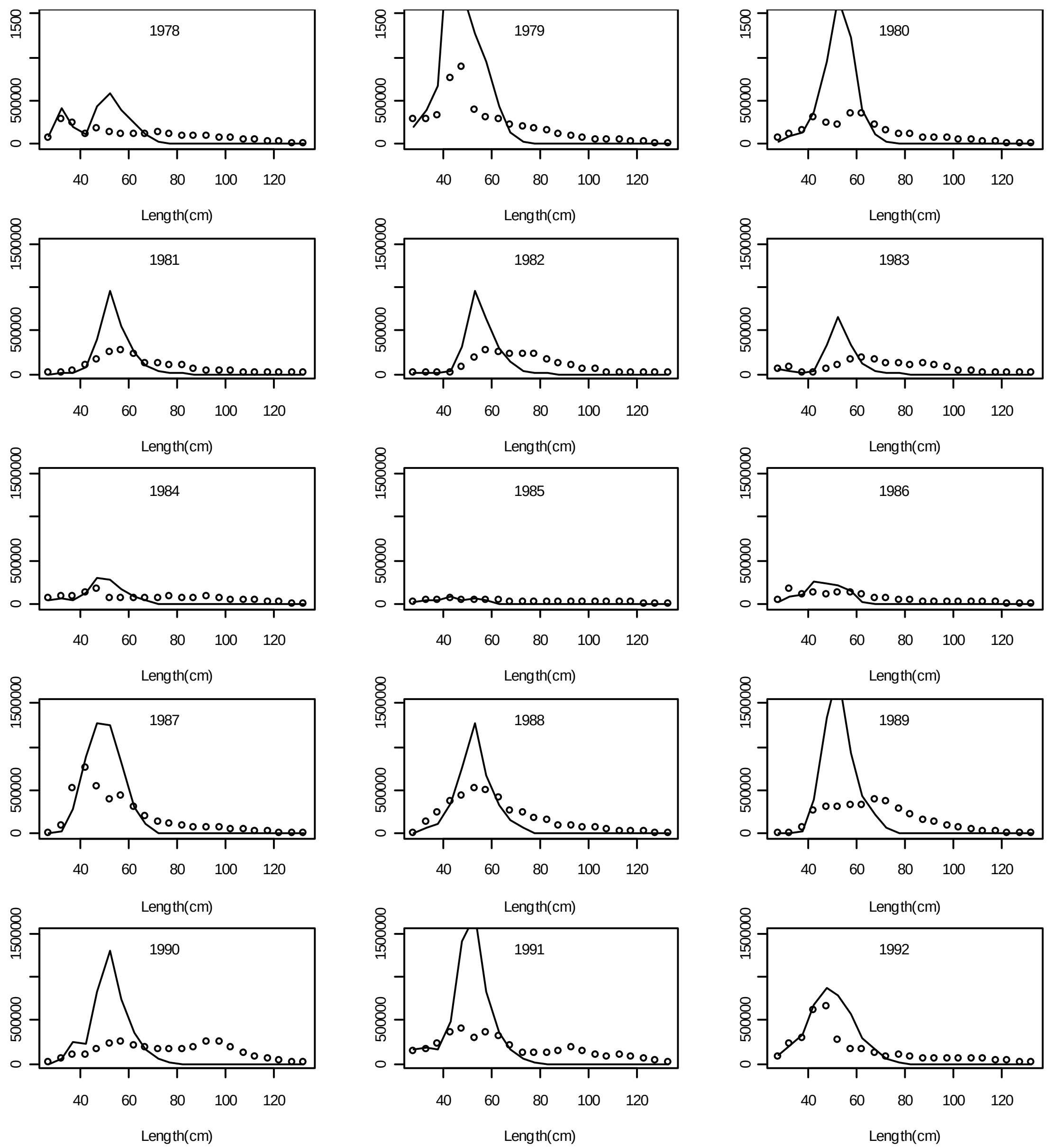


Figure 10. Observed survey numbers 1978 to 1992 by length, males circles, females solid line.

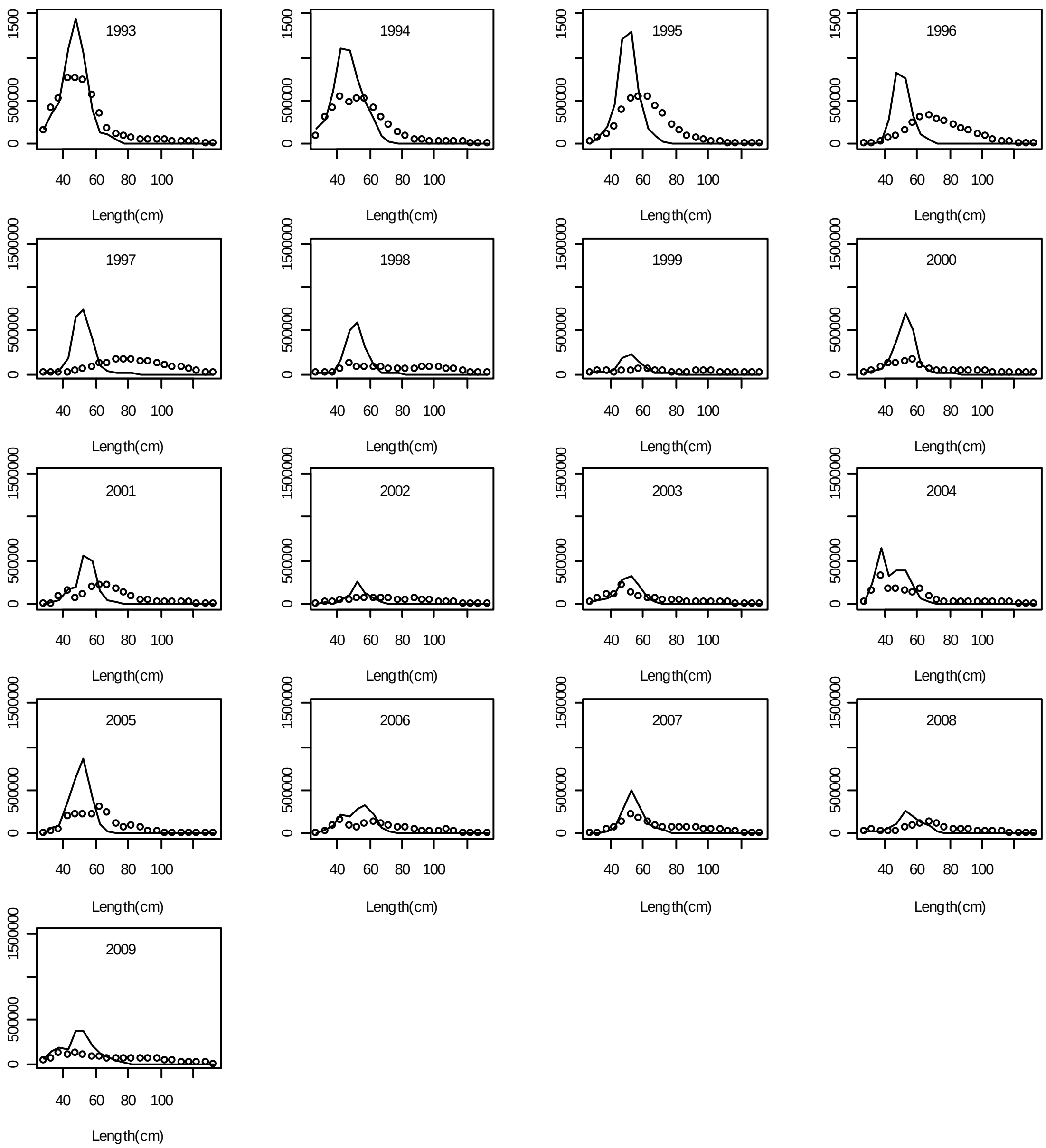


Figure 10 continued. Observed survey numbers 1993 to 2009 by length, males circles, females solid line.

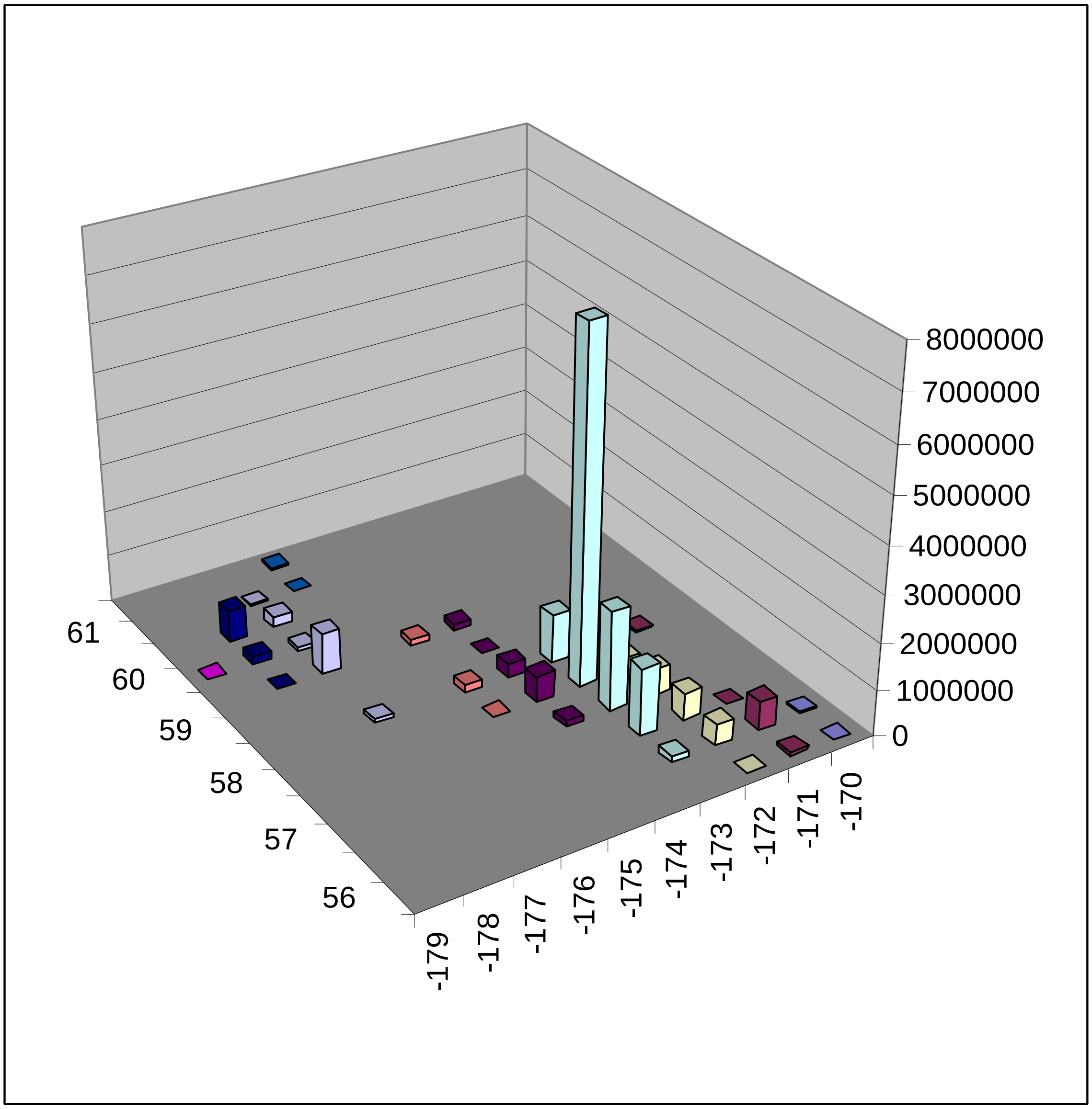


Figure 11. 2003/04 pot fishery retained catch in numbers by statistical area. Longitude in negative degrees. Areas are 1 degree longitude by 0.5 degree latitude.

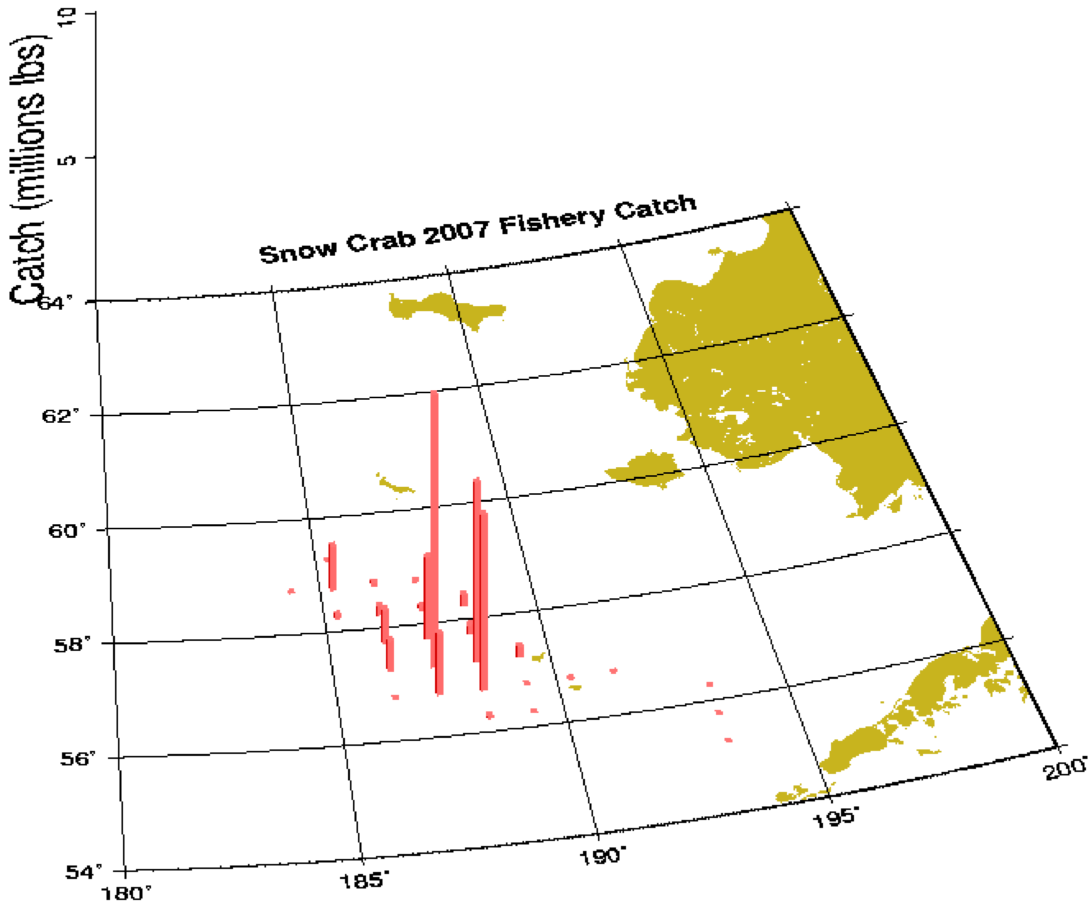


Figure 12. 2006/07 snow crab pot fishery retained catch(million lbs) by statistical area. Longitude increases from west to east (190 degrees = 170 degrees W longitude). Areas are 1 degree longitude by 0.5 degree latitude.

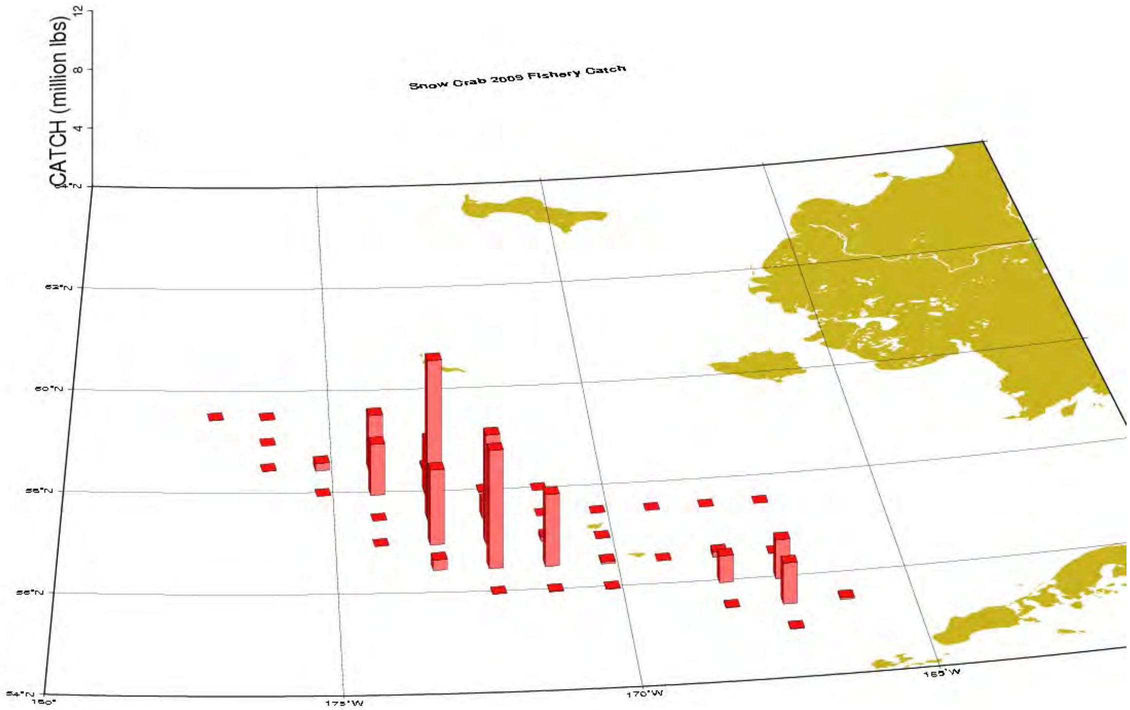


Figure 13. 2008/09 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

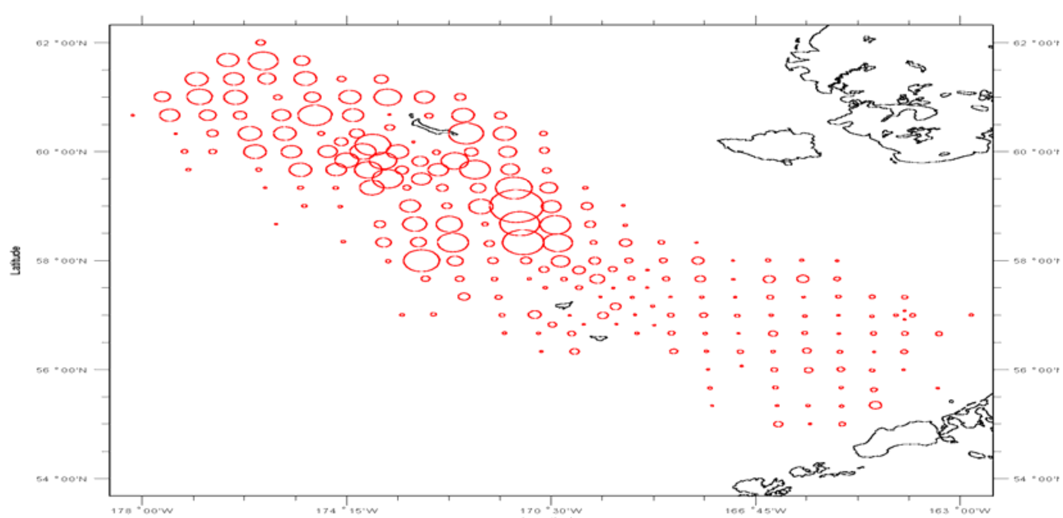


Figure 14. 2004 Survey abundance of males > 79 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle.

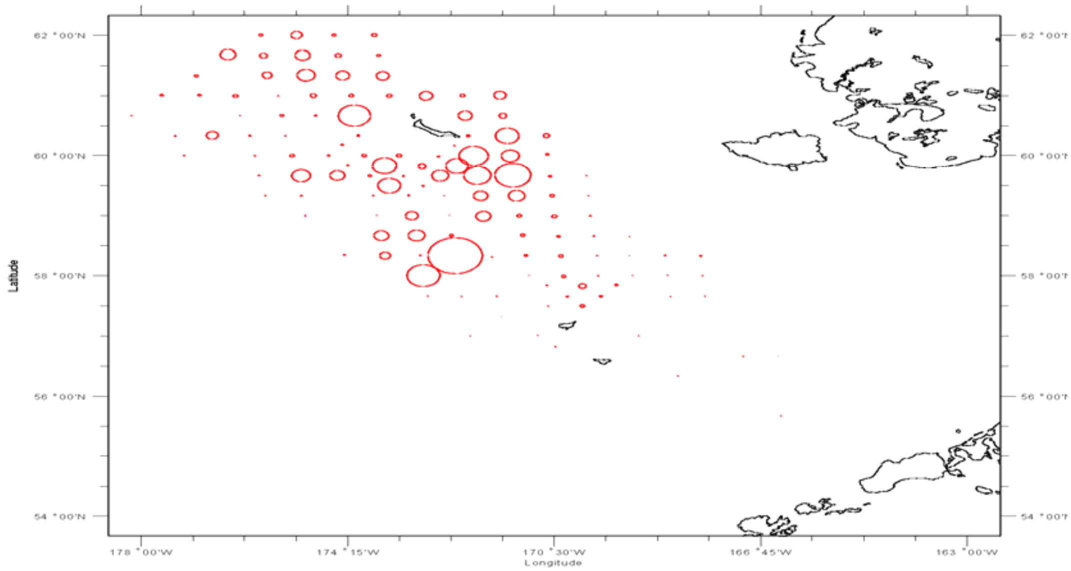


Figure 15. 2004 Survey abundance of females > 49 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle.

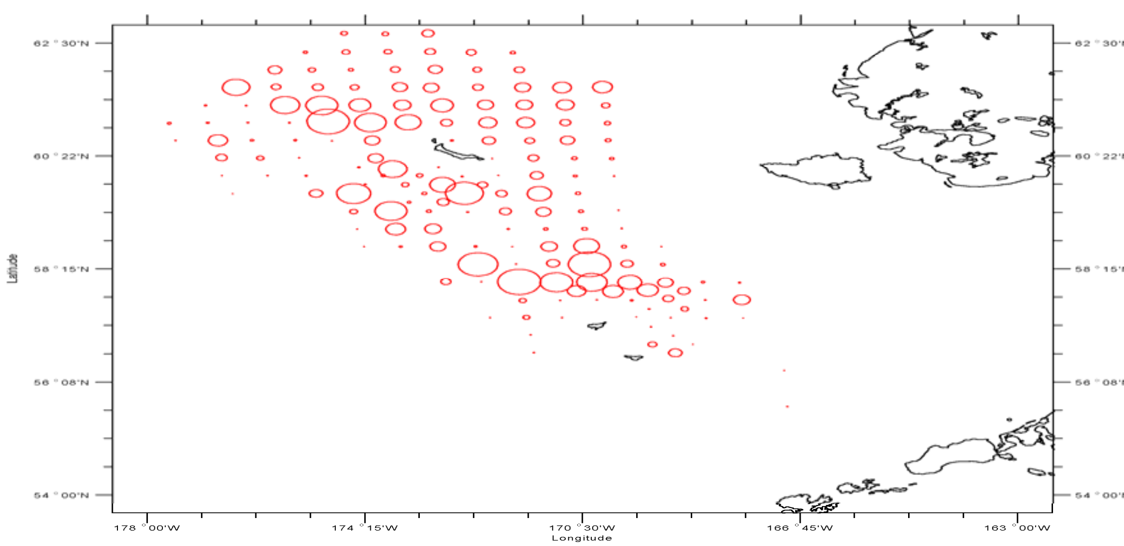


Figure 16. 2005 Survey abundance of females > 49 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle (not on the same scale as male abundance in Figure 54). Includes stations to the north of the standard survey area.

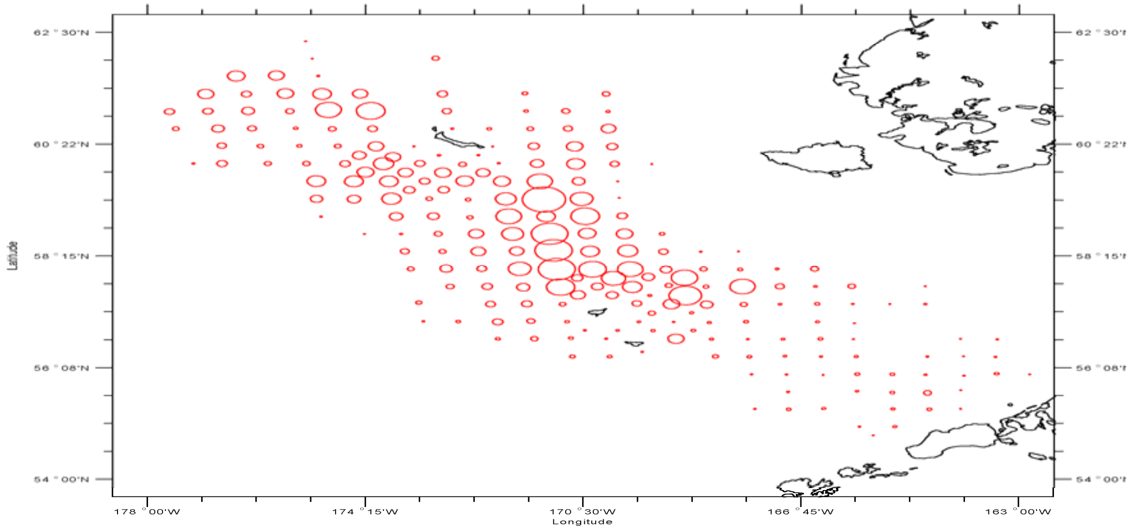


Figure 17. 2005 Survey abundance of males > 79 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle .

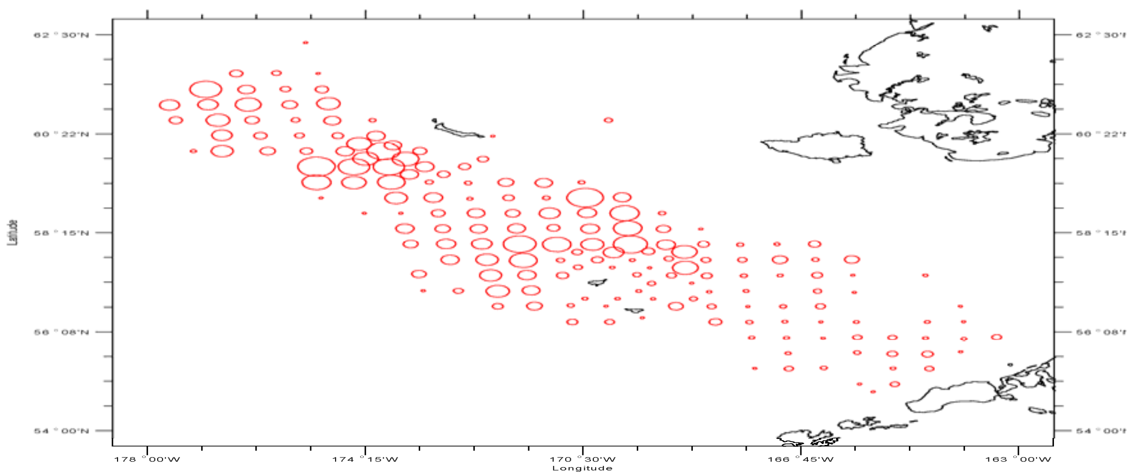


Figure 18. 2005 Survey abundance of males > 101 mm by tow. Abundance is proportional to the area of the circle.

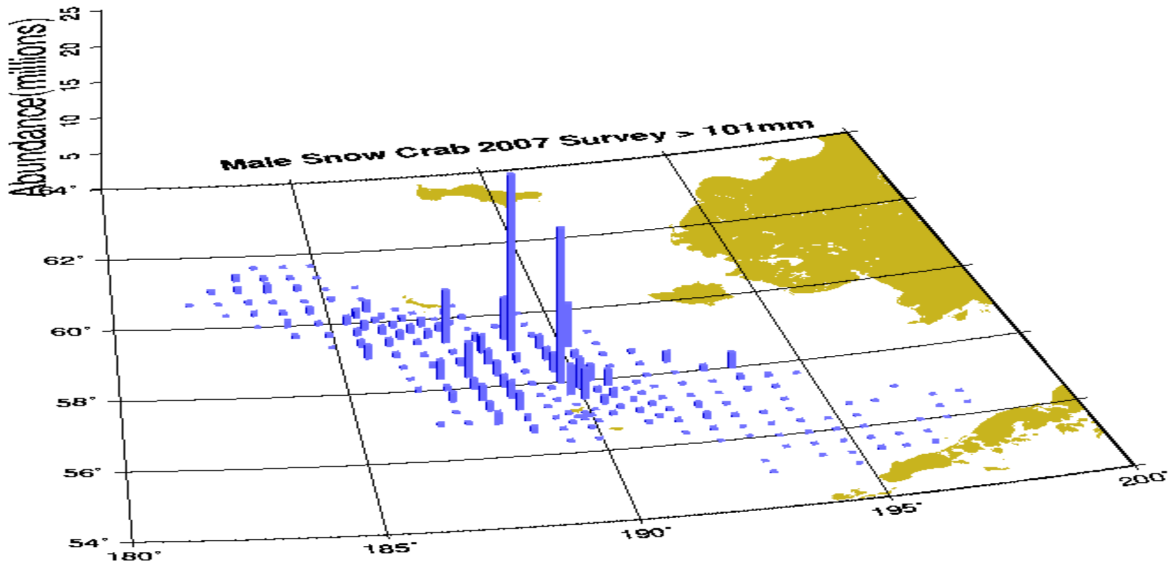


Figure 19. 2007 Survey abundance of males > 101 mm by tow. Abundance is in millions of crab.

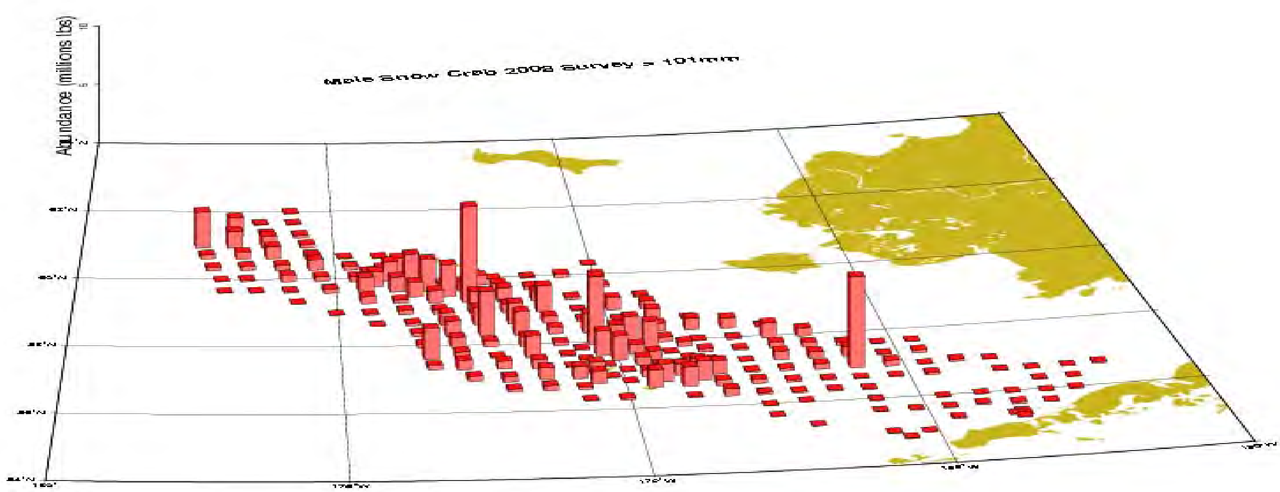


Figure 20. 2008 Survey abundance of males > 101 mm by tow. Abundance is in millions of crab.

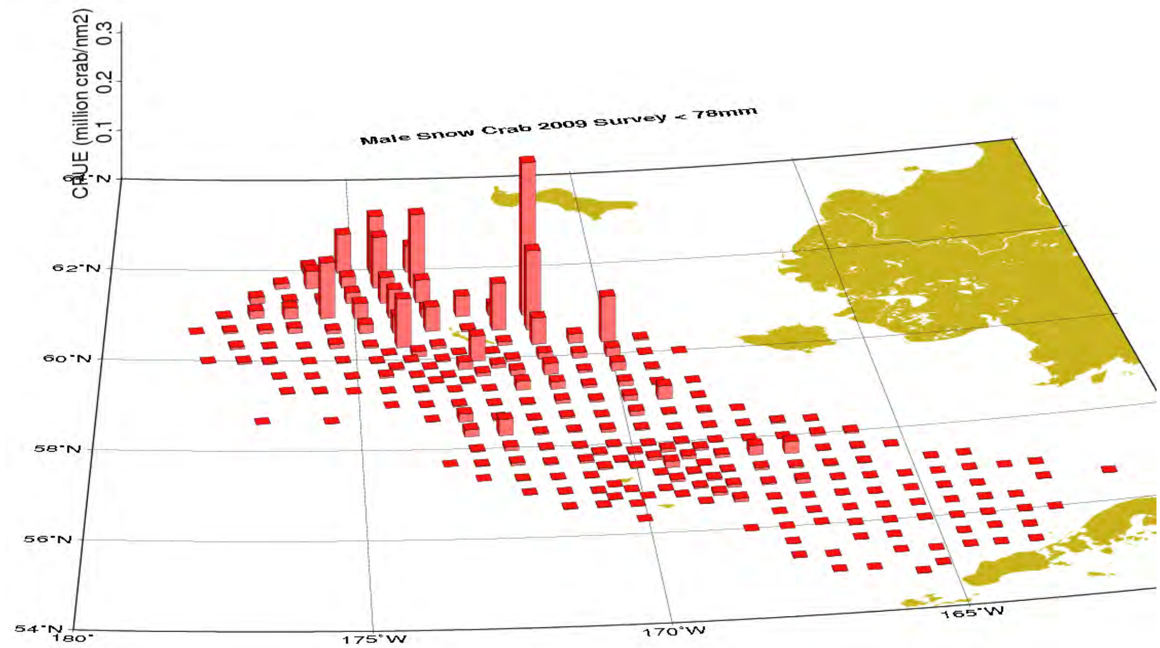


Figure 21a. 2009 Survey CPUE (million crab per nm2) of males < 78 mm by tow.

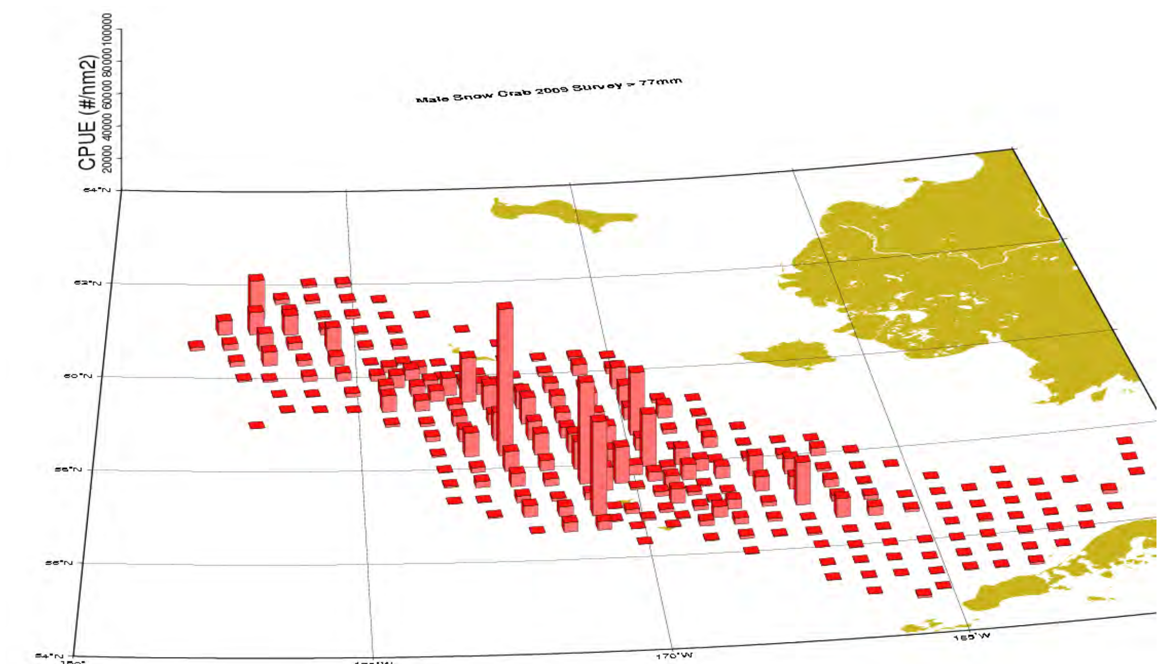


Figure 21b. 2009 Survey CPUE (number per nm2) of males > 77 mm by tow.

Figure 21c. 2009 Survey CPUE (number per nm2) of males > 101 mm by tow.

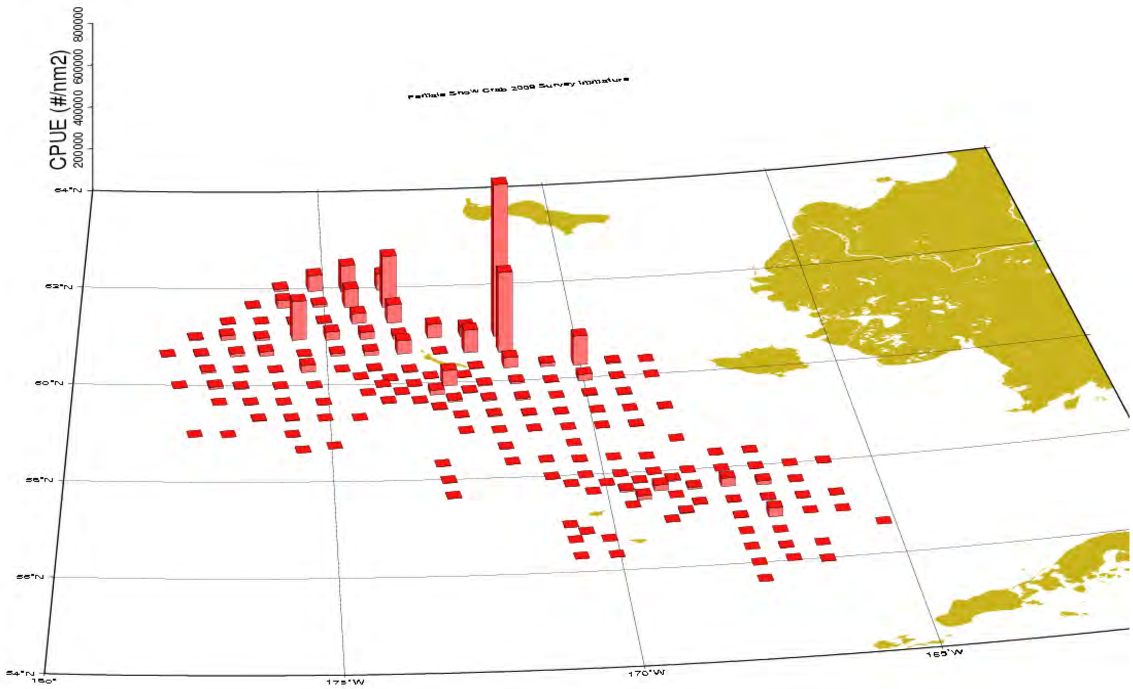


Figure 21d. Snow crab 2009 survey immature female cpue.

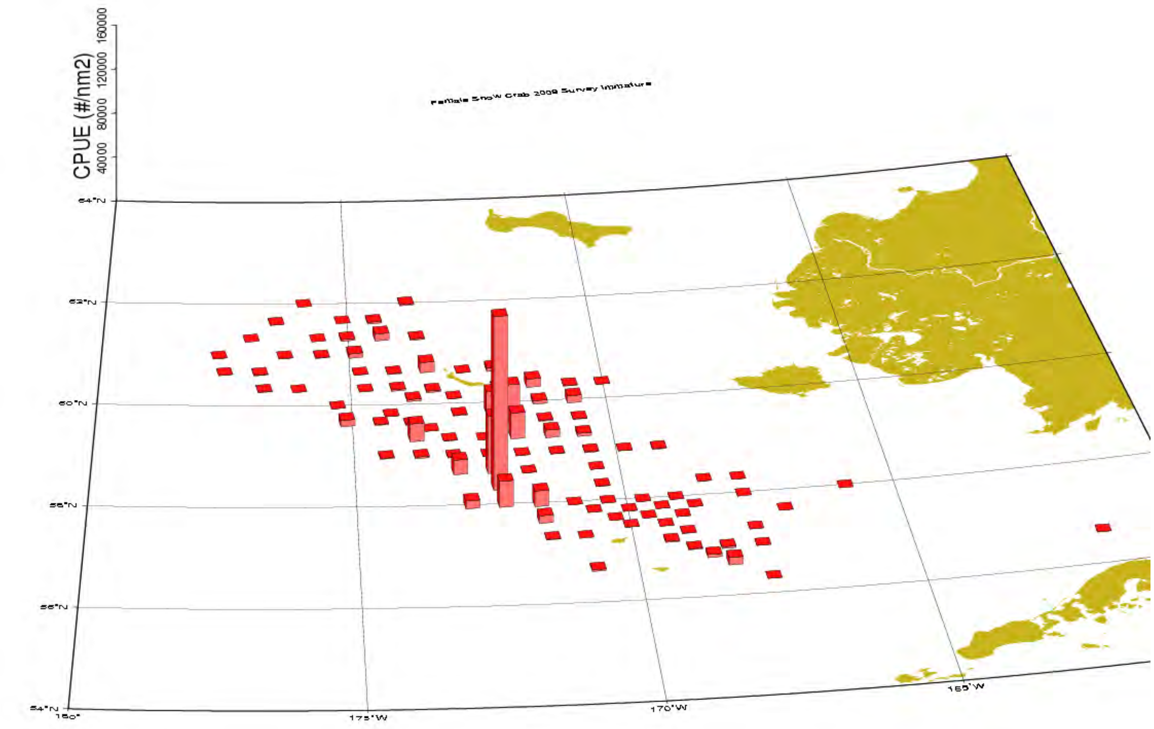


Figure 21e. Snow mature females cpue with less than or equal to half clutch of eggs.

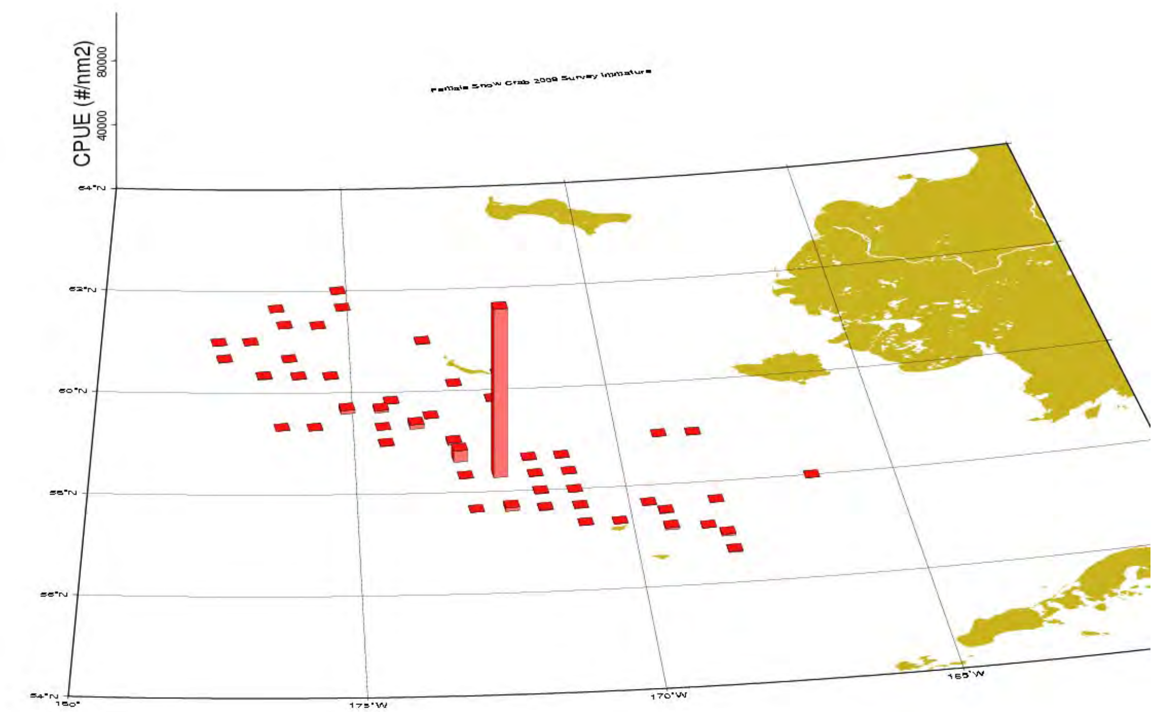


Figure 21f. Mature females with no eggs. Note scale not the same as other plots.

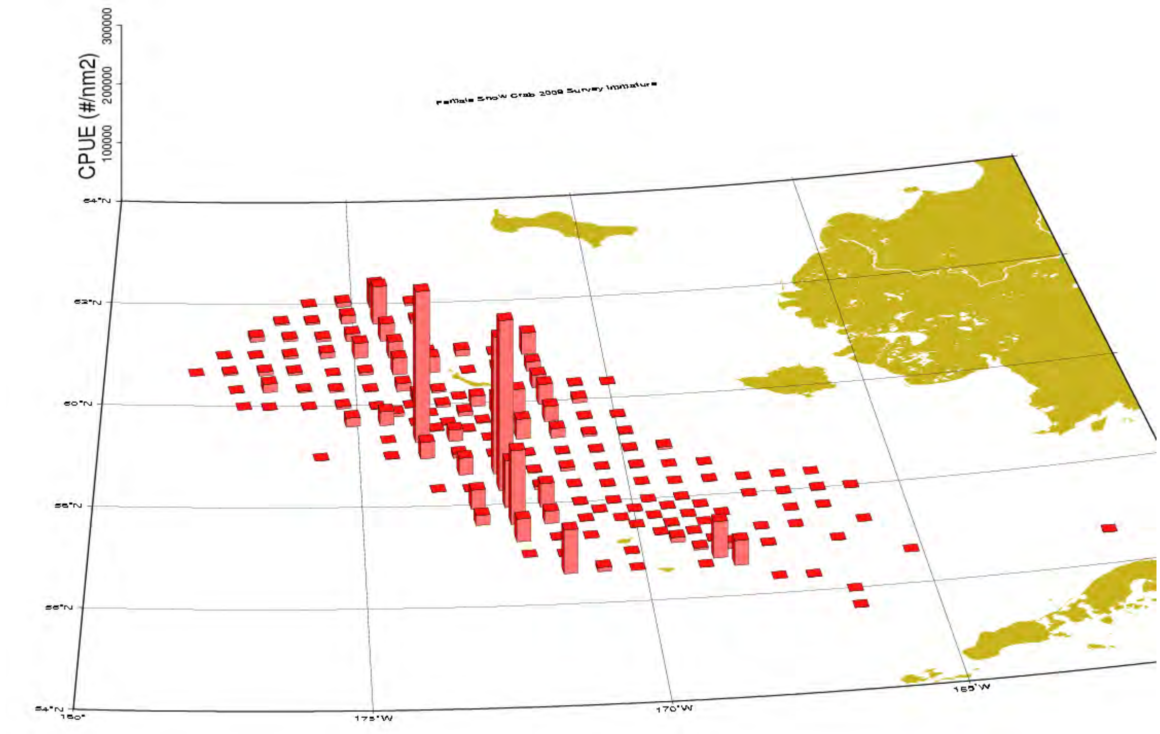


Figure 21g. Female survey cpue by haul for mature females with eggs. Scale not same as other plots.

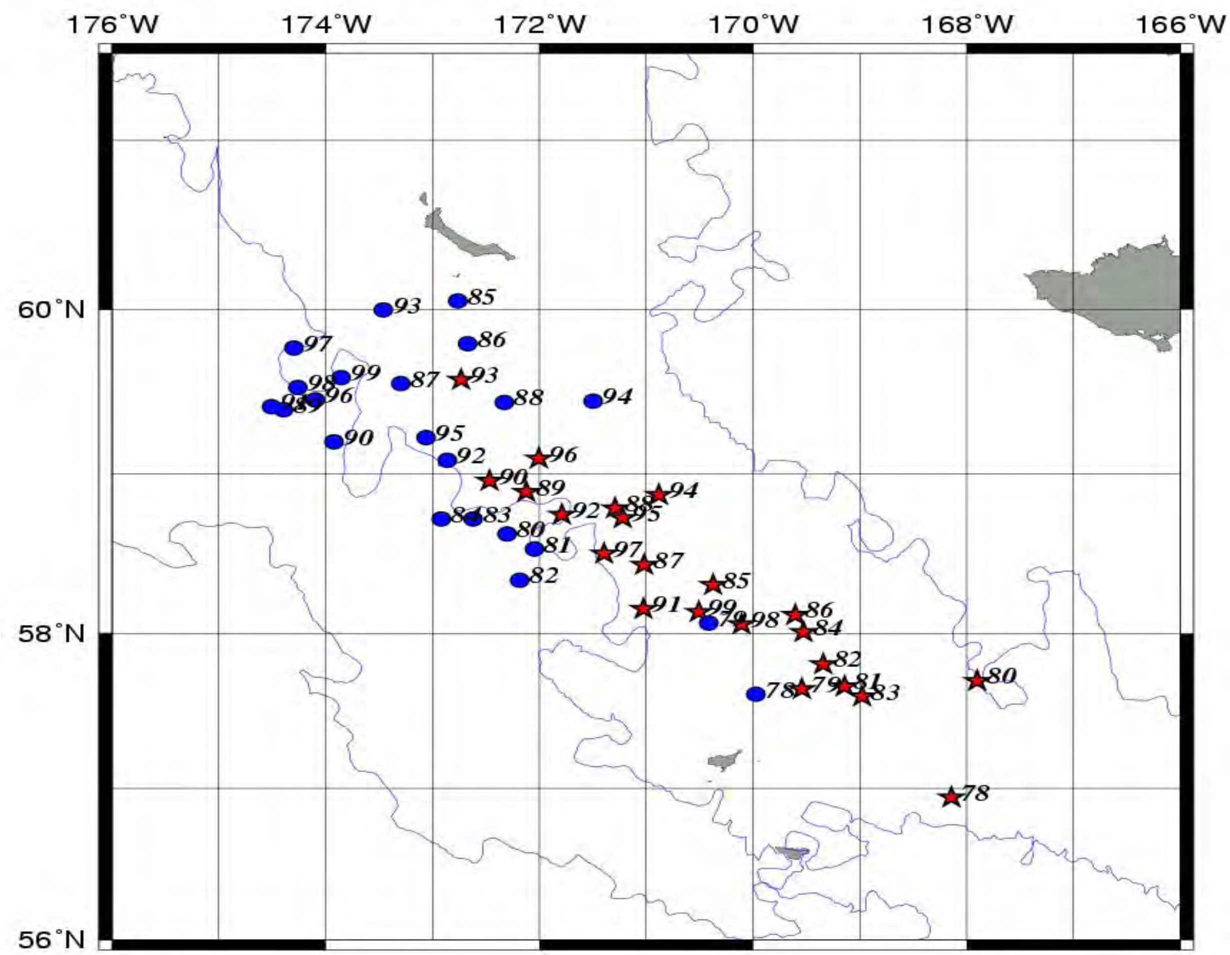


Figure 22. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars (Ernst, et al. 2005).

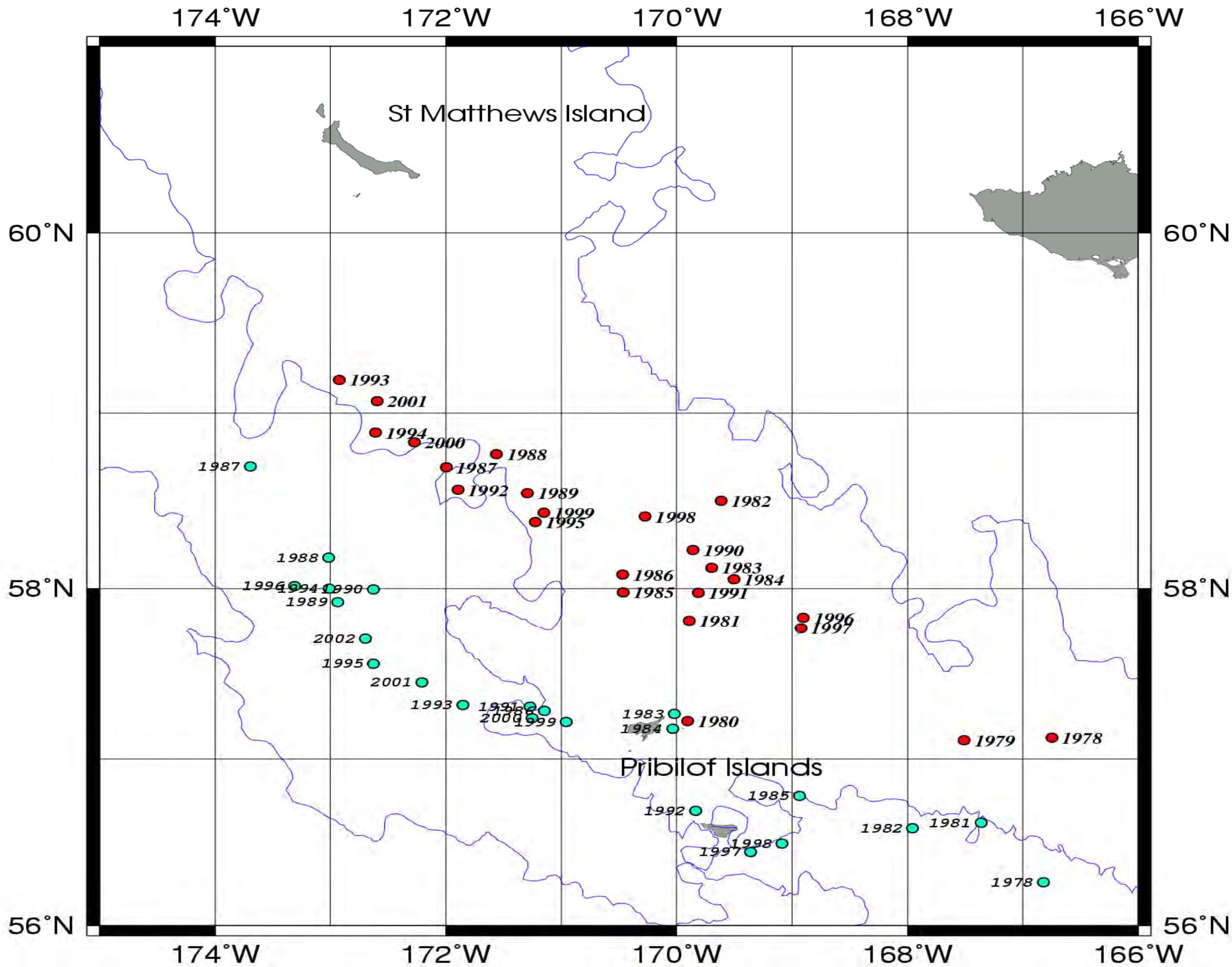


Figure 23. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green) (Ernst, et al. 2005).

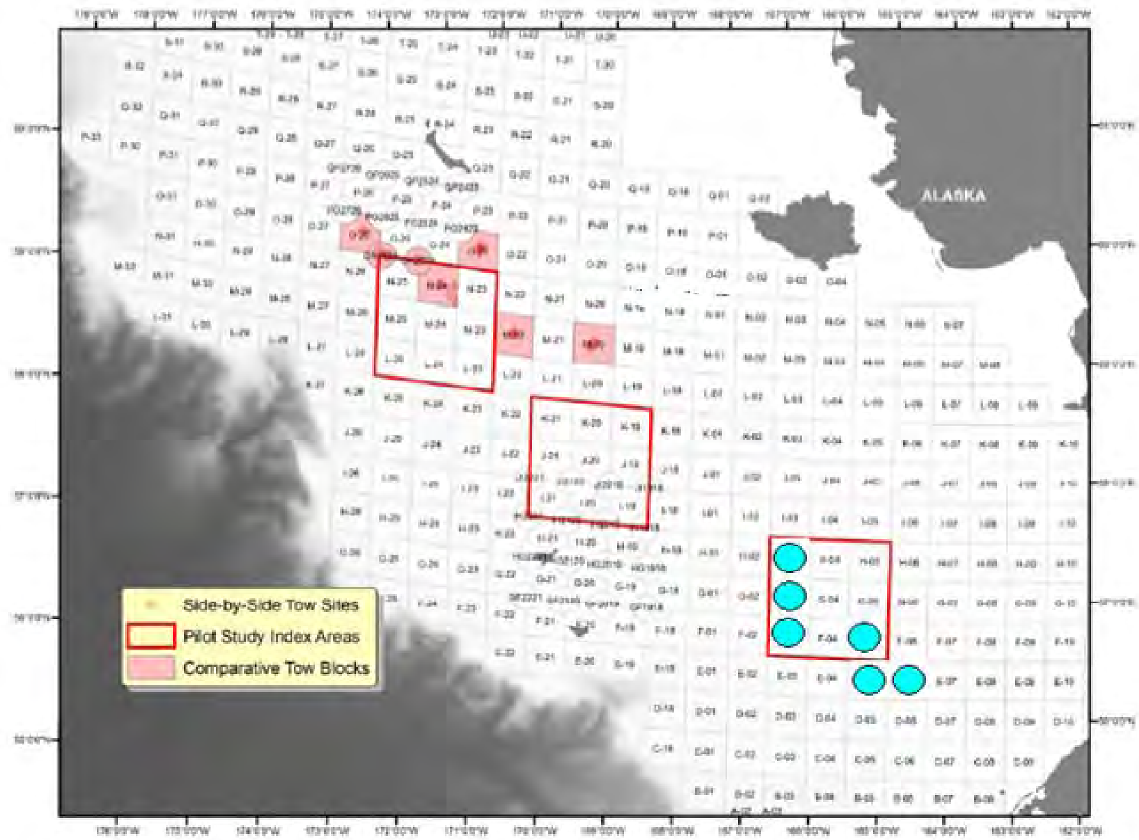


Figure 24. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas are the blue circles.

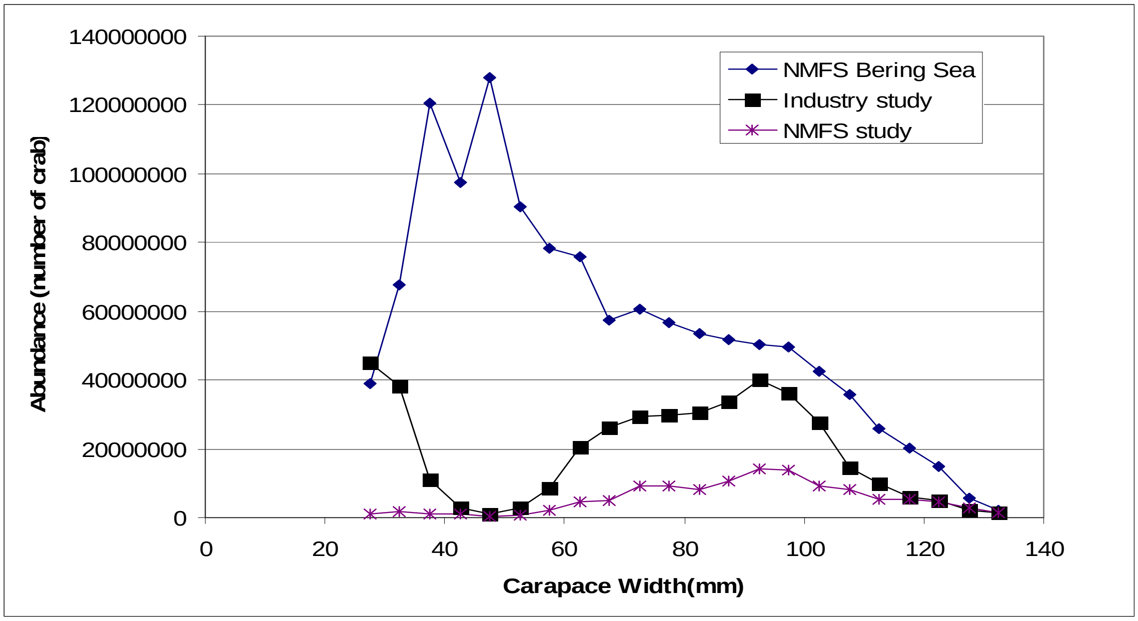


Figure 25. Abundance estimates of male snow crab by 5 mm carapace width(>=25mm) for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the study area.

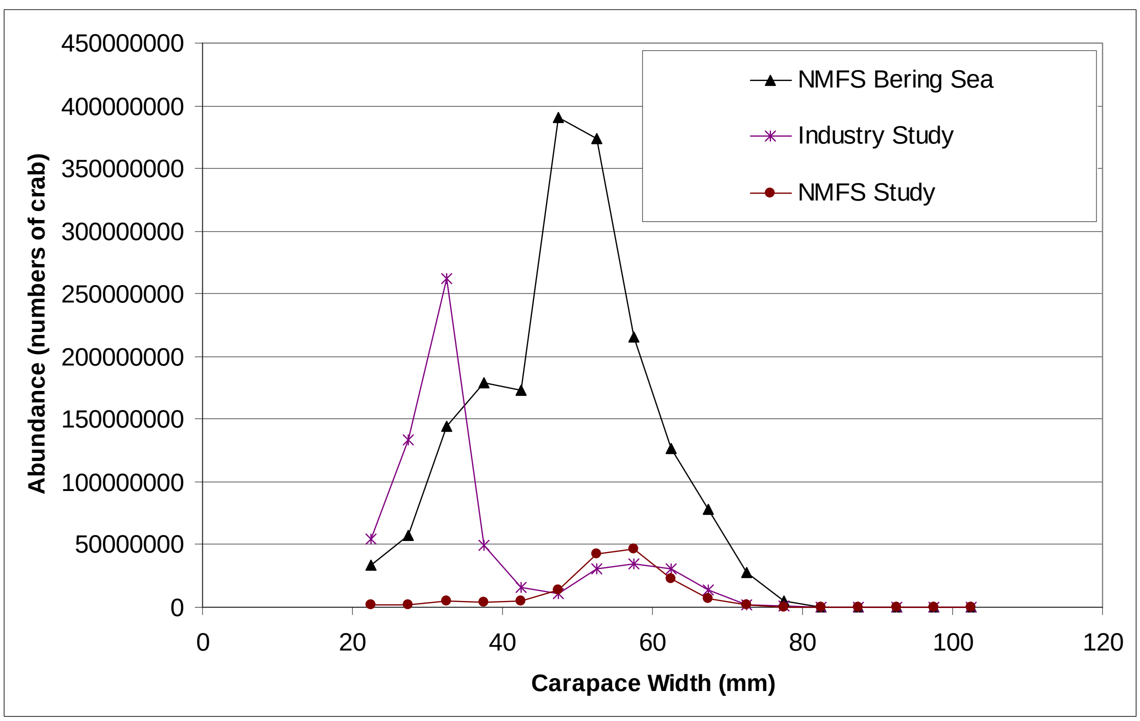


Figure 26. Abundance estimates of female snow crab by 5 mm carapace width for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the study area.

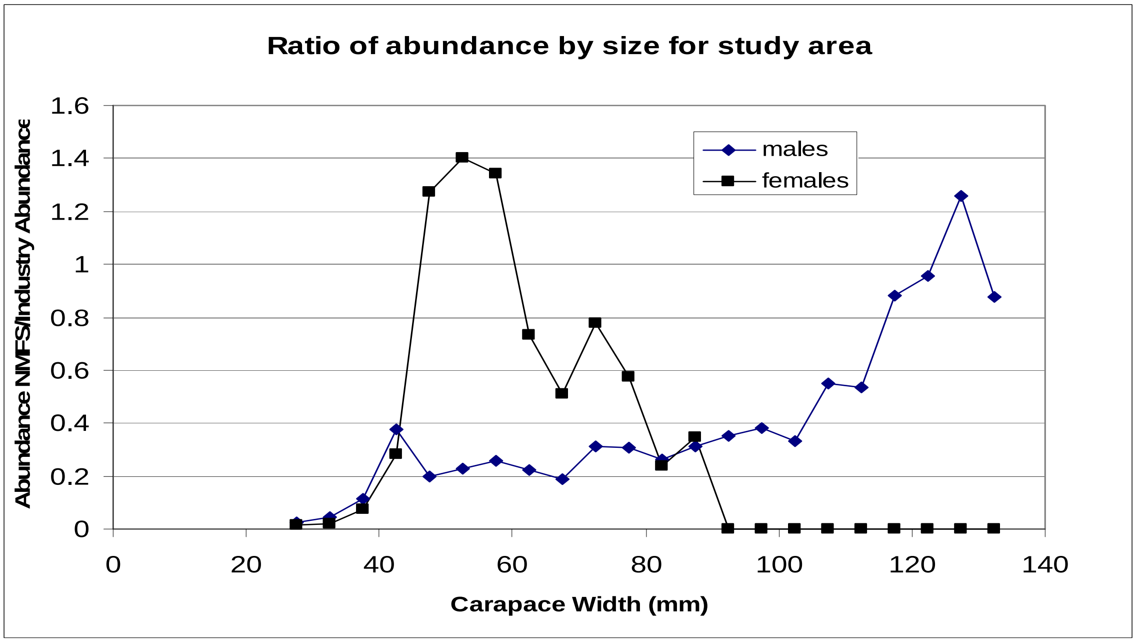


Figure 27. Ratio of abundance in the study area from the NMFS net to the BSFRF net for male and female crab.

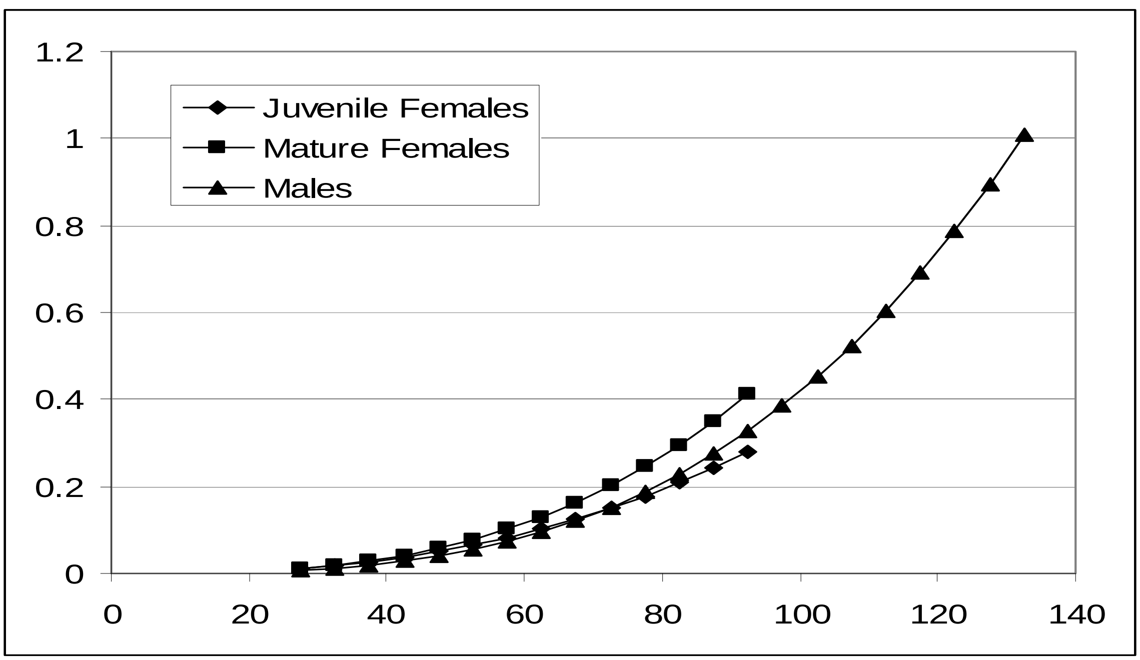


Figure 28. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

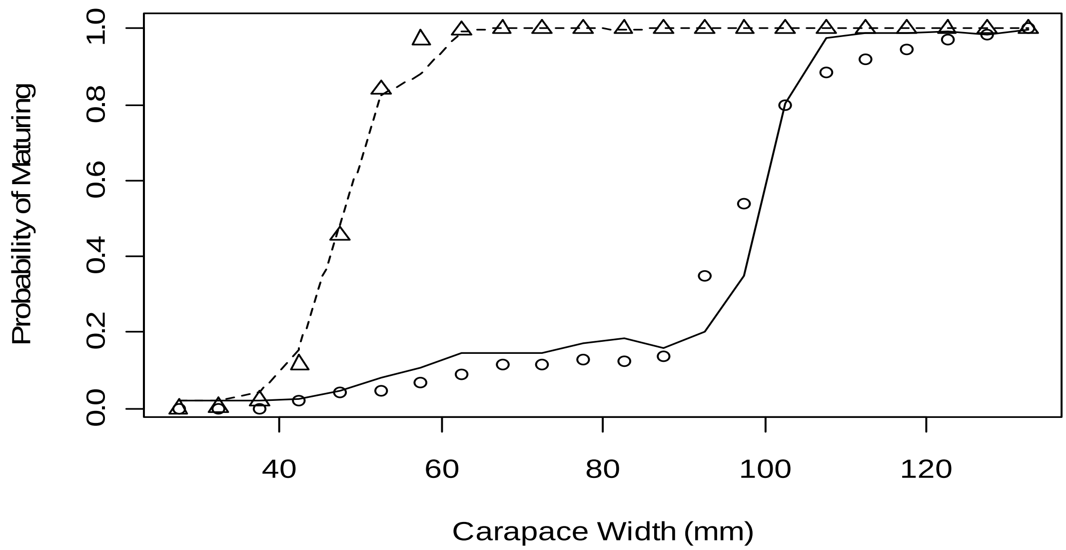


Figure 29. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (<u>not</u> the average fraction mature). Triangles are values for females used in the 2009 assessment. Circles are values for males used in the 2009 assessment.

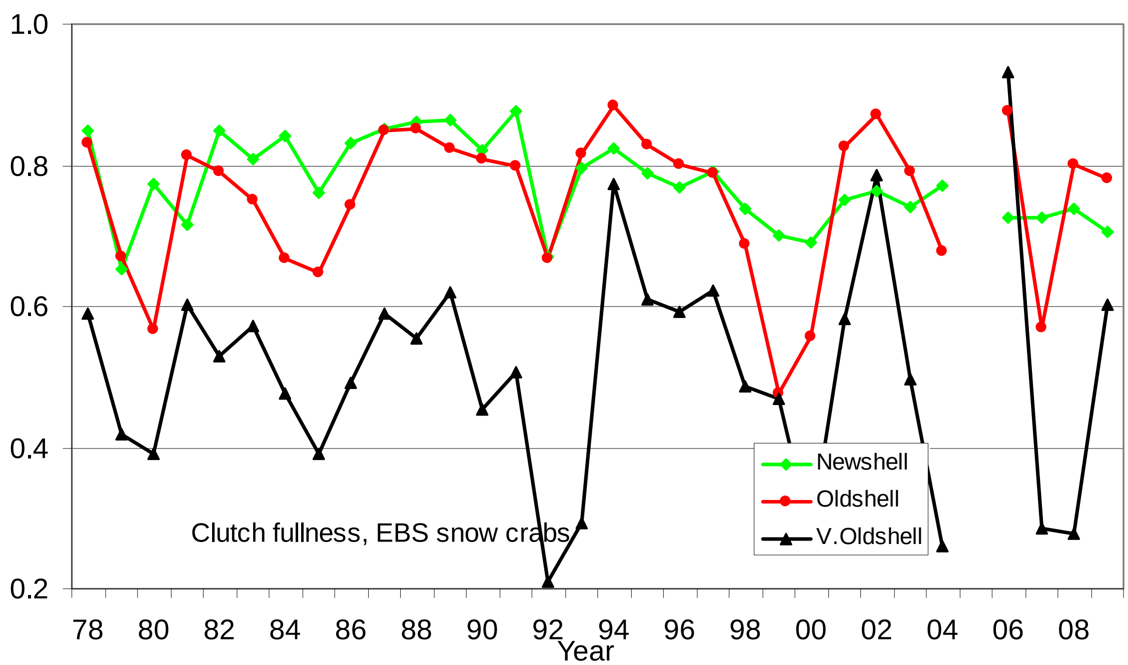


Figure 30. Clutch fullness for Bering sea snow crab survey data by shell condition for 1978 to 2009.

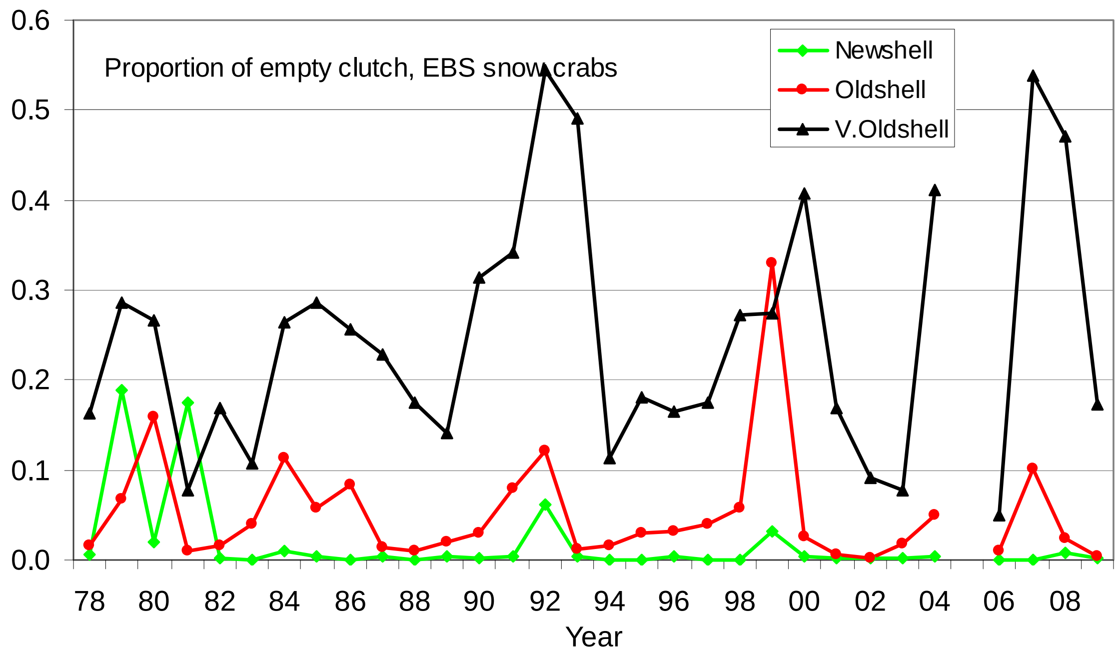


Figure 31. Proportion of barren females by shell condition from survey data 1978 to 2009.

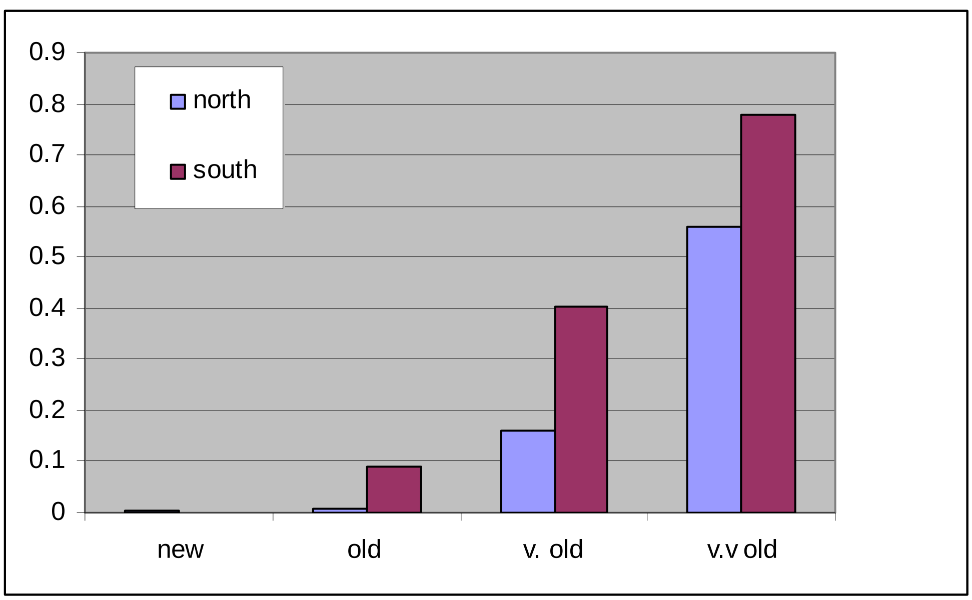


Figure 32. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

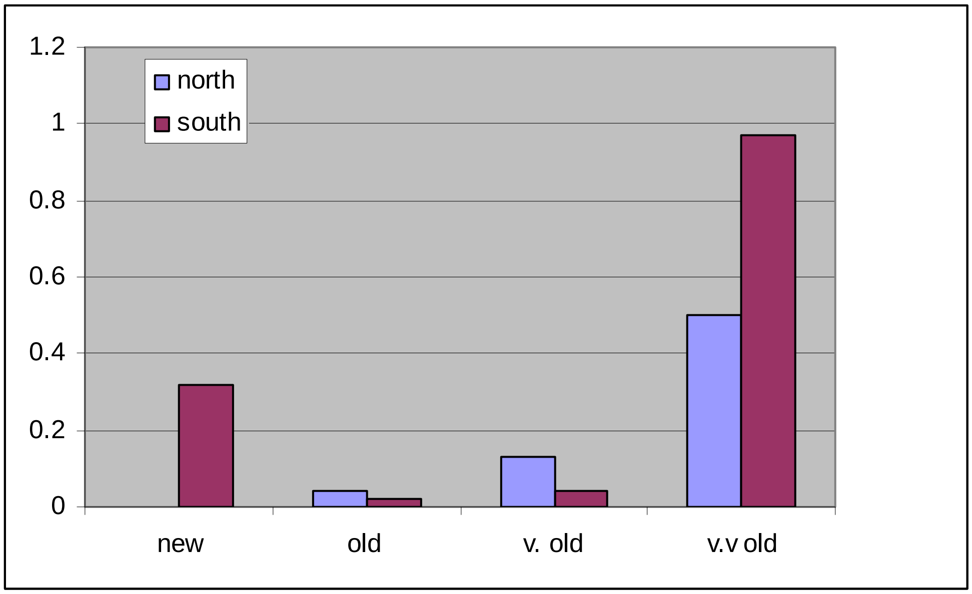


Figure 33. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

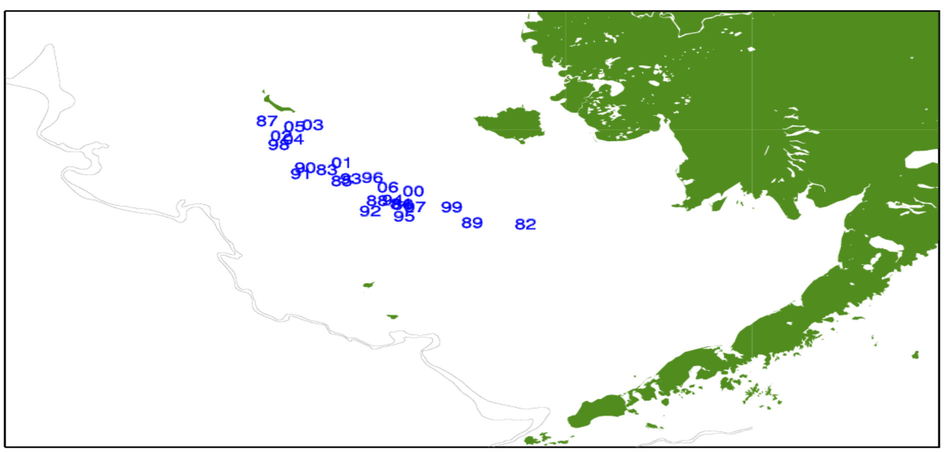


Figure 34. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

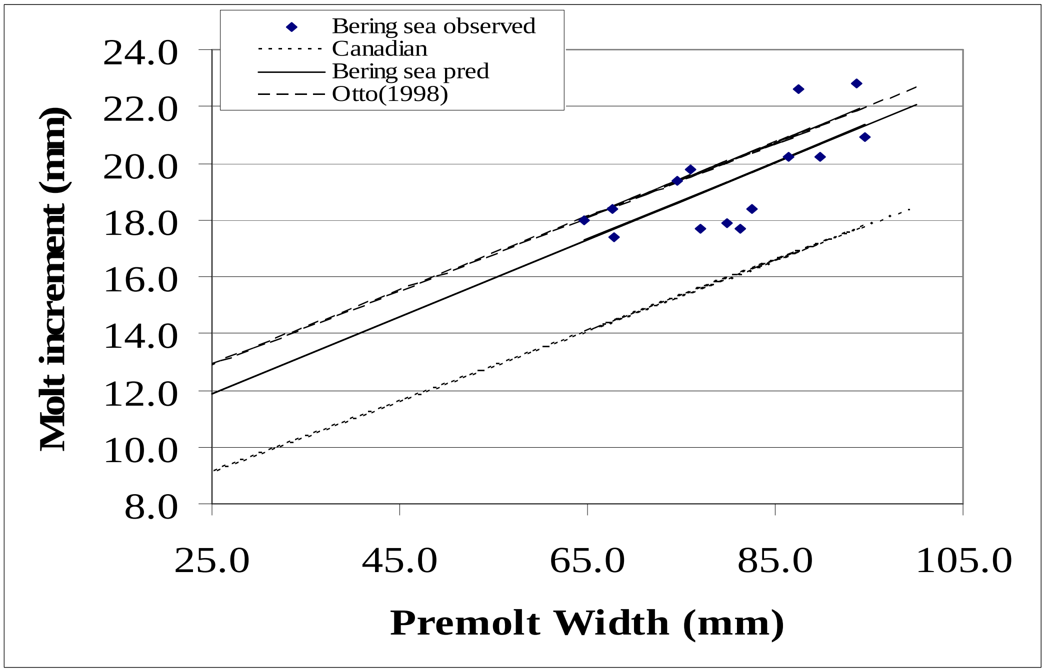


Figure 35. Growth increment as a function of premolt size for male snow crab. Points labeled Bering sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering sea pred is the predicted line from the Bering sea observed growth, which is used as a prior for the growth 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.

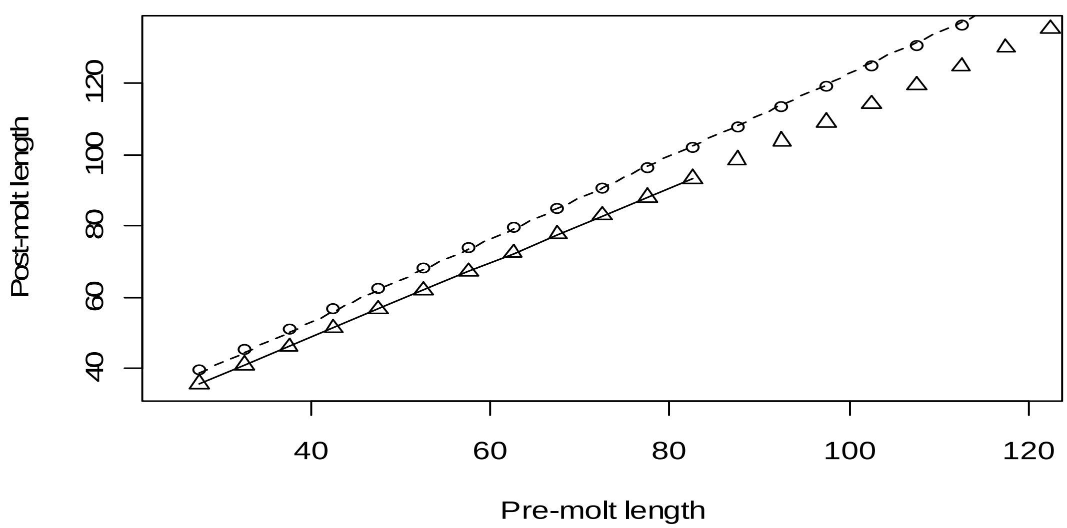


Figure 36. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the model. Circles are the observed growth curve.

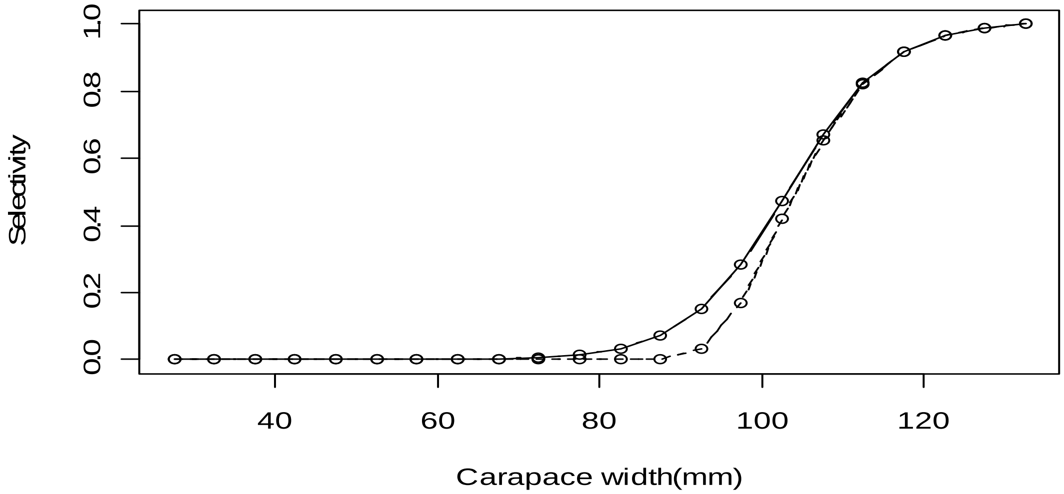


Figure 37. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

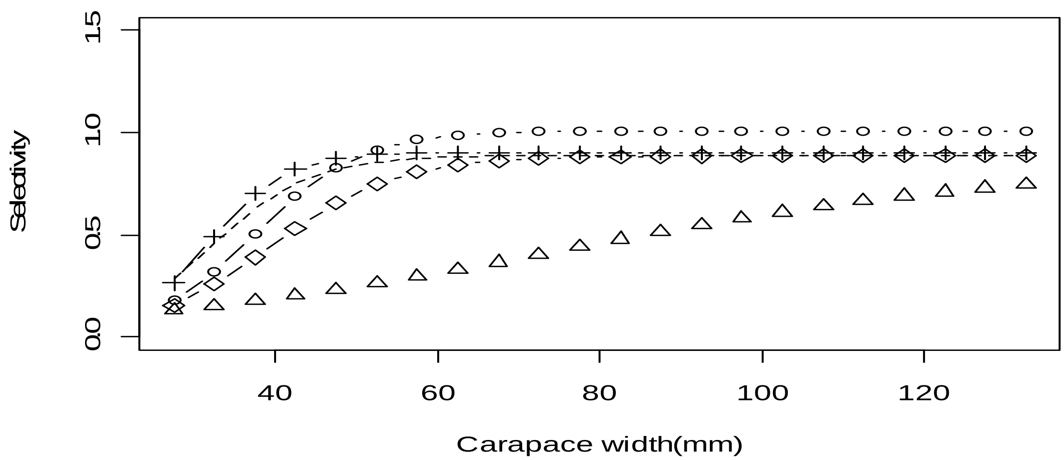


Figure 38. Survey selectivity curves for female (dotted lines) and male snow crab (solid lines) estimated by the model for 1978-1981(circles), for 1982 to 1988 (diamonds), and 1989 to present (pluses). Survey selectivities estimated by Somerton from 2009 study area data (2010) are the triangles.

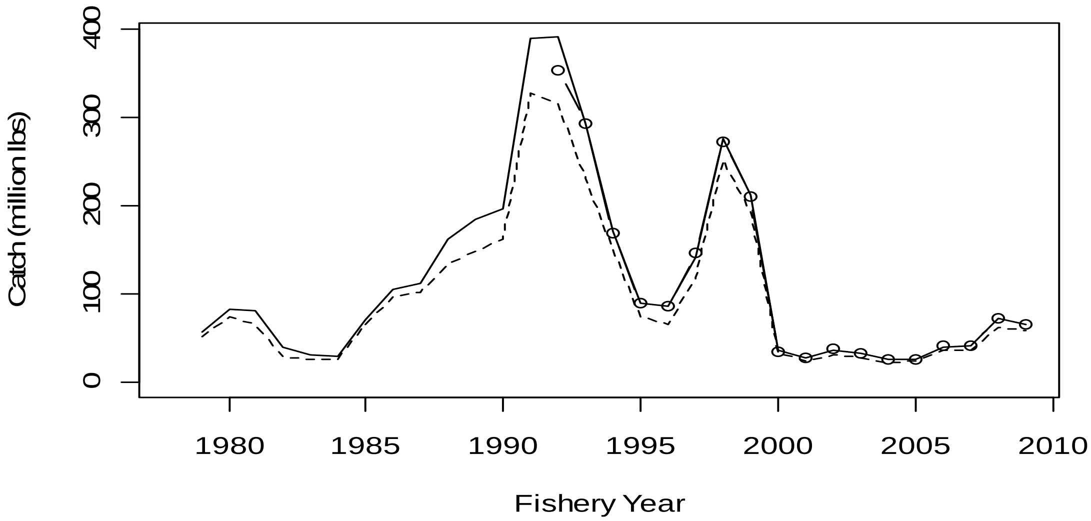


Figure 39. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 50% mortality of discarded crab) and observed retained catch (dotted line) for 1979 to 2008 fishery seasons.

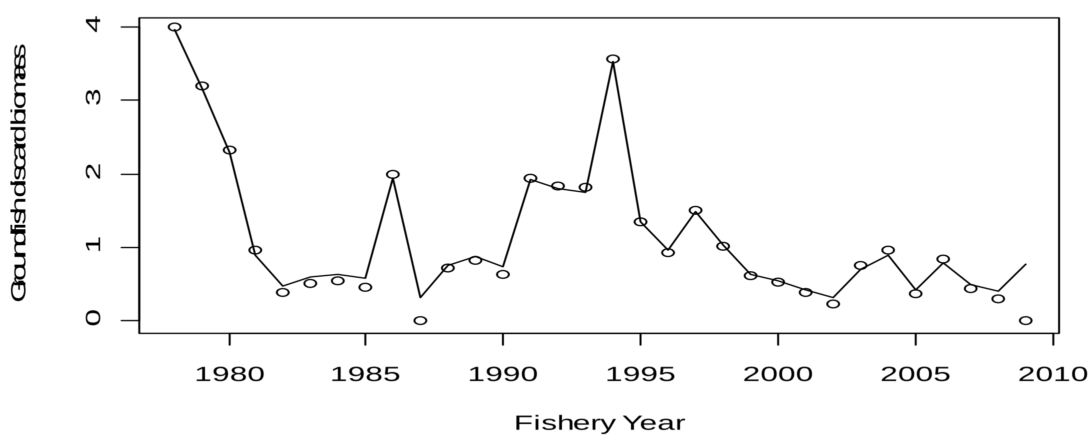


Figure 40. Model fit to groundfish bycatch from 1978 to 2009. Circles are observed catch, line is model estimate.

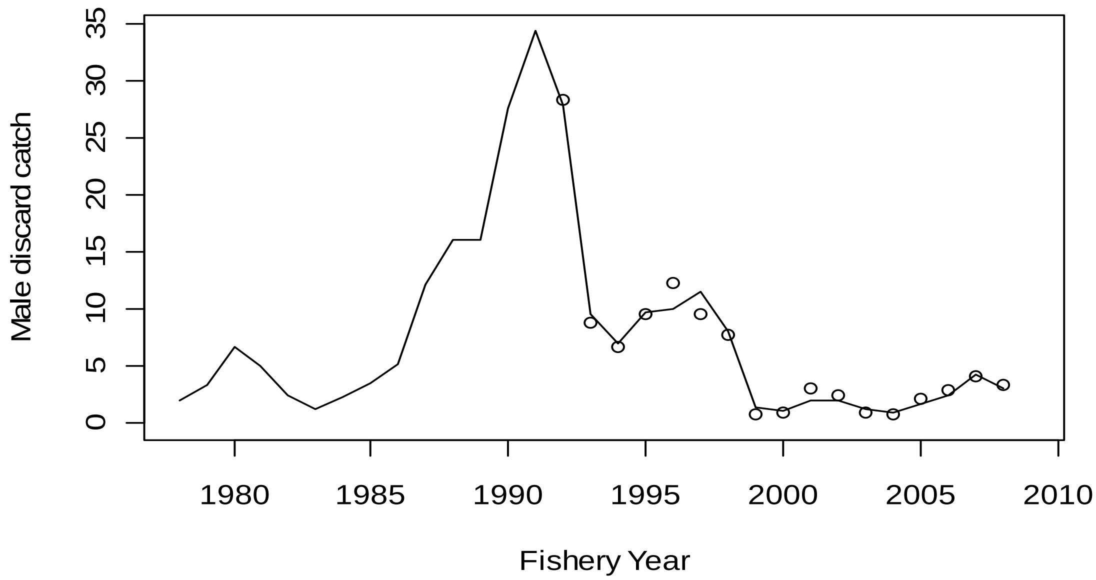


Figure 41. Model fit to male directed discard catch for 1992 to 2009 and estimated male discard catch from 1978 to 1991.

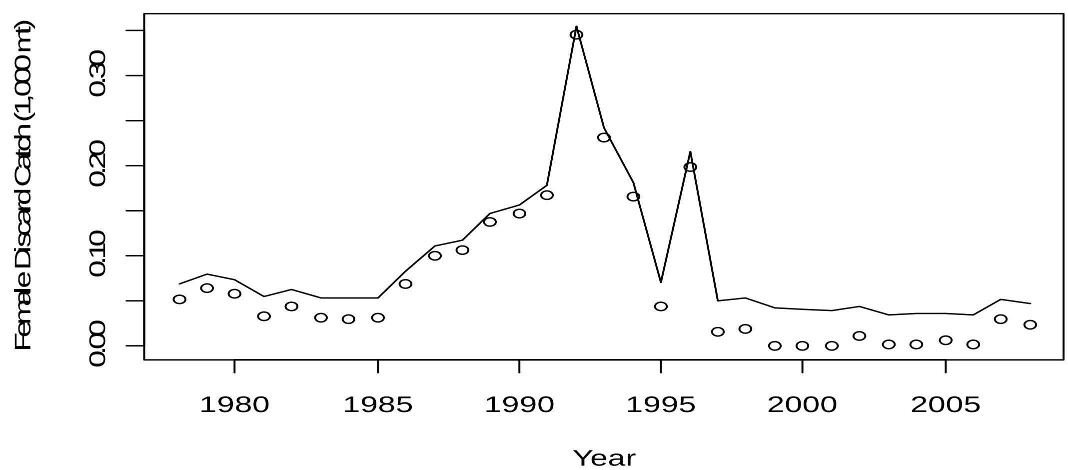


Figure 42. Model fit to female discard bycatch in the directed fishery from 1992 to 2009 and model estimates of discard from 1978 to 1991.

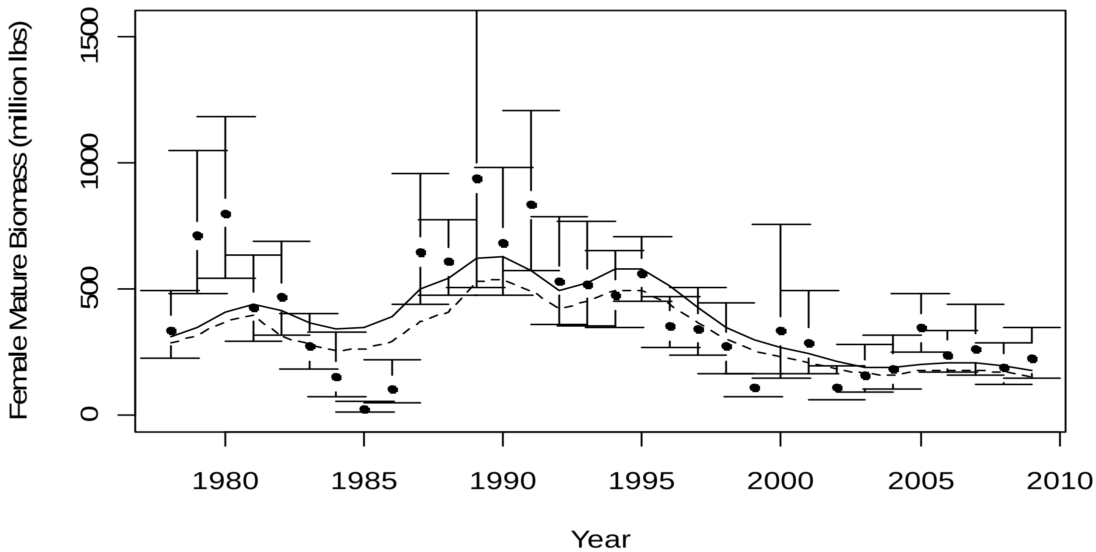


Figure 43. Population female mature biomass (millions of pounds, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

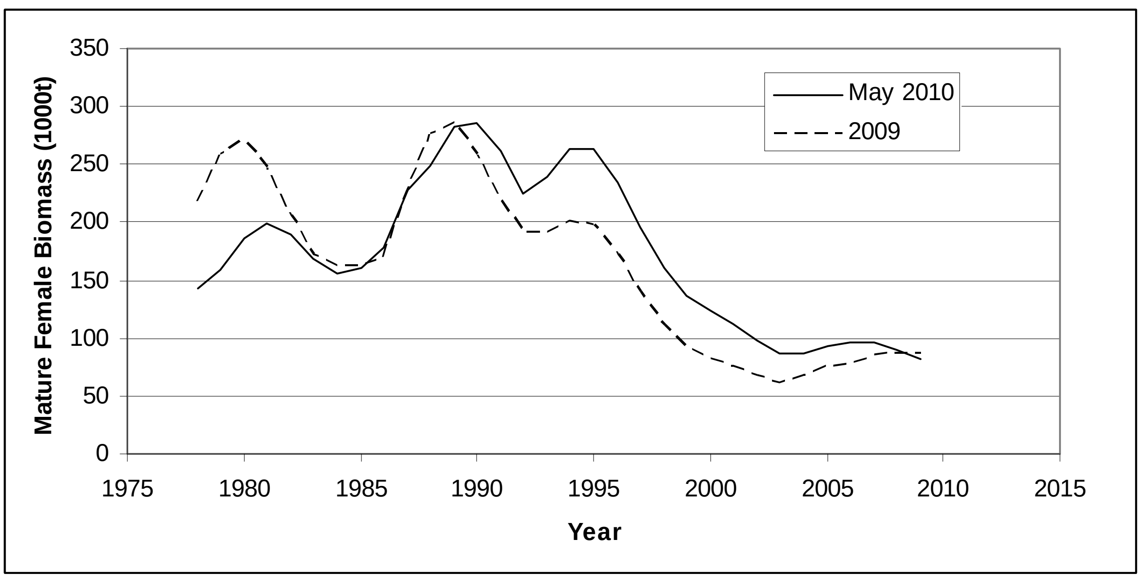


Figure 44. Population female mature biomass from the 2009 and May 2010 assessment.

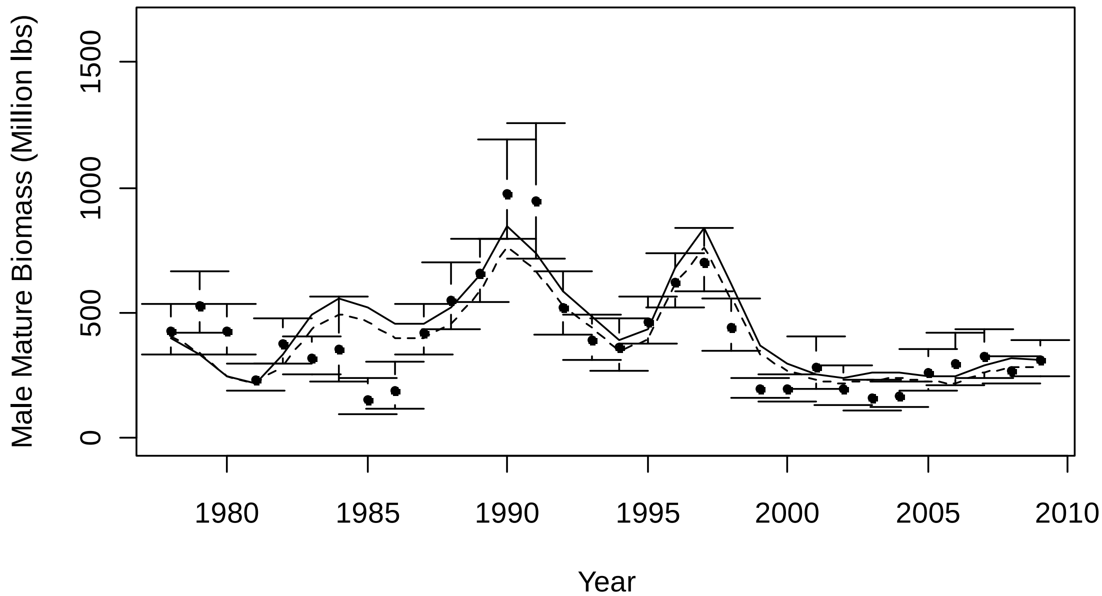


Figure 45. Population male mature biomass (millions of pounds, solid line), model estimate of survey male mature biomass (dotted line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

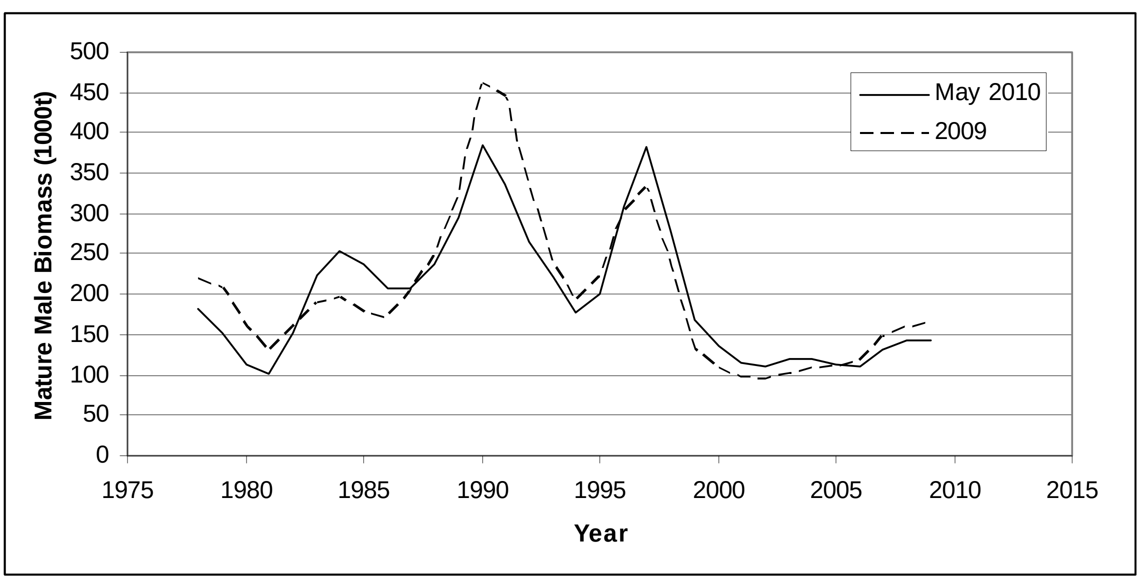


Figure 46. Population male mature biomass from the 2009 assessment and the May 2010 assessment.

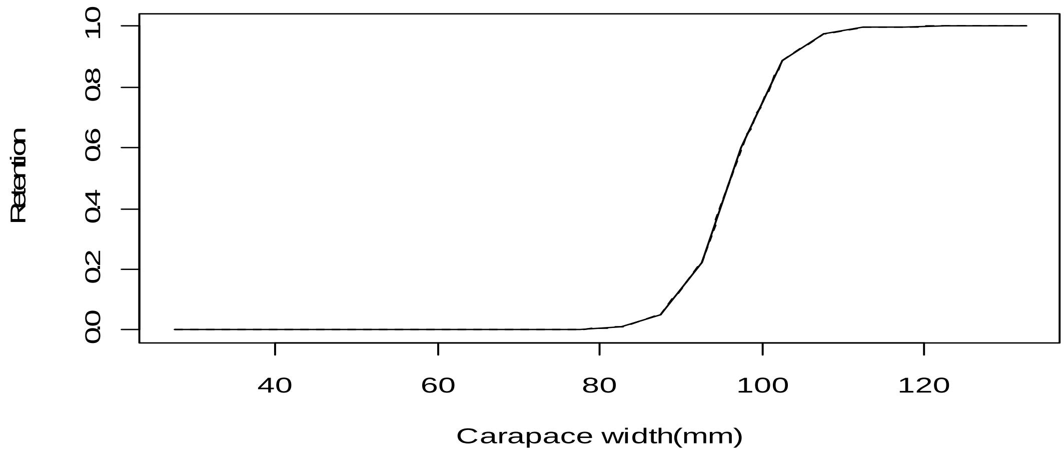


Figure 47. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

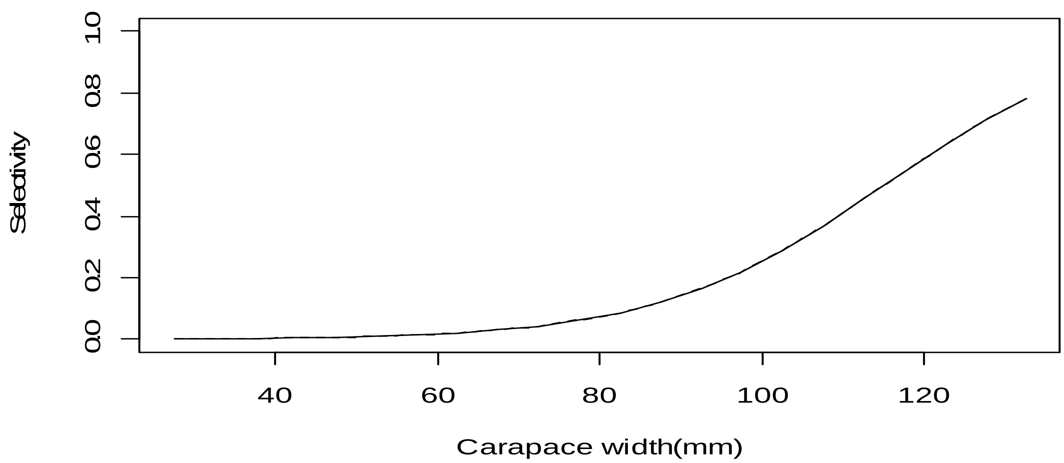


Figure 48. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

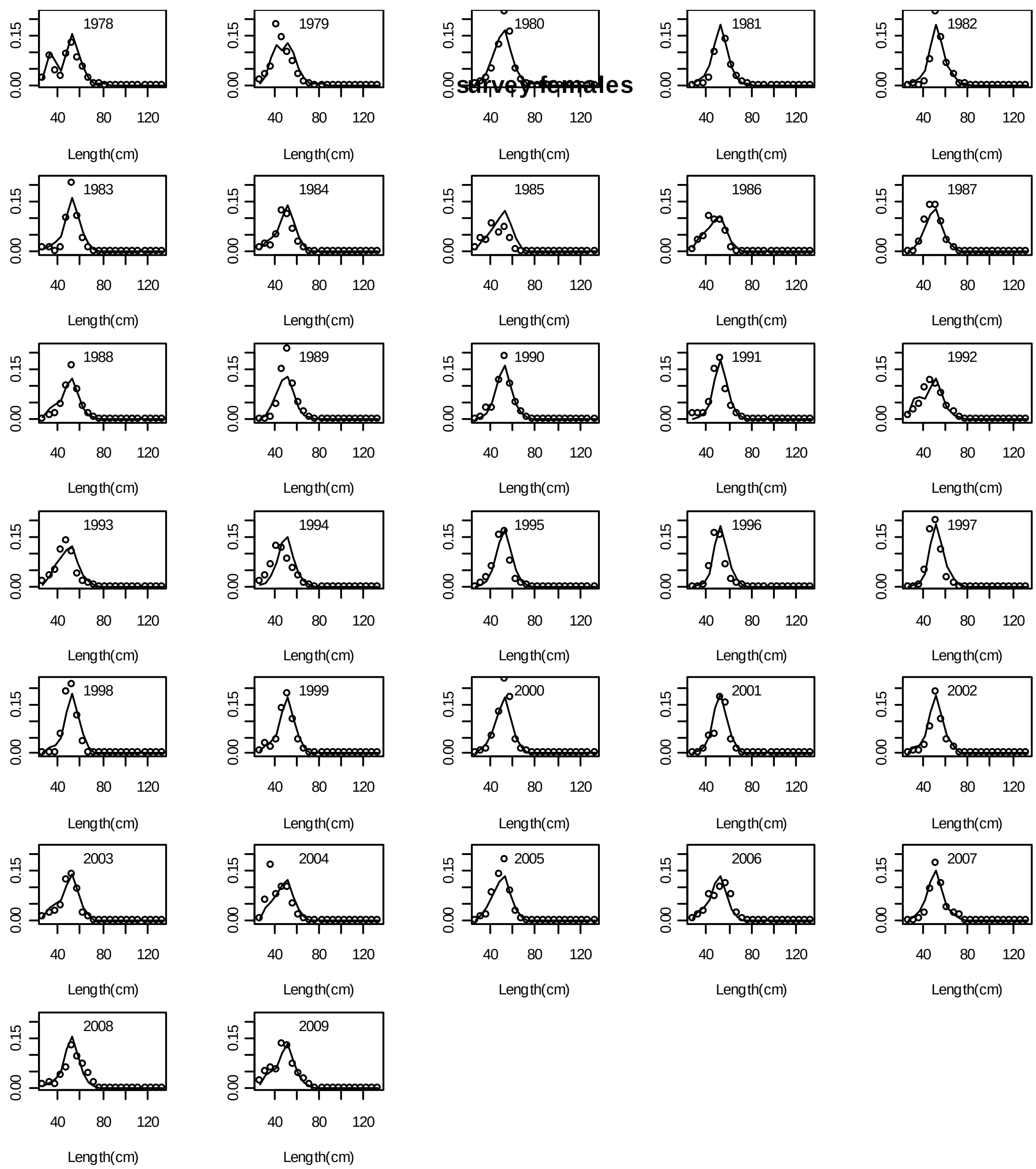


Figure 49. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

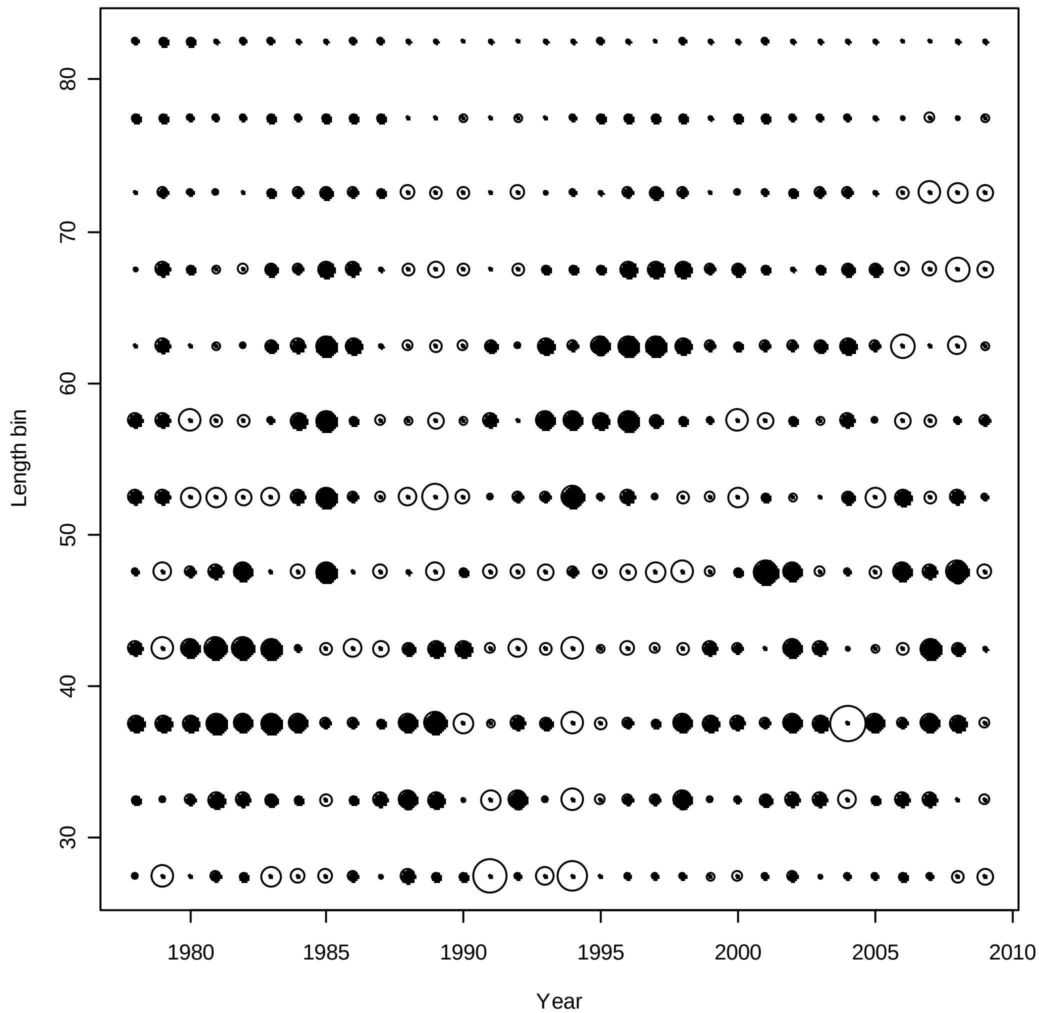


Figure 50. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

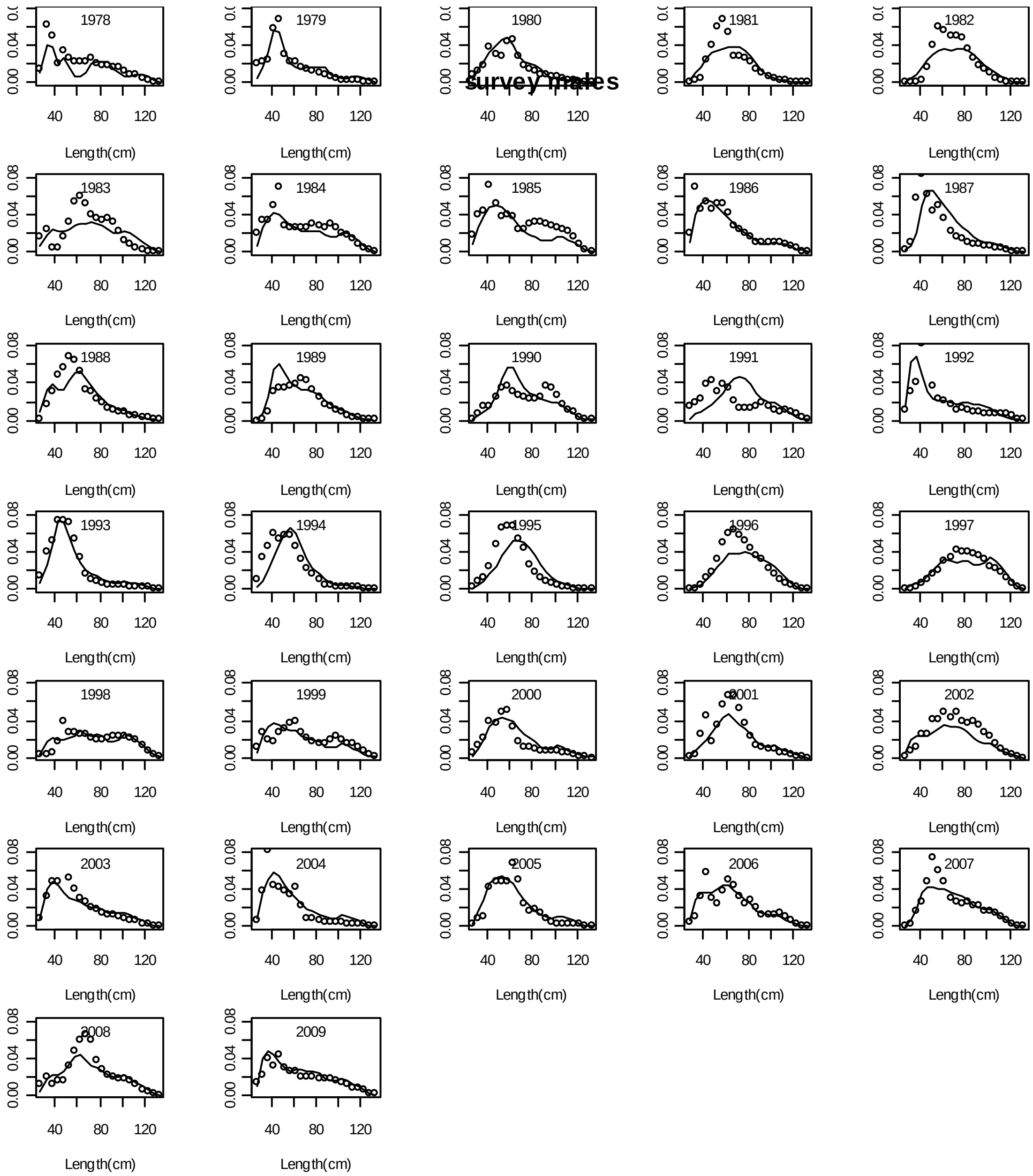


Figure 51. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

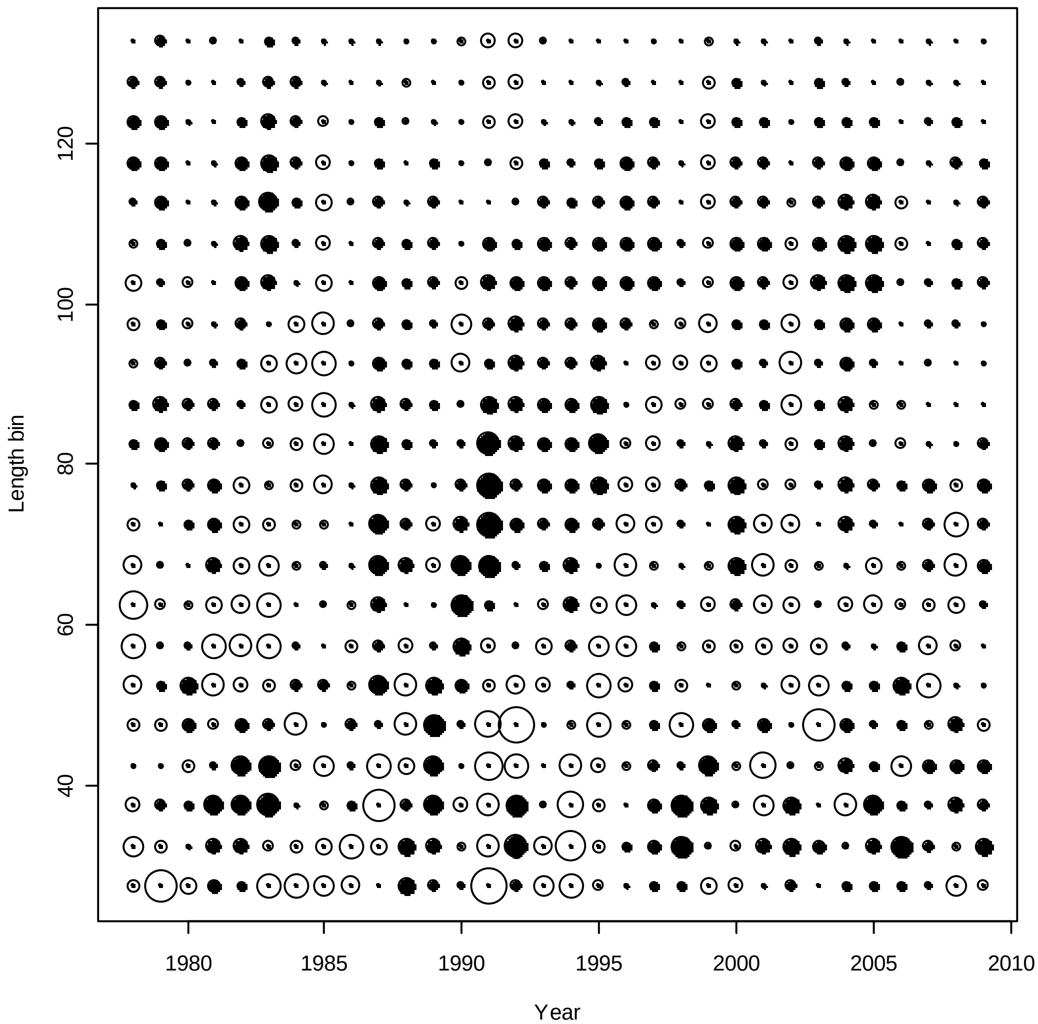


Figure 52. Residuals for fit to survey male size frequency. . Filled circles are negative residuals (predicted higher than observed).

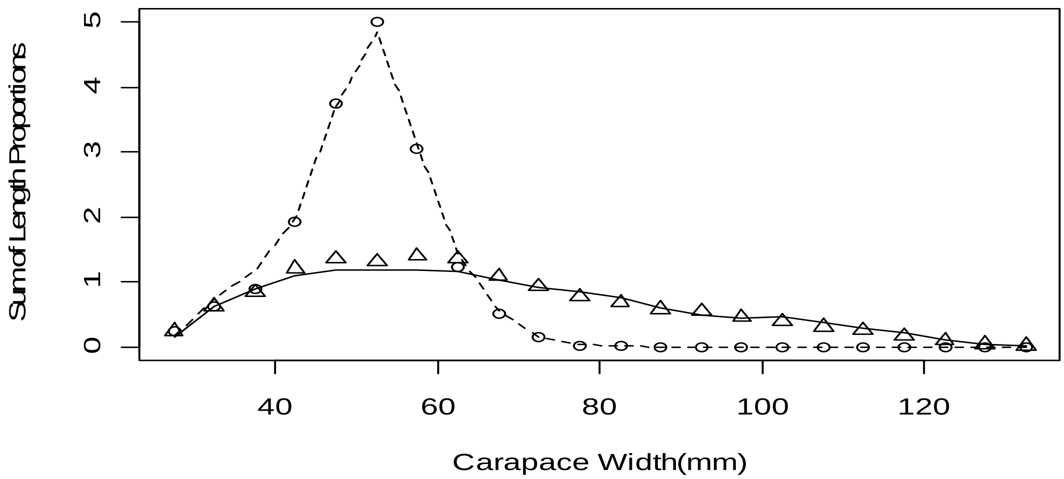


Figure 53. Summary over years of fit to survey length frequency data by sex.

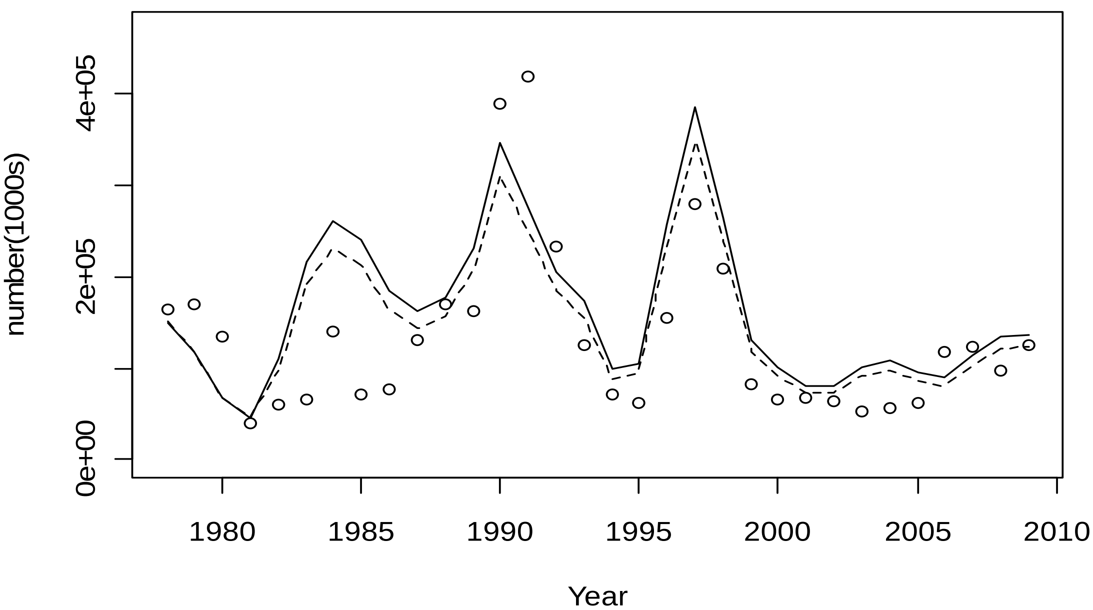


Figure 54. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

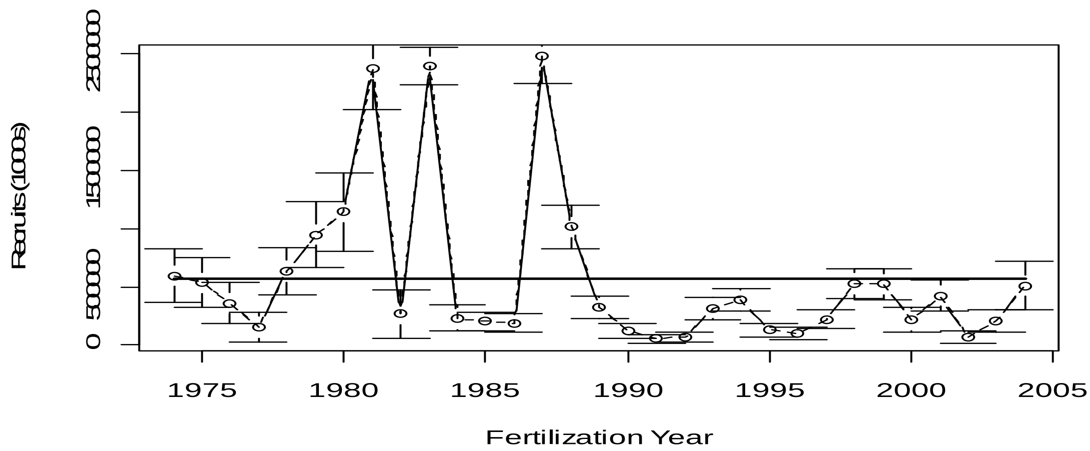


Figure 55. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

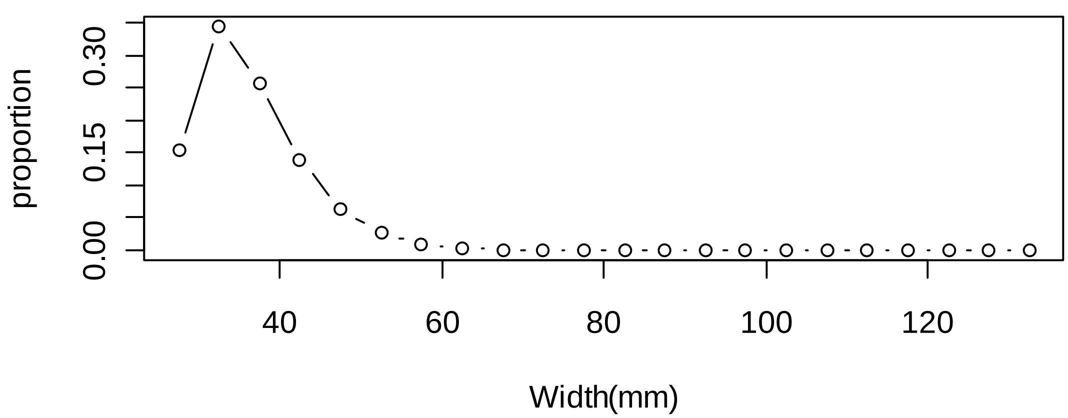


Figure 56. Distribution of recruits to length bins estimated by the model.

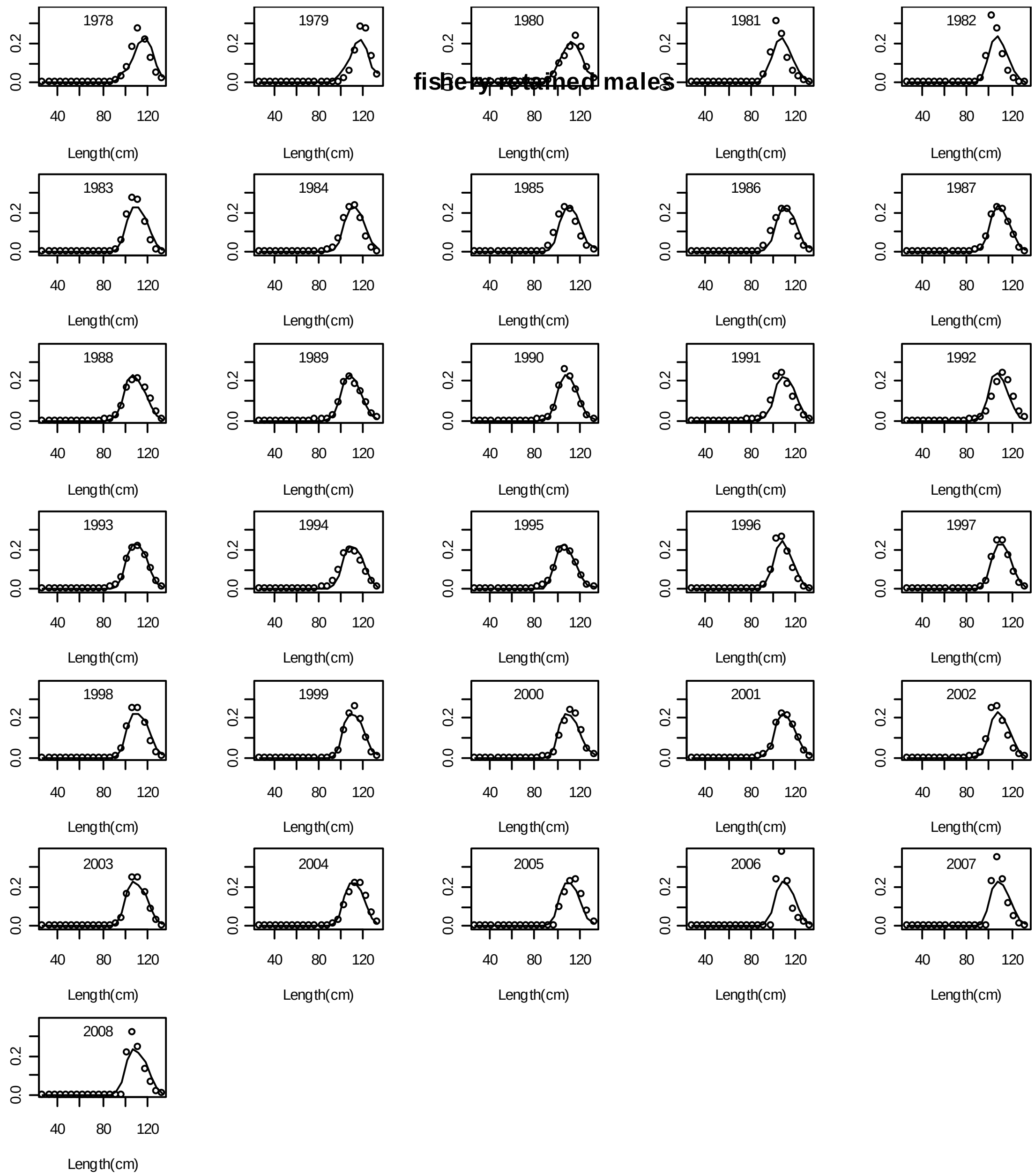


Figure 57. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

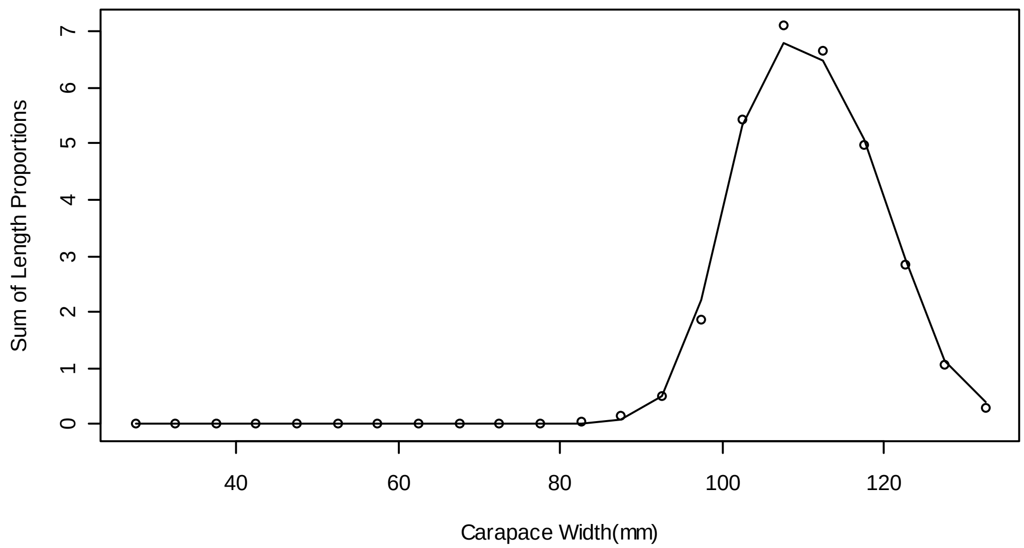


Figure 58. Summary fit to retained male length.

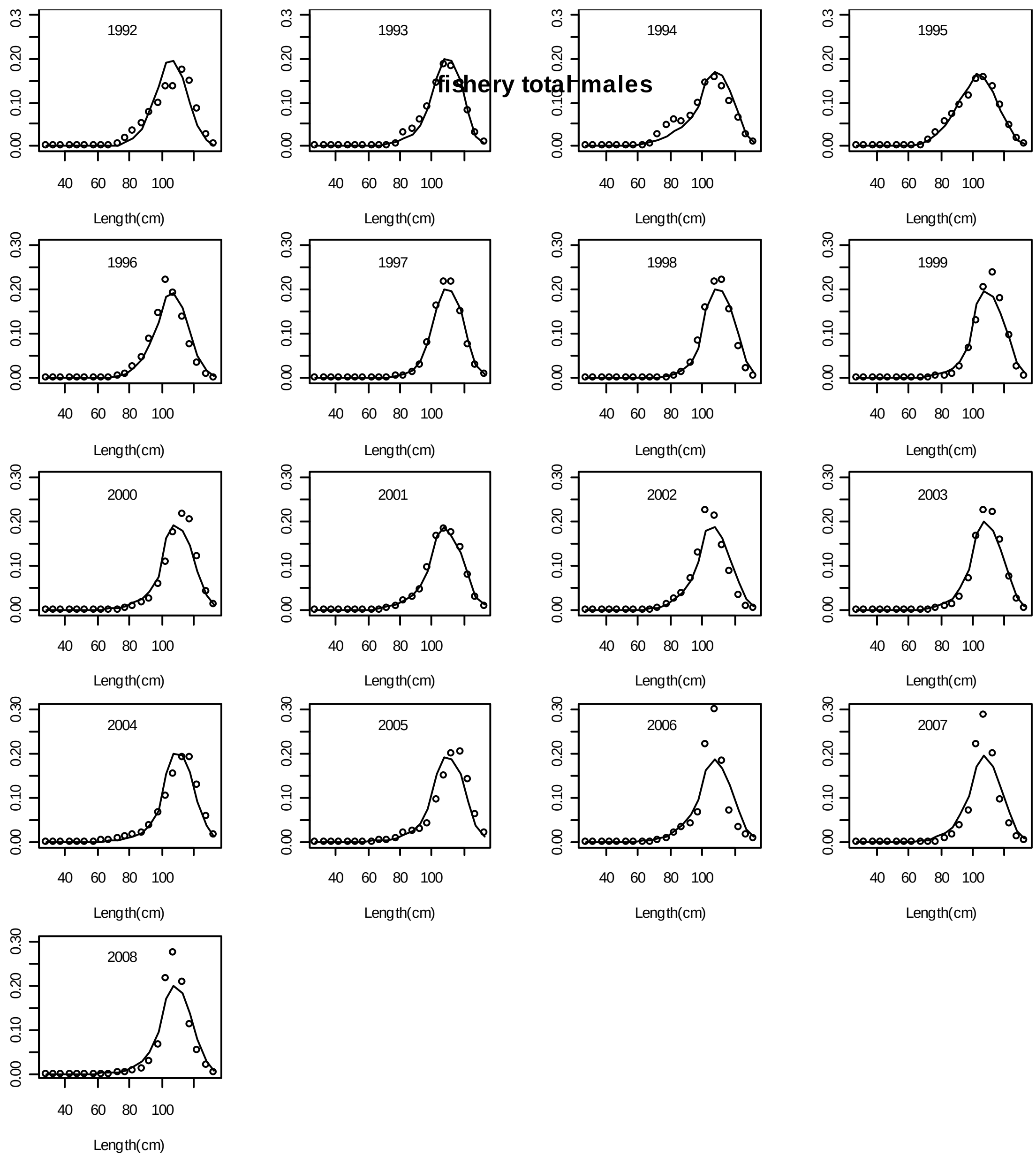


Figure 59. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

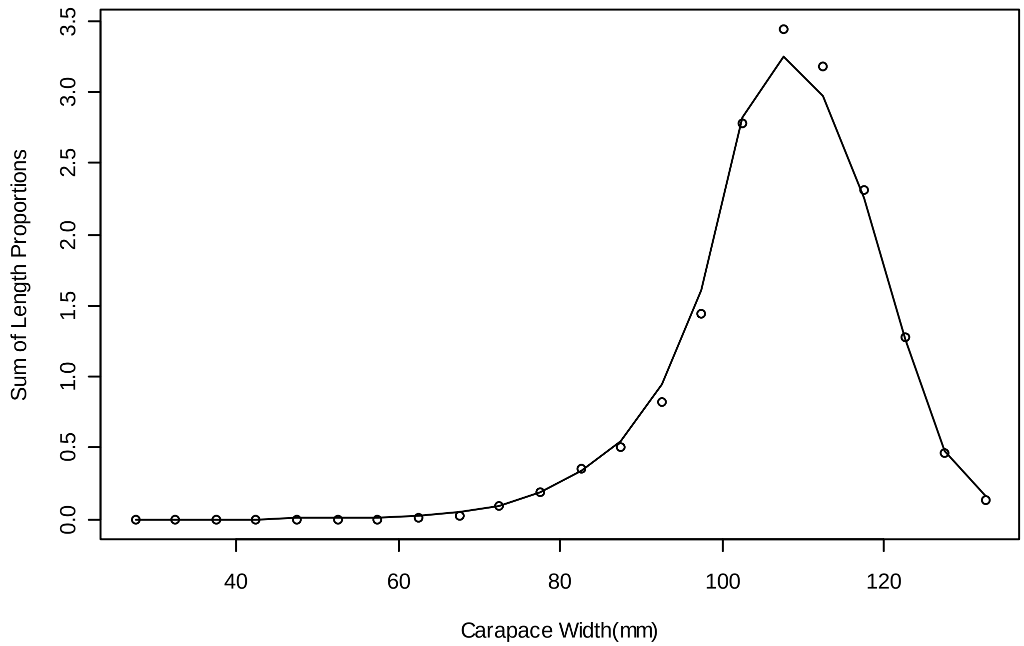


Figure 60. Summary fit to total length frequency male catch.

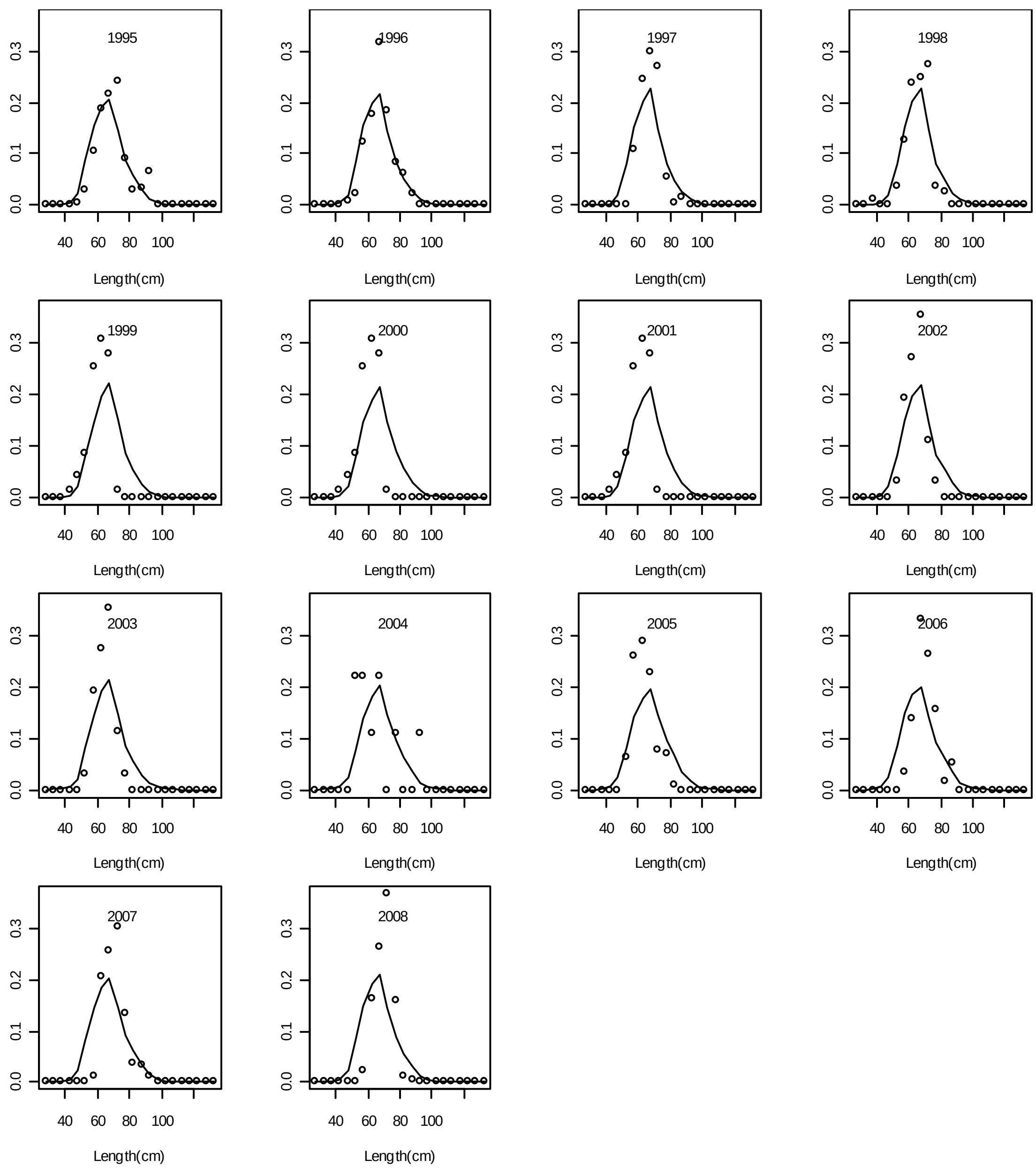


Figure 61. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

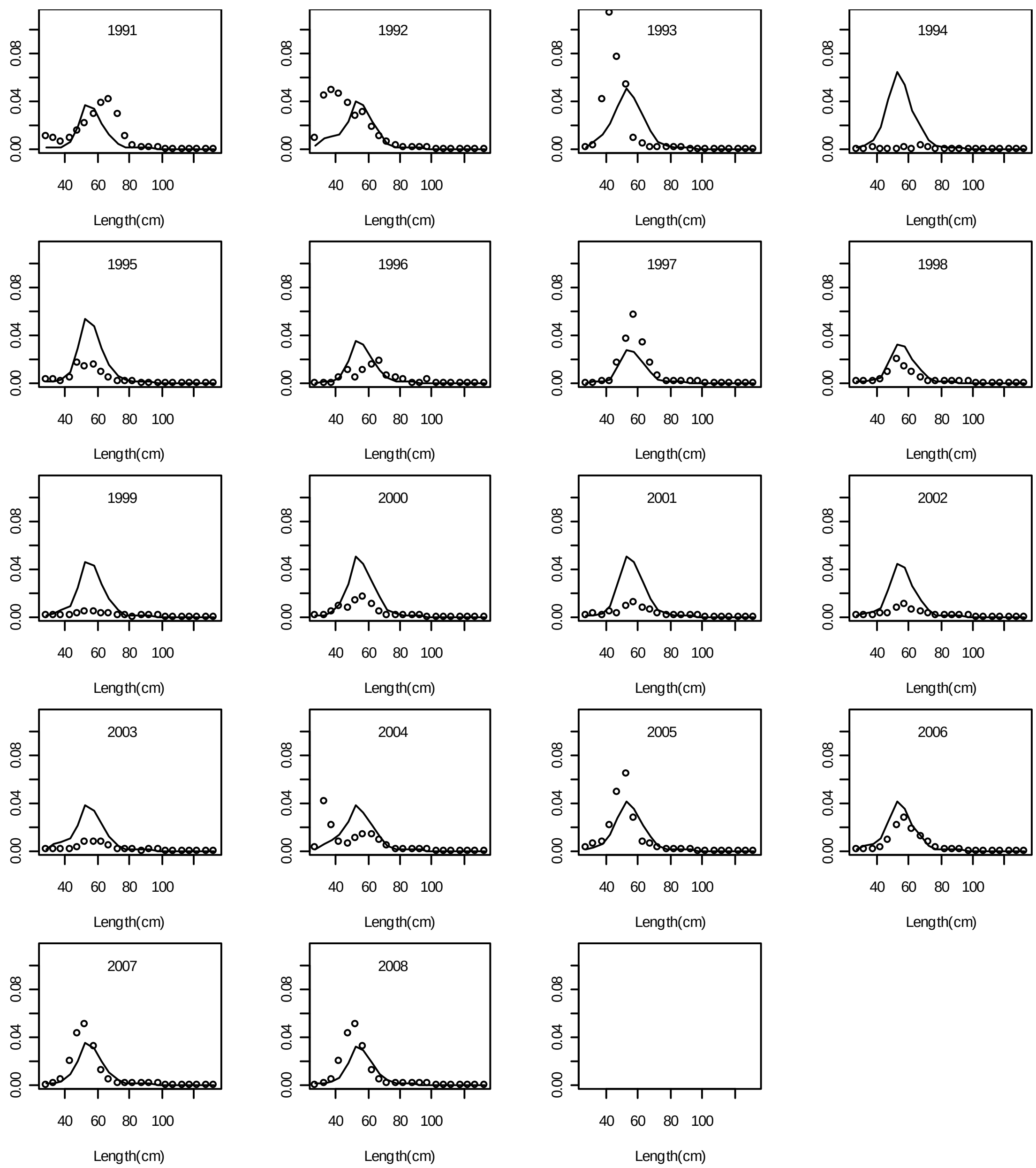


Figure 62. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

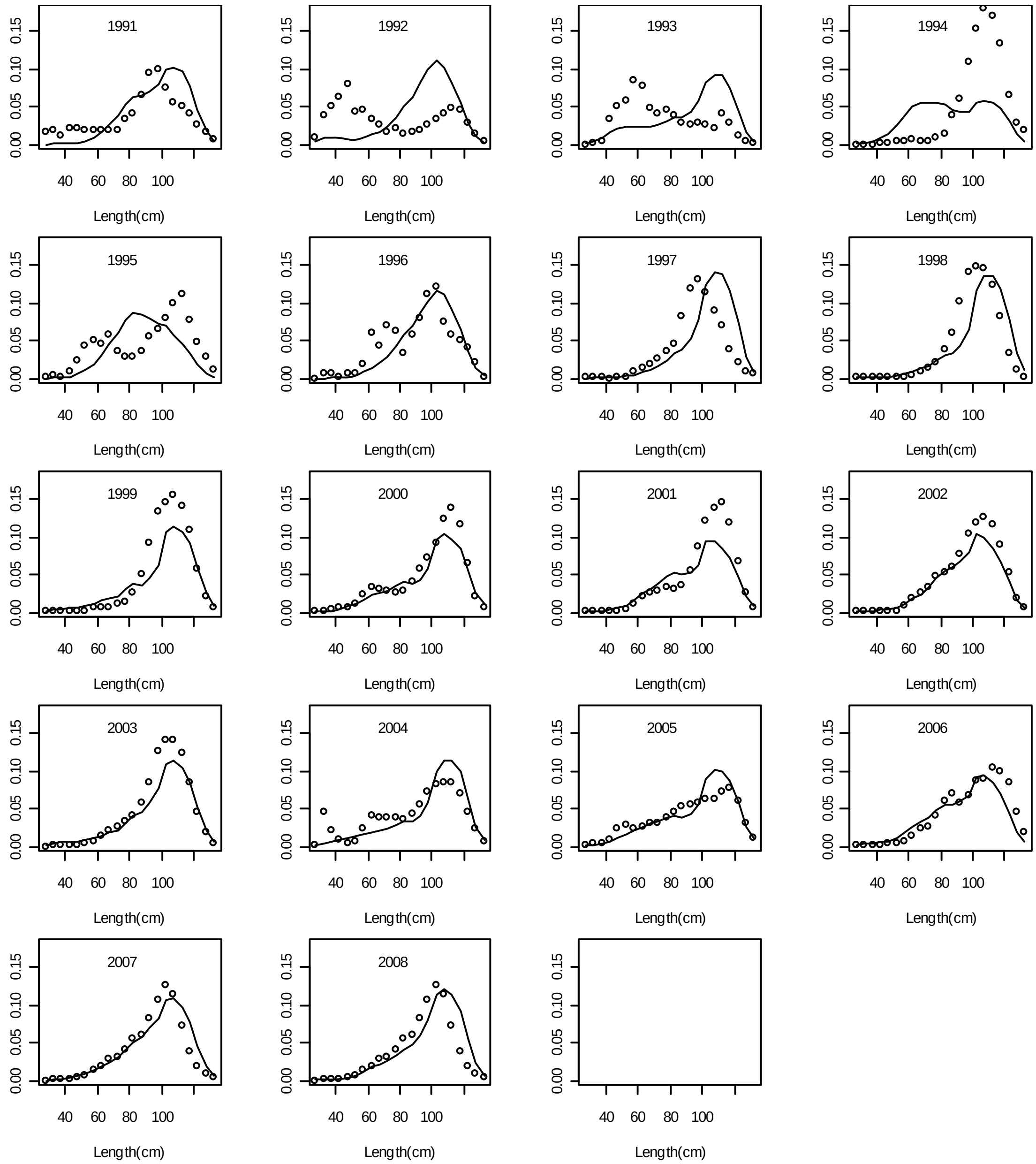


Figure 63. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

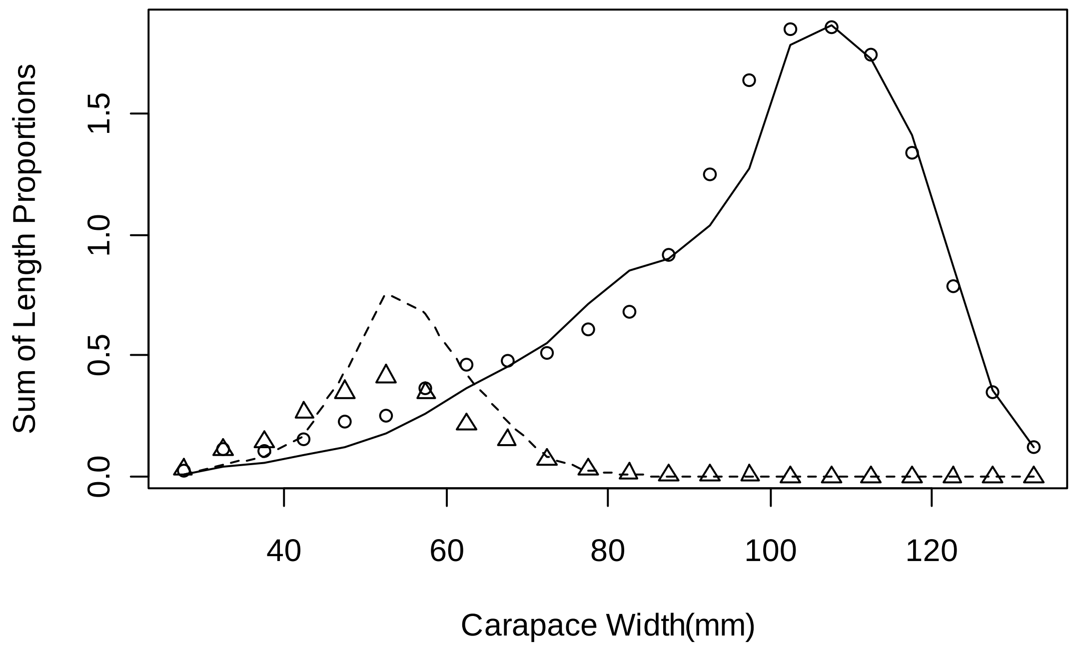


Figure 64. Summary fit to groundfish length frequency.

Figure 65. Full selection fishing mortality estimated in the model from 1979 to 2009 fishery seasons (1978 to 2008 survey years).

Figure 66. Fit to pot fishery cpue for retained males. Solid line is observed fishery cpue, dotted line model fit.

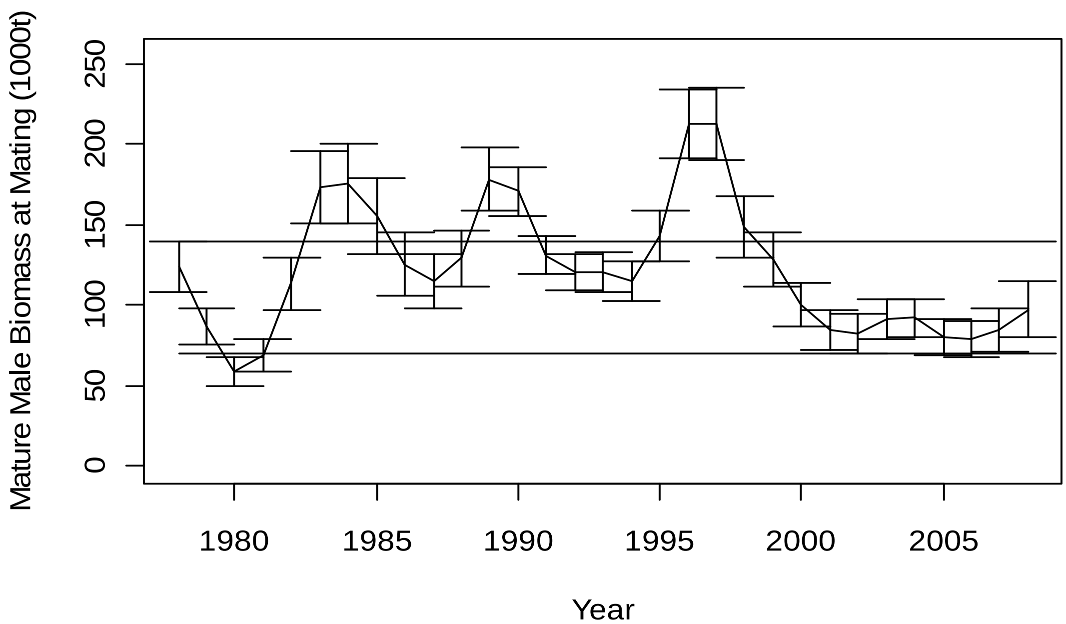


Figure 67. Mature Male Biomass at mating with 95% confidence intervals. Top horizontal line is B35%, lower line is ½ B35%.

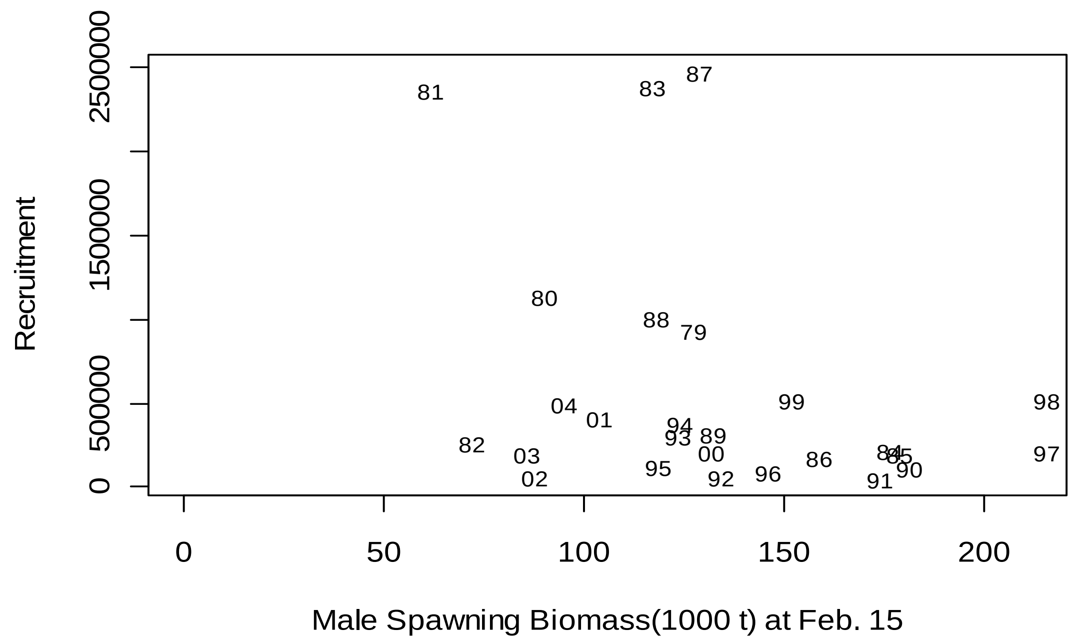


Figure 68. Spawner recruit estimates using male mature biomass at time of mating (1000s tons). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

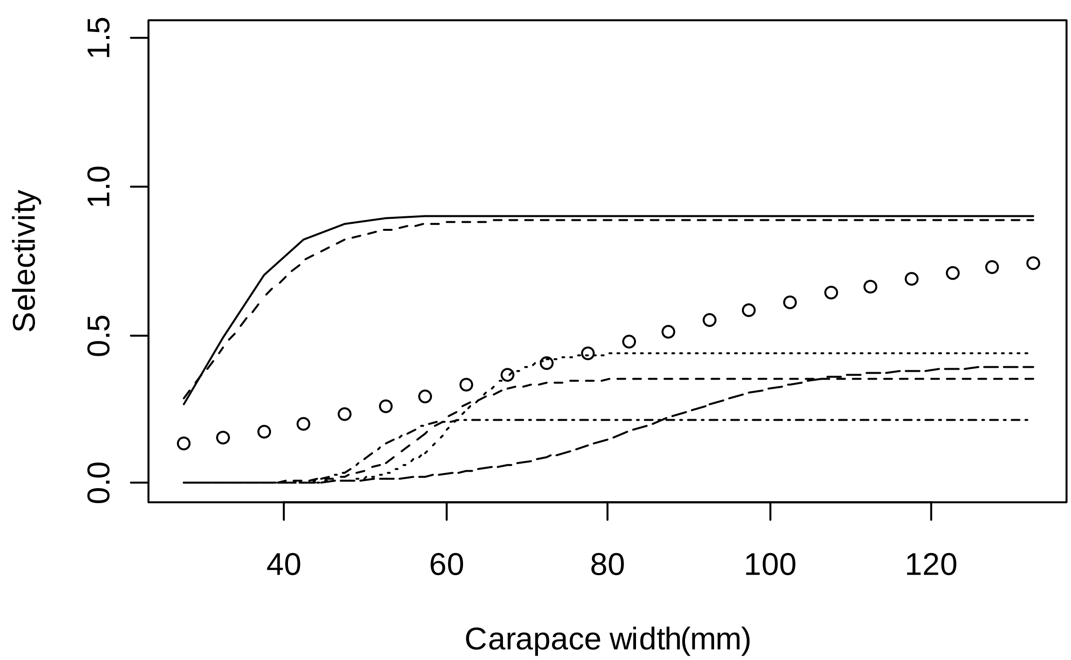


Figure 69. Survey selectivity curves entire Bering sea survey for female (upper dashed line) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton from 2009 study area data (2010) are the circles. Lower lines are survey selectivities in the study area for BSFRF male and female crab and NMFS male and female crab.

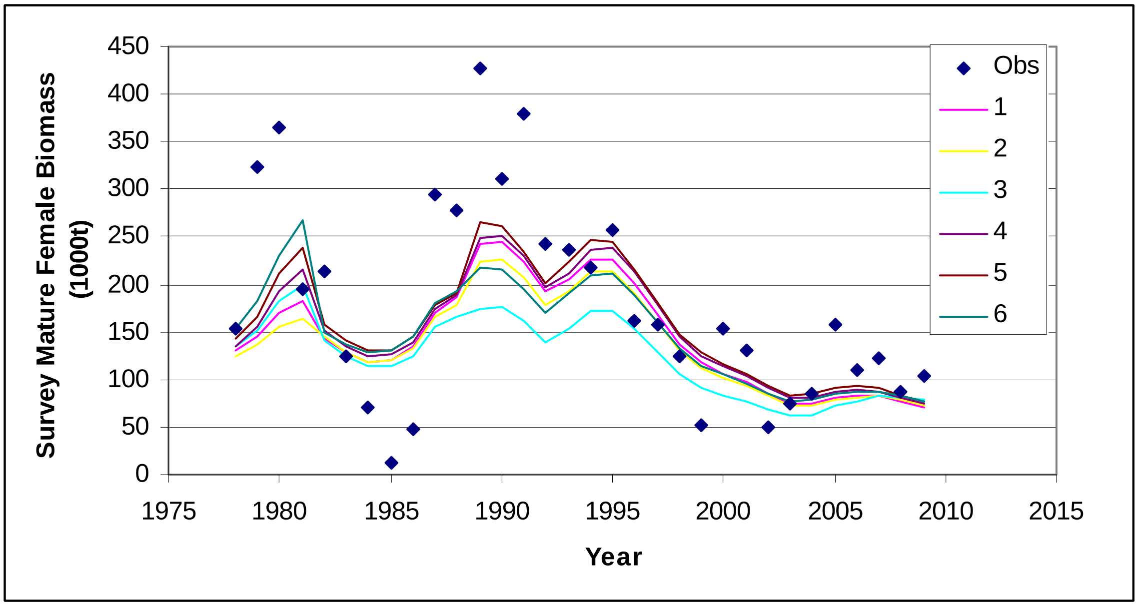


Figure 70. Fit to Female survey mature biomass for Models 1 through 6.

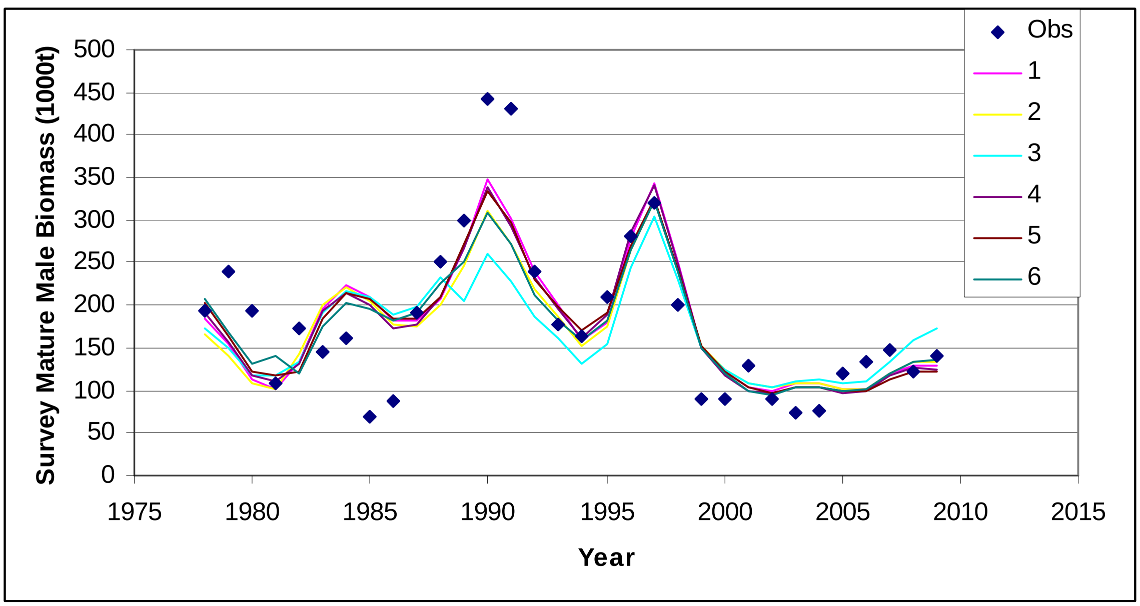


Figure 71. Fit to male survey mature biomass for Models 1 through 6.

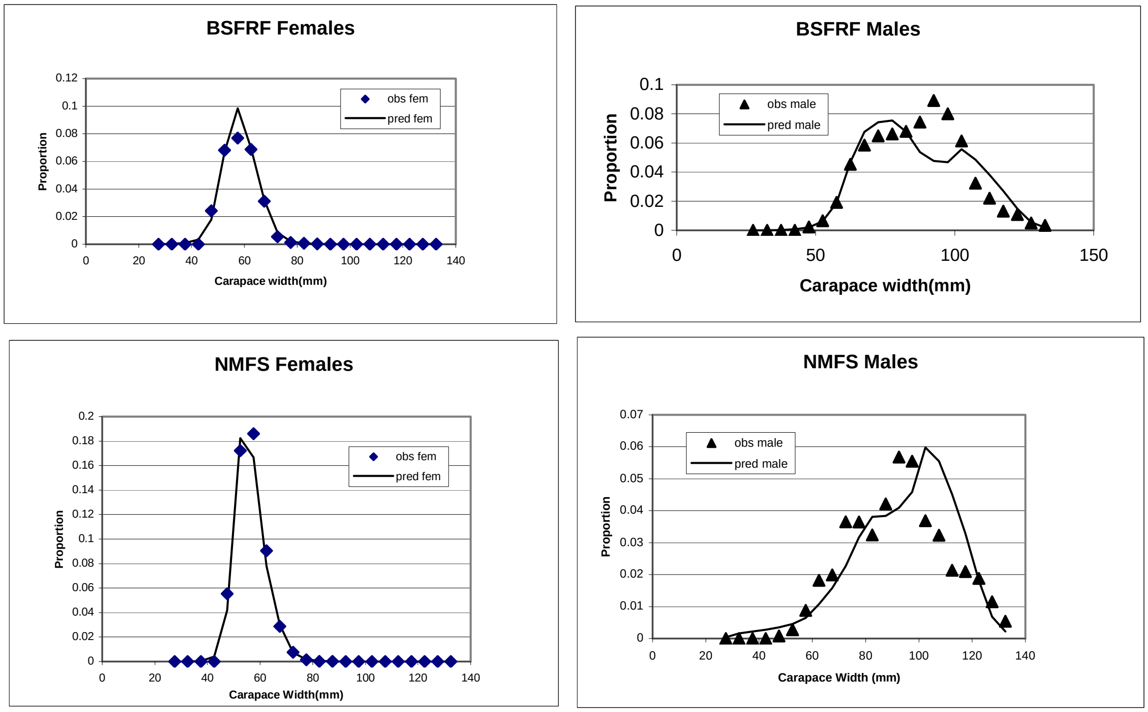


Figure 72. Base model (Model 1) fit to length frequency for BSFRF and NMFS females and males in the study area.

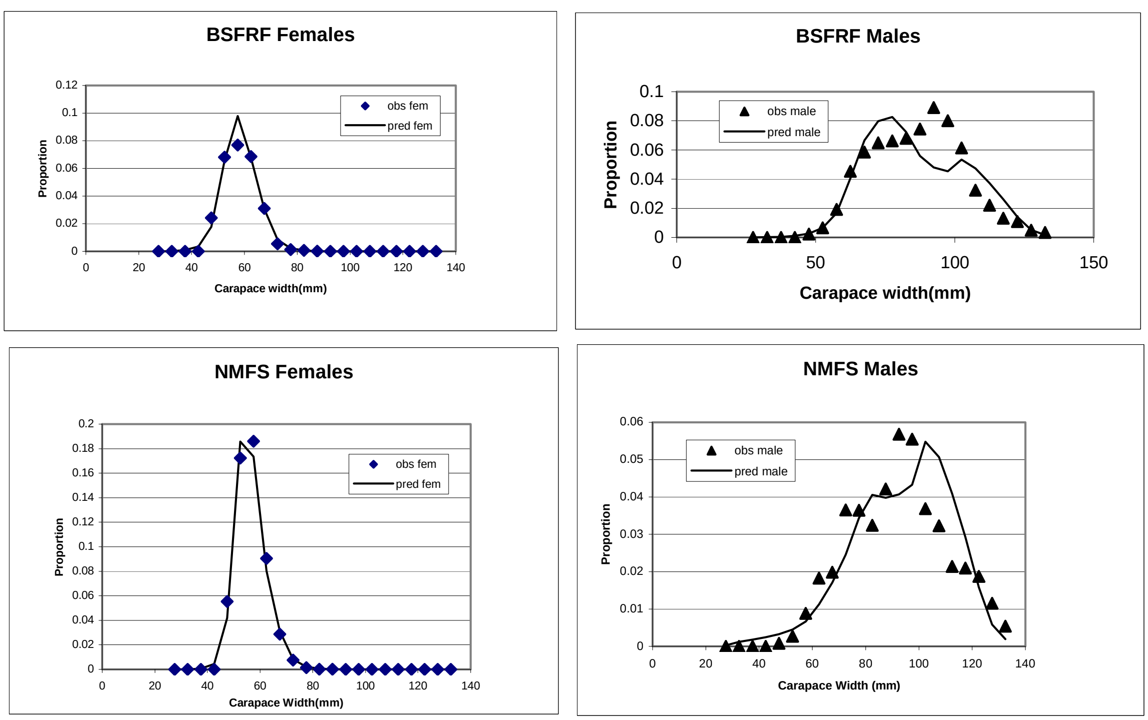


Figure 73. Somerton selectivity curve (Model 3) fit.

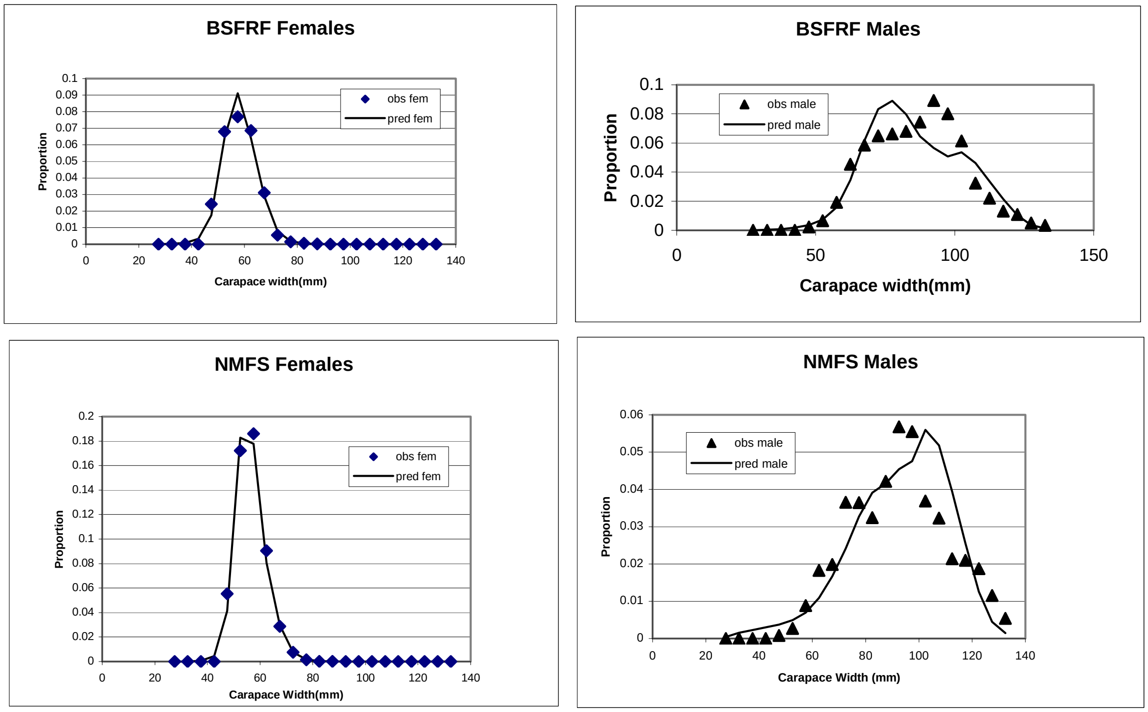


Figure 74. Model 6 (Somerton selectivity curve, male M estimated and growth parameters estimated).

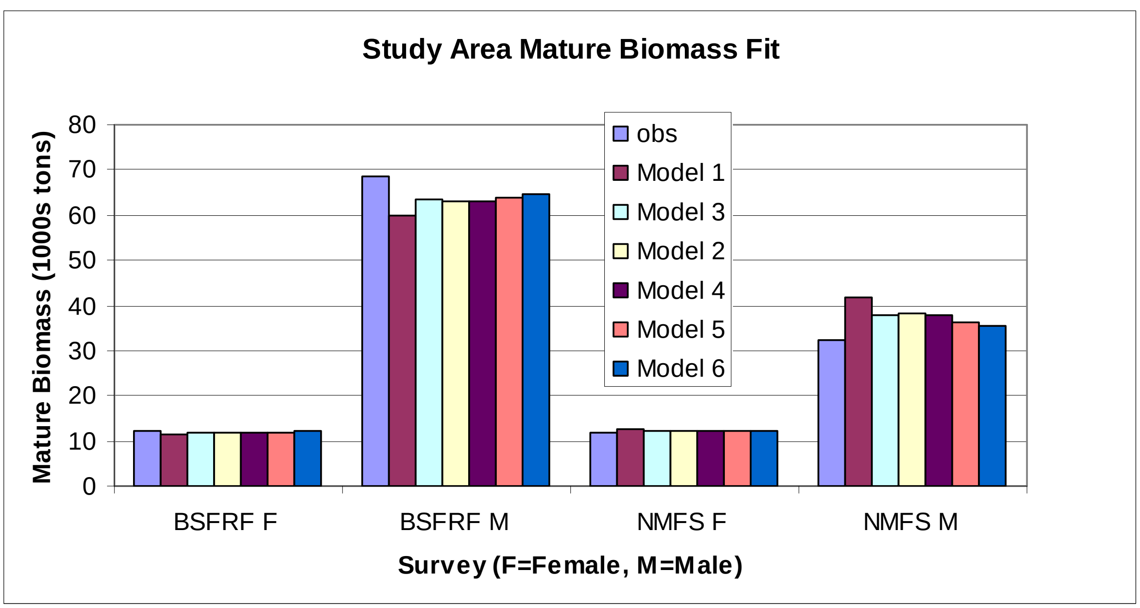


Figure 75. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data and Models 1 through 6.

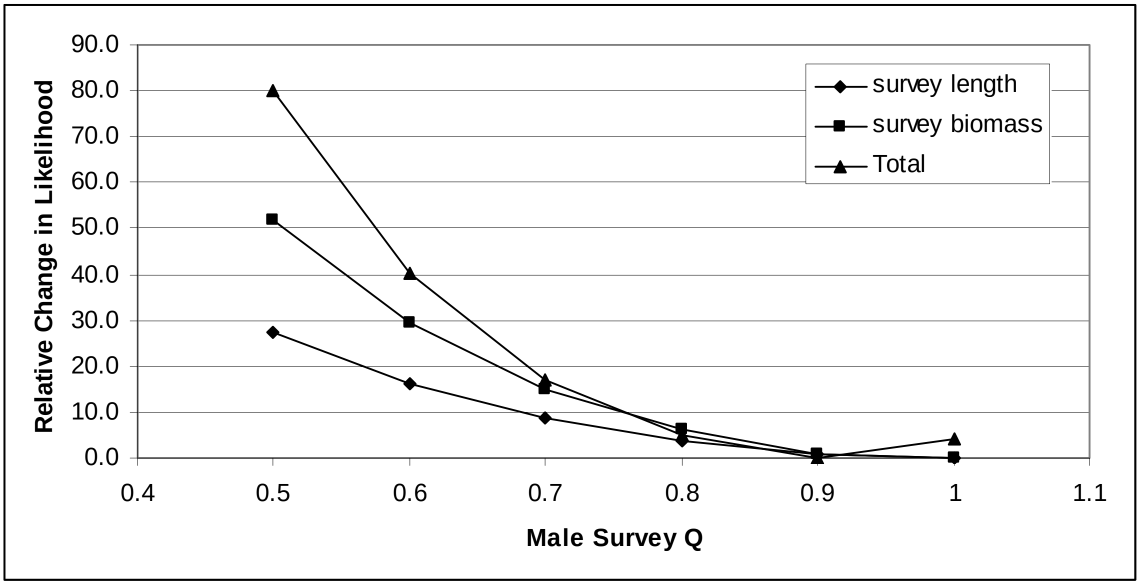


Figure 76. Likelihood profile for Model 1 (Base Model) for male survey Q. Likelihood values are relative to the lowest value for the entire Bering sea survey length and biomass likelihoods and the total likelihood.

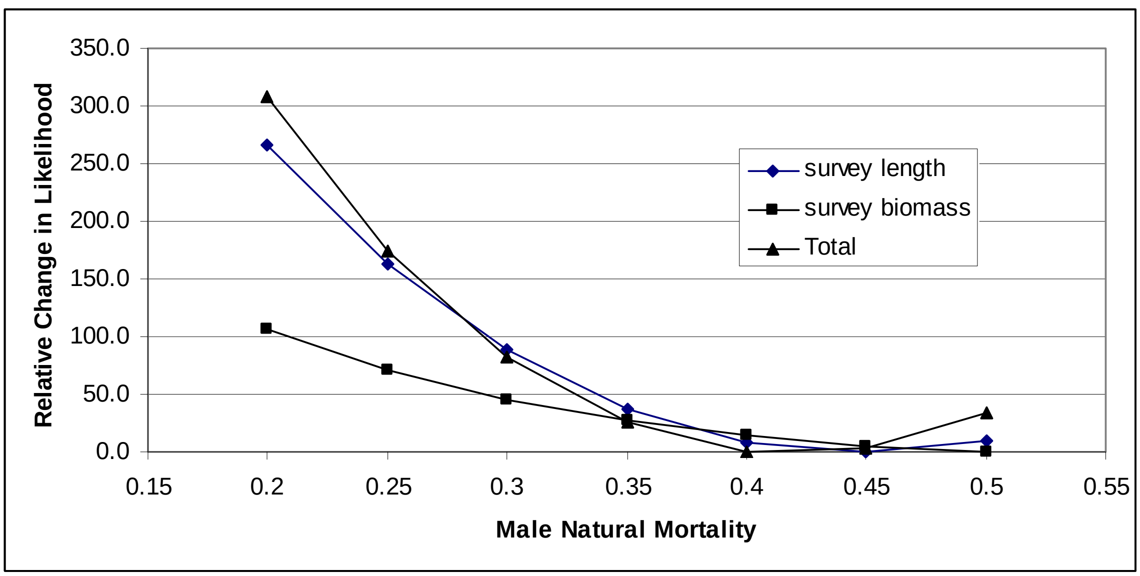


Figure 77. Likelihood profile of Male natural mortality using Model 3 (male survey selectivity fixed at the curve estimated by Somerton (2010).

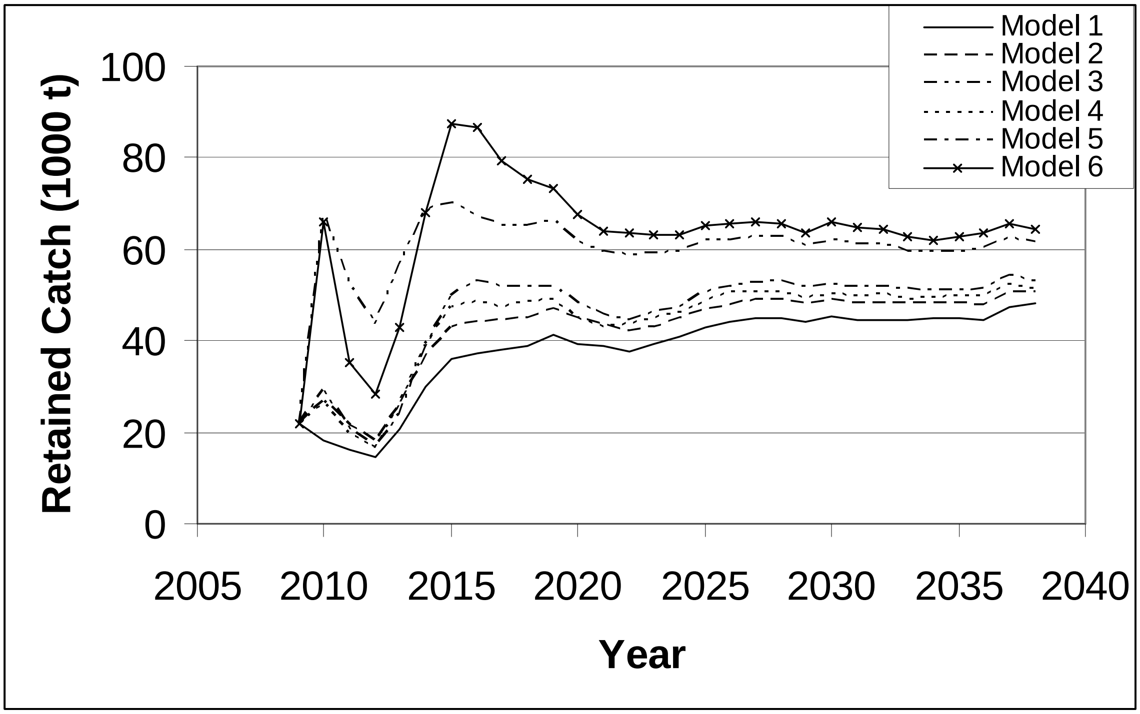


Figure 78. Projected retained catch (1000t) for Models 1 through 6 with the 75% F35% control rule.

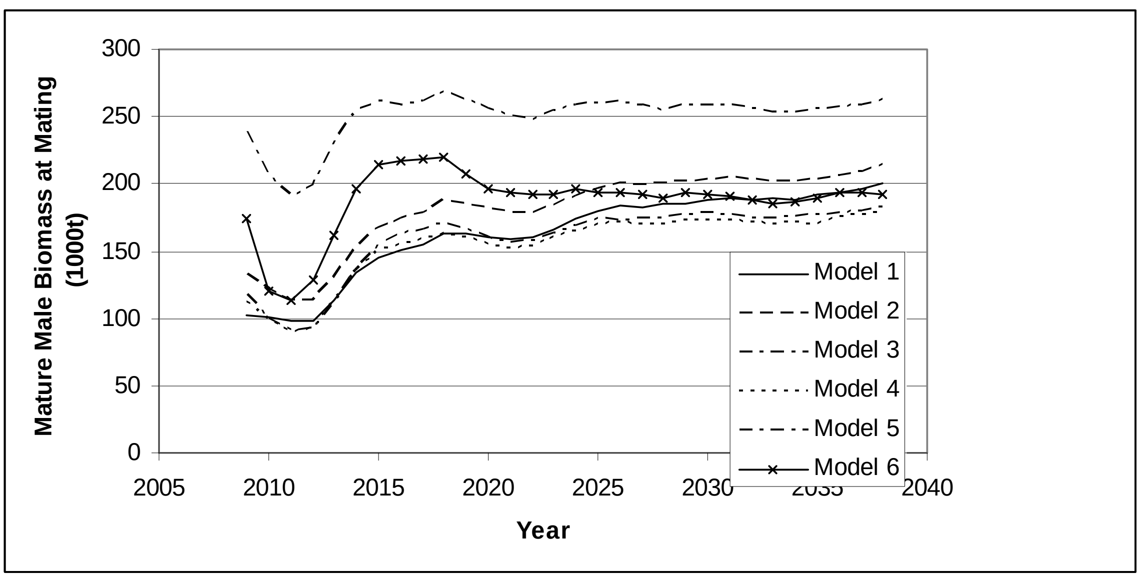


Figure 79. Projected Mature male biomass at mating (1000t) for Models 1 through 6 with the 75% F35% control rule.

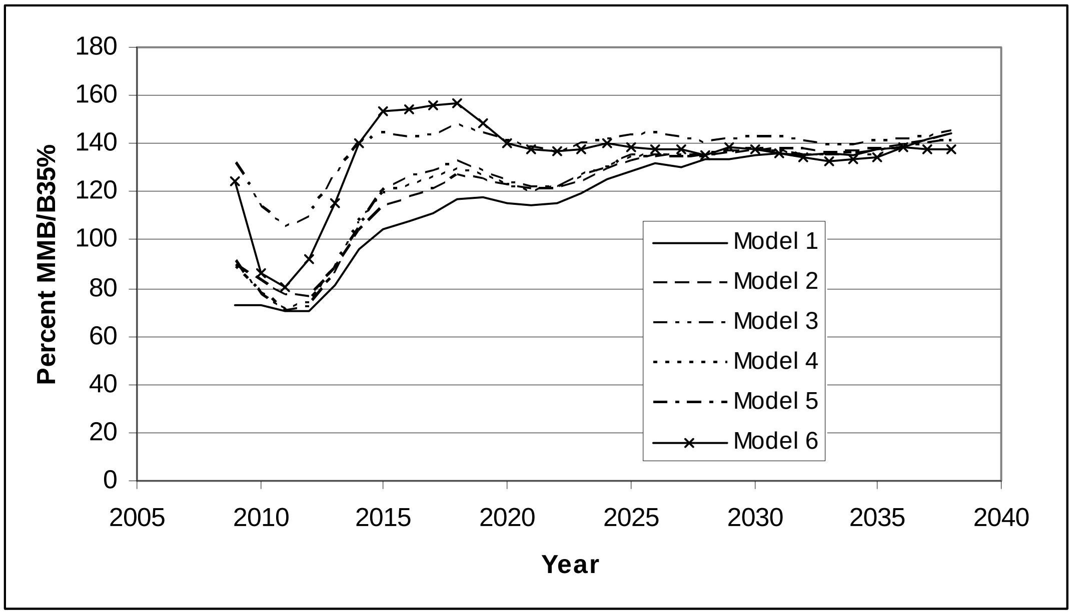


Figure 80. Percent MMB/B35% for Model 1 through 6 projections with the 75% F35% control rule.

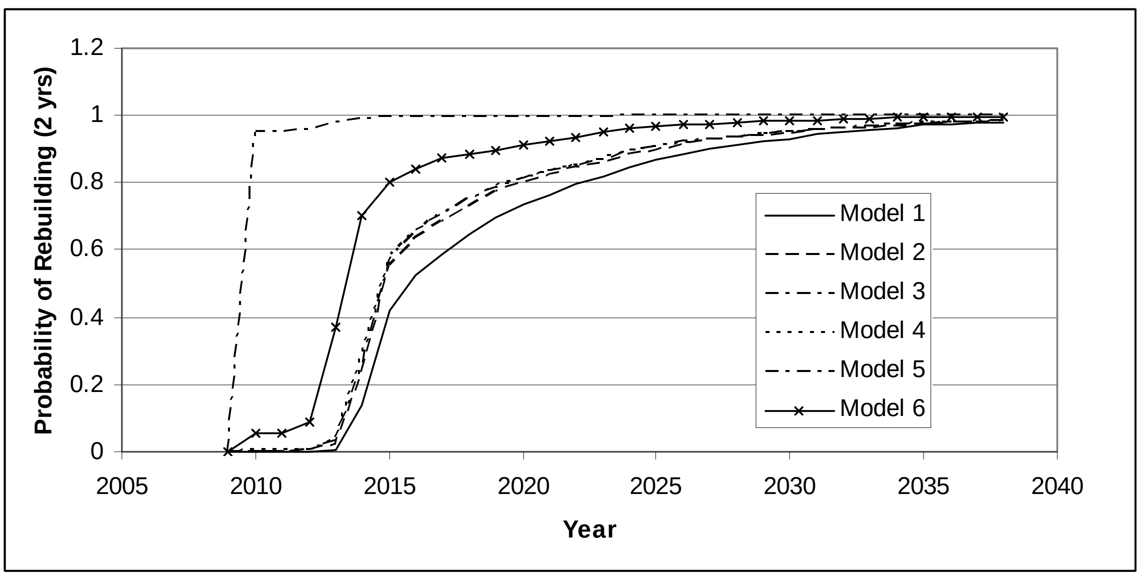


Figure 81. Probability of rebuilding (2 years above B35% in a row) for models 1 through 6 with the 75% F35% control rule.

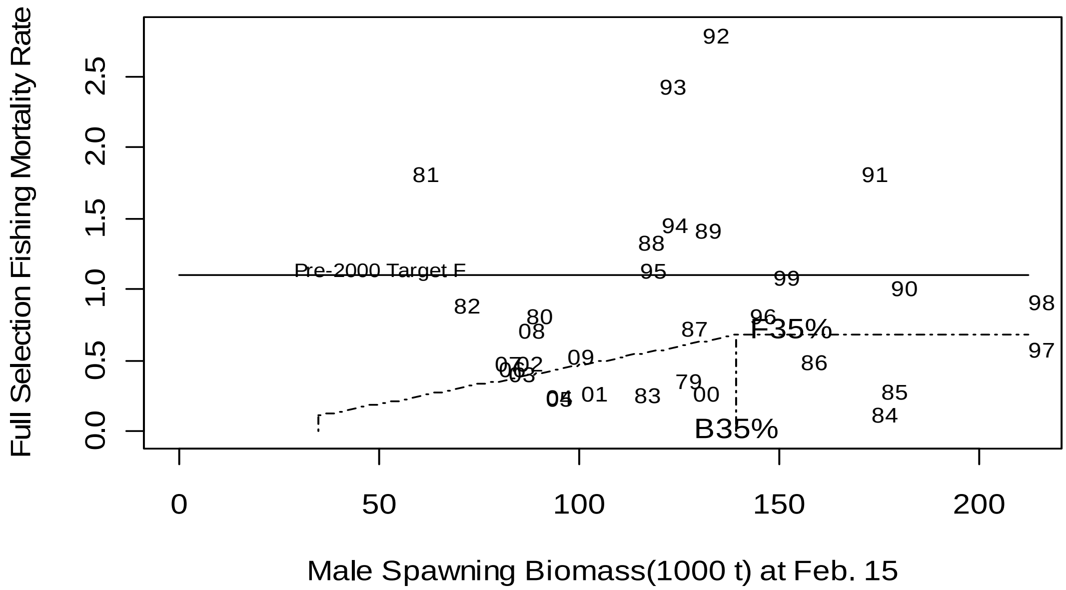


Figure 82. Fishing mortality estimated from fishing years 1979 to 2008/09 (labeled 09 in the plot). The OFL control rule (F35%) is shown for comparison. The pre-2000 target F was about 1.1. The vertical line is B35%, estimated from the product of spawning biomass per recruit fishing at F35% and mean recruitment from the stock assessment model.

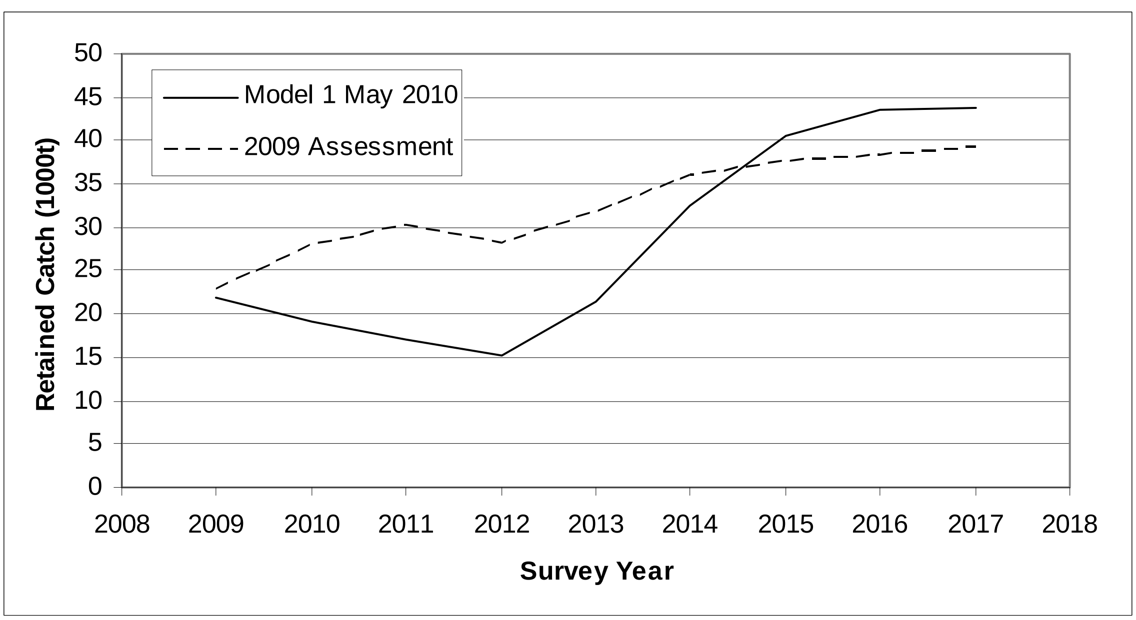


Figure 83. Comparison or mean retained catches for Model 1 and the September 2009 assessment projections fishing at 75% F35% control rule.

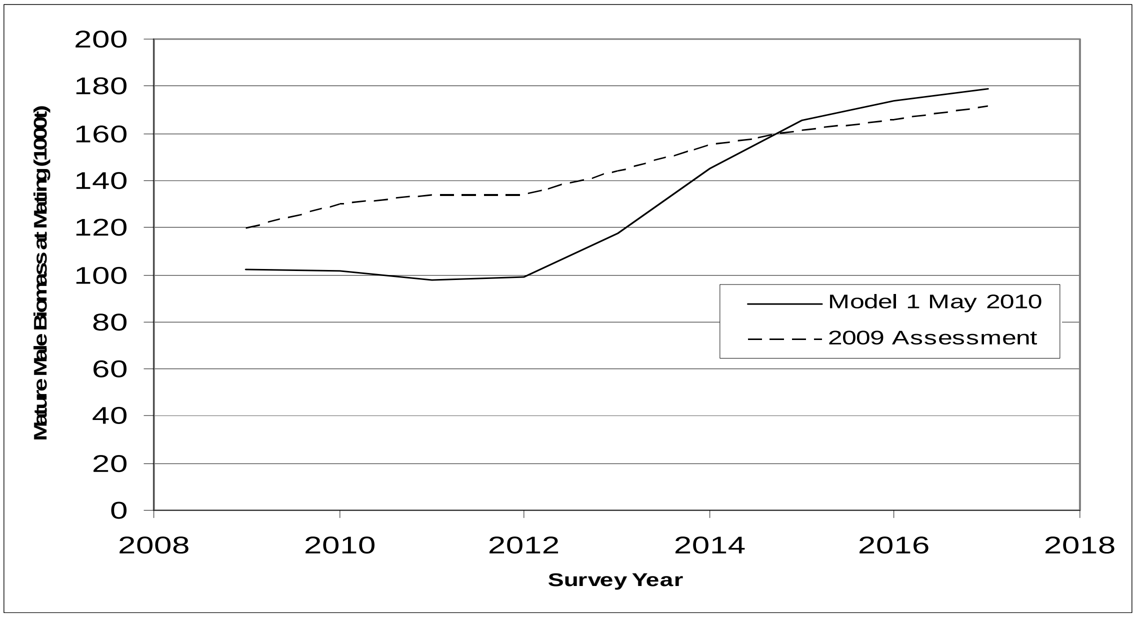


Figure 84. Comparison or mean mature male biomass at mating (1000t) for Model 1 and the September 2009 assessment projections fishing at 75% F35% control rule.

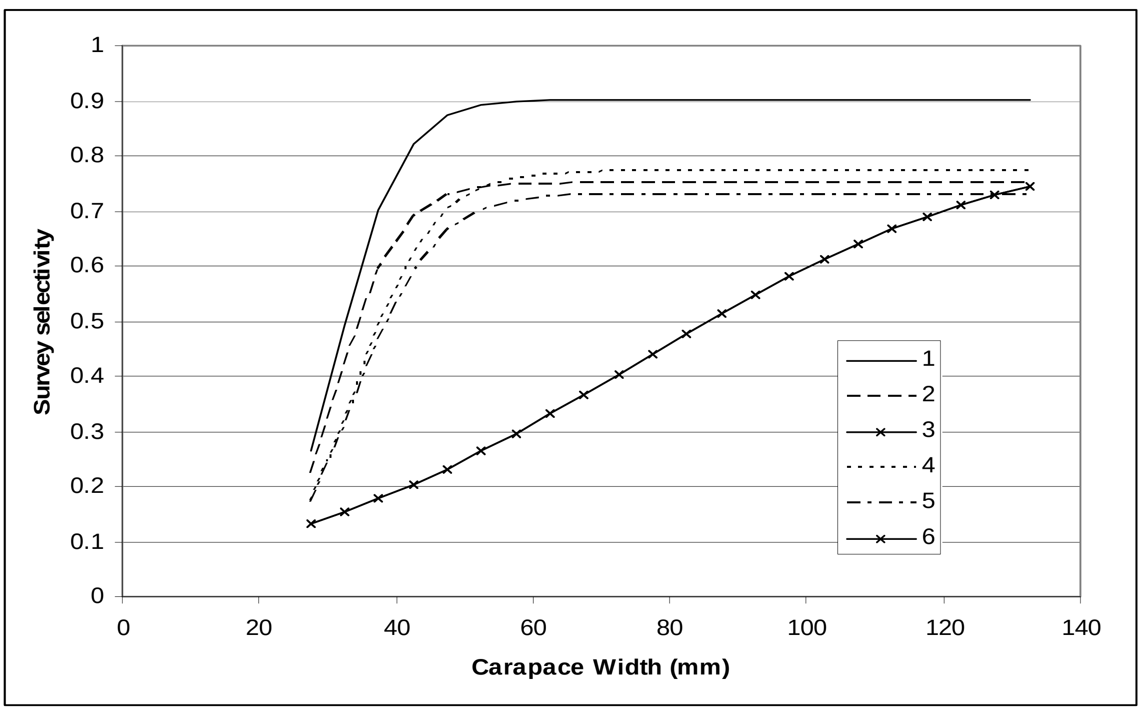


Figure 85. Survey selectivity for male crab for period 1989 to present for models 1 through 6. Models 3 and 6 have survey selectivity fixed at the Somerton estimate.

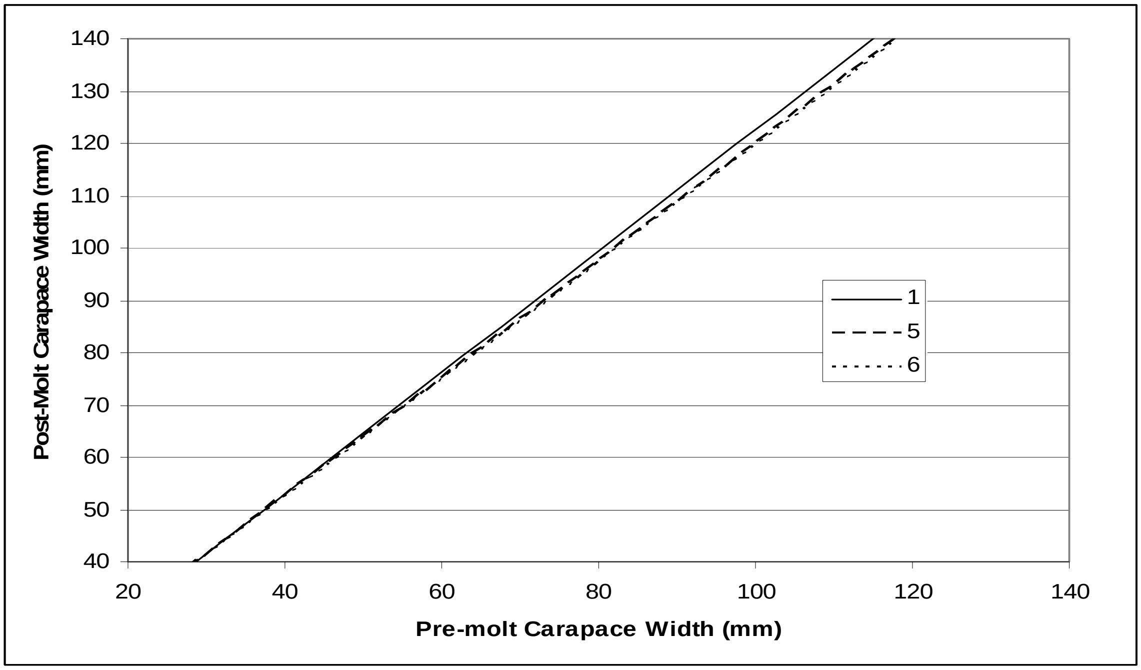


Figure 86. Male growth for Model 1 (also Models 2, 3 and 4) compared to estimated growth for models 5 and 6.

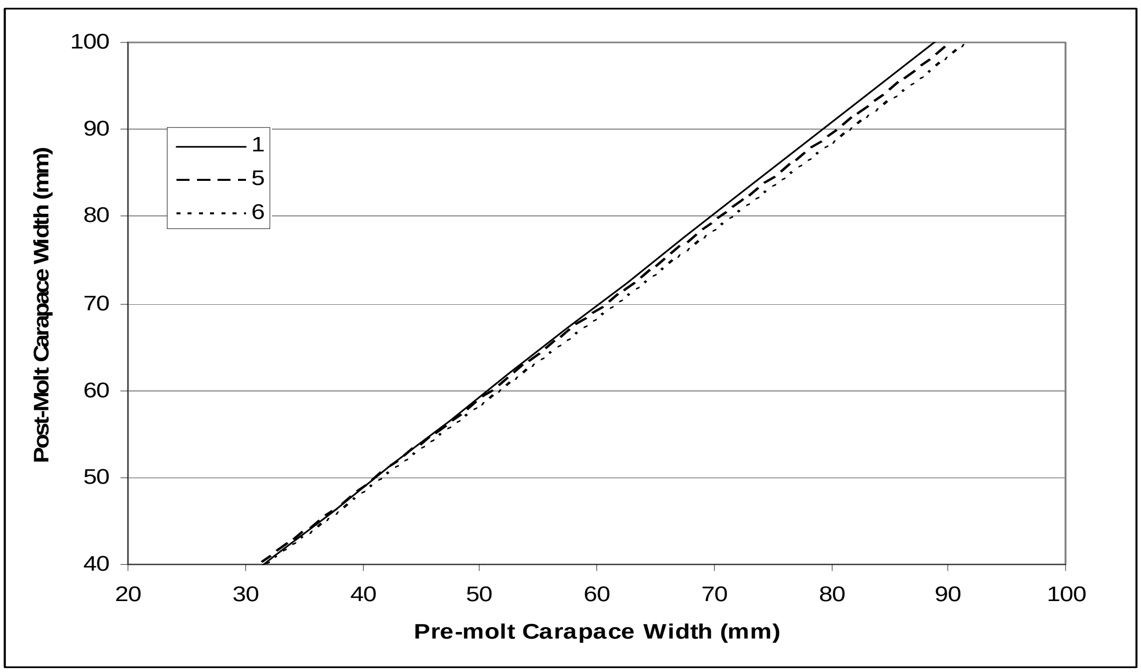


Figure 87. Female growth for Model 1 (also Models 2, 3 and 4) compared to estimated growth for models 5 and 6.

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN SPRING 2010

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

Executive Summary

1. Stock: red king crab (RKC), *Paralithodes camtschaticus,* in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades. Catches during recent years were among the high catches in last 15 years. The retained catch was about 4 million lbs less in 2009/10 than 2008/09. Bycatches from groundfish trawl fisheries were steady 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 4.5 times more abundant in 2009 than in 1985 and mature males being 3.1 times more abundant in 2009 than in 1985.
4. Recruitment: estimated recruitment was high during 1970s and early 1980s and has generally been low since 1985 (1978 year class). During 1985-2009, only estimated recruitment in 1995, 2002 and 2005 was above historical average. Estimated recruitment was extremely low during the last 3 years.
5. Management performance:

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		79.9[A]	18.3	18.5	22.7	N/A
2006/07		82.0[B]	15.5	15.7	17.2	N/A
2007/08		85.9[C]	20.4	20.5	23.2	N/A
2008/09	37.6[D]	87.8[D]	20.4	20.3	23.1	24.2
2009/10	34.3[D]	95.2[D]	16.0	16.0	TBD	22.6

The stock was above MSST in 2009/10 and is hence not overfished. Overfishing did not occur during the 2009/10 fishing year.

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2006
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2007
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2008
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2009

6. Basis for the OFL:

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

Average recruitments during three periods were used to estimate $B_{35\%}$: 1968-present, 1985-present, and 1995-present. We recommend using the average recruitment during 1995-present, which was used in 2008 to set the overfishing limits. There are several reasons for supporting our recommendation. First, estimated recruitment was higher after 1994 than during 1985-1994 and there was a potential regime shift after 1989 (Overland et al. 1999), which corresponded to recruitment in 1995 and later. Second, recruitments estimated before 1985 came from a potentially higher natural mortality than we used to estimate $B_{35\%}$. Third, high recruitments during the late 1960s and 1970s 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 (see the section on Ecosystem Considerations). Stock productivity (recruitment/mature male biomass) was much higher before the 1976/1977 regime shift: the mean value was 1.842 during 1968-1977 and 0.374

during 1978-2009. The Crab Plan Team selected the mean recruitment during 1995-present for setting the overfishing limits for the 2009 season.

A. Summary of Major Changes

1. Catch and bycatch were updated through May 2010.
2. Nine scenarios were compared:

	1	2	3	4	5	6a	6b	7a	7b
M	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Additional mortality during 1980-84 :									
Males	0	0.58	0.58	0	0.59	0.42	0.42	0.53	0.54
Females	0	0.90	0.89	0	0.93	0.79	0.80	0.86	0.86
Additional mortality during 1976-79 and 1985-93:									
Males	0	0	0	0	0	0	0	0	0
Females	0	0.04	0.04	0	0	0.06	0.06	0.05	0.05
Additional bycatch mortality during 1980-84:									
Trawling	0	0	0	0.16	0	0	0	0	0
Tanner	0	0	0	1.20	0	0	0	0	0
BSFRF	Y	N	Y	Y	Y	Y	N	Y	N
Mollt1	N	N	N	N	N	Y	Y	N	N
Molt2	N	N	N	N	N	N	N	Y	Y
Number of parameters estimated:									
	227/229	231	231	230	230	273	273	235	235
Log.Like.	NC	55213	55205	55275	55180	55802	55806	55470	55478
Estimated legal male abundance in 2009 (millions):									
	NA	18.13	15.63	15.33	15.48	13.53	15.20	12.50	14.47

BSFRF: use of Bering Sea Fisheries Research Foundation survey data
Molt1: estimating sizes at 50% molting probability each year for male crabs.
Molt2: Three levels of molting probability for males.
NC: not converge.

B. Responses to SSC and CPT Comments

Response to CPT Comments (from May 2009)

"The Plan Team identified the need for a table showing which parameters are estimated within the assessment and which are fixed, as well as CVs or some other measure of uncertainty. It was also suggested that future assessments include some analysis of model sensitivity to different weightings (lambda's). The magnitudes of lambdas have a direct affect on projected biomass and likelihood profiles because increasing lambdas impact the widths of the profiles. In terms of evaluating uncertainty in some of the forcing parameters, the team recommends that the authors provide a plot of a likelihood profile for some of the parameters such as trawl survey catchability and M. It was also recommended that the author consider parameter estimation in a fully Bayesian context. Figures of standardized residuals should be provided, along with providing clarification on whether the residual patterns reflect a cohort effect or a growth effect. The team also requested clarification of the effect of aging errors on molt probability. The team recommends that a column be added in the catch table for total catch (all sources of catch) for all years."

All these recommendations have been addressed in the September 2009 SAFE except (1) likelihood profiles for natural mortality and survey catchability and (2) Bayesian approach. The likelihood profiles were estimated in the SAFE report in 2008. Due to time constraint, the likelihood profiles and Bayesian approach are not included in this report. They will be included in the report in May 2011.

Response to CPT Comments (from September 2009)

"For the May 2010 assessment, the CPT requests that model scenarios 1, 2 and 3 be reexamined. The Plan Team identified the need for all model input data to be tabulated. The CPT appreciates the preliminary analysis of model sensitivity to different weightings (lambdas). The magnitudes of lambdas have a direct affect on projected biomass and likelihood profiles because increasing lambdas impact the widths of the profiles. In terms of evaluating uncertainty in some of the forcing parameters, the team recommends that the authors provide a plot of a likelihood profile for some of the

parameters such as trawl survey catchability and M. It was also recommended that the author consider parameter estimation in a fully Bayesian context. Figures of standardized residuals were provided in the current assessment and the CPT encourages further analysis of some of the residual patterns for possible cohort or growth effects. The team also requested clarification of the effect of aging errors on molt probability."

Due to time constraint, main effort was focusing on model scenarios in this report. When addressing CIE review comments in the future, we will further examine weighting and survey catchability and natural mortality parameters. Residual patterns were discussed in the report.

Response to SSC Comments specific to this assessment (from June 2009)

"The SSC appreciates the authors' responsiveness to previous requests and the improved documentation of the model, model results, and much of the underlying data. We recognize that the Bristol Bay red king crab model is one of the best developed crab stock assessments and encourage further development of the model in an attempt to move the stock to an eventual Tier 1 designation. However, a number of issues remain to be resolved, and the SSC offers the following points for consideration in the 2010 assessment cycle:

1. *We request that the authors continue to explore a model that uses a constant M over time or other ways of accounting for the large biomass peak in the late 1970s / early 1980s and the subsequent steep decline in crab abundance. It remains unclear whether the decline was due to increased mortality (e.g., predation by Pacific cod), a shift in productivity, or a fishing impact. In particular, any changes in fishing mortality should be modeled as such, based on the history of changes in gear and fishing practices. Although Model 2 fit the data poorly, the reasons for the poor fit, in particular to the latter parts of the time series, are not entirely clear and may, in fact, suggest failure of convergence in the optimization routine, rather than model misspecification."*

All fishing mortalities were modeled in the model. Several more model scenarios were conducted to address different hypotheses in the updated SAFE report to the CIE review in 2009. A hypothesized bycatches from groundfish trawl and Tanner crab fisheries, which are much higher than expected, were used in scenario (4) to illustrate how many crabs needed to account for the loss during 1980-

1984. Model misspecification could be a cause of a failure of convergence. The model has a difficulty to get rid of crabs with a constant *M* of 0.18 during the early 1980s.

2. *"The incorporation of a number of periods that allow for "additional" male and/or female mortality needs to be re-evaluated, and a sound rationale for the choice of these periods must be provided. For example, the rationale for why the time periods are different for males and females and why female mortality differs between 1980 through 1984, 1976 through 1979, and 1985 through 1993 is not clearly stated. To the extent practicable, these periods should be based on clearly documented oceanographic and biological considerations."*

The periods of additional mortality were based on the ADF&G stock assessment model results, which estimated and grouped mortality by periods. Periods of additional mortality for males and females are identical for this model. It looks differently because additional mortality was estimated greater than 0 for females and equal to 0 for males during 1976-1979 and 1985-1993. We will explore this issue in the future report.

3. *"The SSC continues to question the rationale for using the 1995 through the current time period of recruitment for estimating $B_{35\%}$. We recognize that the rationale is more developed for this stock than for some other stocks and that it is primarily based on a perceived shift in productivity in 1989 (first apparent in the 1995 recruitment of 6-year old crab). However, while recruitment was somewhat higher in the post-1988 period, the difference in mean recruitment is not significant (fertilization years 1977-88, i.e. post 76/77 shift, vs. 1989-2002: $t = 0.125$, $p = 0.91$; 1979-88, the period used in the assessment, vs. 1989-2002: $t = 1.57$, $p = 0.13$). Therefore, we request that model runs continue to be based on both periods, for comparison, and that the rationale for using only the post-1988 period be re-evaluated, perhaps as part of a broader evaluation of appropriate productivity periods across crab stocks in this region."*

Agree.

4. *"There is a discrepancy between the recruitment estimates summarized in Table 6, those shown in Figure 33, and those shown in the stock-recruitment relationship in Figure 35. The latter seem to be labeled by year of hatching, rather than the year of mating, as stated in the legend. These need to be checked, in order to provide appropriate recruitments for estimating reference points. In addition to the parameter estimates in Table 6, it would be very useful if the document included a table of actual recruitment estimates."*

The recruitment is based on recruitment year, not mating year, in Table 6.

5. *"The rationale for using three different time periods for estimating average size at 50% maturity (Figure 9) is unclear and needs to be clearly articulated in the document. For example, these periods differ from those that were used to model additional mortality for females, and it could be argued that the same mechanism may be responsible for higher mortalities and smaller size-at-maturity, suggesting that the same periods be used for modeling changes in these parameters. A more objective approach to modeling size-at-maturity might be to fit a smooth trend to size at 50% maturity over time or use an appropriate algorithm to find change points in the time series."*

We are looking for additional data of female red king crab growth, and we will examine this issue in the future report when getting additional data so that we can better estimate growth curves for different 50% maturity sizes.

6. *"The SSC appreciates the inclusion of likelihood components that incorporate appropriate coefficients of variation, rather than arbitrary weights. We request that the weighting issue be explored further, following recommendations from the recent stock assessment/data weighting workshop. Possible approaches to pursue include conducting additional sensitivity analyses to examine the influence of different weights, estimating effective N for multinomial likelihood components within the model, as is done for many groundfish assessments, or employing a fully Bayesian implementation of the model with appropriate priors, as recommended by the CPT."*

Some work has been done on this issue (estimating effective sample sizes and examining the weights). We will further examine effective sample sizes and the Bayesian approach in the future report.

7. *"In addition to using the BSFRF data to get an improved estimate of capture probability by size, the data should also be included in a model alternative presented to the CPT and SSC. However, as noted earlier, all data must be clearly described and documented and the model fit to the data should be shown."*

All input data were presented in the report. A simple figure (Figure 12c) was created in this report to compare the results from the model and the BSFRF surveys.

Response to SSC Comments specific to this assessment (from October 2009)

"The OFL for Bristol Bay red king crab was estimated using the model selected by the plan team and SSC. Model runs including 2009 survey data and the revised survey time series were completed over the summer and the impacts of changes to data weightings were explored. Changes to effective sample size estimates appeared to be quite influential and will be further explored for the May 2010 crab plan team meeting. A CIE review of this assessment was completed in June 2009 and the SSC looks forward to the seeing the results of this review and the author's responses at some future date. Moreover, the SSC commented on two emerging issues and has the following comments. First, there is evidence for increasing movement of the stock into the Northern District (Federal Area 514). Bycatch occurring in this area currently does not accrue to any fishery and survey catches from this area are not included in estimates of survey abundance in the Bristol Bay red king crab assessment. Bycatch data and survey data from the Northern District should be included in the assessment as soon as possible. Second, the Bristol Bay red king crab stock has shifted to the south in recent years. This has prompted concerns over potential habitat damage in southern Bristol Bay due to groundfish trawling in this area. The SSC agrees with plan team recommendations that these concerns should be raised in the context of the upcoming EFH analyses."

Due to time constraint, CIE review comments will not be addressed in this report. They will be examined in the May 2011 report. Spatial distributions and habitat issues were addressed in EFH analysis.

C. Introduction

1. Stock Structure

Red king crab (RKC), *Paralithodes camtschaticus*, are found in several areas of the Aleutian Islands and eastern Bering Sea. 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} 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.

2. 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 2002a). As a result of new regulations for crab rationalization, the fishery was open longer beginning with the 2005/2006 season from October 15, 2005 to January 15, 2006. 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).

3. Fisheries Management

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

The purpose of this report is to document the stock assessments for Bristol Bay RKC. This report includes (1) all data used to conduct the stock assessments, (2) details of the analytic approach, (3) an evaluation of the assessment results, (4) estimates of biological reference points and federal overfishing limits for 2009, and (5) future projections and the near future outlook.

D. Data

1. 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 3. 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 4). 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.

2. NMFS Survey Data

The NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conduct this multispecies, crab-groundfish survey during the summer. Stations are sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972 the trawl survey has covered the full stock distribution. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2009 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 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. We used area-swept abundances estimated by NMFS in July 2009 in this report.

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, 2006-2009: 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 2006-2009 and resurveys of 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), and 32 stations (2007-2009) 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 t-tests of paired two sample for 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. To maximize use of the survey data, we used data from both surveys to assess male abundance but only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundance during these six 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).

3. 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-size 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 are 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 males were estimated to be 22.331 and 19.747 millions in 2007 and 2008 with a CV of 0.0634 and 0.0765.

E. Analytic Approach

1. History of modeling approaches for this stock

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 2009.

2. Model Scenarios

Nine scenarios were examined in this SAFE report (see Summary of Major Changes): (1) constant natural mortality (0.18); (2) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993; (3) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and with the Bering Sea Fisheries Research Foundation (BSFRF) survey data; (4) constant natural mortality (0.18) with BSFRF survey data and hypothesized bycatch from trawl and Tanner crab fisheries beyond expectation during 1980-84; (5) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and with the BSFRF survey data; (6a) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and with the BSFRF survey data and estimating sizes at 50% molting probability for males each year; (6b) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and estimating sizes at 50% molting probability for males each year; (7a) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and with the BSFRF survey data and estimating three levels of molting probabilities for males; and (7b) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and estimating three levels of molting probabilities for males.

The program could not converge for scenario (1). Only results for scenarios (2)-7b) are presented. Scenario (3) is considered as a base scenario, and unless specified, the results in the Figures and Tables are for scenario (3).

3. Main Assumptions for the Model

Many assumptions were made to develop the length-based model. The major assumptions are:

(1) The basic 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).

(2) 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) 1982-2009 (modifying approaches to surveys).

(3) 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 1994-2009). Once mature, female red king crabs grow with a much smaller growth increment per molt.

(4) Molting probabilities are an inverse logistic function of length for males. Females molt annually.

(5) Annual fishing seasons for the directed fishery are short.

(6) 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.

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

(8) 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.

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

3. Model Description

(i). Population model

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002a). 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:

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

$$O_{l+1,t+1} = [(N_{l+1,t} + O_{l+1,t})\, e^{-M_t} - (C_{l+1,t} + D_{l+1,t})\, e^{(y_t - 1)M_t} - T_{l+1,t} e^{(j_t - 1)M_t}](1 - m_l),$$

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 is the molting probability for length class l,
- $R_{l,t}$ 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:

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

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

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

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:

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

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:

$$m_l = 1 - \frac{1}{1 + e^{-\beta\ (l - L_{50})}}, \qquad (5)$$

where

β, L_{50} are parameters, 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

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

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 bycatches from the Tanner crab fishery before 1991. A reasonable index to estimate bycatch fishing mortalities is potlifts of the Tanner crab fishery within the distribution area of Bristol Bay red king crab. Thus, bycatch fishing mortalities from the Tanner crab fishery before 1991 were estimated to be proportional to the smoothing average of potlifts east of 163^o W. The smoothing average is equal to $(P_{t-2}+2P_{t-1}+3P_t)/6$ for the potlift in year t. The smoothing process not only smoothes the annual number of potlifts, it also indexes the effects of lost pots during the previous years. For bycatch, all fishery catch and discard mortality bycatch are estimated as:

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

where

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

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

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

The female crab model is the same as the male crab model except that the retained catch equals zero and molting probability equals 1.0 to reflect annual molting (Powell 1967). 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.

(ii). Fisheries Selectivities

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

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

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:

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

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 highgrading was estimated to be the retained selectivity in each year times a highgrading parameter, hg_t.

(iii). Trawl Survey Selectivities/Catchability

Trawl survey selectivities/catchability are estimated as

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

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 7). 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 7). 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 7). 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.

4. 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. Highgrading 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.

(i). 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.

(ii). Length-weight Relationship

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

$$\begin{aligned} &\text{Immature Females:} && W = 0.010271\, L^{2.388}, \\ &\text{Ovigerous Females:} && W = 0.02286\, L^{2.234}, \\ &\text{Males:} && W = 0.000361\, L^{3.16}, \end{aligned} \tag{11}$$

where

W is weight in grams, and

L is CL in mm.

(iii). 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 8). 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 8). 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 8). 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).

(iv). 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 9 with mean values for three different periods (1975-82, 1983-93 and 1994-08).

(v). 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 10). 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 10).

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 and conservative in terms of managing the fishery.

5. 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.

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.

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

$$Rf = \prod_{l=1}^{L}\prod_{t=1}^{T}\prod_{s=1}^{2}\prod_{sh=1}^{2}\frac{\left\{\exp\left[-\frac{(p_{l,t,s,sh}-\hat{p}_{l,t,s,sh})^2}{2\sigma^2}\right]+0.01\right\}}{\sqrt{2\pi\sigma^2}}, \qquad (12)$$

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

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:

$$\begin{aligned}
&Length\ compositions: \quad -\sum \ln(Rf_i)\,,\\
&Biomasses\ other\ than\ survey: \quad \lambda_j\sum\left[\ln(C_t/\hat{C}_t)^2\right],\\
&NMFS\ survey\ biomass: \quad \sum\left[\ln(B_t/\hat{B}_t)^2/(2\ln(CV_t^2+1))\right],\\
&BSFRF\ mature\ males: \quad \sum[\ln(N_t/\hat{N}_t)^2/(2\ln(CV_t^2+1))], \qquad (13)\\
&R\ variation: \quad \lambda_R\sum[\ln(R_t/\overline{R})^2]\,,\\
&R\ sex\ ratio: \quad \lambda_s[\ln(\overline{R}_M/\overline{R}_F)^2]\,,
\end{aligned}$$

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.

F. Results

1. Population Abundance

The model (scenario 3) fit the fishery biomass data well and the survey biomass reasonably well (Figures 11 and 12). 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 did not fit the mature crab abundance directly and depicted the trends of the mature abundance well (Figure 12). Estimated mature crabs abundance 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 4.5 times more abundant in 2009 than in 1985 and mature males being 3.1 times more abundant in 2009 than in 1985 (Figure 12).

The model also fit the length and shell composition data well (Figures 13-20). 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 2009 than the area-swept estimates (Figure 14). In addition to size, molting probability may also be affected by age and environmental conditions. Tagging data show that molting probability changed over time (Basilger 1974). Therefore, the relatively poor fit to oldshell males may be due to use of a constant molting probability function 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 17). 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 13 and 15). 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 17), 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 19 and 20).

2. Parameter Estimates

Negative log-likelihood values and parameter estimates are summarized in Tables 5 and 6, 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 bycatches 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 21). Both selectivities were applied to the same level of full fishing mortality. Estimated selectivities for female pot bycatch were close to 1 for all mature females, and the estimated full fishing mortalities for female pot bycatch were much lower than for male retained catch and bycatch (Table 6).

One of the most important results is estimated trawl survey selectivity/catchability (Figure 21). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. Estimated survey selectivities in Figure 21 are generally smaller than the capture probabilities in Figure 7 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.

Estimated molting probabilities during 1968-2009 (Figure 22) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crabs, 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.

3. Residual Patterns

Residuals of total survey biomass and proportions of length and shell condition, calculated as observed minus predicted, were plotted to examine their patterns. Residuals of total survey biomass were standardized by the estimated standard deviation. The residuals of total survey biomass did not show any consistent patterns (Figure 23). Standardized residuals of proportions of survey newshell males appear to be random over length and year (Figure 24). Residuals of proportions of survey oldshell males were mostly positive or negative for some years (Figure 25). This is expected since a constant molting probability function over time was used. 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 26). Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors. Further study for female growth and availability for survey gears due to different molting times may be needed.

4. Comparison of Scenarios

Estimated survey biomass, mature male and female abundances with 8 scenarios were compared in Figure 12. Differences of abundance and biomass estimates among scenarios were mainly during the mid 1970s to early 1980s and recent years. When molting probabilities were estimated each year or periodically (scenarios 6 and 7), estimated abundance and biomass were lower during the mid and late 1970s. Including the BSFRF survey data in 2007 and 2008 (scenarios 3, 4, 5, 6a and 7a) would lower male abundance estimates in recent years. None of scenarios fell into the 95% confidence interval of the BSFRF estimate in 2008 (Figure 12c). While the hypothesized bycatch from the trawl fisheries during 1980-84 would have been likely, the hypothesized bycatch from the Tanner crab fishery would be not realistic (Figure 11c). It is impossible for the Tanner crab fishery to cause such a mortality; the hypothesized bycatch biomass was about 100 times as large as expected. Overall, log likelihood values are significantly higher from the order of scenario 6b to scenario 5.

5. Retrospective Analyses

Two kinds of retrospective analyses were conducted for this report: (1) historical results and (2) the 2009 model 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 2009 estimates as the baseline values, we can also evaluate how well the model had done in the past. The 2009 model results are based on sequentially excluding one-year of data to evaluate the current model performance with less data.

(i). Historical Results

The model first fit the data from 1985 to 2004 in 2004. Thus, five 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 27).

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 bycatches. 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 27).

In 2008, estimated coefficients of variation for survey biomass were used to compute likelihood values as suggested by the Crab Plan Team in 2007. Weights were re-configured because of this change: 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 27).

In 2009, the model was extended to the data through 1968. No weight factors were used for the NMFS survey biomass in 2009.

(ii). 2009 Model Results

The performance of the 2009 model includes sequentially excluding one-year of data. The model performed well during 2004-2008 (Figure 28).

Overall, both historical results and the 2009 model results performed reasonably well. No great overestimates or underestimates occurred as observed in Pacific halibut (*Hippoglossus stenolepis*) (Parma 1993) or some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002a; Ianelli et al. 2003). Since the most recent model has not been used to set TAC or overfishing limits, historical implications for management from the stock assessment errors can not be evaluated at the current time. However, management implications of the ADF&G stock assessment model were evaluated by Zheng and Kruse (2002a).

6. Effects of Handling Mortality Rate on Abundance Estimates

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 (Figure 29). Differences of estimated legal abundance and mature male biomass were small among these handling mortality rates (Figure 30).

7. 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 botttom 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 31. The observed red king crab bycatches 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 on older crabs, and disease on 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 (scenarios 1 and 3) than without them (scenario 2).

8. Sensitivity of Weights

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. Estimated mature male biomasses and survey biomasses were compared in Figure 32. Overall, estimated biomasses were very close under different weights except during the mid-1970s (Figure 32). The variation of estimated biomasses in the mid-1970s was mainly caused by the changes in estimates of additional mortalities in the early 1980s.

9. Estimated Effective Sample Sizes for Length Composition Data

We assumed a constant effective sample size for the length/sex composition data. These assumed sample sizes are compared with estimated effective sample sizes in Figure 34. 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. Further study on effective sample sizes are needed for this stock.

10. Exploitation

The average of estimated male recruits from 1995 to 2009 (Figure 34) and mature male biomass per recruit was used to estimate $B_{35\%}$. Alternative periods of 1968-present and 1985-present were compared in our previous report. The choice of this recruitment will be discussed in the "Biological Reference Points" section. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 35). Before the current harvest strategy was adopted in 1996, many fishing mortalities were above $F_{35\%}$ (Figure 35). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, 2007 and 2008 but below the $F_{35\%}$ limits in other years.

Estimated full pot fishing mortalities ranged from 0.0 to 1.05 during 1968-2008 with estimated values over 0.4 during 1968-1981, 1986-1987, 1990-1991, 1993, and 1998 (Table 6, Figure 35). Estimated fishing mortalities for pot female bycatch and trawl bycatch were generally less than 0.06.

11. Stock-Recruitment Relationships

Estimated mature male biomass and recruitment were plotted to illustrate their relationships (Figure 36a). Annual stock productivity was illustrated in Figure 36b.

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 37). The highest proportion of empty clutches (0.2) was in 1986, and they primarily involved soft shell females (shell condition 1). Clutch fullness fluctuated annually around average levels during two periods: before 1991 and after 1990 (Figure 37). The average clutch fullness was almost identical for these two periods (Figure 37).

G. Calculation of the OFL

Bristol Bay RKC is currently placed in Tier 3 (NPFMC 2007). For Tier 3 stocks, estimated biological reference points include $B_{35\%}$, $F_{35\%}$ and $F_{40\%}$. Estimated model parameters were used to conduct mature male biomass per recruit analysis. Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 1999 to 2008 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 1990-2008. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2006-2008 than in 2005 after the fishing industry minimized discards of legal males. Thus, the average of retained selectivities and discard male selectivities during 2006-2008 were used to represent current trends for per recruit analysis and projections.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1968-2009, 1985-2009, and 1995-2009 (Figure 34). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 36. We recommend using the average recruitment during 1995-present, which was used in 2008 to set the overfishing limits. There are several reasons for supporting our recommendation. First, estimated recruitment was higher after 1994 than during 1985-1994 and there was a potential regime shift after 1989 (Overland et al. 1999), which corresponded to recruitment in 1995 and later. Second, recruitments estimated before 1985 came from a potentially higher natural mortality than we used to estimate $B_{35\%}$. Third, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay while the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larva hatched in the southern Bristol Bay (see the section on Ecosystem Considerations). Stock productivity (recruitment/mature male biomass) was much higher before the 1976/1977 regime shift: the mean value was 1.842 during 1968-1977 and 0.374 during 1978-2003 (Figure 36).

Based on the $B_{35\%}$ estimated from the average male recruitment during 1995-2008, the biological reference points were estimated as follows:

Scenario 3

$B_{35\%}$ = 68.498 million lbs, or 31,070 t

$F_{35\%}$ = 0.32

$F_{40\%}$ = 0.26

Based on $B_{35\%}$ and $F_{35\%}$, the retained catch and total catch limits for 2009 were estimated to be:

Retained catch: 19.914 million lbs, or 9033.012 t,

Total catch: 22.561 million lbs, or 10233.415 t,

MMB on 2/15/2010: 95.169 million lbs, or 43168.0 t.

Total catch includes retained catch and all other bycatches. Likelihood profiles of mature male biomass on February 15, exploitable abundance and biomass at fishing time for 2009 are illustrated in Figure 38. The confidence intervals are quite narrow for all three values.

H. 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 1995-2009. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2009. The 2009 abundance was randomly selected from the estimated normal distribution of the assessment model output for each replicate. Four 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.

(4) Current ADF&G harvest strategy with the $F_{35\%}$ constraint.

Each scenario was replicated 1000 times and projections made over 10 years beginning in 2009 (Table 8).

As expected, projected mature male biomasses were much higher without the directed fishing mortality than under the other scenarios. Among three scenarios with directed fishing, the ADF&G harvest strategy produced the most stable mature male biomass and catch over time (Table 8, Figures 39 and 40). With its forward looking feature, the ADF&G harvest strategy reduced fishing mortality one year or two years earlier than the $F_{40\%}$ and $F_{35\%}$ scenarios when recruitment was poor. At the end of 10 years, projected mature male biomass was above $B_{35\%}$ for the $F_{40\%}$ scenario and the ADF&G harvest strategy and similar to $B_{35\%}$ for the $F_{35\%}$ scenario (Figure 39).

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a starting declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 41). 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 this year and will continue to recruit to the legal population next year (Figure 41). However, no strong cohorts have been observed in the survey data after this cohort (Figure 41). Due to lack of recruitment, mature and legal crabs should 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.

I. Ecosystem Considerations

Three aspects of ecosystem considerations are reported in this report: impacts of changes in oceanographic conditions on RKC recruitment strength, predation by groundfish, and impacts of shifts of spatial distribution on crab recruitment success.

1. Impacts of Changes in Oceanographic Conditions on RKC Recruitment

Environmental factors may play important roles in determining recruitment strength. Climate variability, ocean temperature, surface winds, ocean currents and their ecological interactions may affect food availability and larval transport, growth and survival, thus affecting recruitment strength (Shepherd et al. 1984; Koslow et al. 1987). Changes in many of these oceanographic processes are associated with atmospheric pressure patterns in winter, such as the strength and position of the Aleutian Low Pressure System, which affects the direction and intensity of storms, and the Arctic Oscillation, which represents the spin up (or spin down) of the polar vortex and indexes the transfer of mass between high and mid latitudes (Overland et al., 1999). For instance, a climate regime shift in the late 1970s was manifested by increased winter storms and precipitation, faster alongshore currents, warmer sea surface temperatures, and higher coastal sea levels in the northeastern Pacific Ocean (Hollowed and Wooster 1992; Hare and Mantua 2000). Overland et al. (1999) found three shifts of wintertime climate forcing patterns that have been identified in the past three decades: 1967-1976 (positive Aleutian Low, mixed Arctic Oscillation), 1977-1988 (negative Aleutian Low, negative Arctic Oscillation), and 1989-1998 (mixed Aleutian Low, positive Arctic Oscillation).

The relationship between the recruitment strength of Bristol Bay RKC and the Aleutian Low Pressure index were examined by Zheng and Kruse (2000, 2006). They found that the recruitment trends of Bristol Bay RKC may partly relate to decadal shifts in physical oceanography: all strong year classes occurred before 1977 when the Aleutian Low was weak. One of the largest year classes during the last 20 years, the 1990 year class, was also coincidental with the weak Aleutian Low index during 1989-1991 (Zheng and Kruse 2000, 2006). The mechanisms are uncertain, but food availability is hypothesized to be important to RKC (Zheng and Kruse 2000) because their larvae suffer reduced survival and feeding capability if they do not feed within the first 2-6 days after hatching (Paul and Paul 1980). Diatoms such as *Thalassiosira* are important food for first-feeding RKC larvae (Paul et al. 1989) and they are predominate in the spring bloom in years of light winds when the water column is stable (Ziemann et al. 1991; Bienfang and Ziemann 1995). One hypothesis is that years of strong wind mixing associated with intensified Aleutian Lows may depress RKC larval survival and subsequent recruitment (Zheng and Kruse 2000).

2. Predation by Groundfish

During the period from mating to recruitment, many events can modify crab year-class strength. This may explain the weak relationships between recruitment and spawning biomass as well as individual environmental factors. One such event is groundfish predation. Groundfish consume crabs from the pelagic larval to adult stages. Based on routine examination of stomach contents of some groundfish species (Alaska plaice, arrowtooth flounder, flathead sole, northern rock sole, Pacific cod, Pacific halibut, skates, walleye pollock, and yellowfin sole) in the eastern Bering Sea, a huge amount of early juvenile Tanner and snow crabs are consumed by groundfish each year during summer months, May to September (Lang et al. 2003). Predation on large crabs usually occurs during molting periods (Blau 1986), which are generally during spring. Few large crabs have been founded in groundfish stomachs during summer months when sampling occurs. Because female RKC molt later than males, sampling may bias against monitoring of predation on adult male RKC relative to females (Table 9). Likewise, juvenile RKC are usually found in nearshore, shallow waters, where hardly any samples of groundfish are taken. Thus, data are not available to estimate groundfish predation on juvenile RKC. Overall, estimates of RKC biomass to be consumed by groundfish during summer months were low relative to the crab population abundance (Table 10).

Zheng and Kruse (2006) reported statistically significant correlations between Pacific cod biomass and Bristol Bay RKC recruitment with recruitment time lags from ages 0 to 3. Correlations between yellowfin sole biomass and log-transformed Bristol Bay RKC recruitment are also statistically significant with recruitment time lags from ages 0 to 2 (r = -0.85, -0.83, -0.79, and P = 0.03, 0.04, 0.04, respectively, Zheng and Kruse 2006). The spatial distribution of yellowfin sole mainly overlaps with Bristol Bay RKC and has not changed much over time. Higher Pacific cod and yellowfin sole biomass was associated with lower RKC recruitment (Zheng and Kruse 2006). Pacific cod is the main predator of red king crabs (Table 10).

Statistical significance does not necessarily imply biologically meaningful relationships. Multiple statistical tests increase the probability of Type I error. In a detailed study of predation and population trends, Livingston (1989) concluded that cod predation was not responsible for declines of RKC in Bristol Bay in the early 1980s. Estimates of RKC consumed by cod during 1981 and 1983-1996 (Livingston 1991; Livingston et al. 1993, Livingston & deReynier 1996; Lang et al. 2003) constitute only a very small proportion of the crab population. Most RKC in cod stomachs are softshell females >80 mm carapace length (Livingston 1989; Table 9) – well beyond the size at which year class strength is determined. However, as noted earlier, the lack of RKC in groundfish stomachs may also be due to sampling problems. Therefore, the lack of large numbers of early juvenile RKC in groundfish stomach data obtained during summer months in offshore waters does not necessarily invalidate the apparent negative relationships between RKC year-class strength and biomass of Pacific cod and yellowfin sole. Groundfish stomachs must be sampled at the appropriate spatial and temporal scales to resolve questions about groundfish predation on juvenile king crabs.

Spatial distributions of crabs and groundfish may also play an important role on groundfish predation on crabs. Like crab stocks, spatial distributions of groundfish stocks in the eastern Bering Sea changed over time (Figure 40). During recent years, biomass distribution centers of Pacific cod, flathead sole and arrowtooth flounder shifted to the northwest, those of rock sole, skates and Alaska plaice shifted to the northeast, whereas spatial distributions of yellowfin sole remained relatively stable (Figure 40). The northward expansion for some groundfish seems to relate to warmer bottom temperatures, perhaps due to a northward extension of suitable habitat. With warmer temperatures, the center of groundfish spatial distributions moved farther to the north (Zheng and Kruse 2006).

Changes in spatial distributions of groundfish in the eastern Bering Sea are best illustrated by distributions of Pacific cod biomass from 1982 to 2004 (Figure 43). In the early 1980s, Pacific cod mainly occurred in shallow waters <50 m in the Bristol Bay area and in deep waters >100 m in the northwest of the eastern Bering Sea. However, during 1985-1988 and 1991-1996 the distribution of Pacific cod biomass was widespread across the shelf. In recent years, cod abundance concentrated in the north, around St. Matthew Island, and stayed at a relatively low density in Bristol Bay.

Other striking examples of changes in spatial distributions are provided by rock sole and skates (Figure 44). Rock sole mainly occurred in Bristol Bay and the Pribilof Islands in the 1980s. During the last 15 years, rock sole have expanded to the north up to St. Matthew Island. The biomass of skates has also increased greatly during the last 20 years and expanded northward. Among other commercially important species, biomass of arrowtooth flounder and flathead sole has also increased during the 1980s.

3. Impacts of Shifts of Spatial Distribution on Crab Recruitment Success

Spatial distributions of Bristol Bay RKC changed profoundly during the last three decades (Hsu 1987; Loher 2001; Zheng and Kruse 2006; Figure 45). Generally speaking, RKC abundance in southern Bristol Bay was high during the 1970s, declined, and was extremely low after 1979 (Zheng and Kruse 2006). 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. Loher (2001) hypothesized that changes in near bottom temperatures associated with the 1976/77 regime shift are causes for spatial shifts of RKC female distributions. Because small juvenile RKC are generally located downstream of the mature females (Zheng and Kruse 2006), larval advection appears to be an important process for RKC.

Zheng and Kruse (2008) used the ocean surface current simulator (OSCURS) to perform retrospective analyses of movements of Bristol Bay red king crab larvae from 1967 to 2002. Simulations started at the annual distribution centers of mature females >99 mm CL. The distribution centers were assumed to be the centers of larval hatching. Mature RKC females >99 mm CL are mostly multiparous females. The locations of larval settlements were taken to be the places where 325 degree-days were estimated to have been reached. To estimate larval durations, monthly sea surface temperatures for each year from 1967 to 2002 were estimated for grids of 1 degree longitude and 0.5 degree latitude in the eastern Bering Sea based on the Comprehensive Ocean-Atmosphere Dataset (COADS) from the National Climate Data Center (NCDC). To demonstrate the larval drift tracking for different locations and years, Zheng and Kruse (2008) also simulated the RKC larval drifts in 1975, 1987, and 2004 for two months starting at three locations −− south, middle and north − representing hatching locations of larvae from the southern, middle and northern range of the mature female distribution.

RKC larval drifts were similar among three years (1975, 1987 and 2004) but very different among different hatching locations (Figure 46). At southern and middle locations, larvae generally drifted to the northeast, and at the northern location, larvae drifted to the north or northwest. Larvae hatched in the southern location were estimated to reach central Bristol Bay, whereas larvae hatched in central Bristol Bay were estimated to settle in the northernmost reaches of Bristol Bay. Owing to prevailing currents, larvae hatched in central and northern Bristol Bay are very unlikely to settle in the southern portions of Bristol Bay (Figure 46).

Settling locations appear to have an important impact on resultant year-class strength for Bristol Bay RKC (Figure 47). For years with strong year classes, crab larvae were generally estimated to have settled in the central portion of Bristol Bay (Zheng and Kruse 2008). Because the simulations started at the centers of the annual distribution of the brood stock, larval settling locations from these years likely also represent the centers of a broader distribution of settling larvae that are well dispersed from south to north along the shallow shelf of Bristol Bay. Larvae associated with weak year-classes generally settled farther downstream in northern Bristol Bay or to the northwest outside of Bristol Bay. Occasionally, larvae hatched in the southern Bristol Bay settled there. Larvae hatching in the middle or later portion of the hatching period may contribute disproportionately to subsequent recruitment; early hatching larvae had longer larval stages and were dispersed farther downstream from the hatching locations than those hatched late in a spawning season (Figure 47).

The simulation results by Zheng and Kruse (2008) show that the northward shifts in mature female distributions made it very difficult to supply larvae to the southern portions of their traditional nursery areas. This reduces the number of suitable habitats to which larvae are delivered (Armstrong et al. 1983; Loher 2001) and may affect recruitment strength. Perhaps this has contributed to long-term decline in recruitment and subsequent mature biomass of Bristol Bay RKC.

J. Acknowledgements

We thank Doug Woodby and the Crab Plan Team for reviewing the earlier draft of this manuscript.

K. Literature Cited

Alaska Department of Fish and Game (ADF&G). 2005. Commercial king and Tanner crab fishing regulations, 2005-2006. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau. 162 pp.

Armstrong, D.A., L.S. Incze, D. Wencker, and J.L. Armstrong. 1983. Distribution and abundance of decapod crustacean larvae in the southeastern Bering Sea with emphasis on commercial species. U.S. Department of Commerce, NOAA, NOS, Anchorage, Alaska. 386 pp.

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

Bienfang, P.K., and D.A. Ziemann. 1995. APPRISE: A multi-year investigation of environmental variation and its effects on larval recruitment. Pages 483-487 *In* R.J. Beamish (ed.). Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Blau, S.F. 1986. Recent declines of red king crab (*Paralithodes camtschatica*) populations and reproductive conditions around the Kodiak Archipelago, Alaska. Pages 360-369 *In* G. S. Jamieson and N. Bourne (eds). North Pacific Workshop on stock assessment and management of invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92.

Bowers, F.R., M. Schwenzfeier, S. Coleman, B. Failor-Rounds, K. Milani, K. Herring, M. Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the westward region's shellfish observer program, 2006/07. Alaska Department of Fish and Game, Fishery Management Report No. 08-02, Anchorage. 230 pp.

Burt, R., and D.R. Barnard. 2006. Alaska Department of Fish and Game summary of the 2004 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 06-03, Anchorage.

Dew, C. B., and R. A. McConnaughey. 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? Ecol. Appl. 15:919-941.

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

Griffin, K. L., M. F. Eaton, and R. S. Otto. 1983. An observer program to gather in-season and post-season on-the-grounds red king crab catch data in the southeastern Bering Sea. Contract 82-2, North Pacific Fishery Management Council, 605 West 4th Avenue, Suite 306, Anchorage, Alaska 99501. 39 pp.

Hare, S.R., and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography 47:103–145.

Hollowed, A.B., and W.S. Wooster. 1992. Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish. ICES Mar. Sci. Symp. 195:433-444.

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

Hsu, C-C. 1987. Spatial and temporal distribution patterns of female red king crabs in the southeastern Bering Sea. Ph.D. dissertation, University of Washington, Seattle, WA. 300 pp.

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

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

Koslow, J.A., K.R. Thompson, and W. Silvert. 1987. Recruitment to northwest Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) stocks: influence of stock size and climate. Can. J. Fish. Aquat. Sci. 44*:*26-39.

Lang, G.M, C.W. Derrh, and P.A. Livingston. 2003. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1993 to 1996. Alaska Fisheries Science Center, Processed Rep. 2003-04. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 7600 Sand Point Way NE, Seattle, WA 99115. 351 pp.

Livingston, P.A. 1989. Interannual trends in Pacific cod, *Gadus macrocephalus*, predation on three commercially important crab species in the eastern Bering Sea. Fishery Bulletin (U.S.)*, 87*, 807-827.

Livingston, P.A., editor. 1991. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1984 to 1986. NOAA Technical Memorandum NMFS- AFSC-207, Seattle, WA. 240 pp.

Livingston, P.A., and Y. deReynier. 1996. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1990 to 1992. Alaska Fisheries Science Center, Processed Rep. 96-04. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 7600 Sand Point Way NE, Seattle, WA 99115. 214 pp.

Livingston, P.A., A. Ward, G.M. Lang, and M.-S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. NOAA Technical Memorandum NMFS- AFSC-11, Seattle, WA. 192 pp.

Loher, T. 2001. Recruitment variability in southeast Bering Sea red king crab (*Paralithodes camtschaticus*): The roles of early juvenile habitat requirements, spatial population structure, and physical forcing mechanisms. Ph. D. dissertation. University of Washington, Seattle, WA. 436 pp.

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

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

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

Overland, J.E., J.M. Adams, and N.A. Bond. 1999. Decadal variability of the Aleutian Low and its relation to high-latitude circulation. J. Climate 12:1542-1548.

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

Paul, A.J., and J.M. Paul. 1980. The effect of early starvation on later feeding success of king crab zoea. J. Exp. Biol. Ecol. 44:247-251.

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

Paul, A.J., J.M. Paul, and K.O. Coyle. 1989. Energy sources for first-feeding zoea of king crab *Paralithodes camtschatica* (Tilesius) (Decapoda, Lithodidae). J. Exp. Mar. Biol. Ecol. 130:55-69.

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

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

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

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

Reeves, J.E., R.A. MacIntosh, and R.N. McBride. 1977. King and snow (Tanner) crab research in the eastern Bering Sea, 1974. Int. North Pac. Fish. Comm. Annu. Rep. 1974:84-87.

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

Shepherd, J.G., J.G. Pope, and R.D. Cousens. 1984. Variations in fish stocks and hypotheses concerning their links with climate. Rapp. P.-v Reun. Cons. int. Explor. Mer 185:255-267.

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

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

Stevens, B.G., R.A. MacIntosh, and J.A. Haaga. 1991. Report to industry on the 1991 eastern Bering Sea crab survey. Alaska Fisheries Science Center, Processed Rep. 91-17. 51 pp. NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 99115.

Urban, D. 2009 (in press). Seasonal predation of Pacific cod on Tanner crab in Marmot Bay, Alaska. In: Biology and management of exploited crab populations under climate change, Lowell Wakefield Symposium, Anchorage, Alaska.

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

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

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

Witherell, D., and C. Pautzke. 1997. A brief history of bycatch management measurements for eastern Bering Sea groundfish fisheries. Marine Fisheries Review 59(4): 15-20.

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

Zheng. J., and G.H. Kruse. 2000. Recruitment patterns of Alaskan crabs and relationships to decadal shifts in climate and physical oceanography. ICES J. Mar. Sci. 57:438-451.

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

Zheng, J., and G.H. Kruse. 2002b. Assessment and management of crab stocks under uncertainty of massive die-offs and rapid changes in survey catchability. Pages 367-384 *In* A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Zheng, J., and G.H. Kruse. 2006. Recruitment variation of eastern Bering Sea crabs: climate-forcing or top-down effects? Prog. Oceanography, 68: 184-204.

Zheng, J. and G.H. Kruse. 2008. Crab larval advection and recruitment in the eastern Bering Sea. A manuscript.

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

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

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

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

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

Ziemann, D.A., L.D. Conquest, M. Olaizola, and P.J. Bienfang. 1991. Interannual variability in the spring phytoplankton bloom in Auke Bay, Alaska. Mar. Biol. 109:321-334.

Table 1. Bristol Bay red king crab annual catch and bycatch mortality biomass (million lbs) 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	0.600		26.898	27.498				27.498
1961	0.427		44.592	45.019				45.019
1962	0.068		54.275	54.343				54.343
1963	0.653		54.963	55.616				55.616
1964	0.823		58.170	58.993				58.993
1965	1.429		41.294	42.723				43.410
1966	0.997		42.356	43.353				44.732
1967	3.102		33.636	36.738				38.430
1968	8.686		27.469	36.155				34.523
1969	10.403		14.383	24.786				24.463
1970	8.559		12.984	21.543				20.516
1971	12.946		6.134	19.080				20.459
1972	21.745		4.720	26.465				27.296
1973	26.914		0.228	27.142				24.167
1974	42.266		0.476	42.742				42.742
1975	51.326		0.000	51.326				51.326
1976	63.920		0.000	63.920			1.426	65.346
1977	69.968		0.000	69.968			2.685	72.653
1978	87.618		0.000	87.618			2.757	90.375
1979	107.828		0.000	107.828			2.783	110.611
1980	129.948		0.000	129.948			2.135	132.083
1981	33.591		0.000	33.591			0.448	34.039
1982	3.001		0.000	3.001			1.201	4.202
1983	0.000		0.000	0.000			0.885	0.885
1984	4.182		0.000	4.182			2.316	6.498
1985	4.175		0.000	4.175			0.829	5.004
1986	11.394		0.000	11.394			0.432	11.825
1987	12.289		0.000	12.289			0.311	12.600
1988	7.388		0.000	7.388			1.174	8.561
1989	10.265		0.000	10.265			0.374	10.638
1990	20.362	0.081	0.000	20.443	1.139	1.154	0.501	23.237
1991	17.178	0.206	0.000	17.384	0.881	0.142	0.576	18.982
1992	8.043	0.074	0.000	8.117	1.191	0.780	0.571	10.659
1993	14.629	0.053	0.000	14.682	1.649	1.133	0.836	18.300
1994	0.000	0.093	0.000	0.093	0.000	0.000	0.180	0.274
1995	0.000	0.080	0.000	0.080	0.000	0.000	0.213	0.293
1996	8.406	0.108	0.000	8.514	0.356	0.002	0.238	9.109
1997	8.756	0.155	0.000	8.911	0.528	0.034	0.168	9.641
1998	14.757	0.188	0.000	14.946	2.074	1.547	0.355	18.922
1999	11.670	0.186	0.000	11.856	0.679	0.015	0.408	12.958
2000	8.154	0.086	0.000	8.241	0.779	0.078	0.230	9.328
2001	8.403	0.120	0.000	8.523	0.902	0.309	0.330	10.065
2002	9.570	0.096	0.000	9.666	0.956	0.013	0.245	10.881
2003	15.697	0.034	0.000	15.731	1.945	0.709	0.298	18.682
2004	15.245	0.202	0.000	15.447	0.746	0.338	0.277	16.807
2005	18.309	0.209	0.000	18.518	2.923	0.879	0.403	22.723
2006	15.444	0.304	0.000	15.748	1.199	0.067	0.205	17.220
2007	20.366	0.146	0.000	20.512	2.150	0.330	0.233	23.225
2008	20.318	0.000	0.000	20.318	2.518	0.264	0.334	23.100
2009	15.933	0.100	0.000	16.033	2.126	0.165		

Table 2. Comparison of GHL/TAC and actual catch (million lbs) of Bristol Bay red king crab.

	GHL		Actual		
Year	Range	Mid-point	Catch	Rel.Error	%Rel.Error
1980	70-120	95.00	129.95	34.95	36.79
1981	70-100	85.00	33.59	-51.41	-60.48
1982	10-20	15.00	3.00	-12.00	-79.99
1983	0	0.00	0.00	NA	NA
1984	2.5-6	4.25	4.18	-0.07	-1.59
1985	3-5	4.00	4.18	0.18	4.38
1986	6-13	9.50	11.39	1.89	19.94
1987	8.5-17.7	13.10	12.29	-0.81	-6.19
1988		7.50	7.39	-0.11	-1.50
1989		16.50	10.26	-6.24	-37.79
1990		17.10	20.36	3.26	19.08
1991		18.00	17.18	-0.82	-4.57
1992		10.30	8.04	-2.26	-21.91
1993		16.80	14.63	-2.17	-12.93
1994		0.00	0.00	0.00	
1995		0.00	0.00	0.00	
1996		5.00	8.41	3.41	68.11
1997		7.00	8.76	1.76	25.09
1998		16.40	14.76	-1.64	-10.02
1999		10.66	11.67	1.01	9.48
2000		8.35	8.15	-0.20	-2.34
2001		7.15	8.40	1.25	17.52
2002		9.27	9.57	0.30	3.24
2003		15.71	15.70	-0.01	-0.08
2004		15.40	15.25	-0.15	-1.00
2005		18.33	18.31	-0.02	-0.11
2006		15.53	15.44	-0.08	-0.53
2007		20.38	20.37	-0.02	-0.08
Total		461.23	431.38	-29.85	-6.47

Table 3. Annual sample sizes 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	820	540	17,666	1,048	36	16,653	5,187
2000	1,278	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	2,321	2,672	18,027	29,383	3,594	217	168
2007	2,252	2,499	22,387	58,097	12,411	1,981	2,880
2008	2,362	3,352	14,567	49,315	8,488	1,013	673
2009	1,385	1,857	19,033	50,017	6,024		

Table 4. 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	

Table 5. Summary of statistics for the model (scenario 3).

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 highgrading parameters	4
Fixed initial (1968) length composition parameters	56
Total number of fixed parameters	82
Free growth parameters	4
Initial abundance (1968)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	42
Female recruitment deviations	42
Natural and fishing mortality parameters	4
Survey catchability parameters	2
Pot male fishing mortality deviations	43
Bycatch mortality from the Tanner crab fishery	6
Pot female bycatch fishing mortality deviations	21
Trawl bycatch fishing mortality deviations	35
Free selectivity parameters	28
Total number of free parameters	231
Total number of fixed and free parameters	313

Negative log likelihood components

Length compositions---retained catch	-990.080
Length compositions---pot male discard	-711.579
Length compositions---pot female discard	-1880.310
Length compositions---survey	-50277.300
Length compositions---trawl discard	-1644.010
Length compositions---Tanner crab discards	-161.858
Pot discard male biomass	161.700
Retained catch biomass	48.500
Pot discard female biomass	0.100
Trawl discard	6.400
Survey biomass	75.178
Recruitment variation	162.317
Sex ratio of recruitment	0.060
Total	-55205.000

Table 6. Summary of model parameter estimates (scenario 3) for Bristol Bay red king crab. Estimated values and standard deviations. All values are on a log scale. Male recruit is exp(mean+male dev), and female recruit is exp(mean+male dev+female dev).

	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	16.229	0.023	16.22 9	0.023	-2.057	0.033	0.010	0.001	-4.688	0.073
1968					2.099	0.009				
1969	-0.288	0.110	0.916	0.066	2.080	0.059				
1970	0.600	0.116	0.872	0.098	1.799	0.063				
1971	-0.346	0.099	2.034	0.051	1.484	0.067				
1972	0.685	0.222	0.045	0.170	1.558	0.070				
1973	-0.495	0.121	1.558	0.057	1.316	0.075				
1974	0.186	0.092	1.542	0.059	1.507	0.070				
1975	0.292	0.063	2.460	0.047	1.353	0.066				
1976	-0.344	0.243	0.702	0.125	1.435	0.067			-0.328	0.080
1977	0.601	0.168	0.476	0.124	1.510	0.066			0.220	0.079
1978	0.560	0.136	0.941	0.100	1.647	0.057			0.137	0.077
1979	0.274	0.132	1.250	0.098	1.702	0.045			0.096	0.077
1980	-0.038	0.124	1.524	0.101	2.099	0.003			0.054	0.077
1981	0.241	0.086	1.244	0.079	1.769	0.061			-0.591	0.076
1982	-0.163	0.048	2.138	0.049	-0.188	0.061			1.062	0.081
1983	-0.233	0.081	1.136	0.055	-10.030	0.399			1.072	0.079
1984	0.154	0.063	1.079	0.044	0.736	0.059			2.000	0.002
1985	0.426	0.188	-1.472	0.143	0.904	0.060			1.303	0.078
1986	0.312	0.060	0.304	0.046	1.555	0.058			0.289	0.077
1987	0.101	0.129	-0.455	0.083	1.267	0.053			-0.232	0.076
1988	-0.345	0.267	-1.546	0.163	0.395	0.048			0.946	0.075
1989	0.440	0.141	-0.853	0.113	0.532	0.046			-0.368	0.075
1990	-0.226	0.095	0.082	0.062	1.182	0.043	1.849	0.127	-0.132	0.075
1991	-0.203	0.112	-0.543	0.075	1.165	0.045	-0.277	0.126	0.110	0.075
1992	-0.219	0.359	-2.515	0.226	0.653	0.046	2.000	0.068	0.231	0.076
1993	-0.361	0.094	-0.610	0.057	1.320	0.049	1.821	0.126	0.625	0.075
1994	-0.300	0.406	-2.768	0.240	-10.460	0.391	0.914	6.191	-0.805	0.076
1995	0.003	0.038	0.910	0.035	-10.720	0.390	1.099	5.757	-0.809	0.076
1996	-0.035	0.103	-0.464	0.071	0.331	0.043	-3.801	0.181	-0.826	0.076
1997	-0.780	0.411	-2.812	0.243	0.455	0.043	-1.252	0.130	-1.180	0.076
1998	-0.211	0.105	-0.478	0.065	1.163	0.045	1.862	0.128	-0.472	0.074
1999	-0.105	0.059	0.560	0.043	0.713	0.045	-2.335	0.135	-0.339	0.074
2000	-0.083	0.174	-0.713	0.106	0.318	0.044	-0.399	0.130	-0.979	0.075
2001	1.032	0.191	-1.681	0.162	0.303	0.044	0.955	0.129	-0.681	0.075
2002	0.164	0.040	0.974	0.035	0.390	0.044	-2.334	0.137	-1.036	0.075
2003	-0.034	0.184	-0.862	0.123	0.890	0.044	1.025	0.130	-1.255	0.075
2004	0.052	0.102	0.356	0.093	0.712	0.045	0.303	0.131	-0.959	0.076
2005	0.167	0.050	0.947	0.046	1.106	0.048	0.760	0.131	-1.133	0.076
2006	-0.403	0.133	0.046	0.086	0.778	0.050	-1.609	0.132	-1.232	0.077
2007	-0.545	0.196	-0.476	0.110	1.031	0.054	-0.306	0.132	-1.245	0.078
2008	0.195	0.330	-1.833	0.229	1.001	0.061	-0.461	0.134	-1.027	0.080
2009	-0.122	0.414	-2.148	0.259						

Table 6 (continue). Summary of model parameter estimates for Bristol Bay red king crab. Estimated values and standard deviations.

Parameter	Value	St.dev.	Parameter	Value	St.dev.
Mm80-84	0.575	0.017	log_srv_L50, m, 70-72	5.200	0.000
Mf80-84	0.889	0.020	srv_slope, f, 70-72	0.146	0.010
Mf76-79,85-93	0.043	0.006	log_srv_L50, f, 70-72	4.387	0.014
log_betal, females	0.130	0.053	log_srv_L50, m, 73-81	4.395	0.032
log_betal, males	0.681	0.075	srv_slope, f, 73-81	0.064	0.003
log_betar, females	-0.360	0.069	log_srv_L50, f, 73-81	4.423	0.017
log_betar, males	-0.281	0.059	log_srv_L50, m, 82-08	4.625	0.046
Q, females, 70-72	0.173	0.018	srv_slope, f, 82-08	0.038	0.002
Q, males, 70-72	0.878	0.100	log_srv_L50, f, 82-08	4.577	0.025
Q, 68-69, 73-08	NA	NA	log_srv_L50, m, 68-69	4.504	0.015
moltp_slope	0.088	0.003	srv_slope, f, 68-69	0.019	0.002
log_moltp_L50	4.939	0.003	log_srv_L50, f, 68-69	5.024	0.073
log_N68	18.953	0.032	TC_slope, females	0.283	0.066
log_avg_L50, 73-08	4.926	0.001	log_TC_L50, females	4.540	0.013
log_avg_L50, 68-72	4.864	0.005	TC_slope, males	0.293	0.020
ret_fish_slope, 73-08	0.500	0.021	log_TC_L50, males	5.019	0.042
ret_fish_slope, 68-72	0.310	0.037	log_TC_F, males, 91	-2.847	0.351
pot disc.males, φ	-0.242	0.011	log_TC_F, males, 92	-4.014	0.326
pot disc.males, κ	0.003	0.000	log_TC_F, males, 93	-5.149	0.303
pot disc.males, γ	-0.012	0.000	log_TC_F, females, 91	-2.939	0.084
sel_62.5mm, 68-72	1.400	0.000	log_TC_F, females, 92	-4.128	0.083
post disc.fema., slope	0.380	0.107	log_TC_F, females, 93	-4.722	0.083
log_pot disc.fema., L50	4.389	0.019			
trawl disc slope	0.059	0.004			
log_trawl disc L50	5.004	0.042			

Table 7. Annual abundance estimates (million crabs), mature male biomass (MMB, million lbs), and total survey biomass estimates (million lbs) for red king crab in Bristol Bay estimated by length-based analysis from 1968-2009. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm CL.

	Males				Females	Total Survey Biomass	
Year (t)	Mature (>119mm)	Legal (>134mm)	MMB (>119mm)	MMB SD	Mature (>89mm)	Model Est. (>64mm)	Area-swept (>64mm)
1968	14.828	8.725	34.154	1.317	61.340	177.181	176.524
1969	14.600	6.277	34.316	1.880	62.575	179.110	192.111
1970	17.659	6.917	45.798	2.702	65.439	79.192	94.888
1971	20.637	8.936	60.097	3.525	72.729	97.509	
1972	26.709	11.749	76.927	4.594	90.635	121.113	110.820
1973	33.546	14.806	103.464	5.514	107.843	414.723	351.646
1974	49.200	20.370	145.062	6.881	112.485	481.604	424.121
1975	54.470	27.673	168.587	7.930	118.851	583.773	461.200
1976	56.873	31.010	172.806	7.797	153.984	667.756	626.366
1977	64.629	31.975	190.579	7.212	193.747	712.325	800.168
1978	83.524	36.587	236.666	7.249	186.257	721.066	710.799
1979	84.666	44.747	235.487	8.563	168.029	692.390	536.477
1980	66.384	42.427	100.912	4.293	159.404	635.976	503.933
1981	25.039	15.159	45.511	2.902	65.036	283.836	247.233
1982	13.236	6.953	34.050	1.897	29.320	152.547	292.355
1983	9.969	5.176	27.525	1.318	18.693	113.646	104.135
1984	8.765	4.156	19.881	0.944	15.601	95.424	331.782
1985	8.749	3.247	28.368	1.086	11.519	66.250	72.763
1986	12.979	5.536	37.682	1.407	16.438	86.684	102.052
1987	15.542	7.263	48.564	1.629	20.317	97.179	145.811
1988	15.794	8.989	58.190	1.755	25.746	102.830	111.488
1989	16.988	10.368	63.841	1.806	24.957	109.564	129.489
1990	17.204	11.120	57.930	1.795	22.444	112.160	116.127
1991	13.918	9.819	47.204	1.735	22.149	102.401	182.621
1992	11.247	7.863	43.737	1.666	22.059	91.392	76.571
1993	12.018	7.328	39.173	1.631	19.753	89.036	103.969
1994	11.511	6.761	50.873	1.681	16.722	78.559	65.674
1995	11.875	8.491	56.591	1.646	15.882	93.857	79.206
1996	11.935	9.120	51.775	1.571	21.225	107.433	90.138
1997	11.398	8.152	48.199	1.527	30.846	112.685	174.149
1998	15.469	7.949	52.530	1.632	30.083	118.427	168.189
1999	17.249	9.261	62.767	1.857	26.427	120.724	123.648
2000	15.635	10.755	63.418	1.913	29.091	125.488	139.183
2001	14.811	10.537	61.876	1.879	33.038	130.211	104.985
2002	17.151	10.329	68.532	1.949	32.014	143.784	142.274
2003	18.105	11.509	67.014	2.038	38.807	153.356	192.746
2004	16.351	11.087	63.326	2.083	47.656	160.079	194.642
2005	19.382	10.758	66.679	2.342	47.915	177.451	212.034
2006	20.503	11.664	74.720	2.733	55.878	188.240	189.854
2007	21.985	12.943	76.412	3.306	63.409	201.223	206.408
2008	25.536	13.584	87.826	4.402	58.893	202.628	219.671
2009	26.878	15.626	95.169	4.379	51.699	196.504	178.893

Table 8. Comparison of projected mature male biomass (million lbs) on Feb. 15, retained catch (million lbs), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, $F_{35\%}$, and ADF&G harvest strategy with $F_{35\%}$ constraint during 2010-2019.

Year	MMB	95% limits of MMB		Catch	95% limits of catch	
No directed fishery						
2010	116.319	105.944	126.081	0	0	0
2011	130.805	119.137	141.783	0	0	0
2012	132.148	120.354	143.234	0	0	0
2013	126.473	115.065	137.952	0	0	0
2014	124.943	107.925	146.750	0	0	0
2015	129.776	100.878	173.687	0	0	0
2016	136.699	94.736	194.917	0	0	0
2017	143.664	90.484	212.313	0	0	0
2018	150.289	89.095	226.829	0	0	0
2019	156.842	88.529	238.456	0	0	0
$F_{40\%}$						
2010	98.470	89.687	106.734	17.674	16.097	19.157
2011	94.450	86.025	102.377	19.843	18.073	21.509
2012	80.299	73.130	87.034	19.308	17.586	20.929
2013	65.071	60.099	70.404	15.788	13.299	18.024
2014	59.499	49.949	74.665	11.736	9.164	14.768
2015	61.981	42.625	96.070	10.699	6.414	15.365
2016	66.333	39.099	107.904	11.314	4.937	19.184
2017	70.034	37.592	117.344	12.363	4.348	21.662
2018	72.865	38.543	122.611	13.294	4.255	23.878
2019	75.352	39.017	124.816	14.024	4.513	24.967
$F_{35\%}$						
2010	94.892	86.428	102.856	21.194	19.304	22.973
2011	88.025	80.173	95.412	22.879	20.839	24.800
2012	72.268	66.360	78.283	21.460	18.986	23.309
2013	58.322	54.176	62.811	15.265	13.057	17.789
2014	53.702	44.668	67.537	11.514	8.855	15.475
2015	56.604	38.217	88.430	10.907	6.138	16.627
2016	60.946	35.305	99.180	11.867	4.799	21.034
2017	64.380	34.382	107.791	13.129	4.303	23.841
2018	66.817	35.337	111.463	14.184	4.338	26.112
2019	68.864	35.859	113.899	14.979	4.656	26.914
ADF&G harvest strategy						
2010	97.246	88.572	105.408	18.879	17.195	20.463
2011	95.646	89.420	103.236	17.455	13.566	19.363
2012	86.406	80.721	92.080	14.170	12.107	16.782
2013	73.796	69.457	78.799	12.479	10.364	14.308
2014	66.889	58.915	79.826	12.174	8.714	16.167
2015	66.476	49.330	95.637	12.769	7.490	19.405
2016	68.432	43.709	105.690	13.084	6.701	20.917
2017	70.737	39.813	115.144	13.342	6.282	22.290
2018	72.968	39.400	118.936	13.634	6.190	22.805
2019	80.008	44.537	121.046	9.244	0.000	23.412

Table 9. List of years, survey stations, dates and red king crab sizes founded in groundfish stomachs during NMFS summer trawl surveys. All identified crabs are females, mostly mature females. (Source: G.M. Lang, NMFS, Seattle).

YEAR	RLAT	RLONG	STATION	DATE	PRED_LEN	RKC CL(mm)
1984	57.99	-160.87	J-12	6/13/1984	92	110
1984	57.33	-162.16	H-10	6/14/1984	79	130
1981	57.34	-162.13	H-10	5/29/1981	67	121
1981	57.34	-162.13	H-10	5/29/1981	67	106
1981	56.69	-161.00	F-12	6/1/1981	66	100
1981	56.69	-161.00	F-12	6/1/1981	69	53
1981	57.01	-160.95	G-12	6/1/1981	69	160
1981	57.99	-160.87	J-12	6/21/1981	51	91
1981	57.99	-160.87	J-12	6/21/1981	62	95
1985	56.95	-159.85	G-14	10/29/1985	85	52
1986	57.67	-161.49	I-11	6/7/1986	89	91
1989	56.17	-161.52	D-11	6/4/1989	95	84
1989	56.17	-161.52	D-11	6/4/1989	95	99
1991	57.00	-159.12	G-15	6/8/1991	56	17
1992	57.32	-162.15	H-10	6/9/1992	98	101
1992	57.32	-162.15	H-10	6/9/1992	98	87
1992	57.32	-162.15	H-10	6/9/1992	98	95
1992	57.32	-162.15	H-10	6/9/1992	97	117
1992	56.67	-160.99	F-12	6/7/1992	89	144
1985	56.42	-161.58	E-11	4/25/1985	82	94
1992	56.67	-160.99	F-12	6/7/1992	89	144
1992	57.32	-162.15	H-10	6/9/1992	98	101
1992	57.32	-162.15	H-10	6/9/1992	98	87
1992	57.32	-162.15	H-10	6/9/1992	98	95
1992	57.32	-162.15	H-10	6/9/1992	97	117
2000	56.00	-162.25	D-10	5/28/2000	75	120
2002	57.68	-160.27	I-13	6/3/2002	70	125

Table 10. Summary of red king crab biomass (million lbs) in Bristol Bay that were consumed by groundfish during late May to September. Pacific cod is the main predator. (Source: G.M. Lang, NMFS, Seattle).

Year	Red king crab biomass
1984	3.719
1985	0.000
1986	14.457
1987	7.403
1988	0.000
1989	0.203
1990	1.853
1991	0.039
1992	4.488
1993	3.833
1994	1.545
1995	0.993
1996	0.000
1997	0.000
1998	2.192
1999	1.718
2000	1.199
2001	0.000
2002	2.008
2003	0.000
2004	0.000
2005	11.677

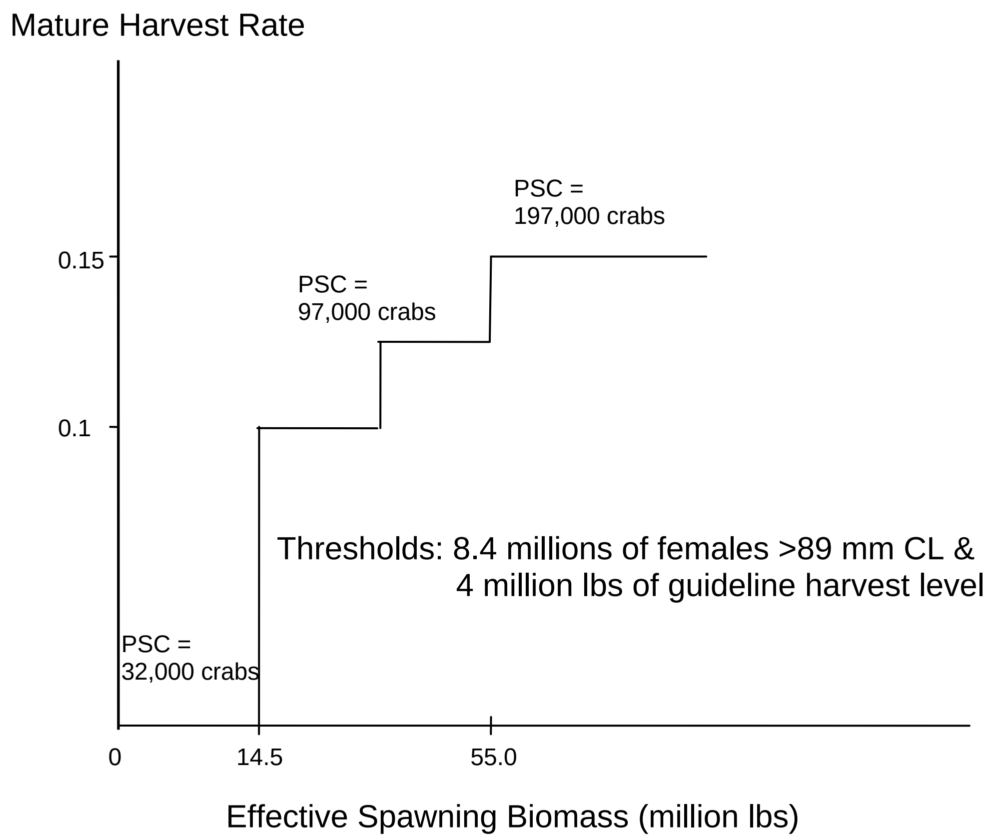


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crabs) of Bristol Bay red king crabs in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates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

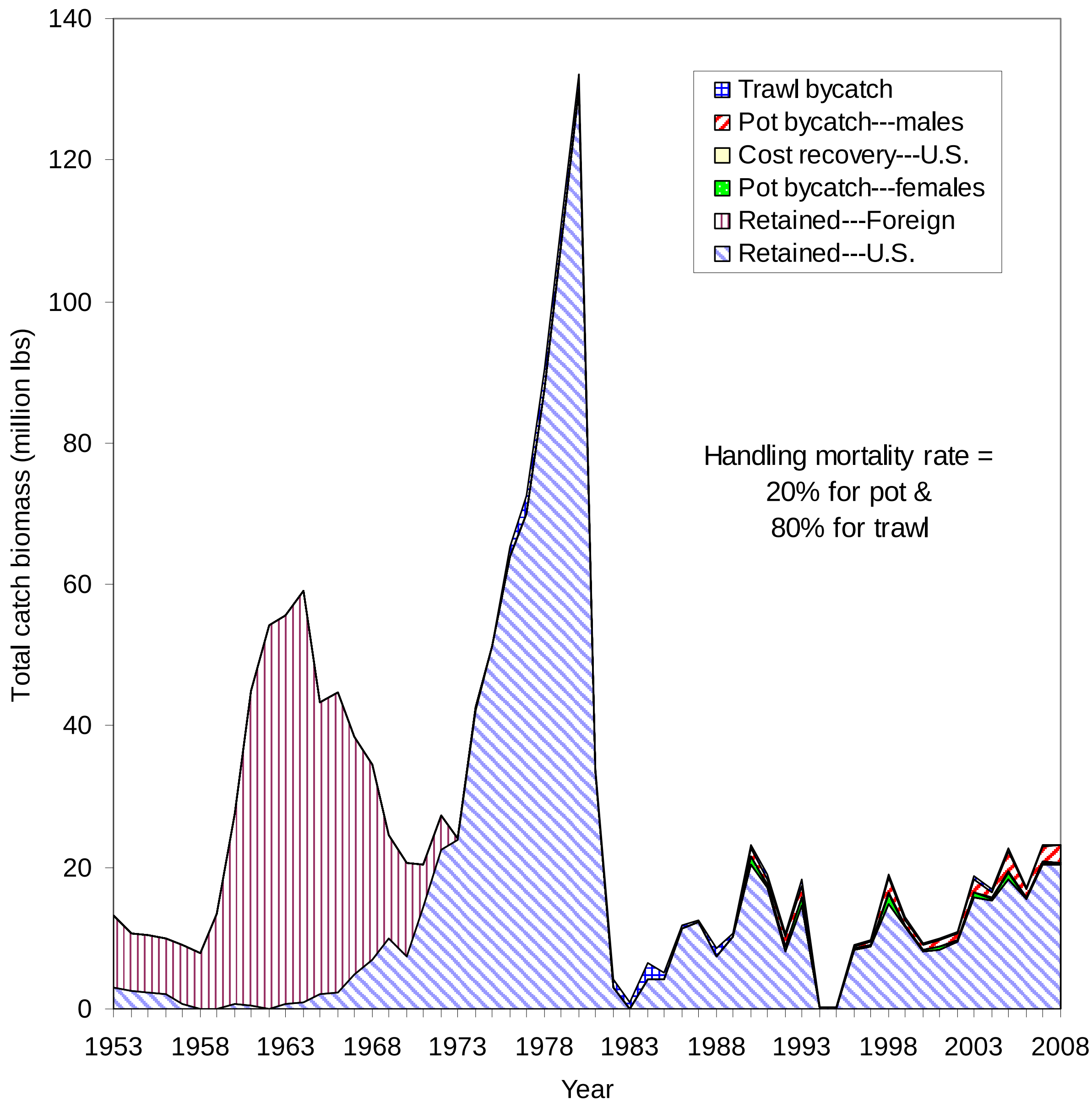


Figure 2. Retained catch biomass and bycatch mortality biomass (million lbs) for Bristol Bay red king crab from 1960 to 2008. Handling mortality rates were assumed to be 0.2 for the directed pot fishery and 0.8 for the trawl fisheries.

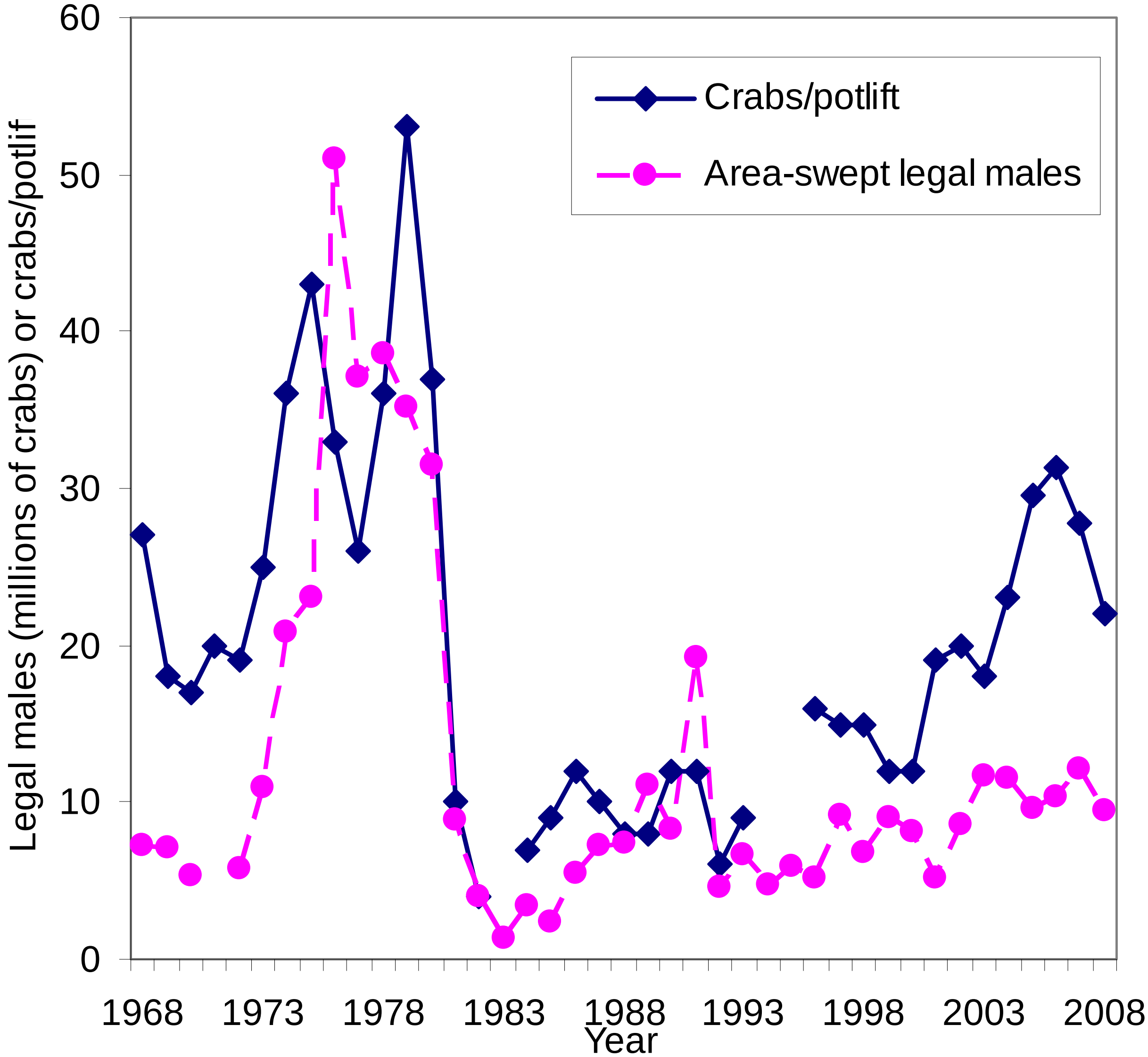


Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2008.

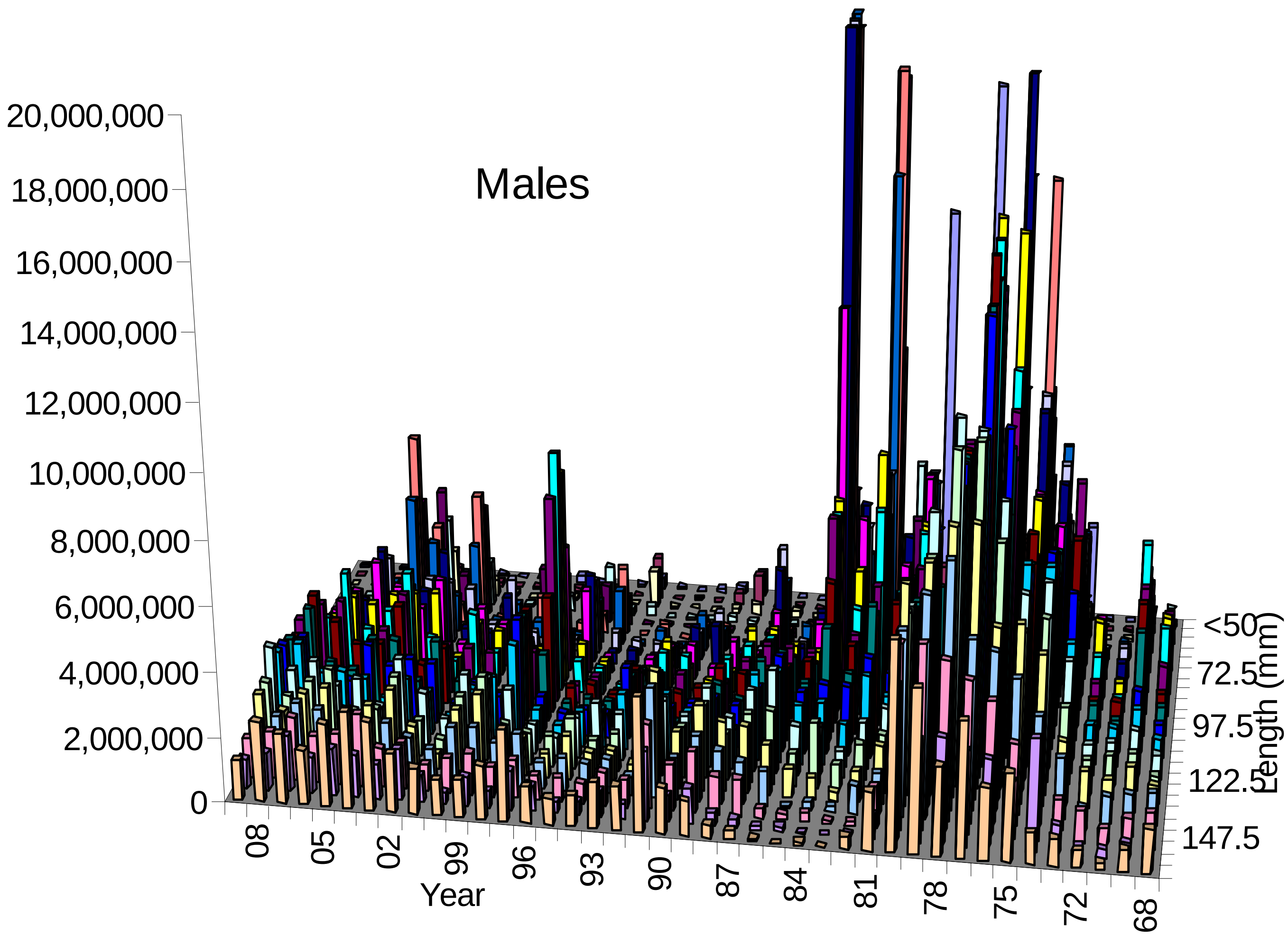


Figure 4. Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2009.

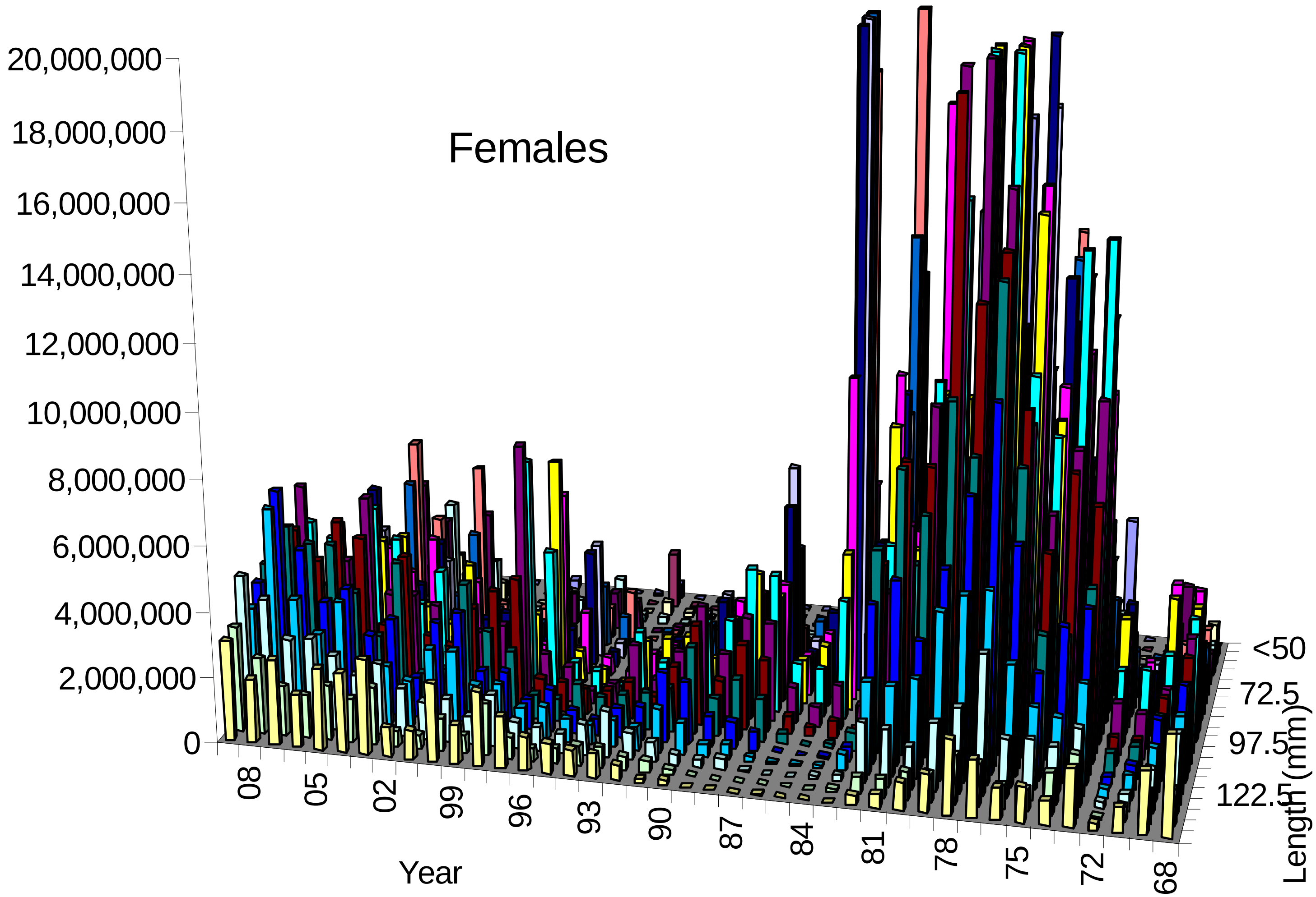


Figure 5. Survey abundances by length for female Bristol Bay red king crabs from 1968 to 2008.

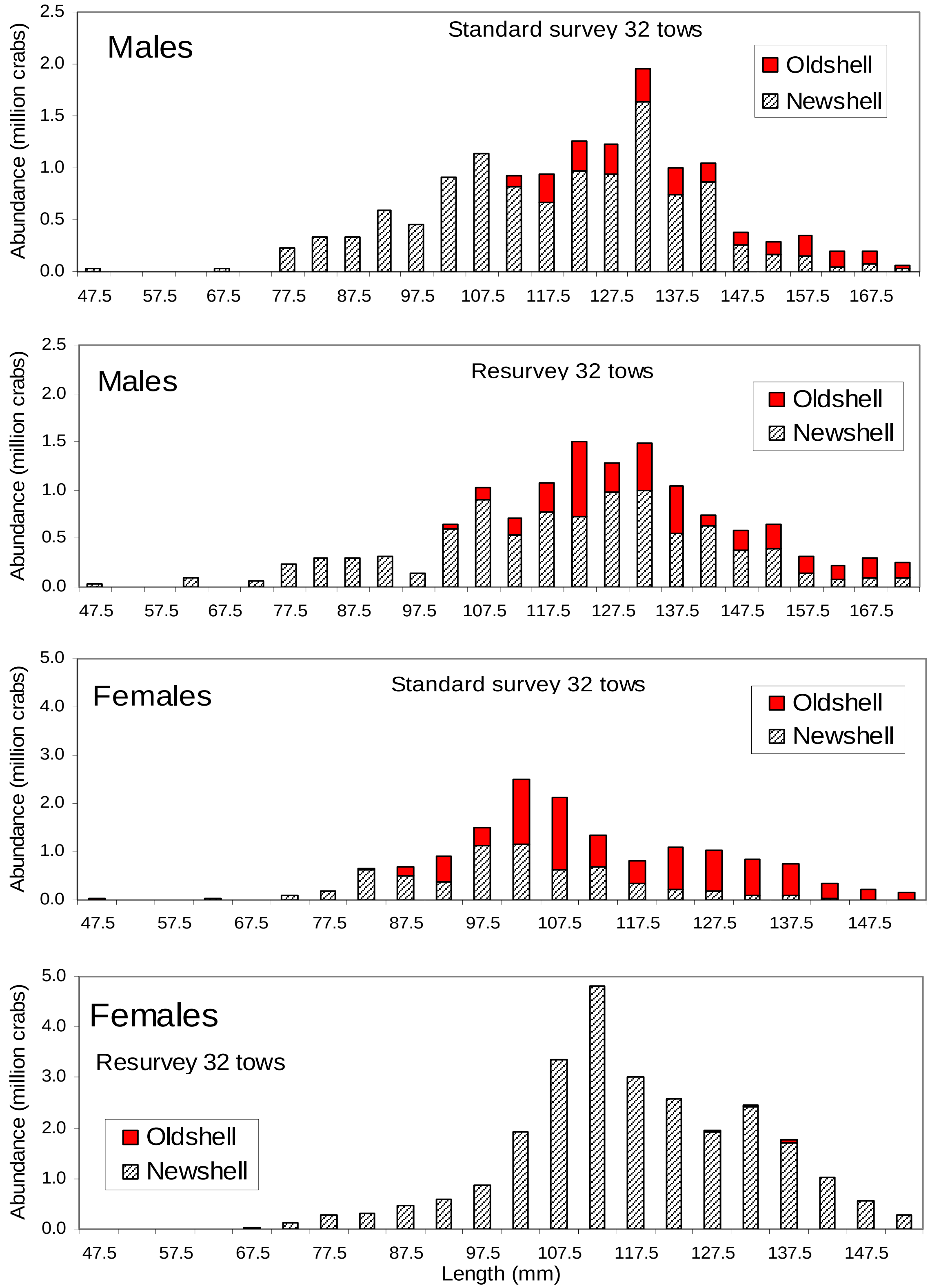


Figure 6. Comparison of area-swept estimates of abundance in 32 stations from the standard trawl survey and resurvey in 2009.

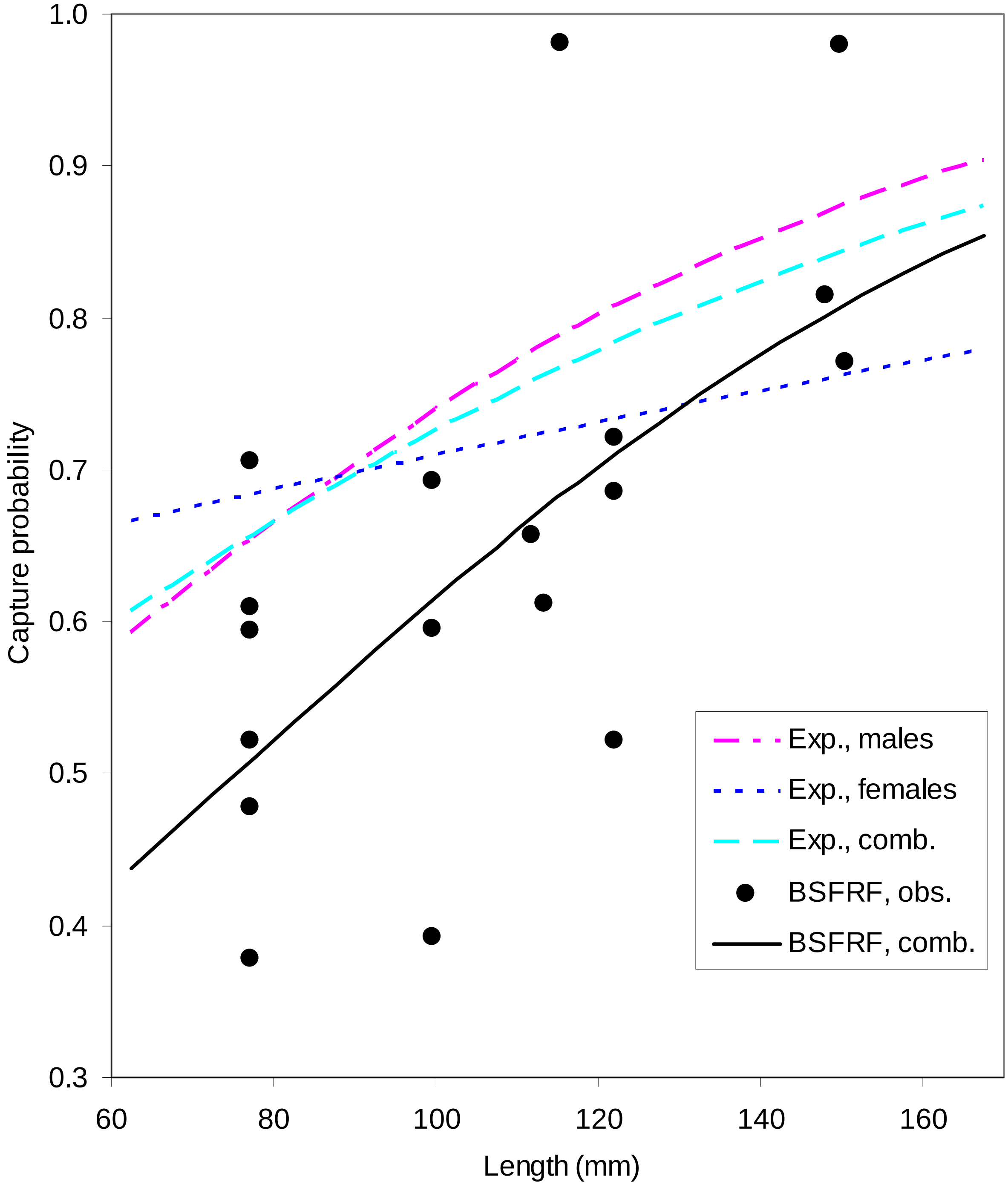
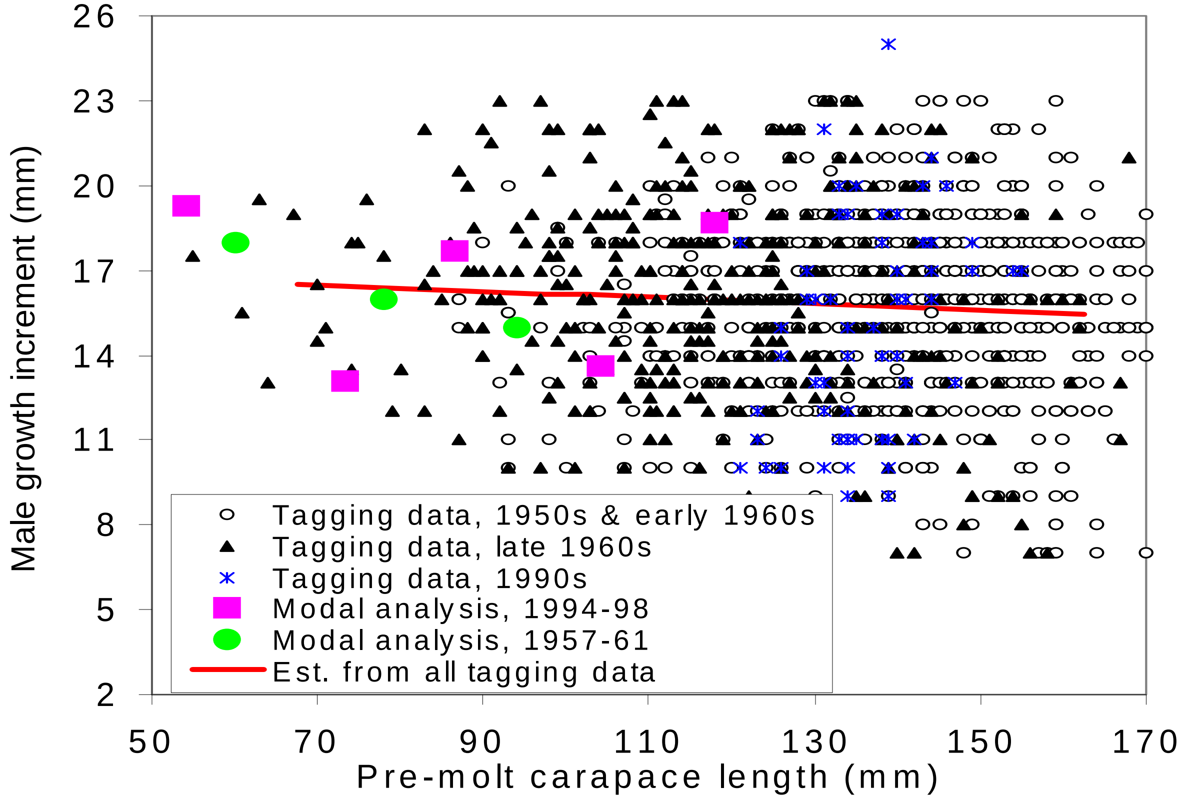


Figure 7. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.



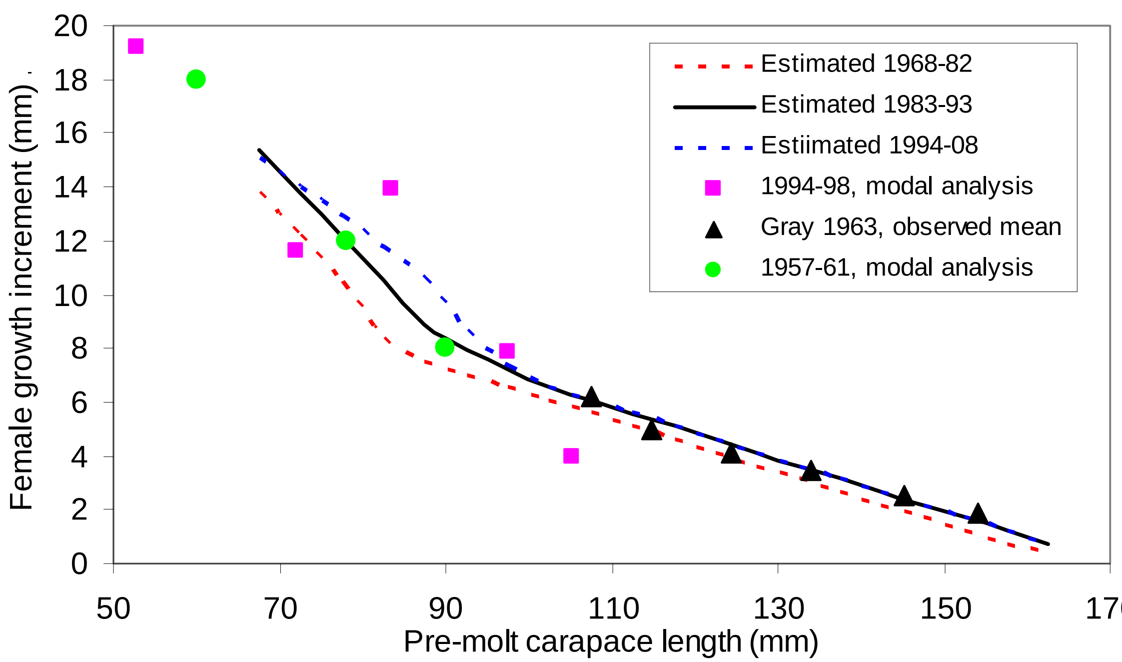


Figure 8. Mean growth increments per molt for Bristol Bay red king crab. Note: “tagging”---based on tagging data; “mode”---based on modal analysis.

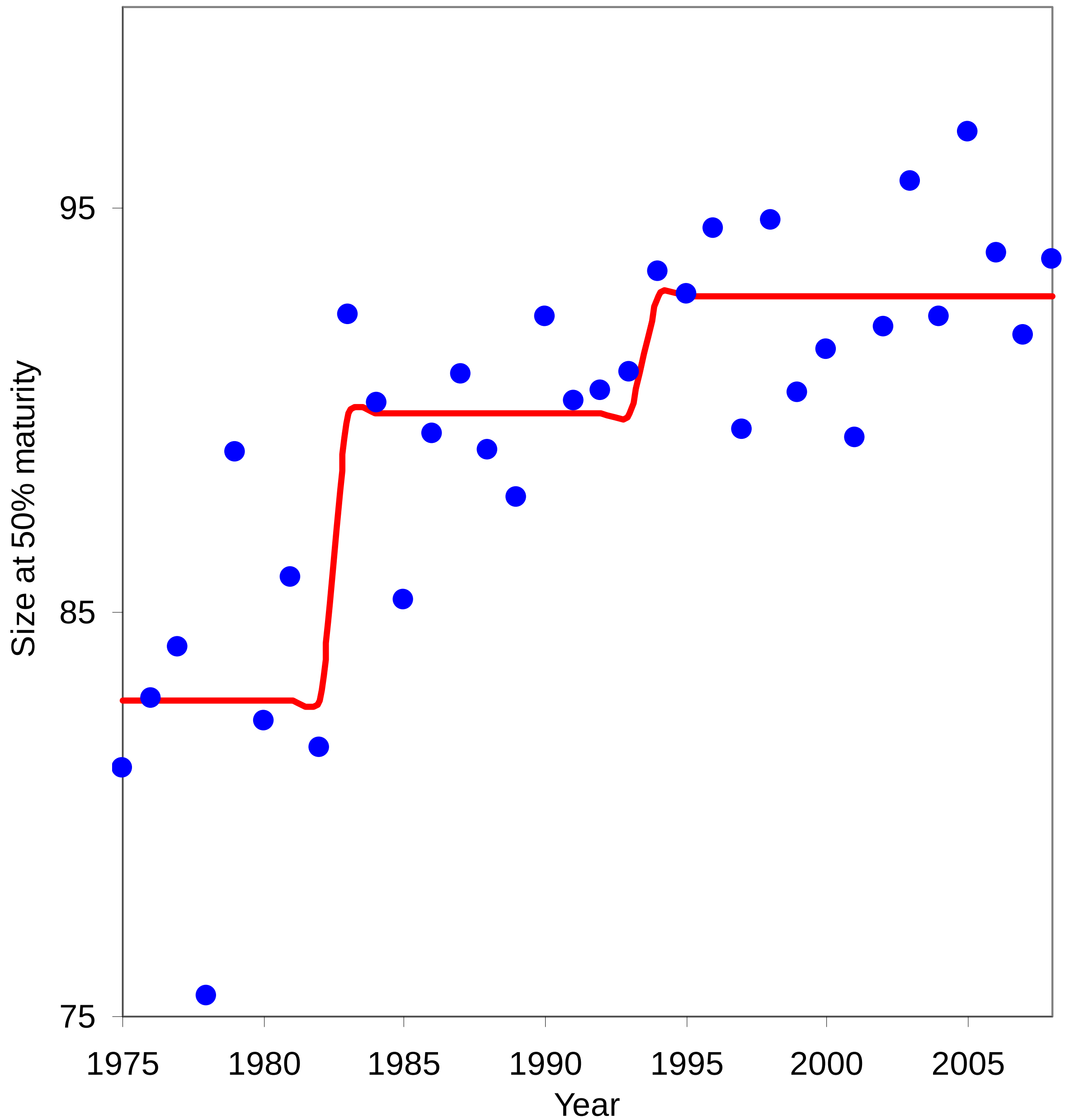


Figure 9. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

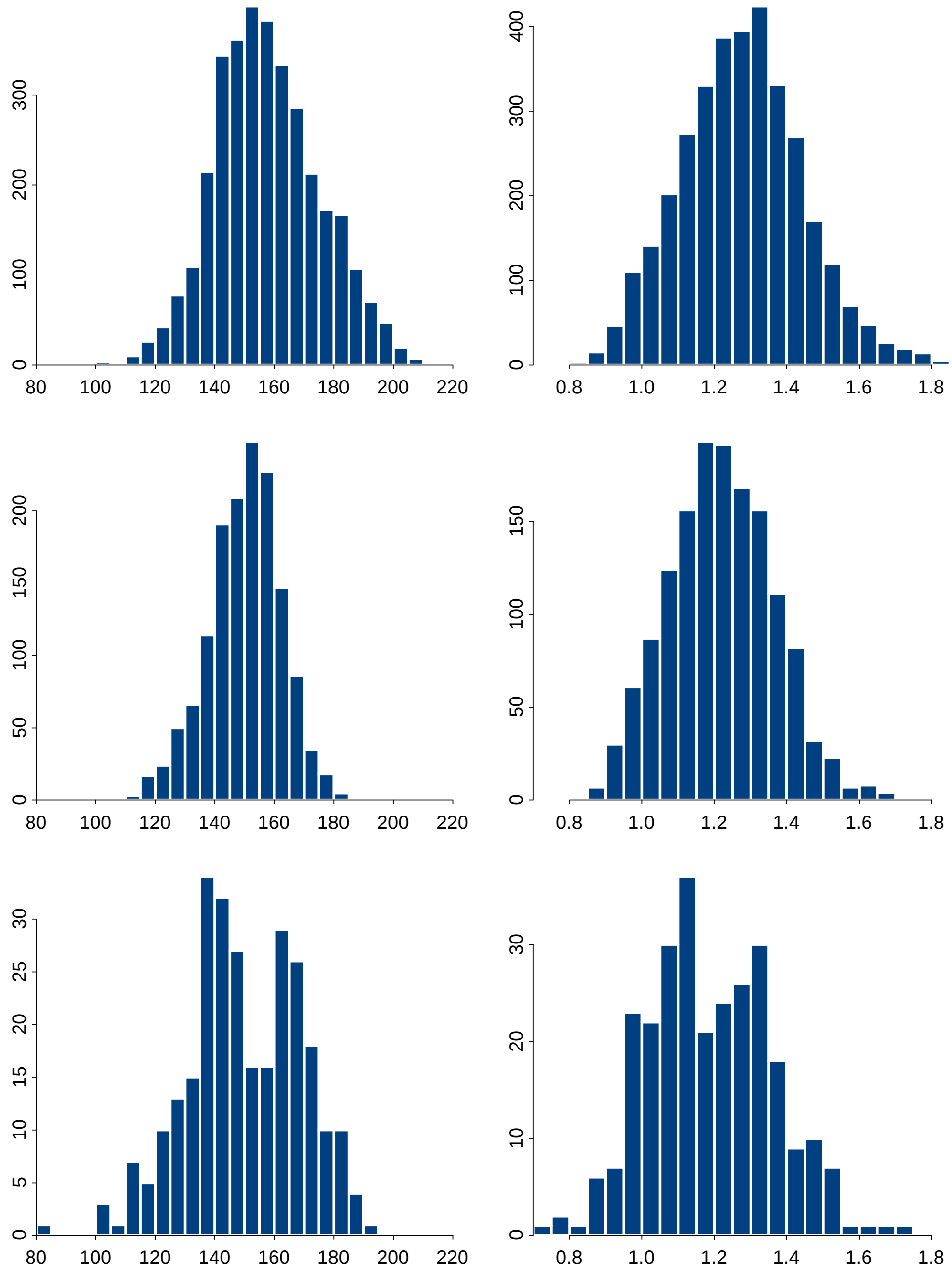
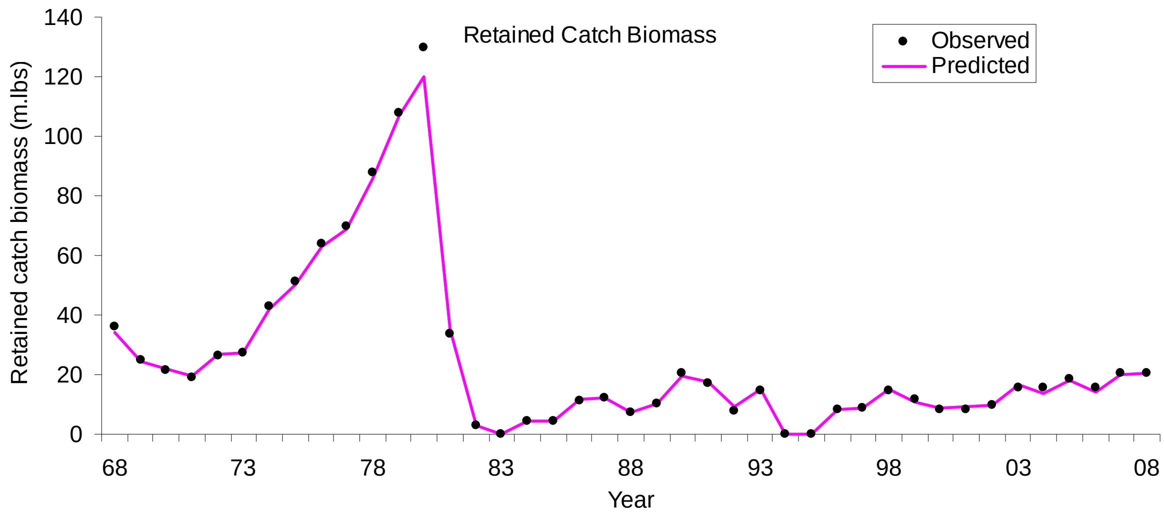
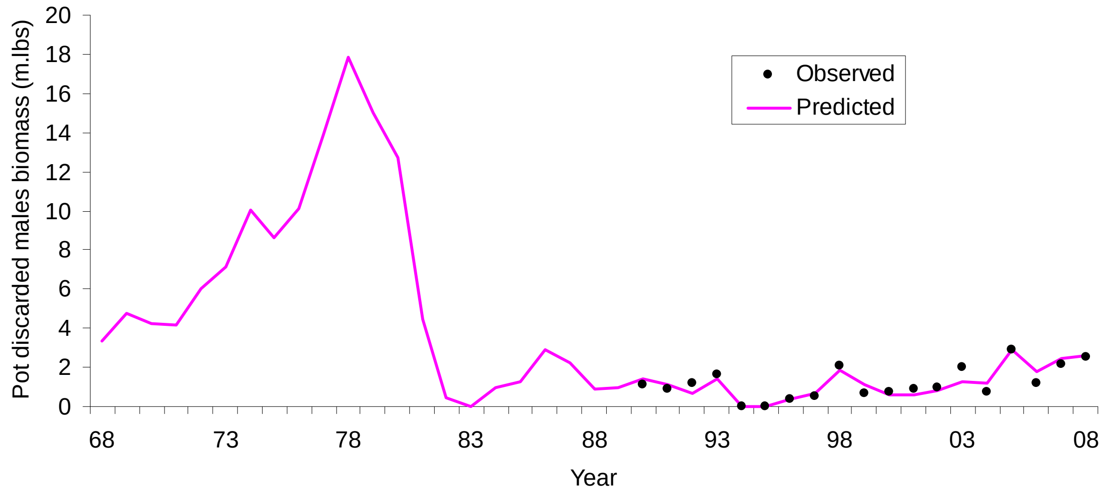
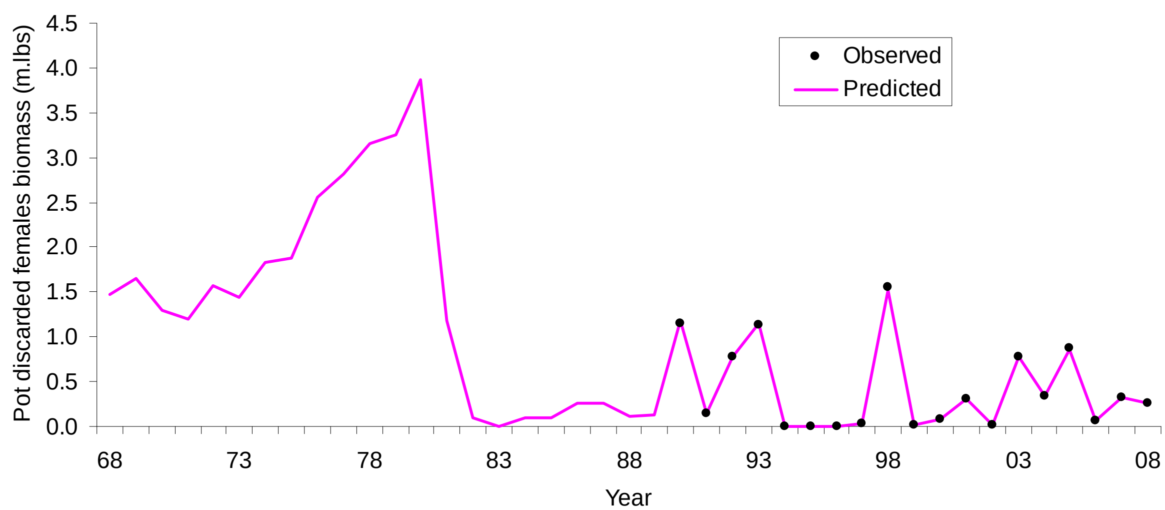


Figure 10. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak red king crab are about 15 mm larger than those for Bristol Bay red king crab. (Source: Doug Pengilly, ADF&G).







Fi

Figure 11a. Observed and predicted catch mortality biomass. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

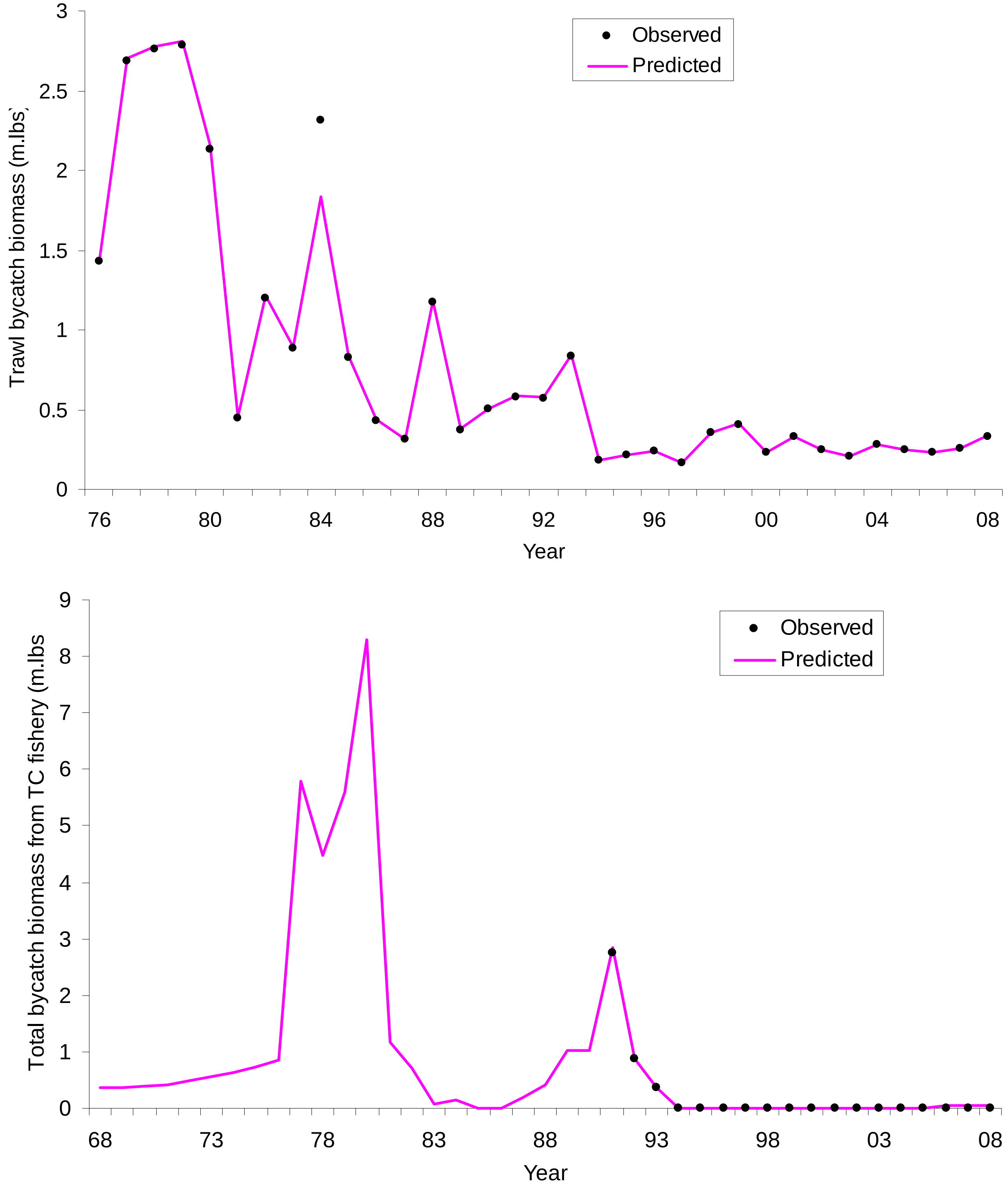


Figure 11(b). Observed and predicted catch mortality biomass from trawl fisheries and Tanner crab fishery with scenario (3). Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25.

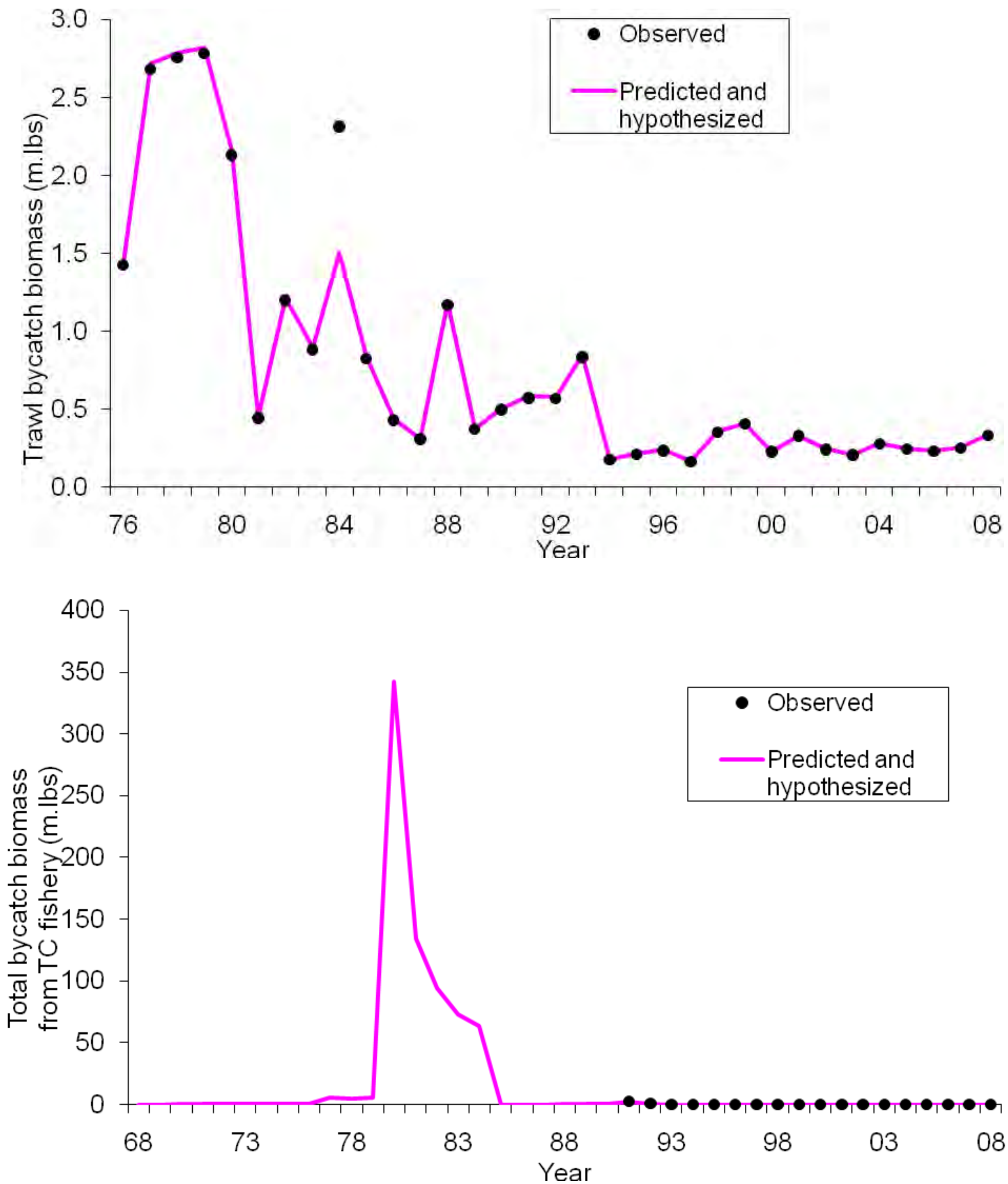


Figure 11(c). Observed and predicted/hypothesized catch mortality biomass from trawl fisheries and Tanner crab fishery with scenario (4). Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25.

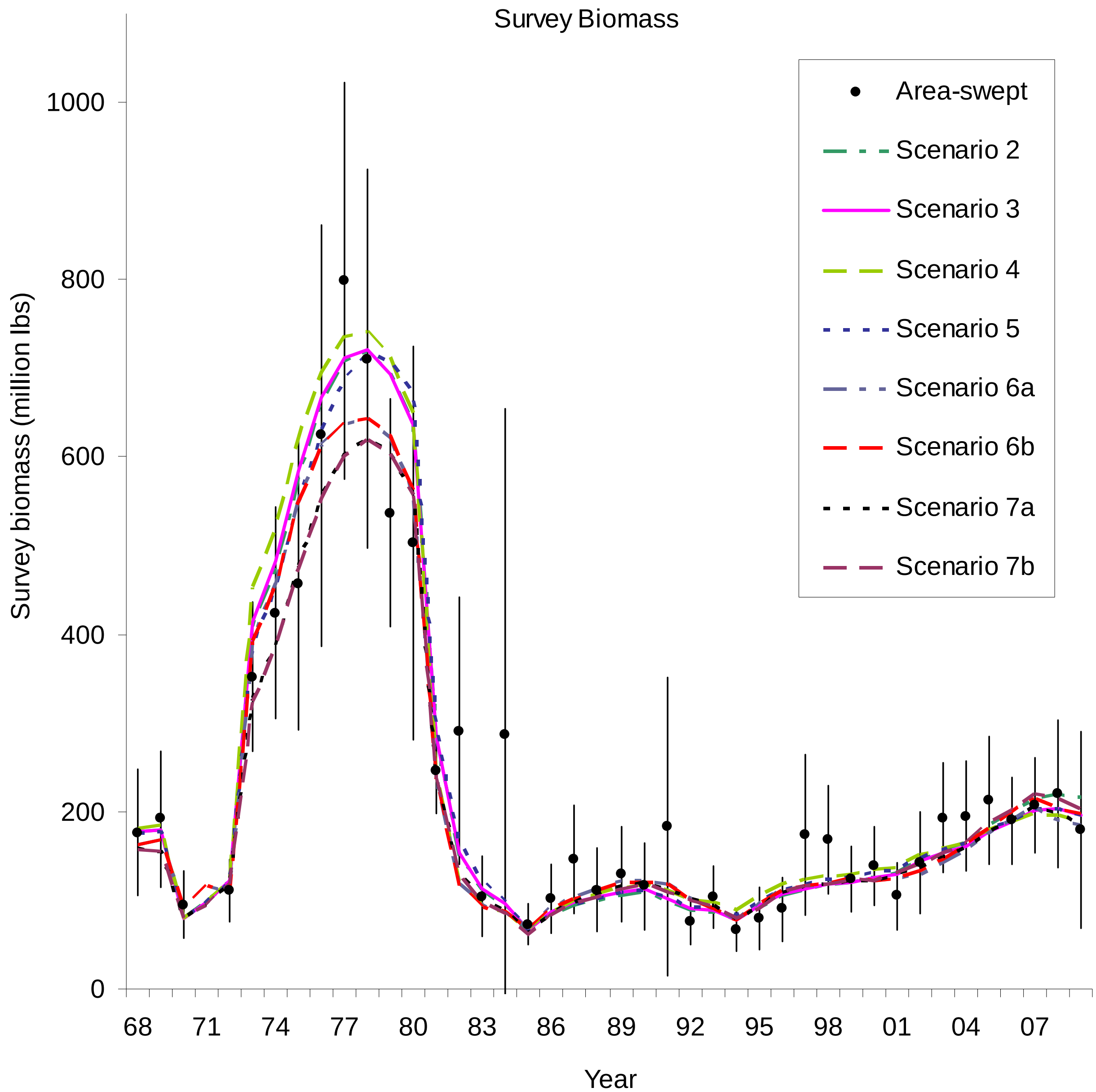


Figure 12a. Comparisons of area-swept estimates of total survey biomass and model prediction for 8 scenarios (see Summary of Major Changes for scenarios). Pot handling mortality rate is 0.2. The error bars are plus and minus 2 standard deviations.

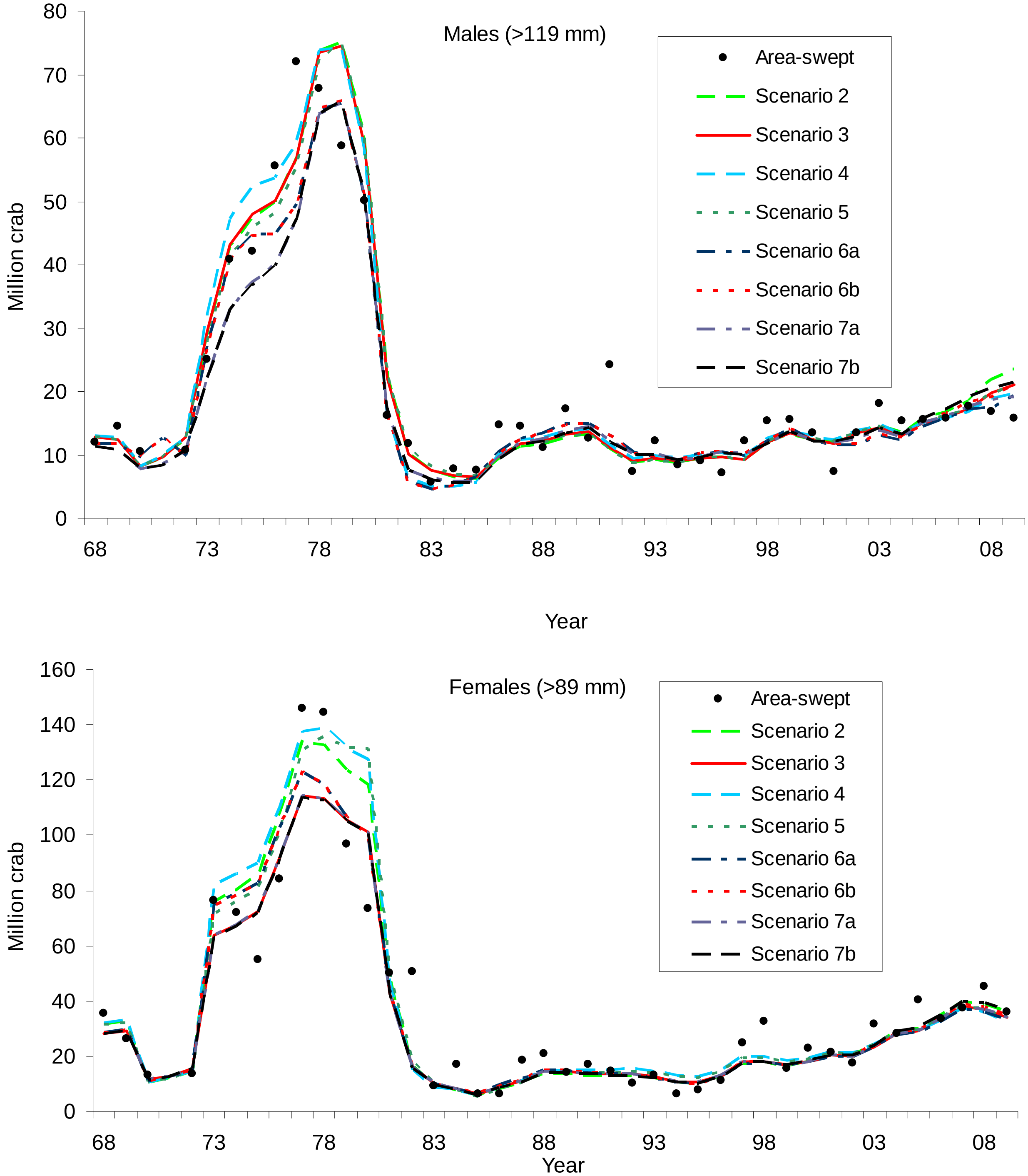


Figure 12b. Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for 8 scenarios (see Summary of Major Change for scenarios). Pot handling mortality rate is 0.2.

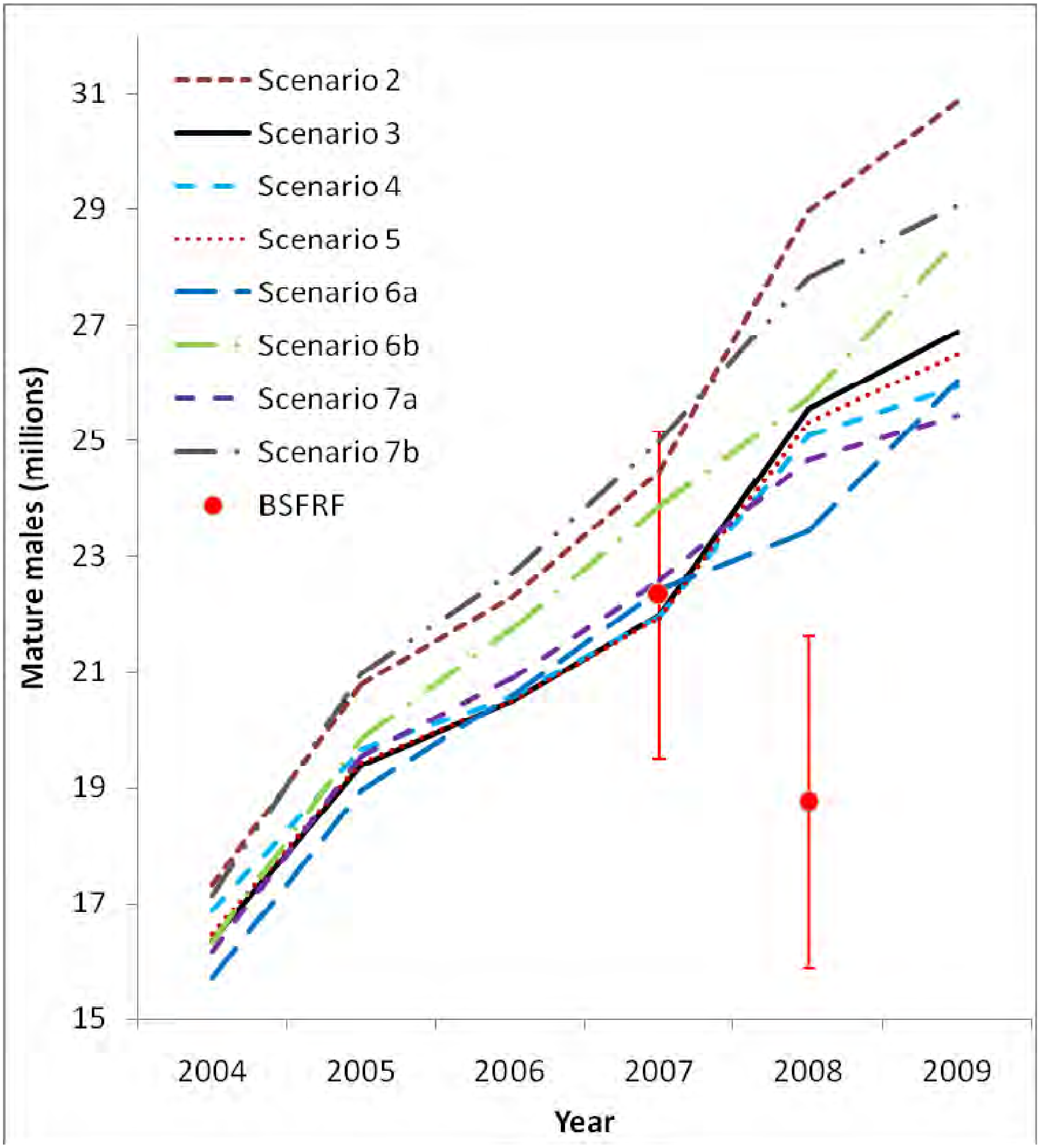


Figure 12c. Comparisons of total mature male abundance estimates by the BSFRF survey and the model for 8 scenarios (see Summary of Major Changes for scenarios). Pot handling mortality rate is 0.2. The error bars are plus and minus 2 standard deviations.

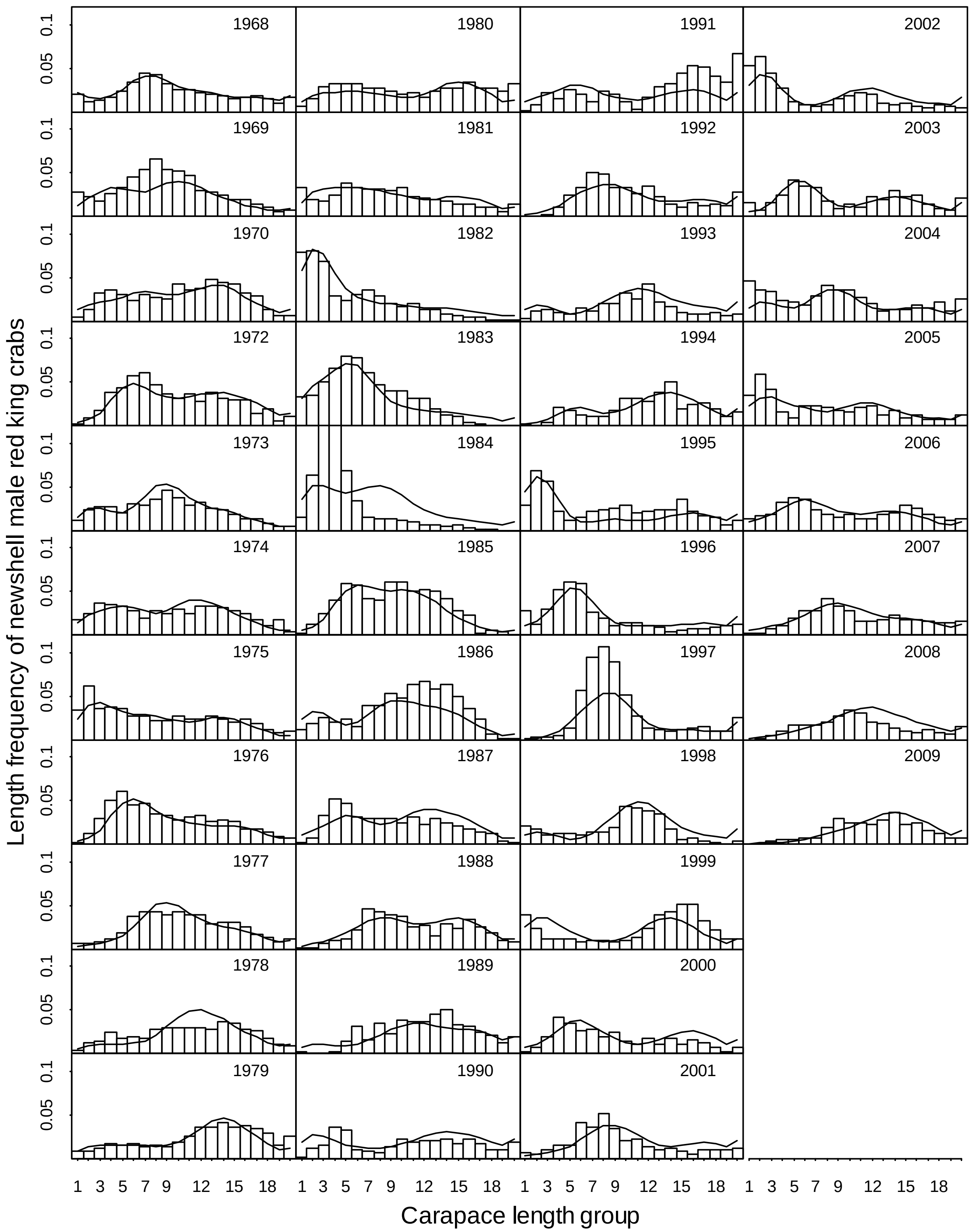


Figure 13. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay all-shell (before 1986) and newshell (1986-2009) male red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

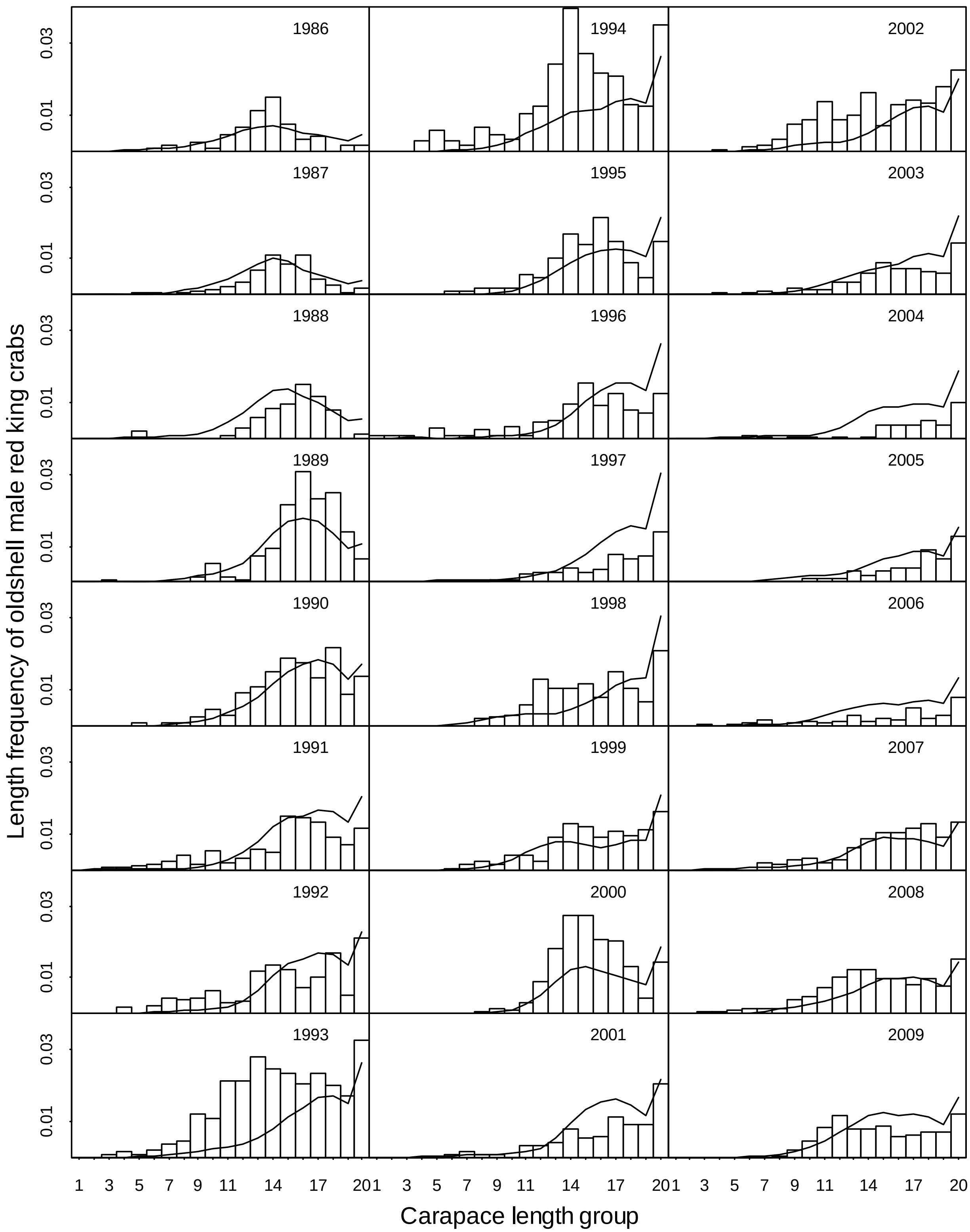


Figure 14. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay oldshell male red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

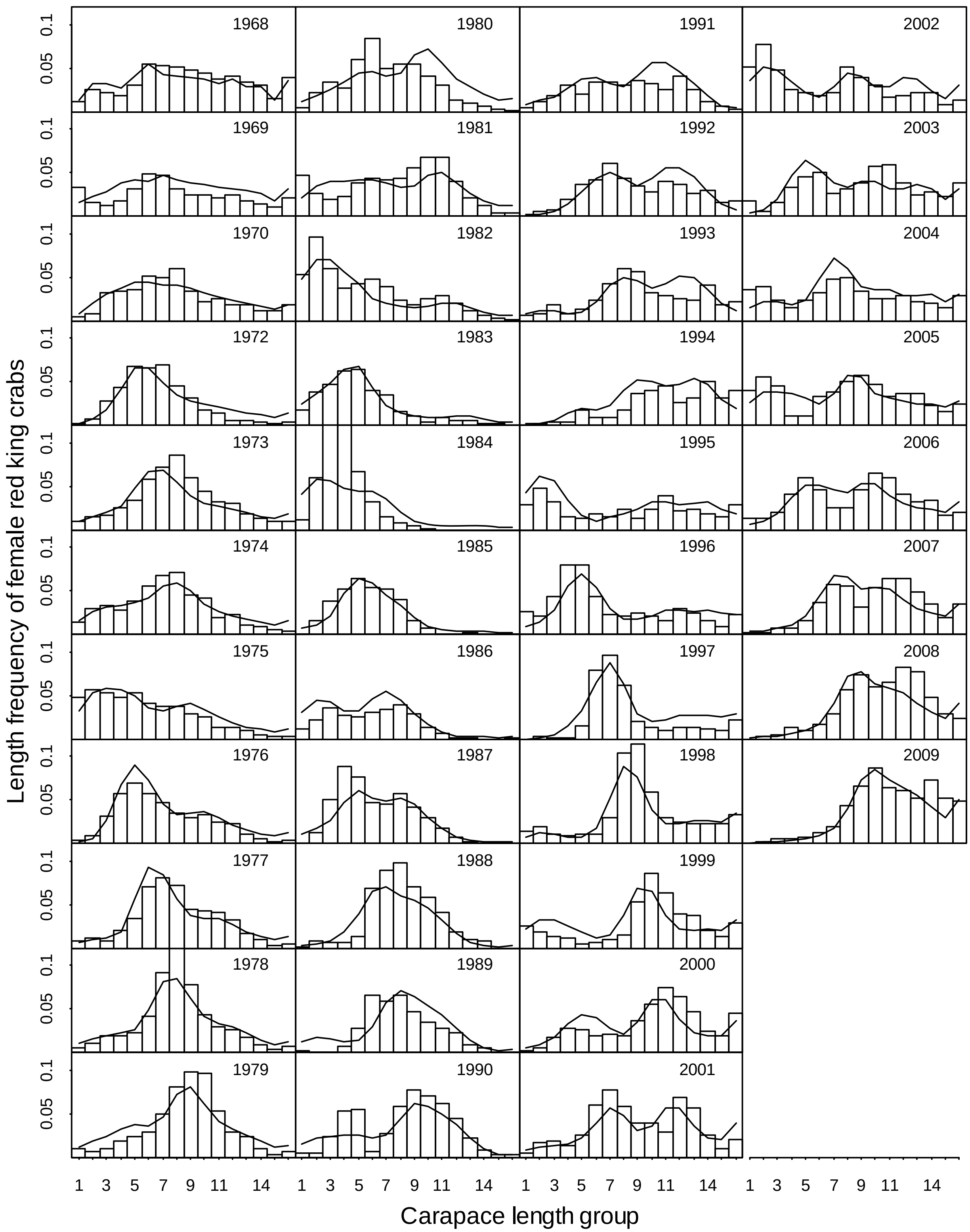


Figure 15. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

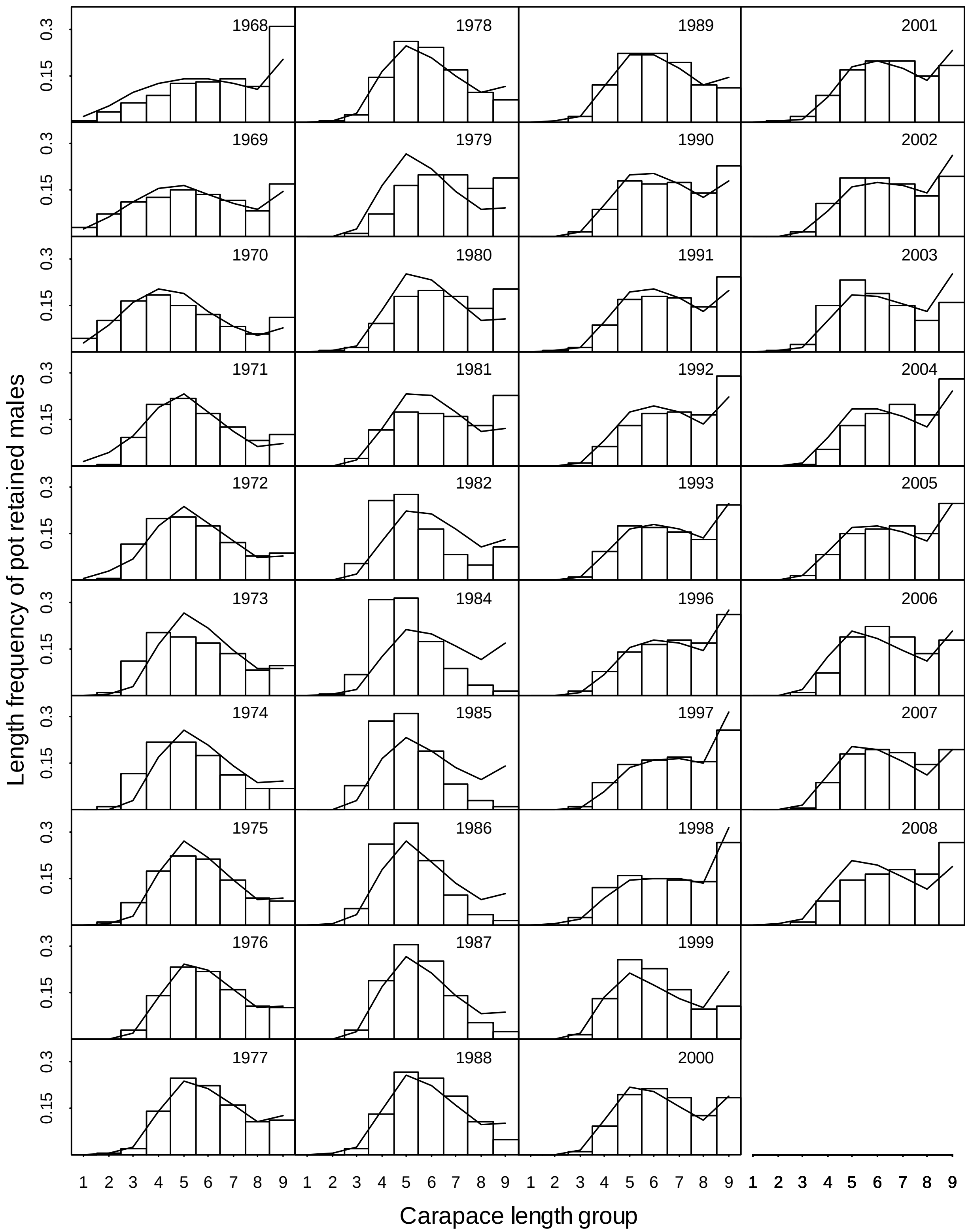


Figure 16. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 122.5 mm.

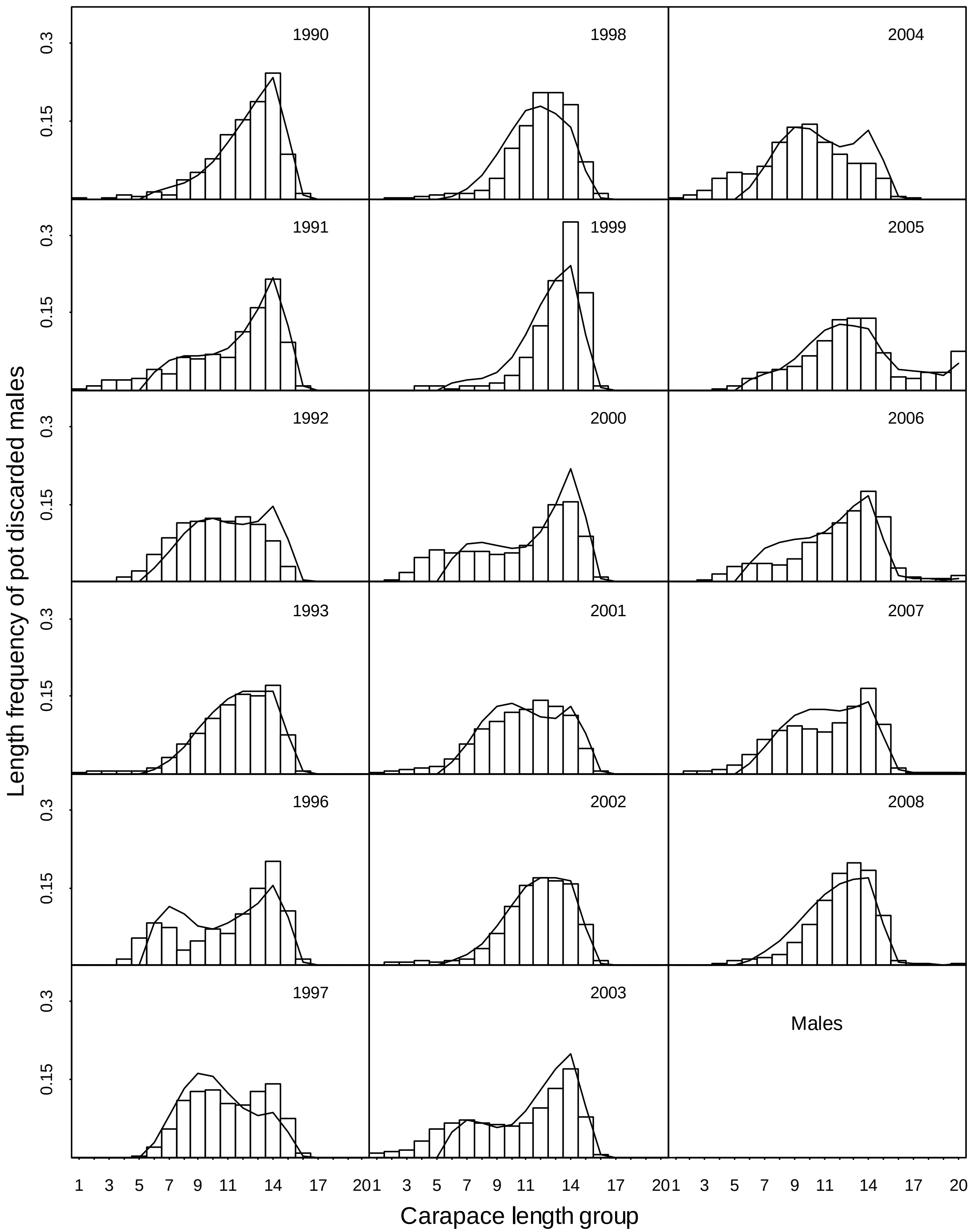


Figure 17. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

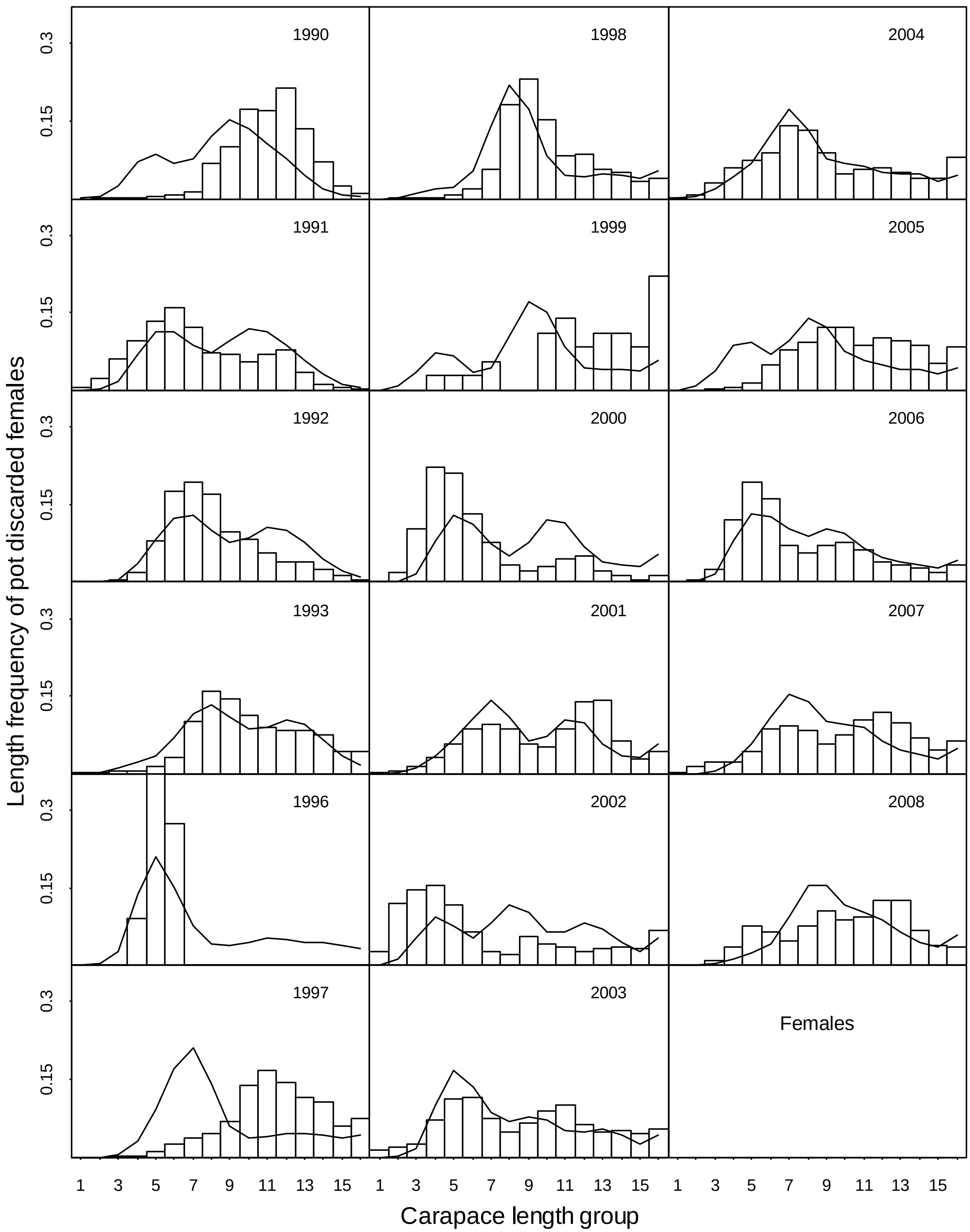


Figure 18. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

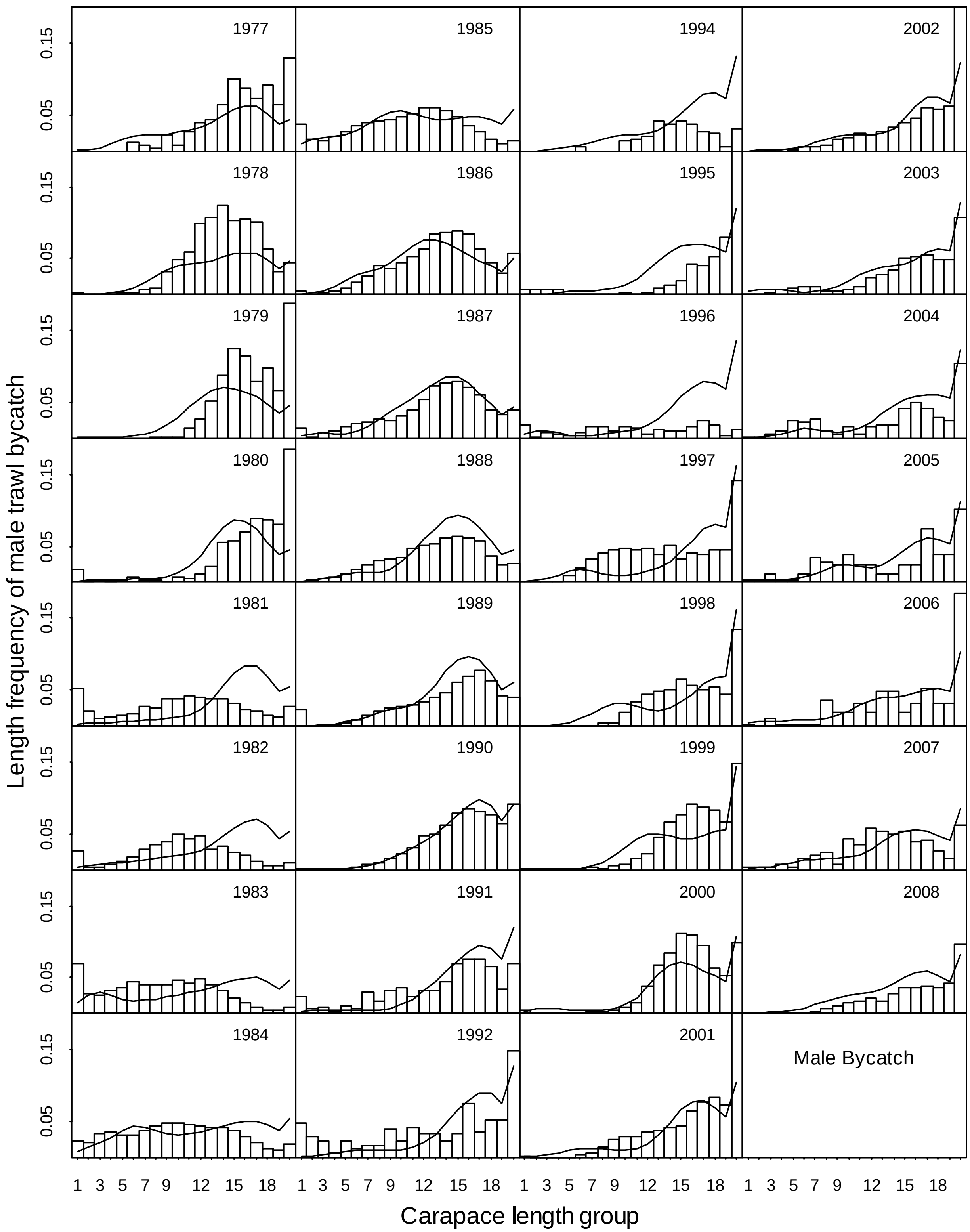


Figure 19. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

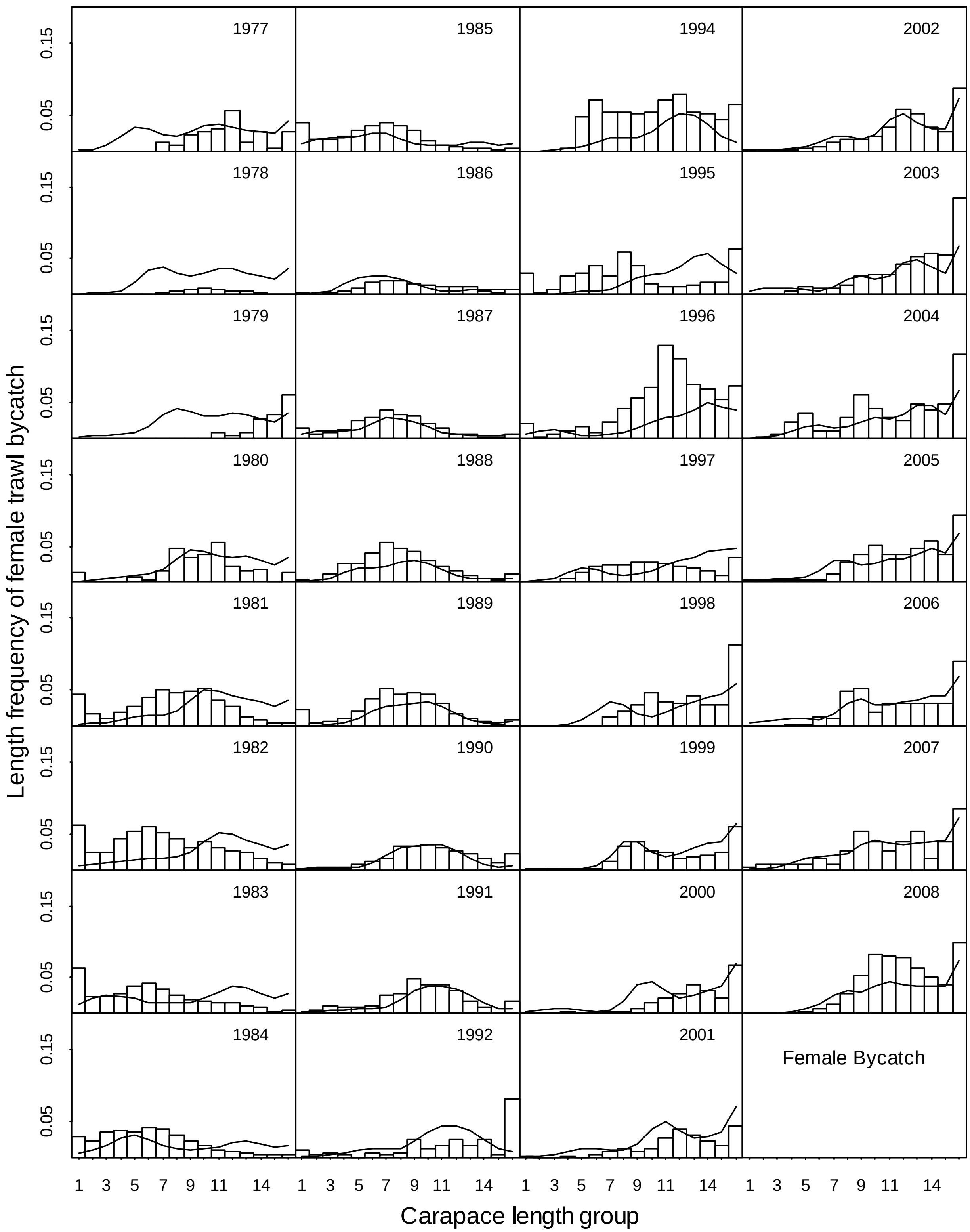


Figure 20. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

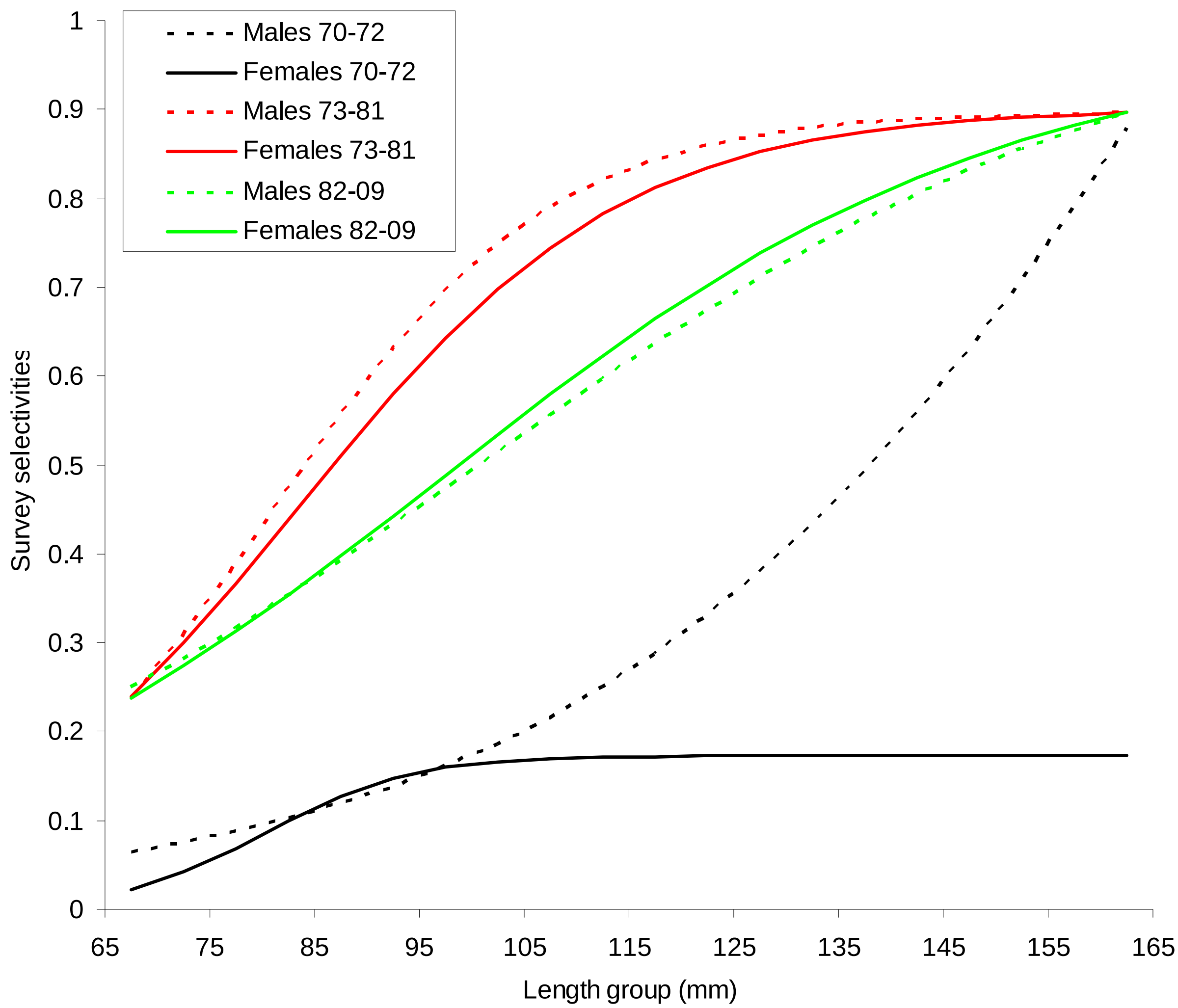
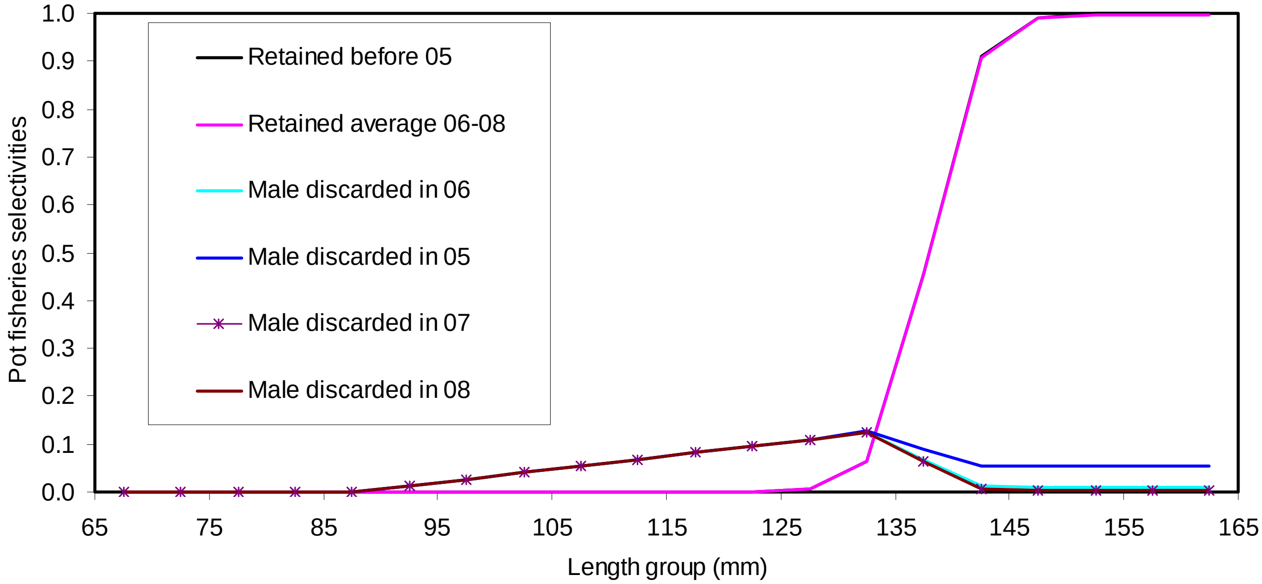


Figure 21a. Estimated trawl survey selectivities. Pot handling mortality rate is 0.2.



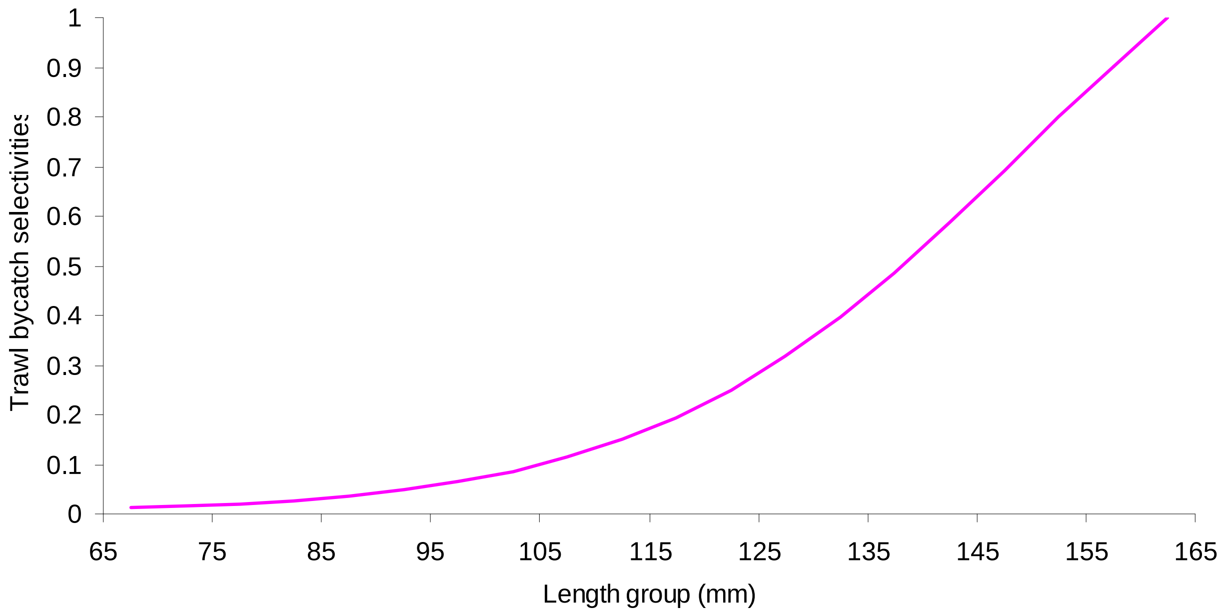


Figure 21b. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities. Pot handling mortality rate is 0.2.

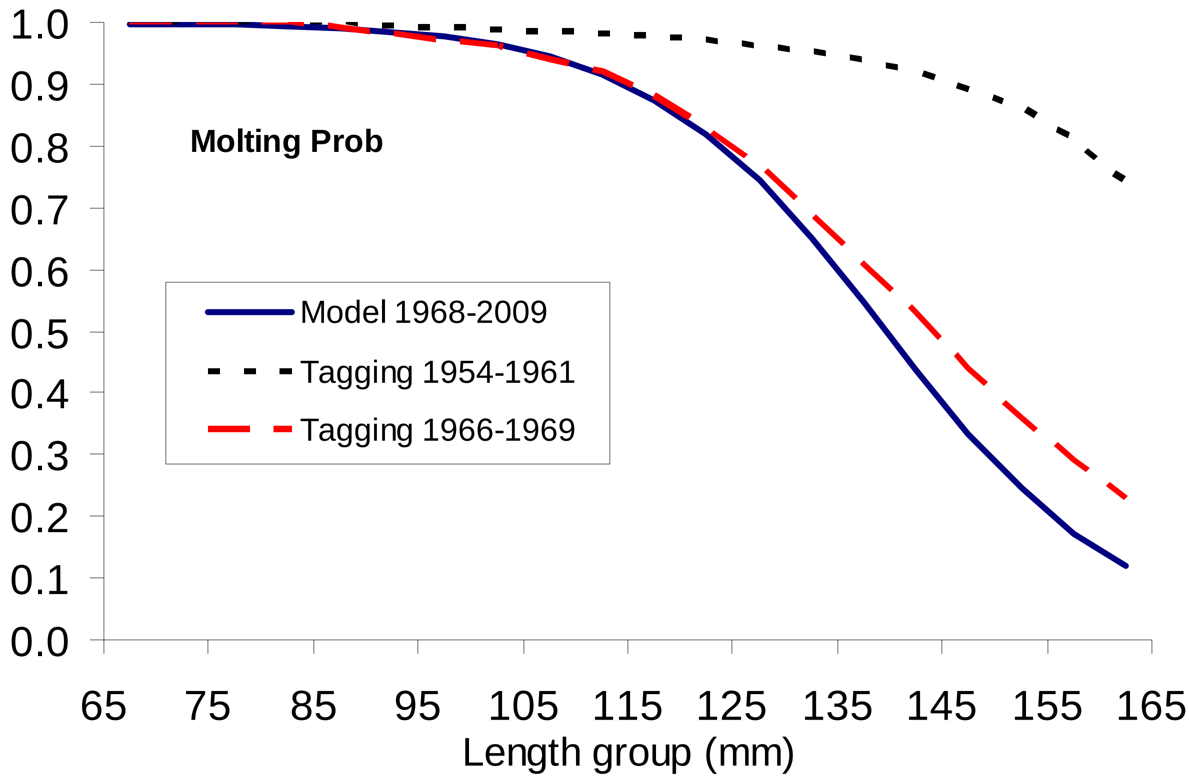


Figure 22. Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1968-2009 were estimated with a length-based model with pot handling mortality rate to be 0.2.

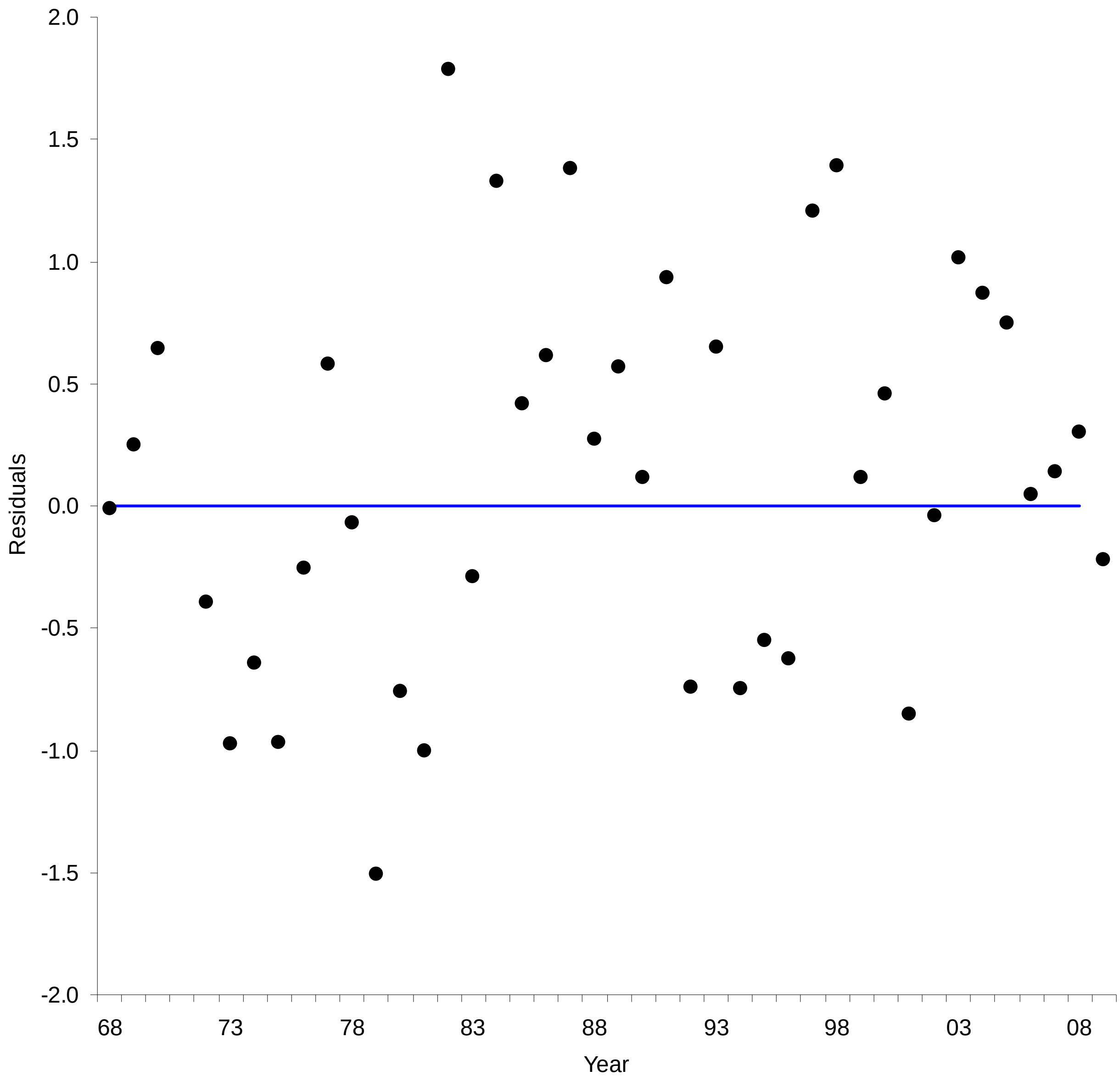


Figure 23. Standardized residuals of total survey biomass. Pot handling mortality rate is 0.2.

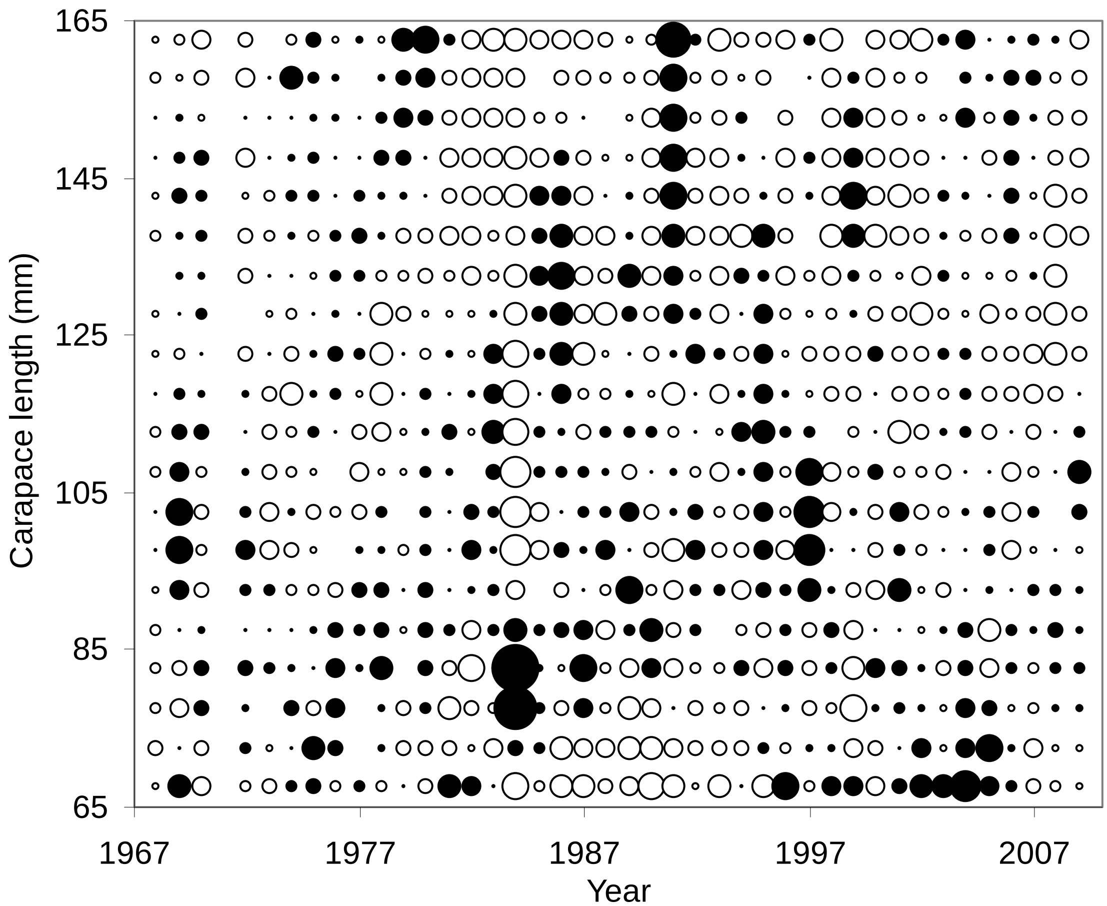


Figure 24. Standardized residuals of proportions of survey all-shell (1968-1985) and newshell (1986-2009) male red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.

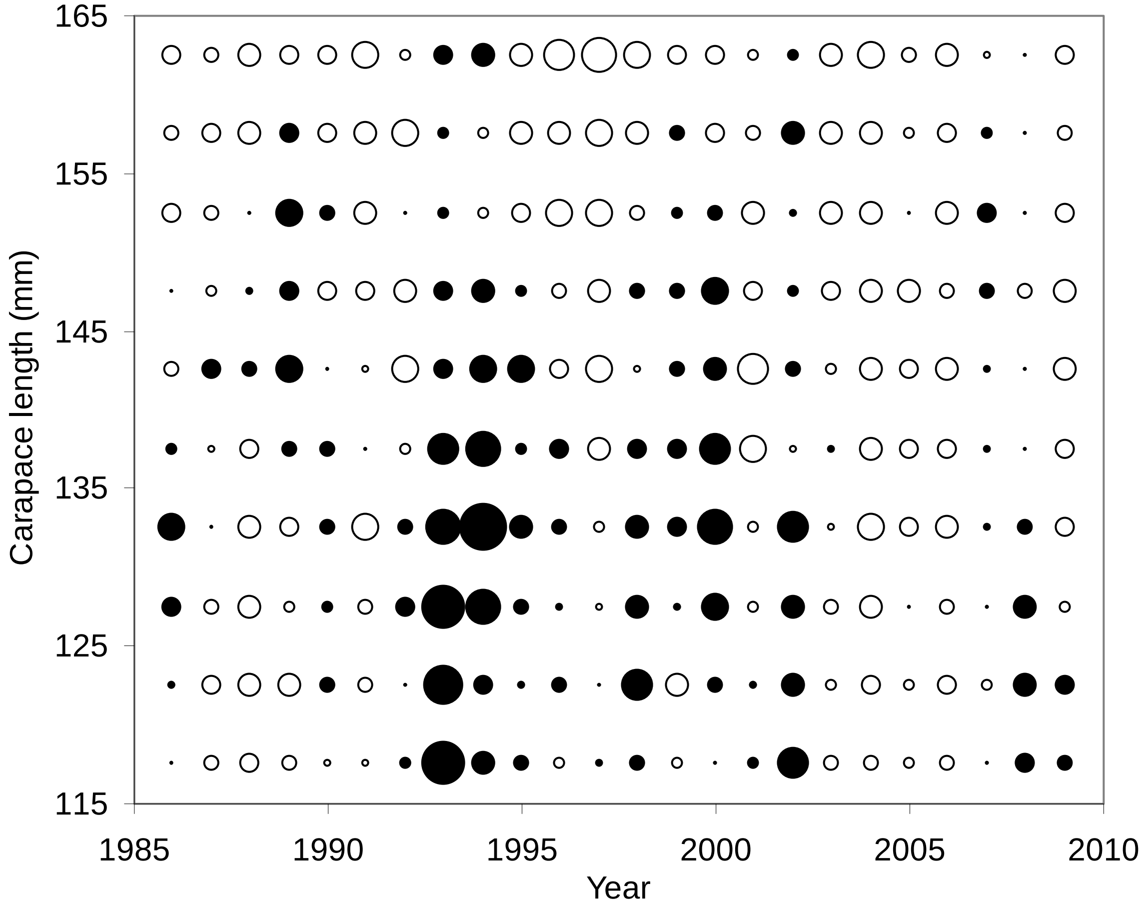


Figure 25. Standardized residuals of proportions of survey oldshell male red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.

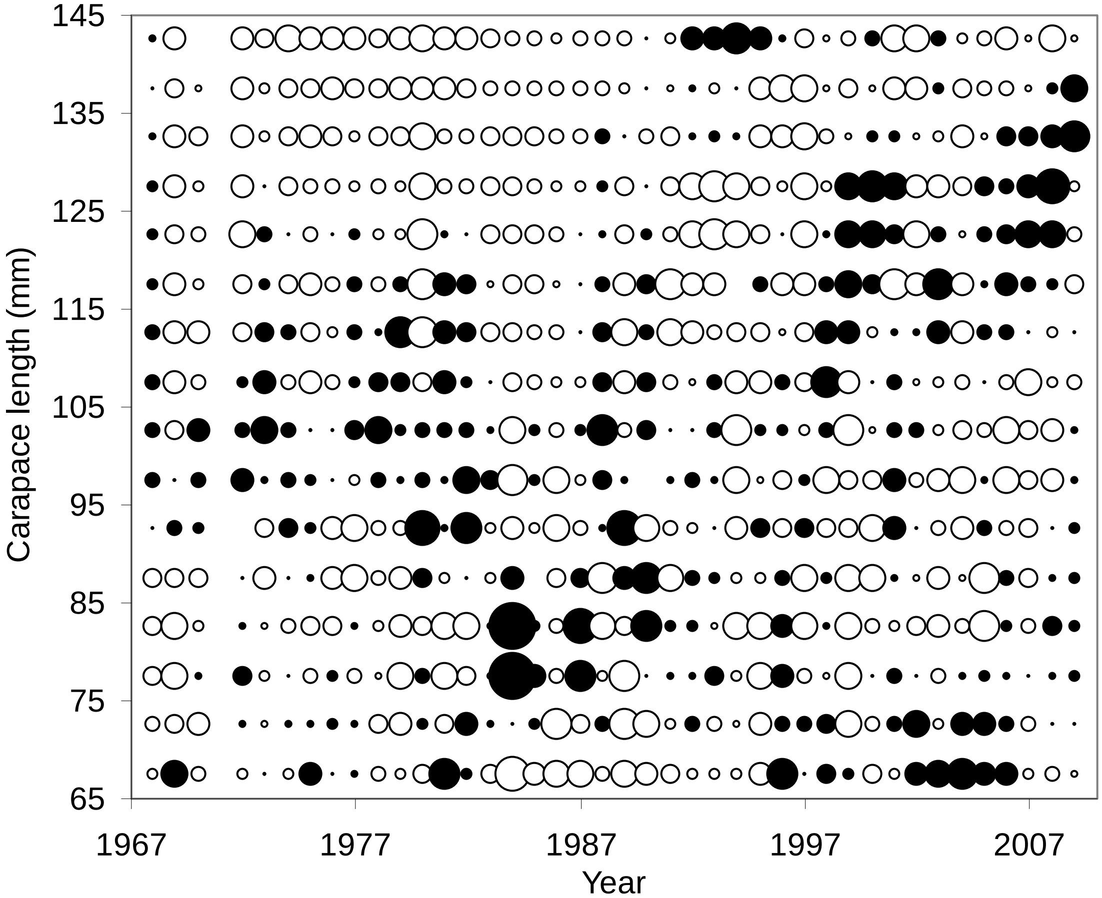
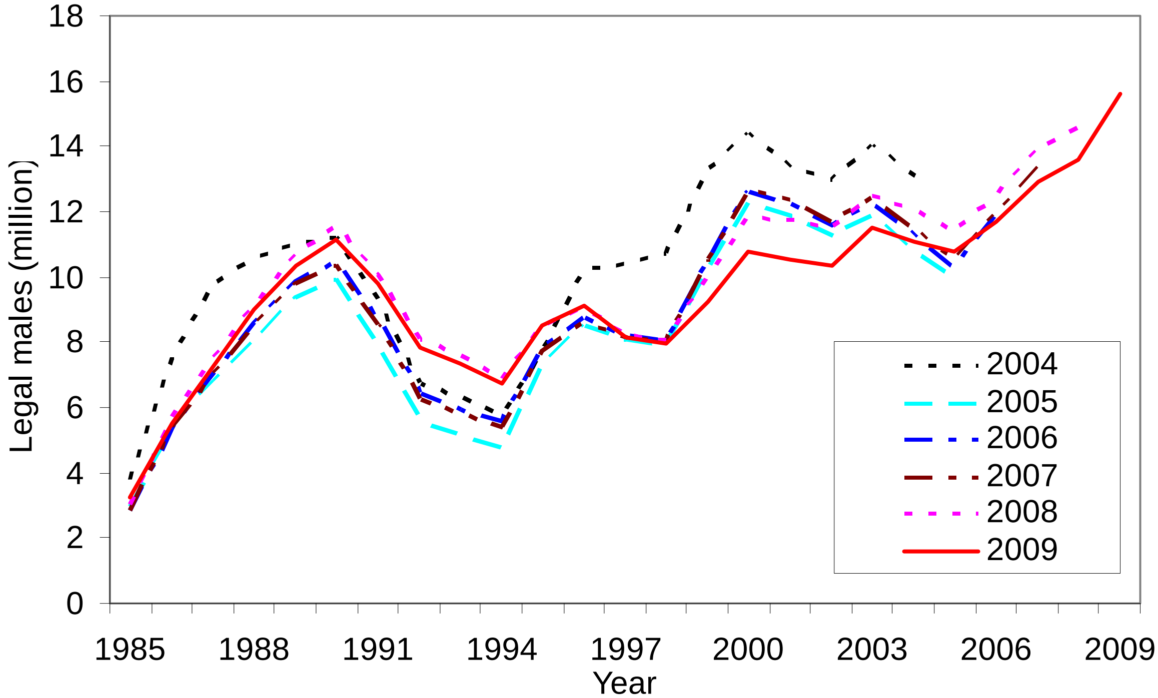


Figure 26. Standardized residuals of proportions of survey female red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.



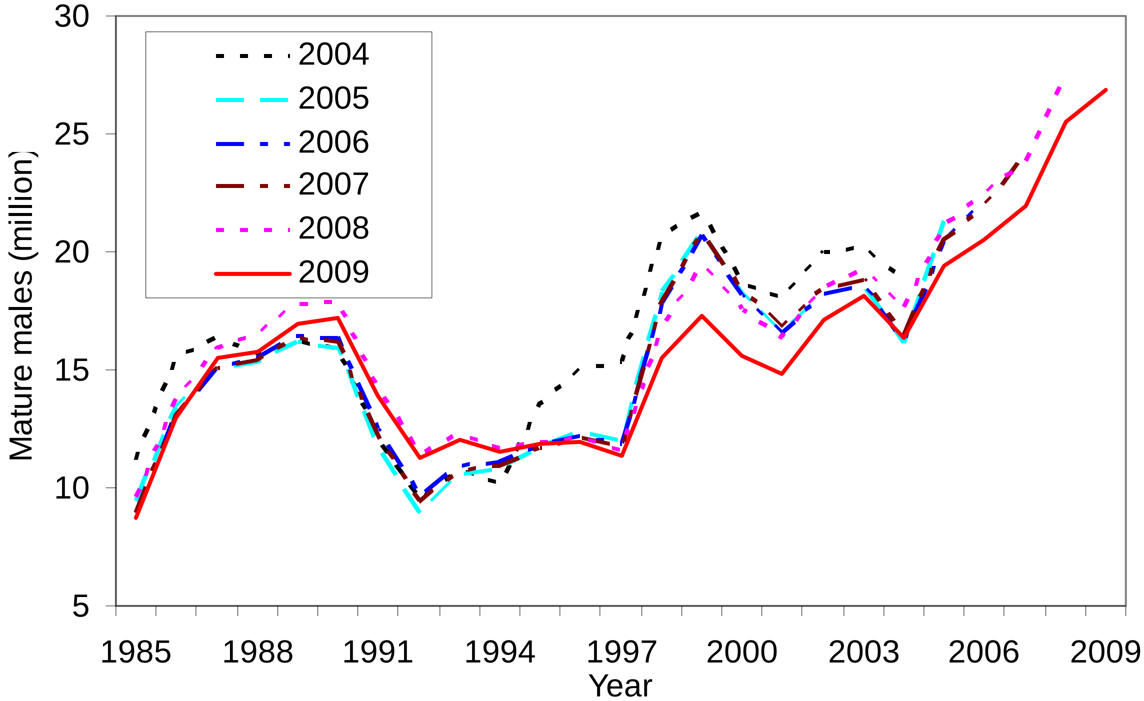


Figure 27. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1985 to 2009 made with terminal years 2004-2009 with scenario (3). These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot handling mortality rate is 0.2.

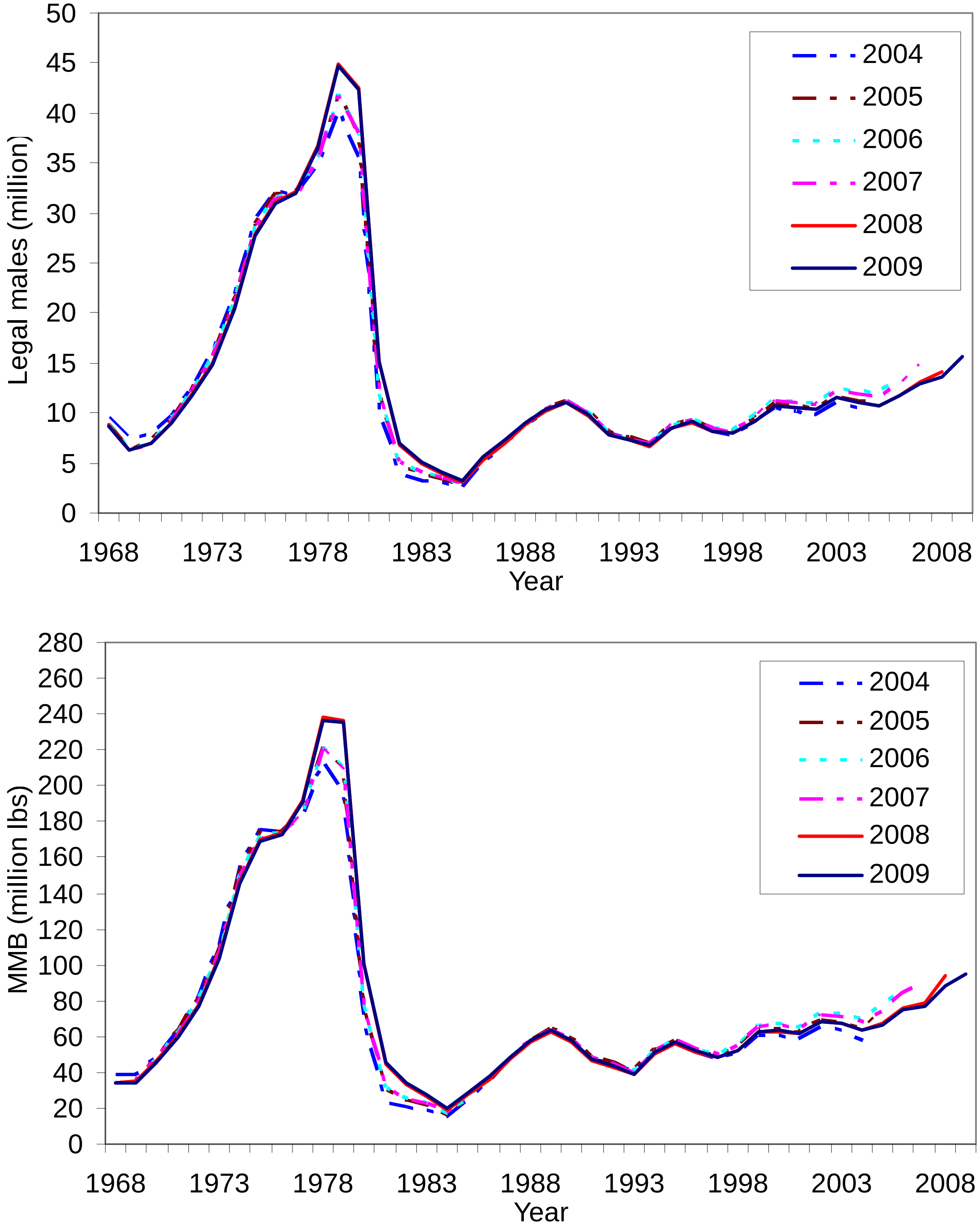


Figure 28. Comparison of estimates of legal male abundance (top) and mature male biomass (bottom) on Feb. 15 of Bristol Bay red king crab from 1968 to 2009 made with terminal years 2004-2009 with scenario (3). These are results of the 2009 model. Legend shows the year in which the assessment was conducted. Pot handling mortality rate is 0.2.

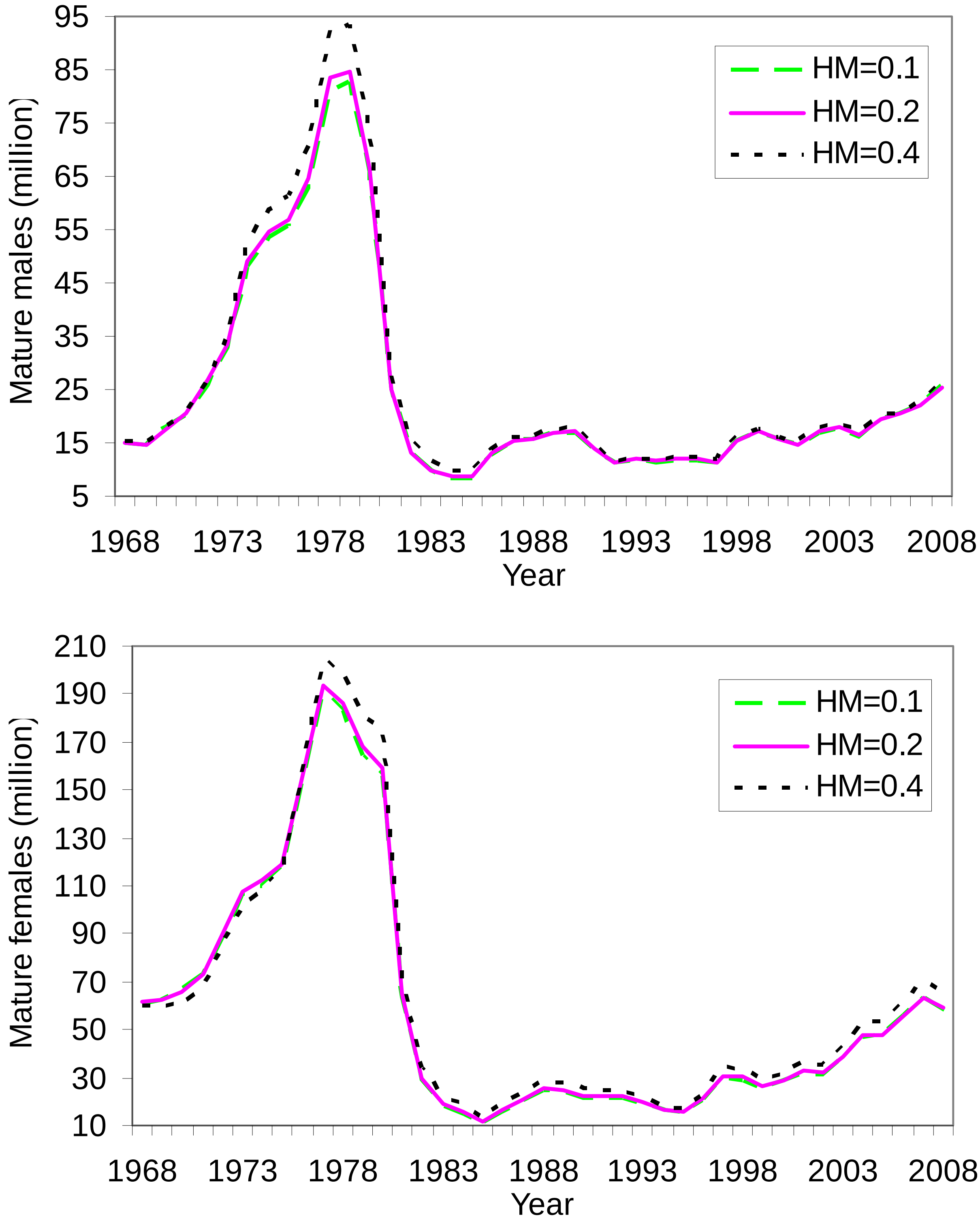
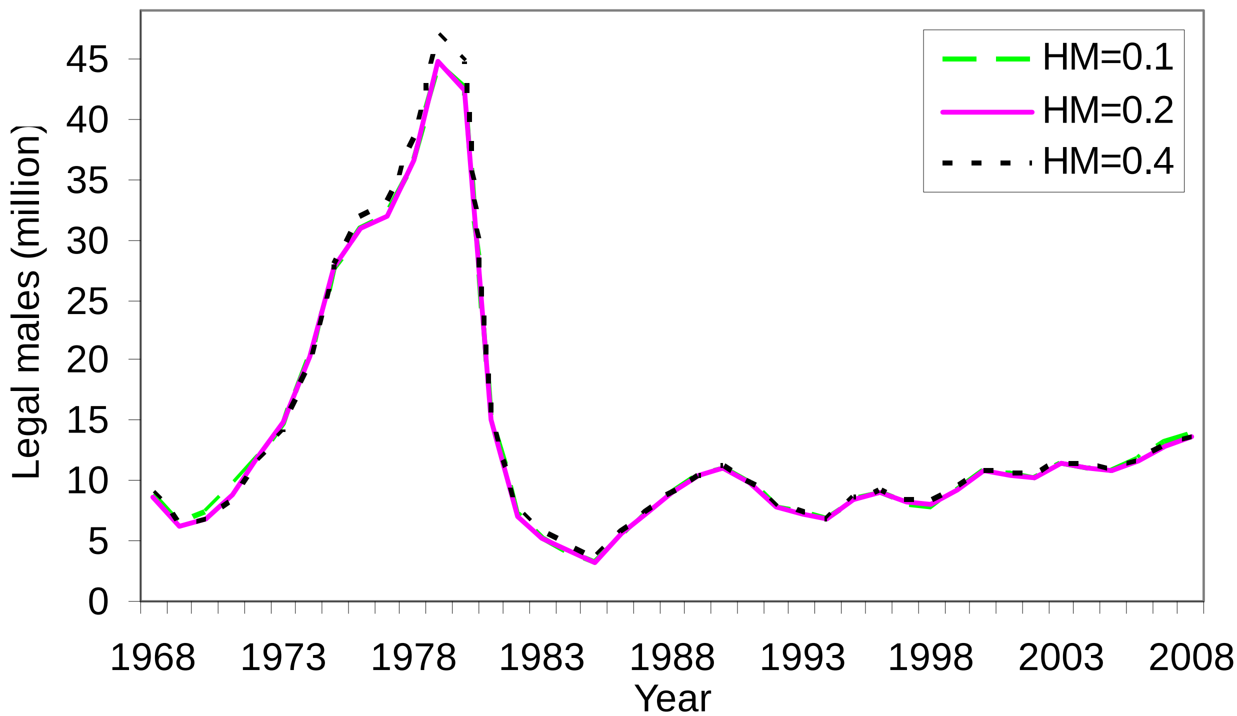


Figure 29. Comparison of mature abundance estimates for pot handling mortality rates of 0.1, 0.2 and 0.4. Mature females are for crabs >89 mm CL in this plot.



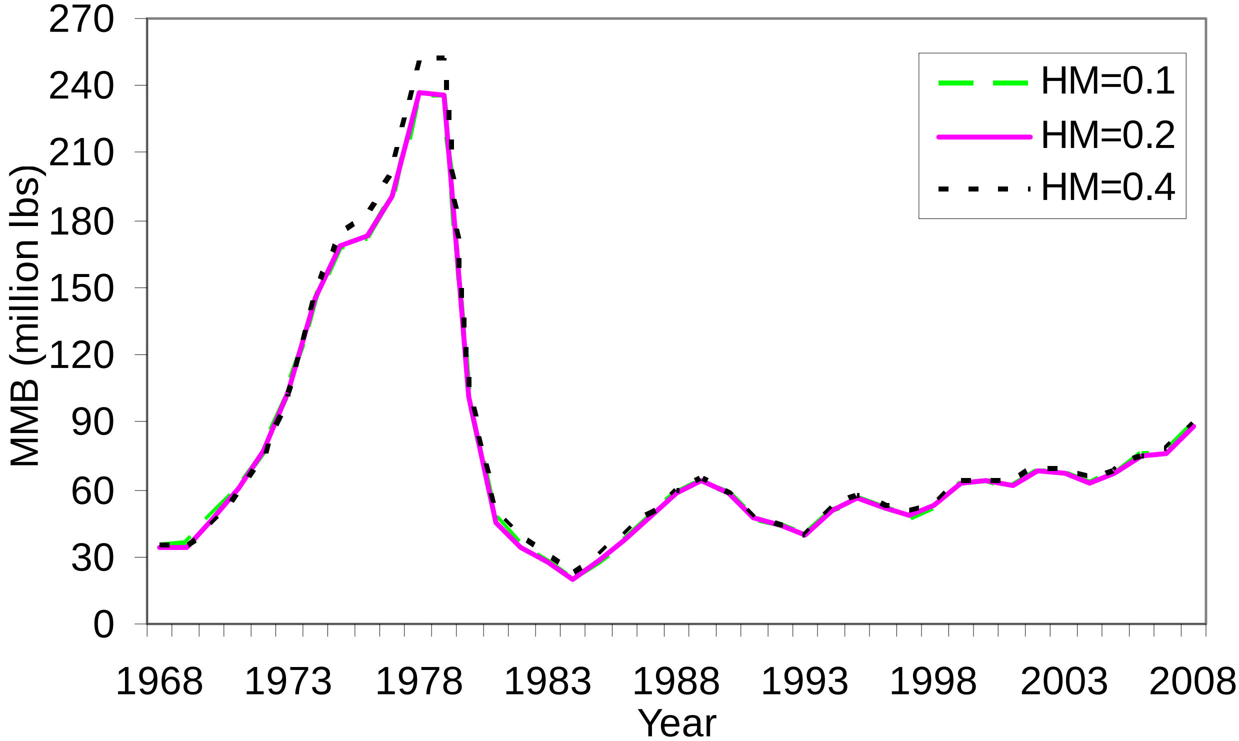
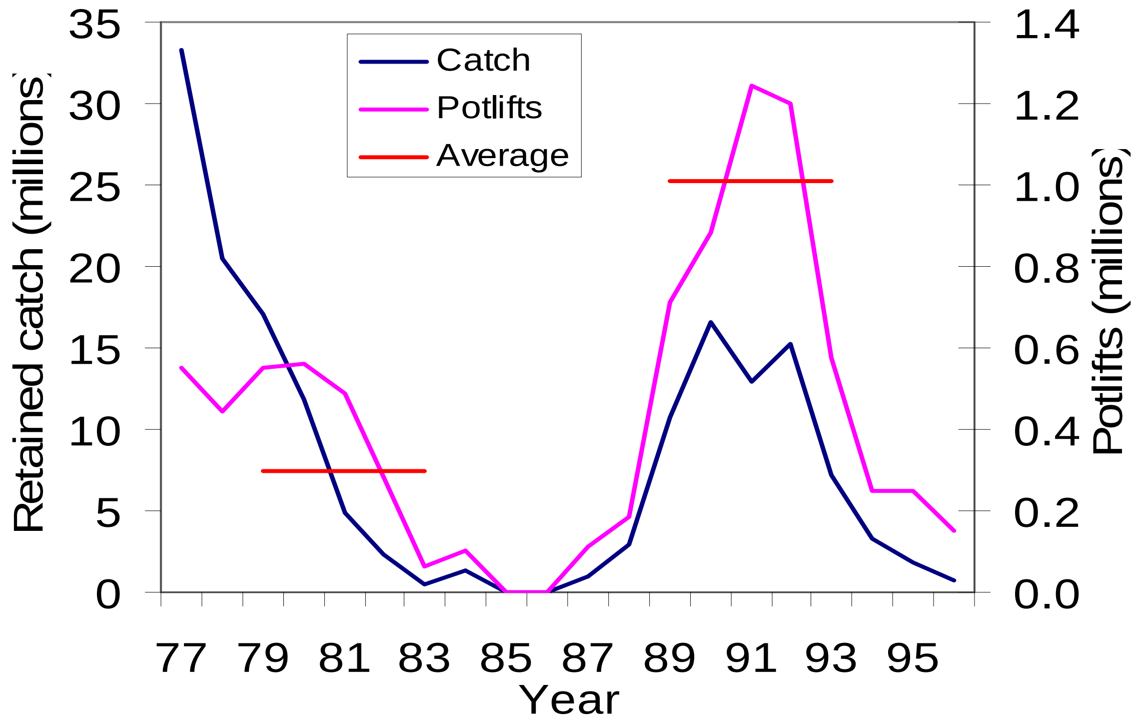


Figure 30. Comparison of legal male abundance estimates and mature male biomass on Feb. 15 for pot handling mortality rates of 0.1, 0.2 and 0.4.



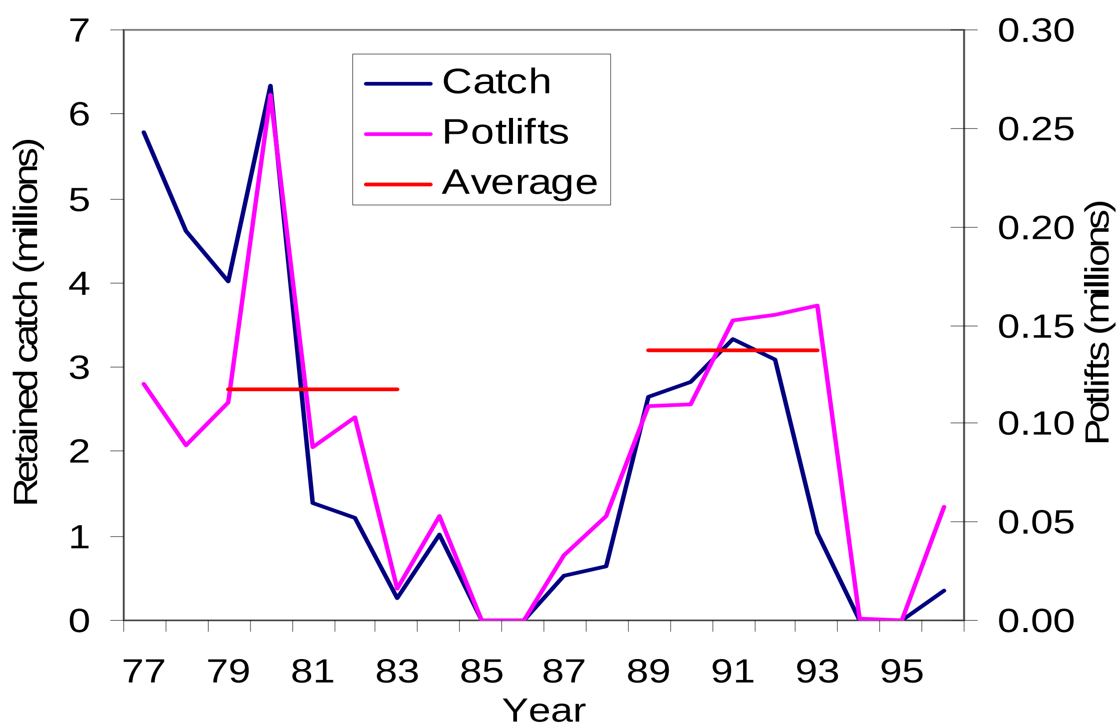
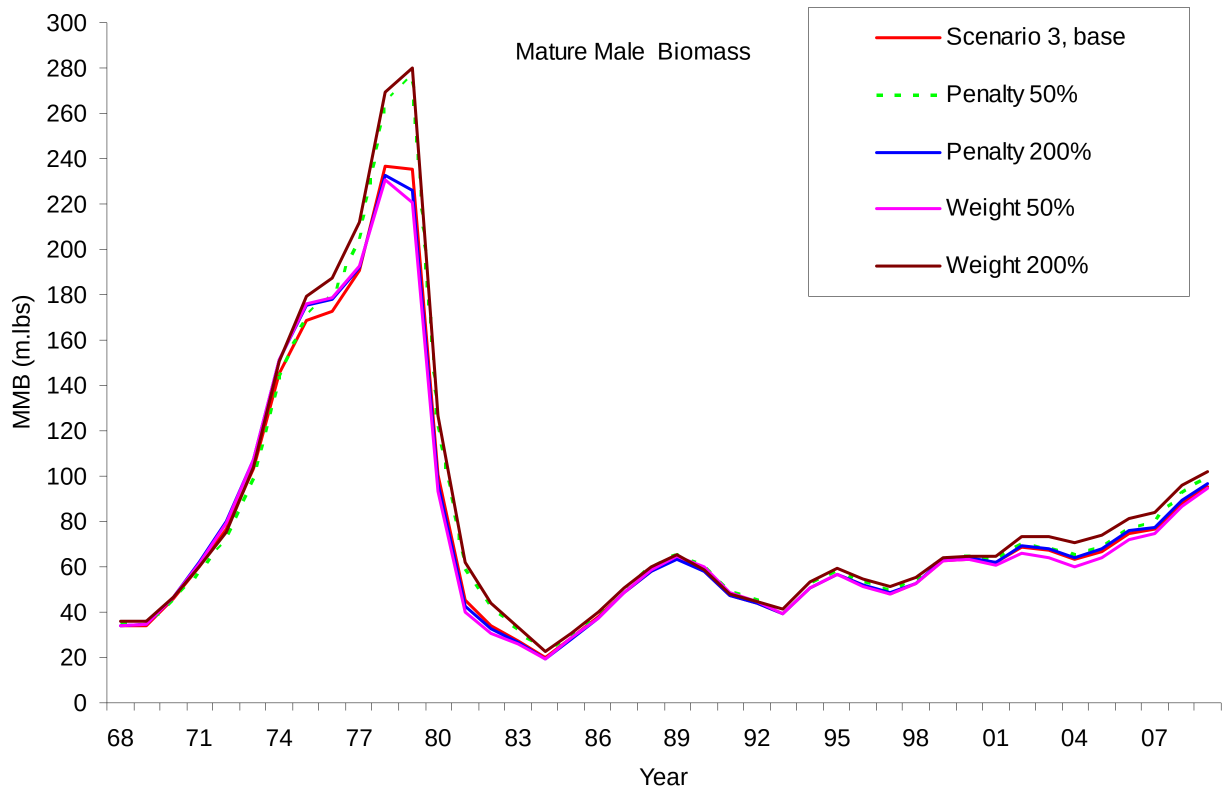


Figure 31. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163^{o} W (bottom).



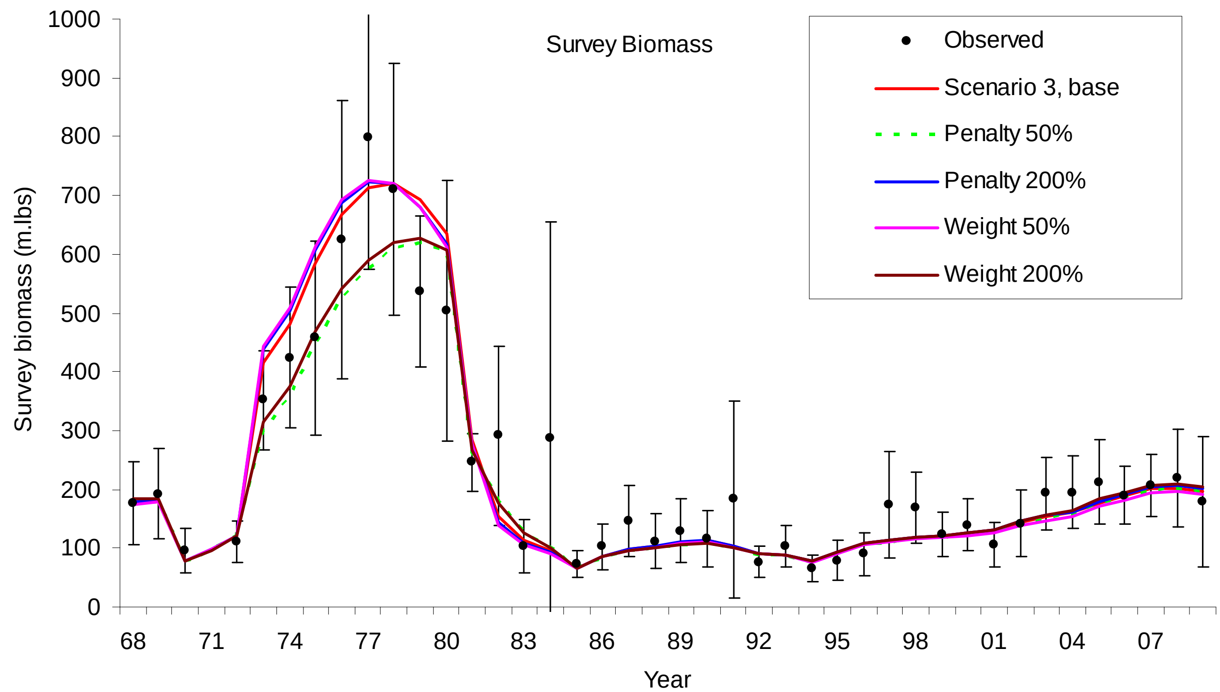


Figure 32. Comparison of estimated mature male biomasses and survey biomasses with alternative weights on biomass and penalty terms. The weights to all biomasses and penalty terms were reduced to 50% or increased to 200%.

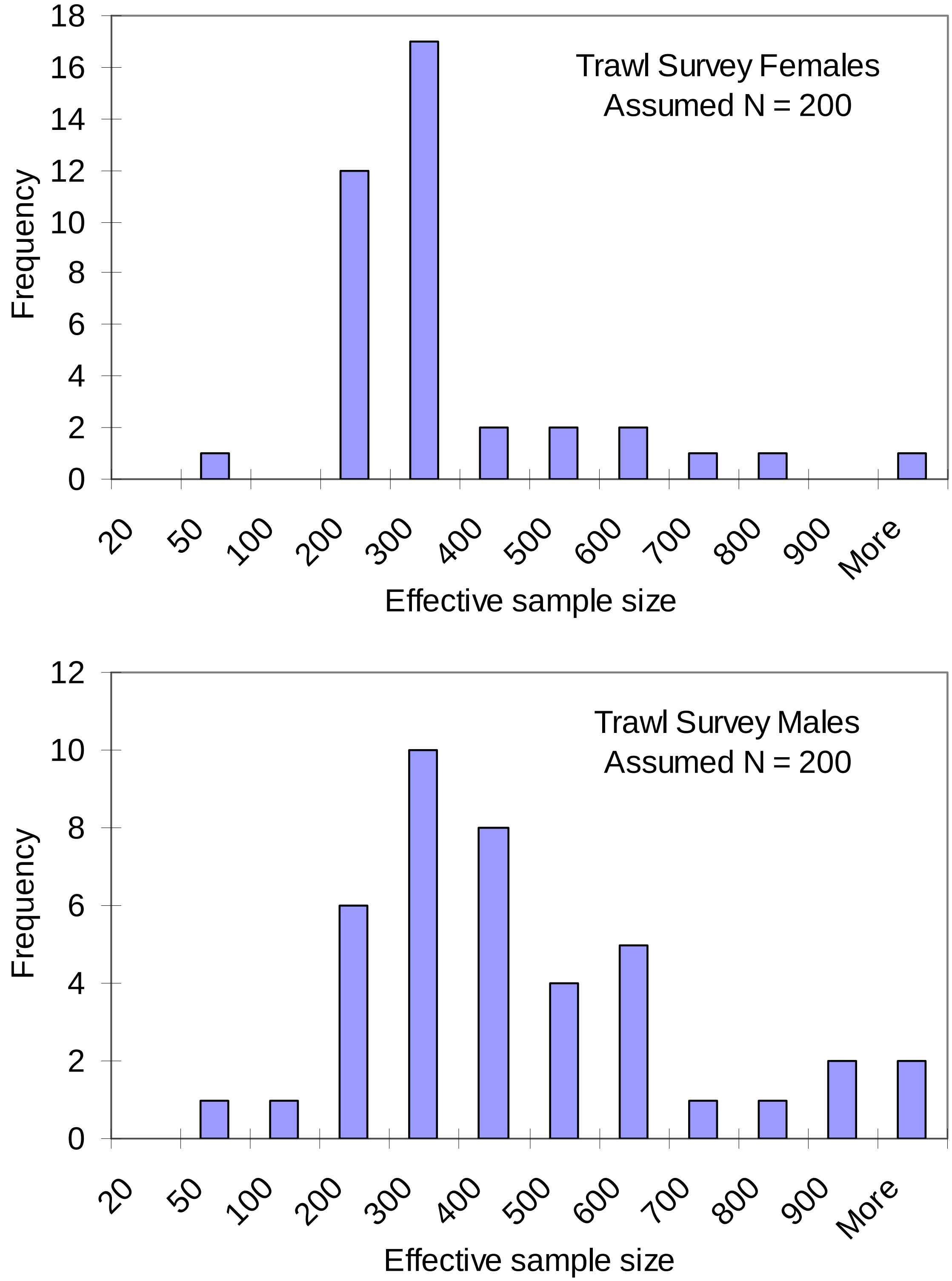


Figure 33a. Estimated effective sample sizes for length/sex composition data: trawl survey data.

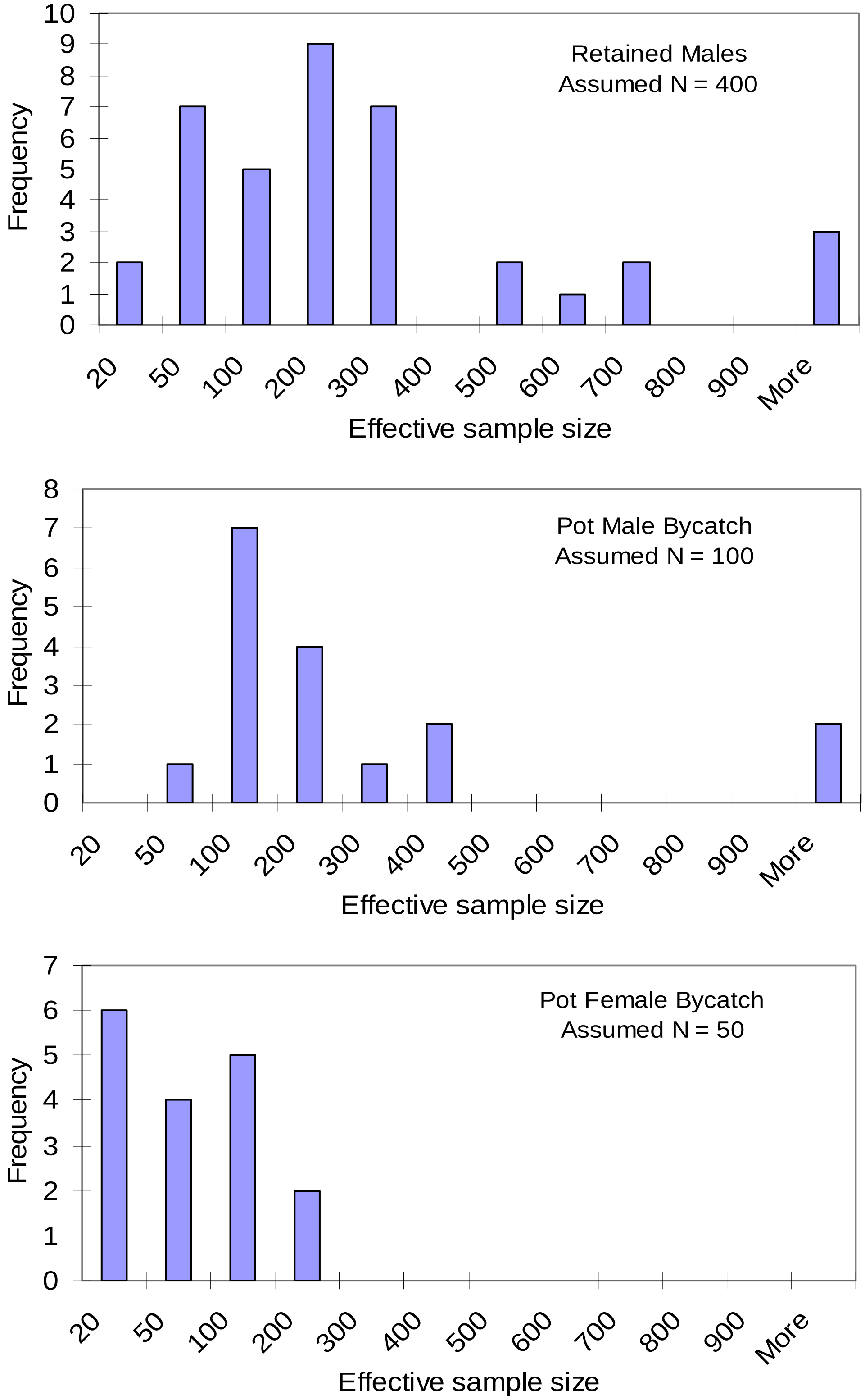
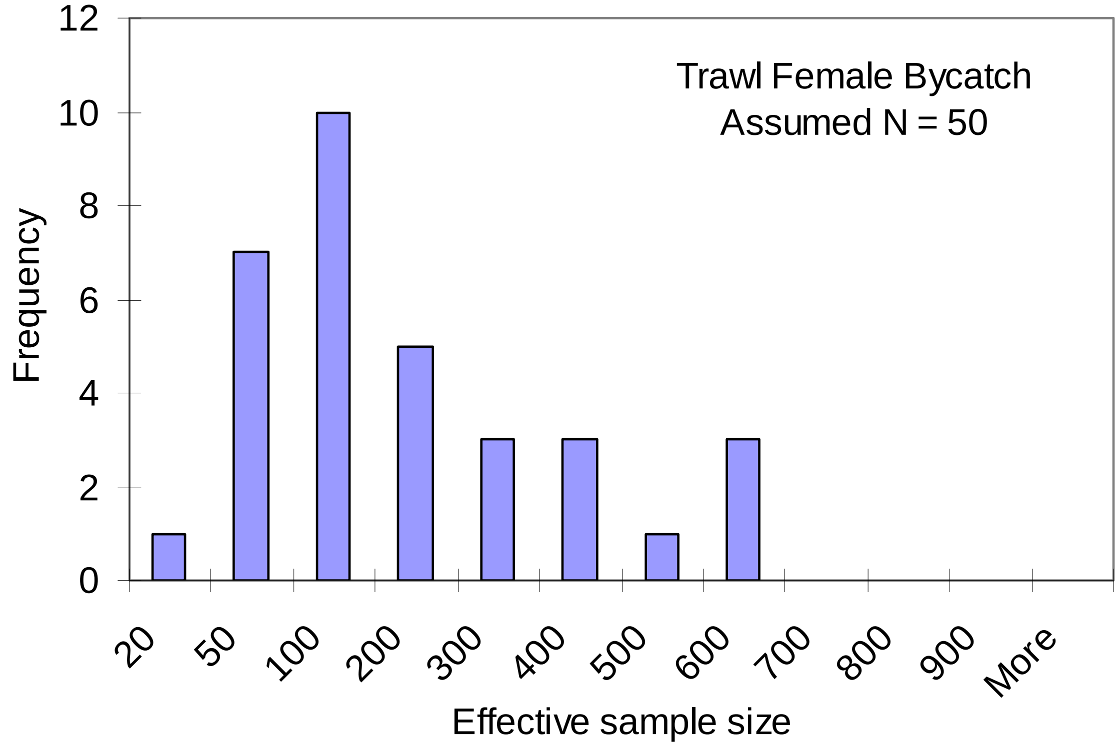


Figure 33b. Estimated effective sample sizes for length/sex composition data: directed pot fishery data



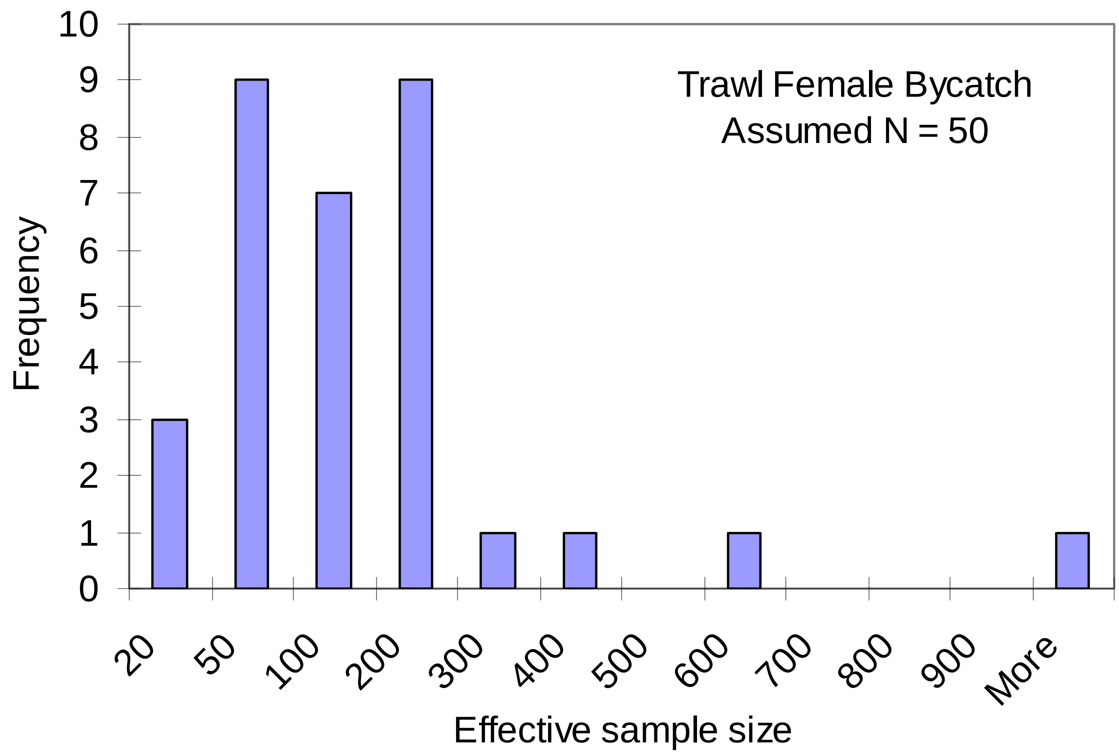


Figure 33c. Estimated effective sample sizes for length/sex composition data: trawl bycatch data.

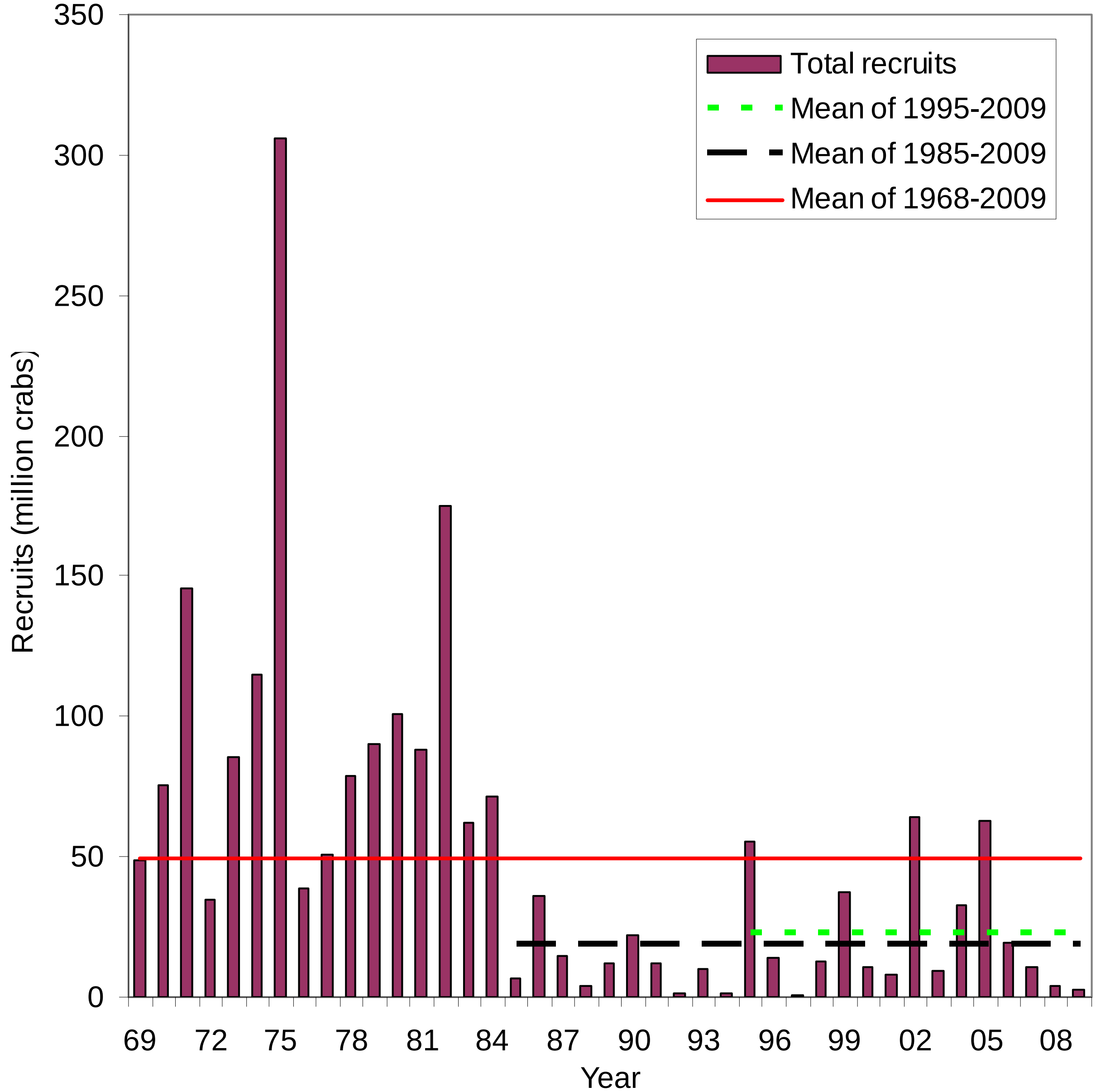


Figure 34. Estimated recruitment time series during 1969-2009 (occurred year) with scenario (3). Mean male recruits during 1995-2009 was used to estimate $B_{35\%}$.

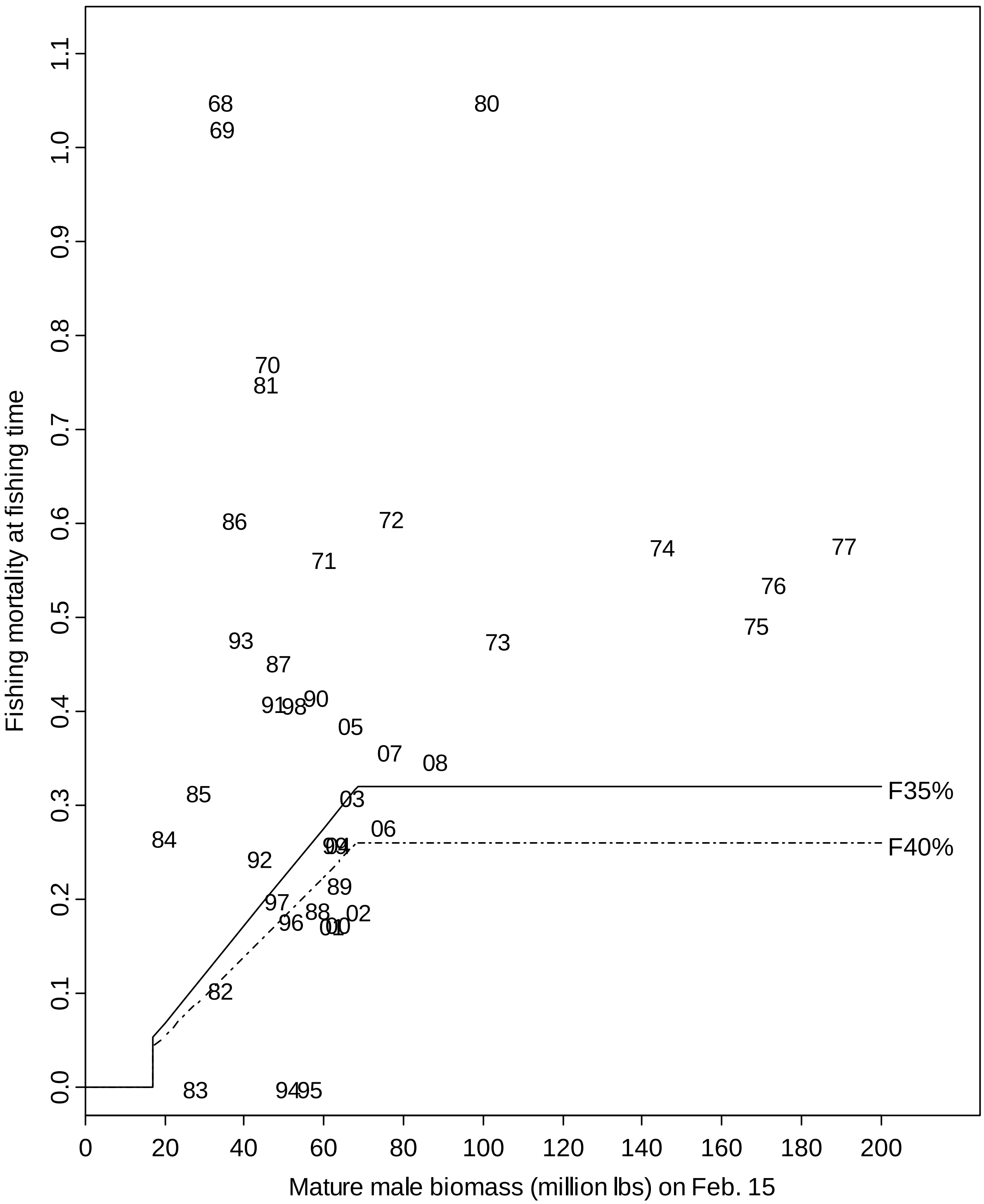


Figure 35. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1968-2008. Average of recruitment from 1995 to 2008 was used to estimate B_{MSY}. Pot handling mortality rate is 0.2.

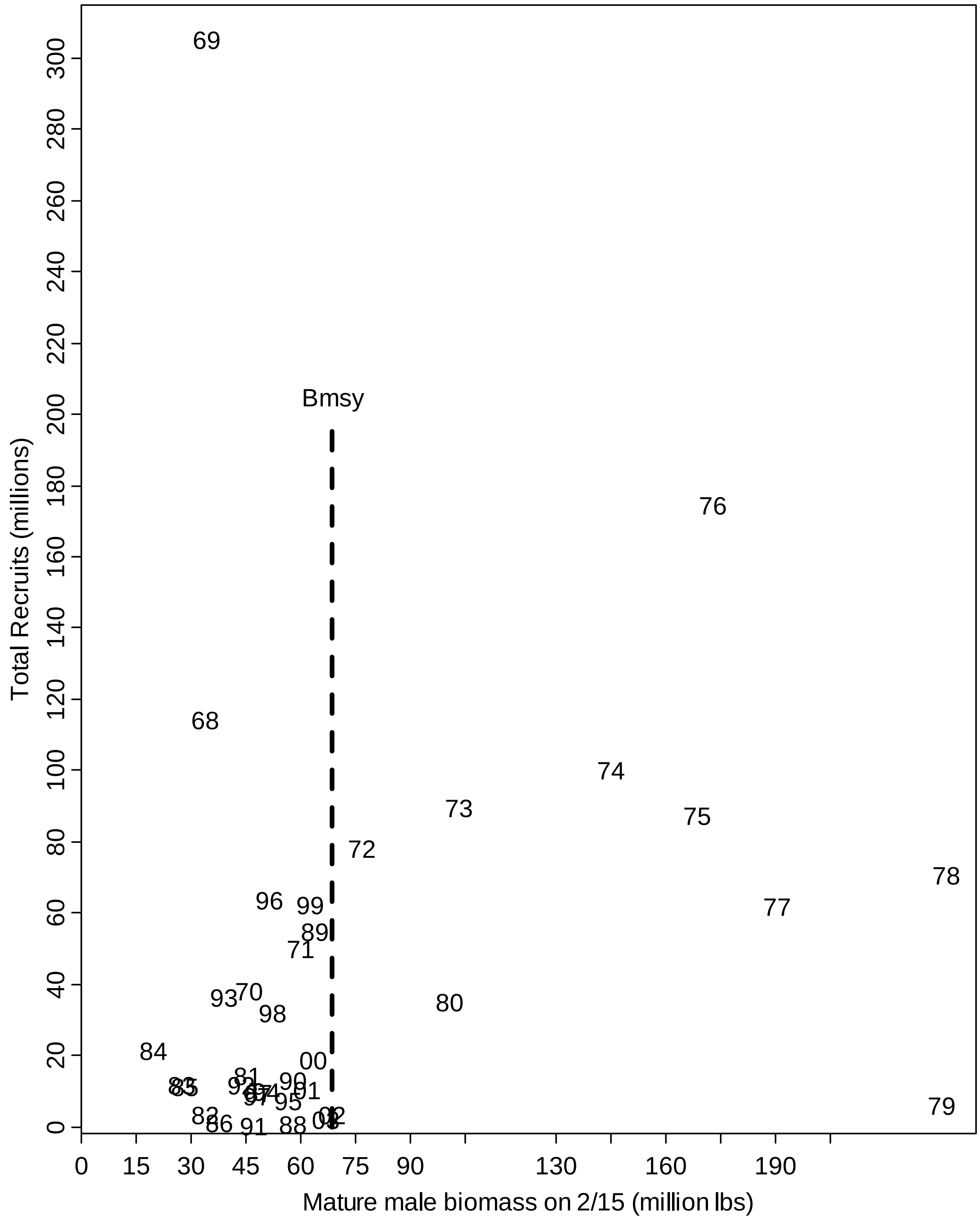


Figure 36a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2. Numerical labels are years of mating, and the vertical dotted lines are the estimated $B_{35\%}$ based on three different recruitment levels.

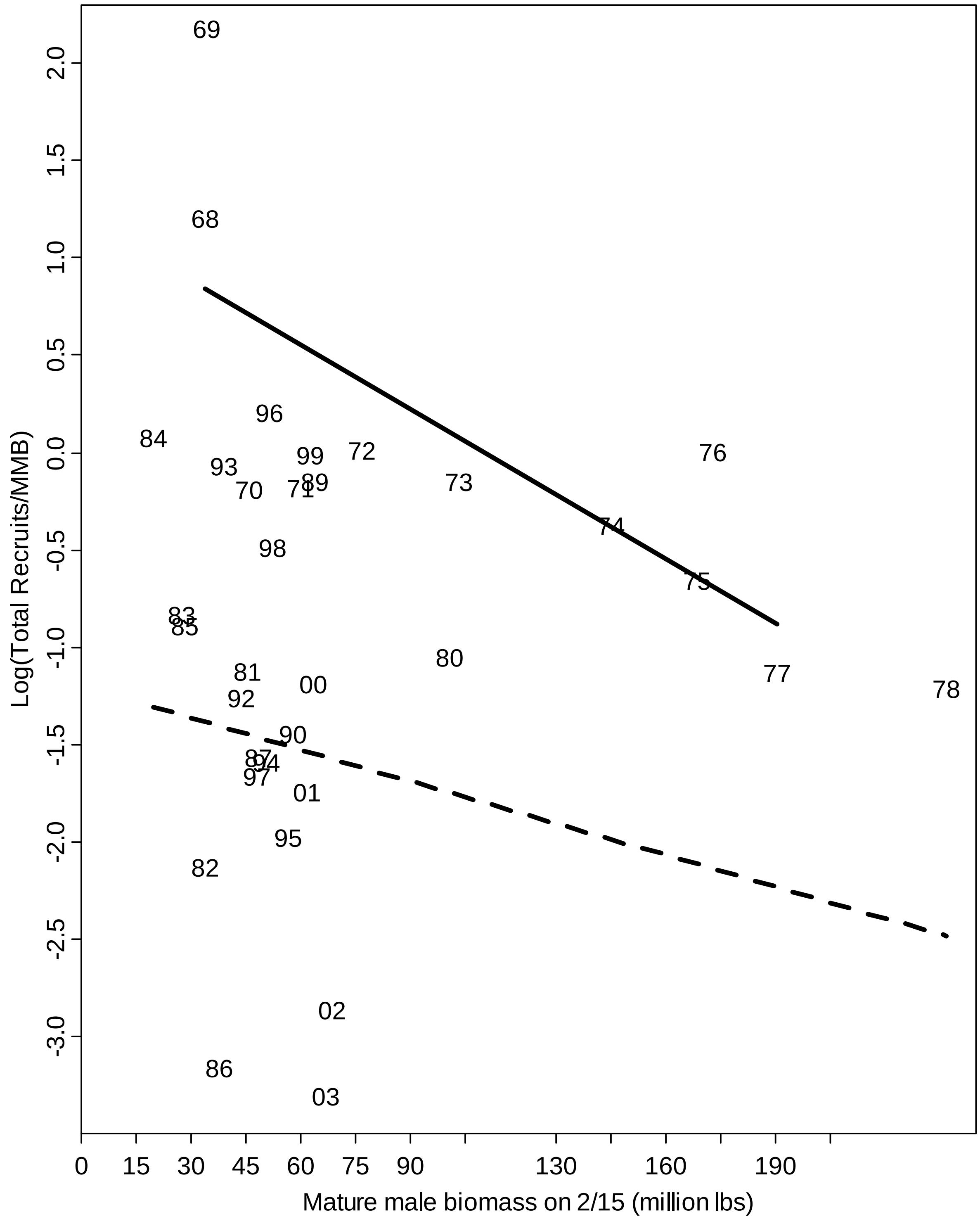


Figure 36b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2. Numerical labels are years of mating, the solid line is the regression line for data of 1968-1977, and the dotted line is the regression line for data of 1978-2003.

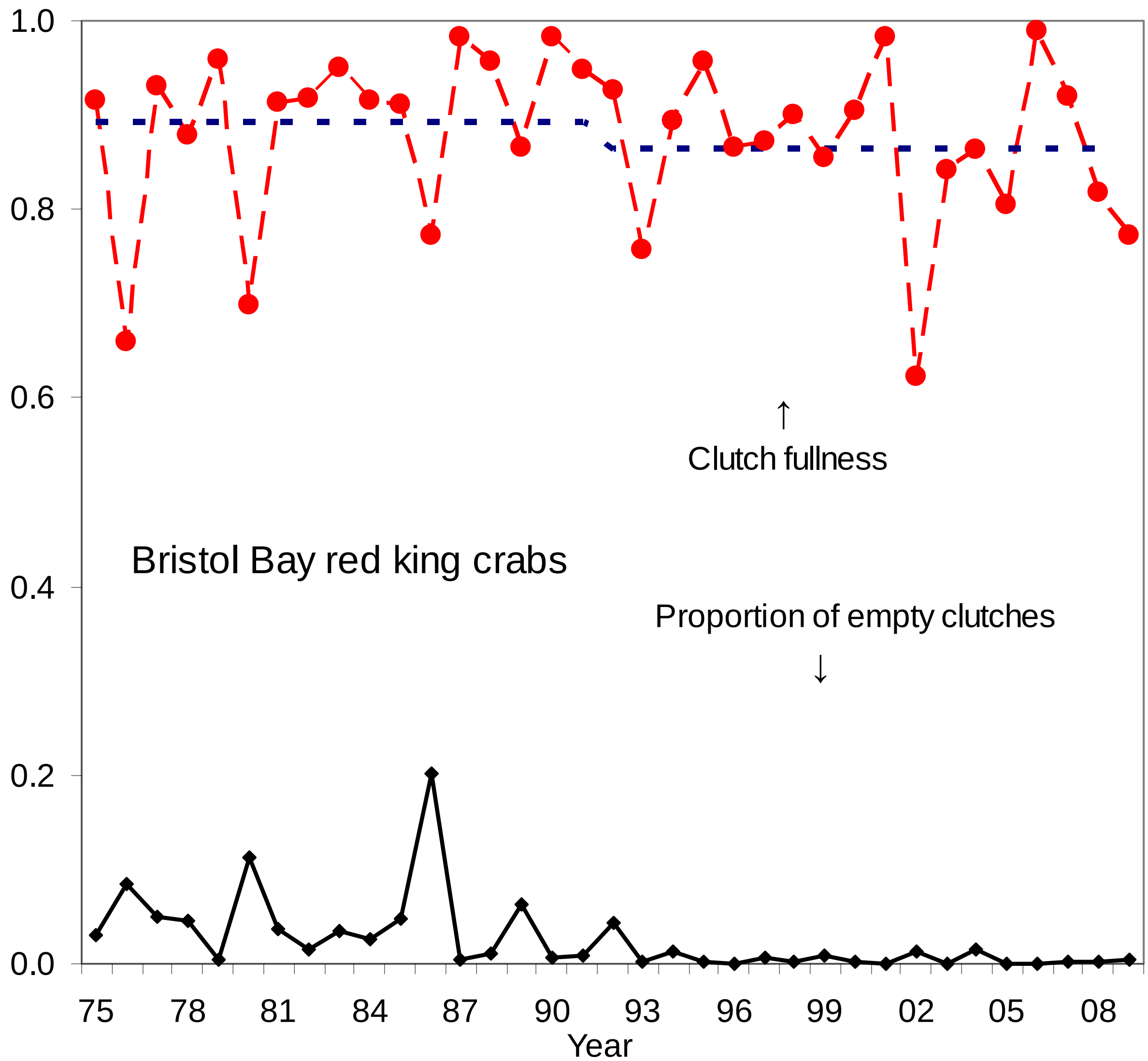


Figure 37. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crabs >89 mm CL from 1975 to 2009 from survey data. Oldshell females were excluded.

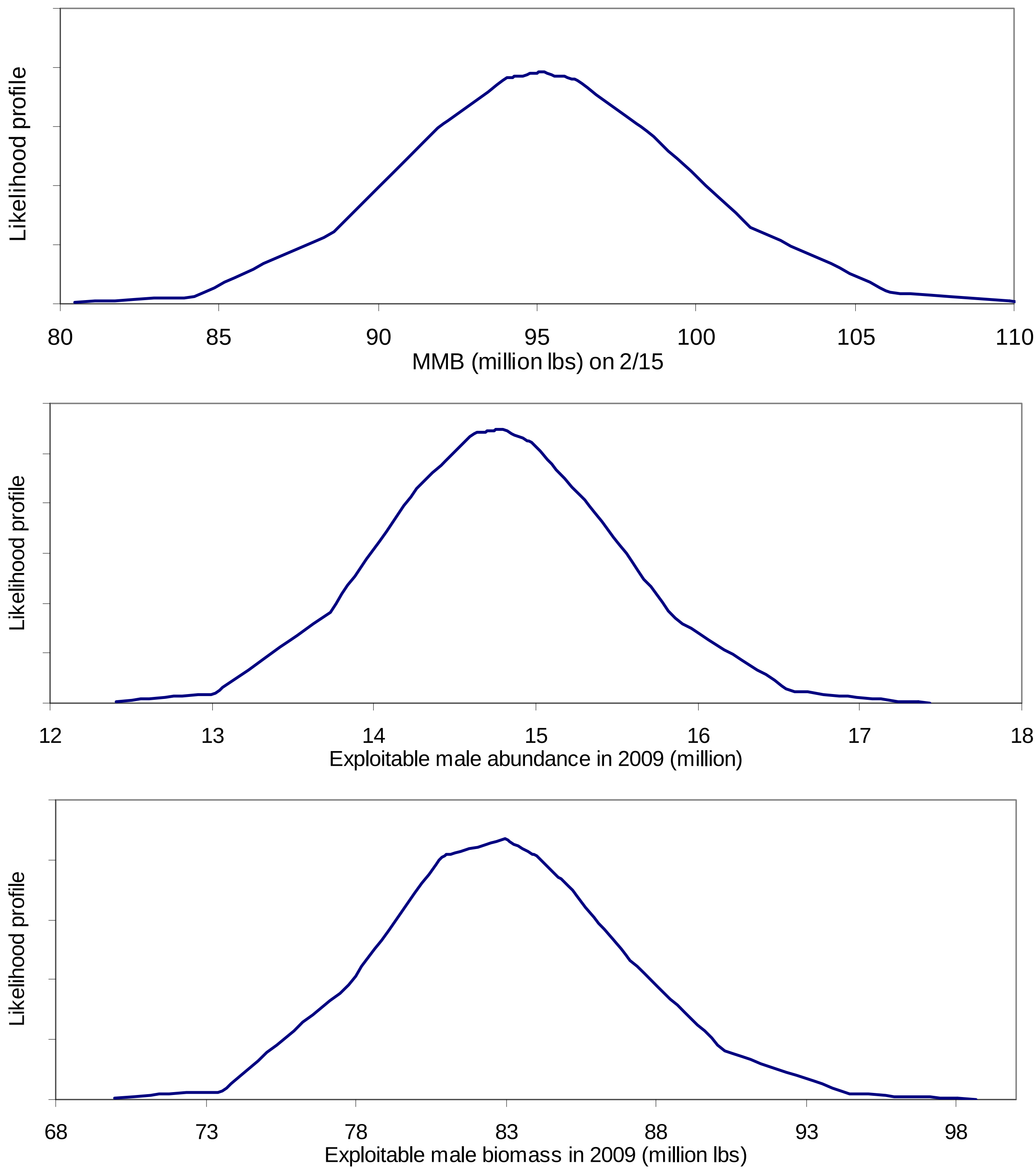


Figure 38. Likelihood profiles for estimated mature male biomass on Feb. 15 and exploitable male abundance and biomass at the fishing time for the 2009 season with $F_{35\%}$. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

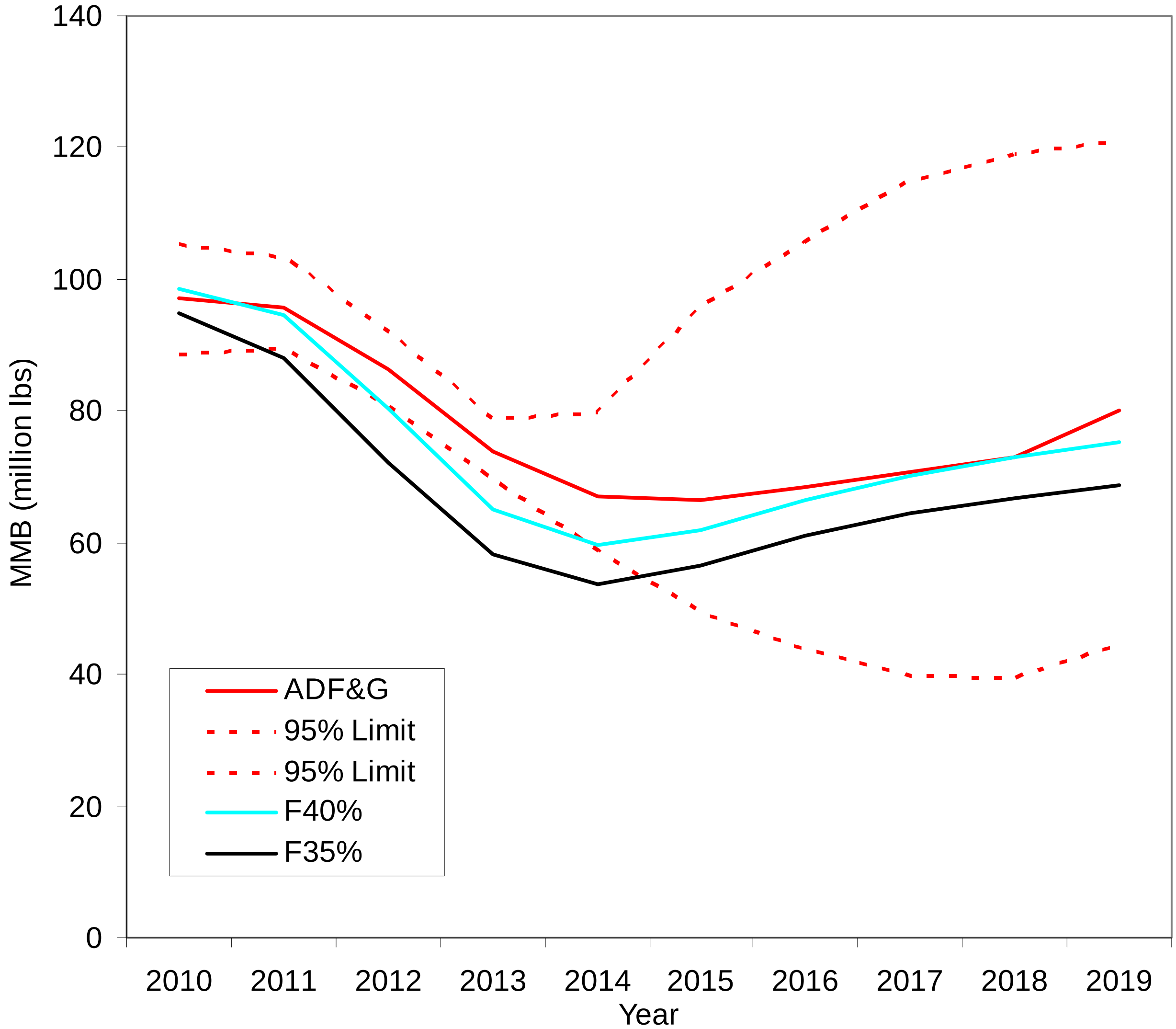


Figure 39. Projected mature male biomass on Feb. 15 with $F_{40\%}$, $F_{35\%}$ and the ADF&G harvest strategy with $F_{35\%}$ constraint during 2010-2119. Pot handling mortality rate is 0.2 and the confidence limits are for the ADF&G harvest strategy.

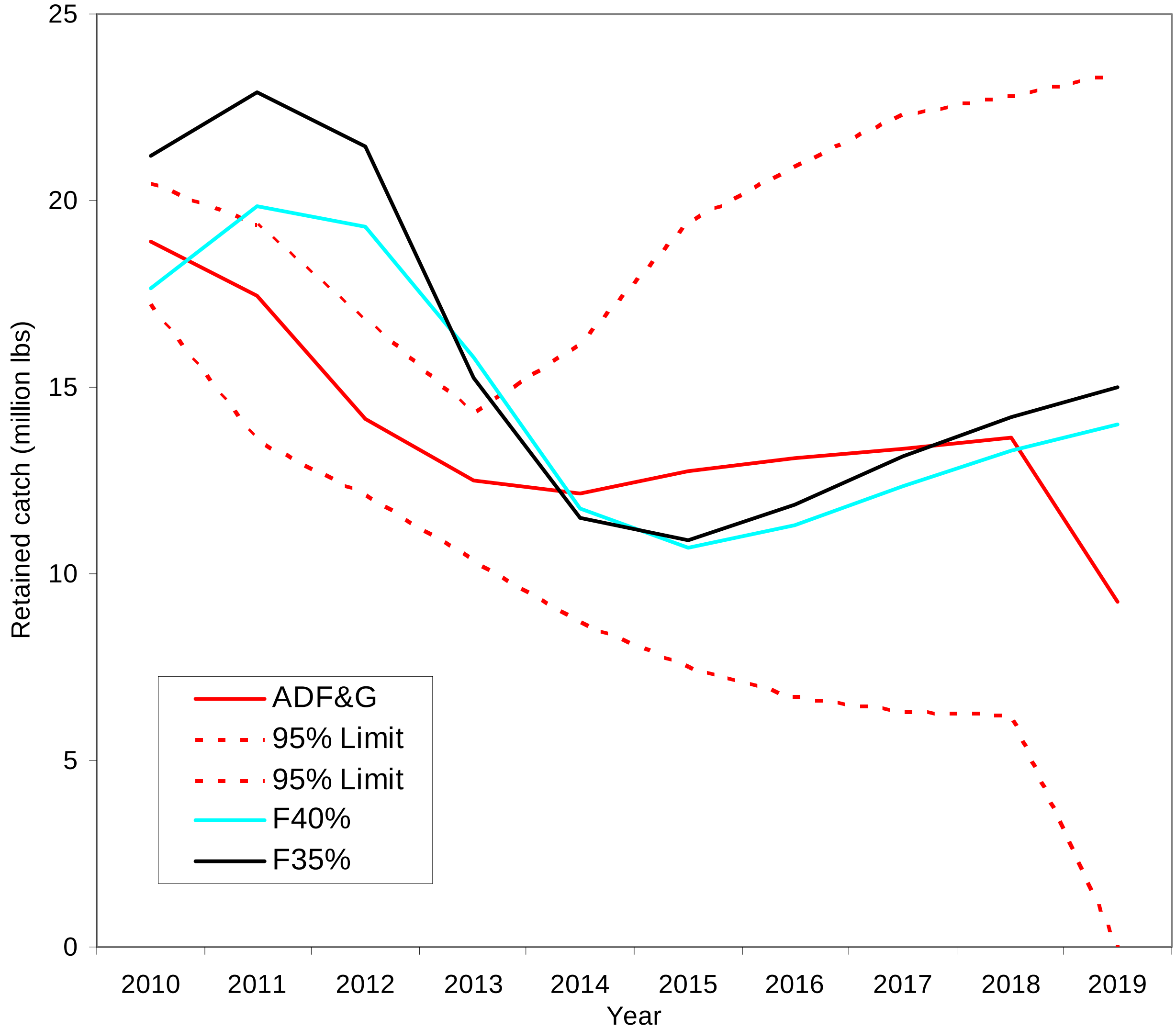


Figure 40. Projected retained catch biomass with $F_{40\%}$, $F_{35\%}$ and the ADF&G harvest strategy with $F_{35\%}$ constraint during 2010-2119. Pot handling mortality rate is 0.2 and the confidence limits are for the ADF&G harvest strategy.

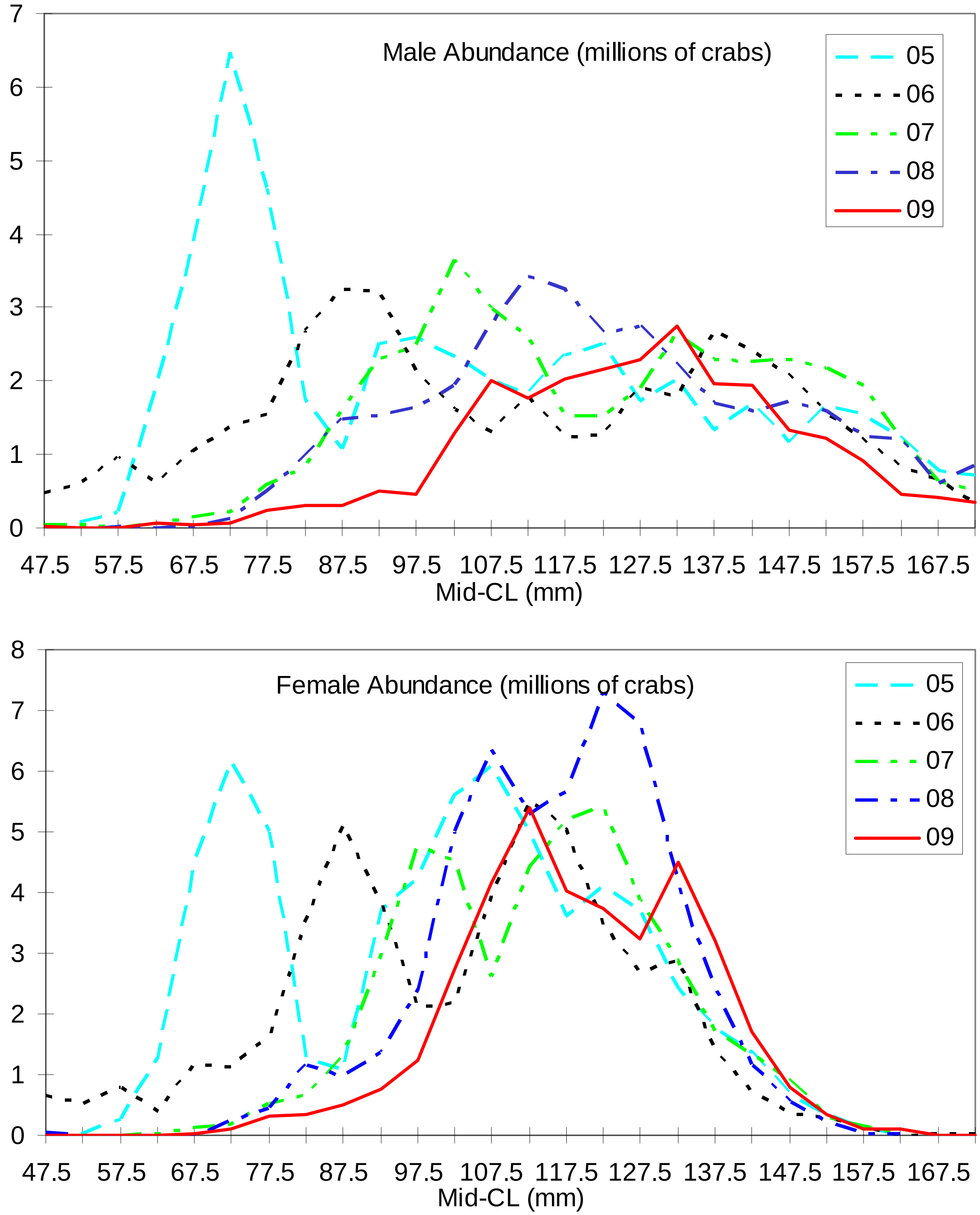


Figure 41. Length frequency distributions of male (top panel) and female (bottom panel) red king crabs in Bristol Bay from NMFS trawl surveys during 2005-2009. For purposes of these graphs, abundance estimates are based on area-swept methods.

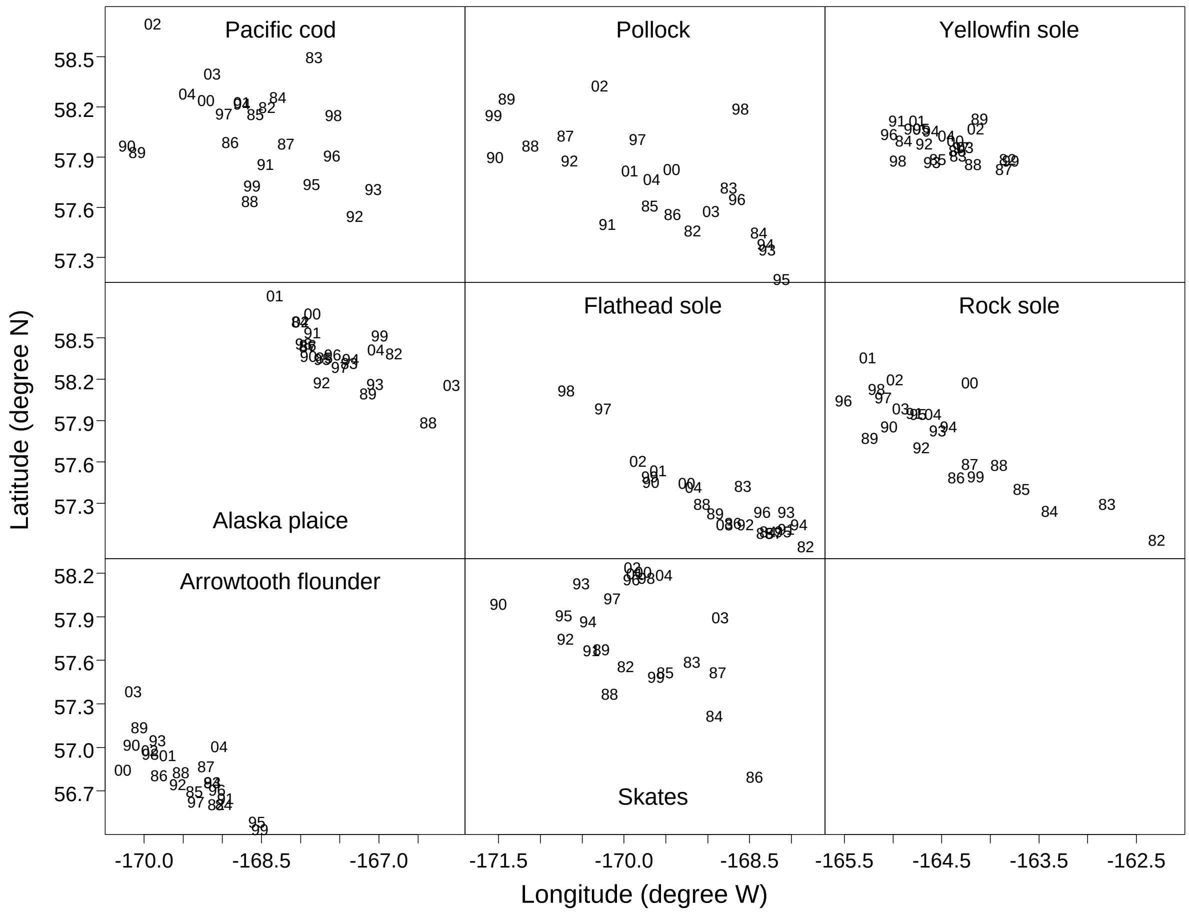


Figure 42. Biomass distribution centers of Pacific cod, walleye pollock, yellowfin sole, Alaska plaice, flathead sole, rock sole, arrowtooth flounder, and skates derived from NMFS summer trawl survey data in the eastern Bering Sea. (Source: Zheng and Kruse 2006).

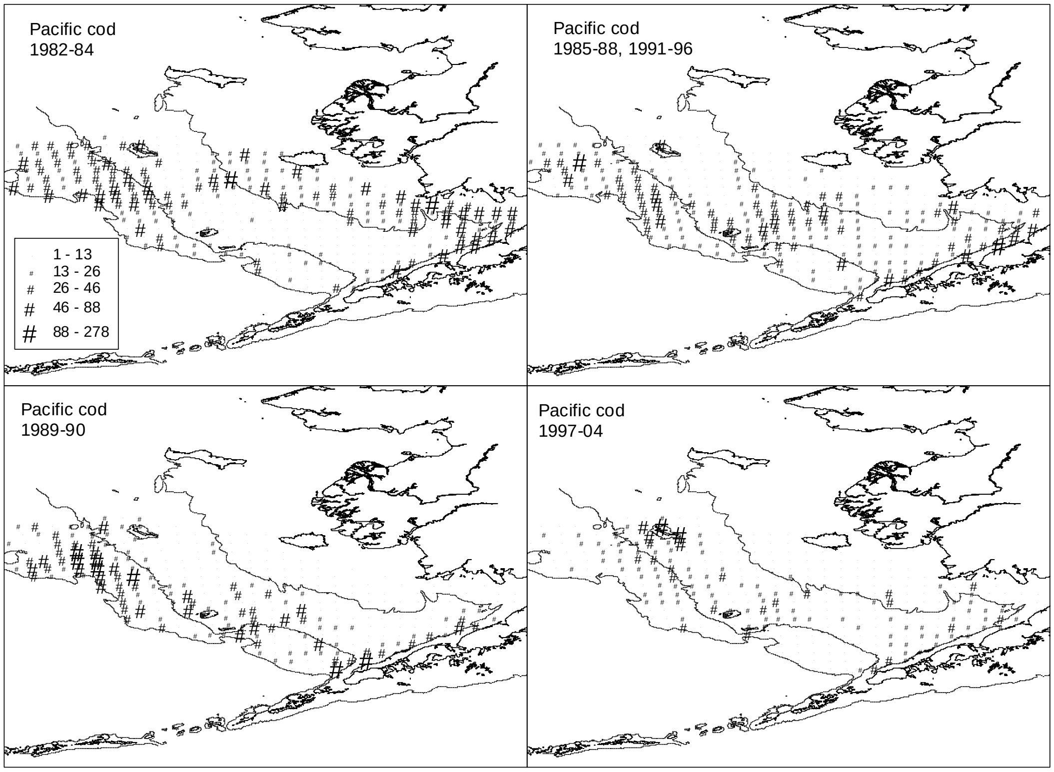


Figure 43. Distributions of relative biomass of Pacific cod in the eastern Bering Sea from 1982 to 2004 derived from NMFS summer trawl survey data. Relative biomass is expressed as kg/ha. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

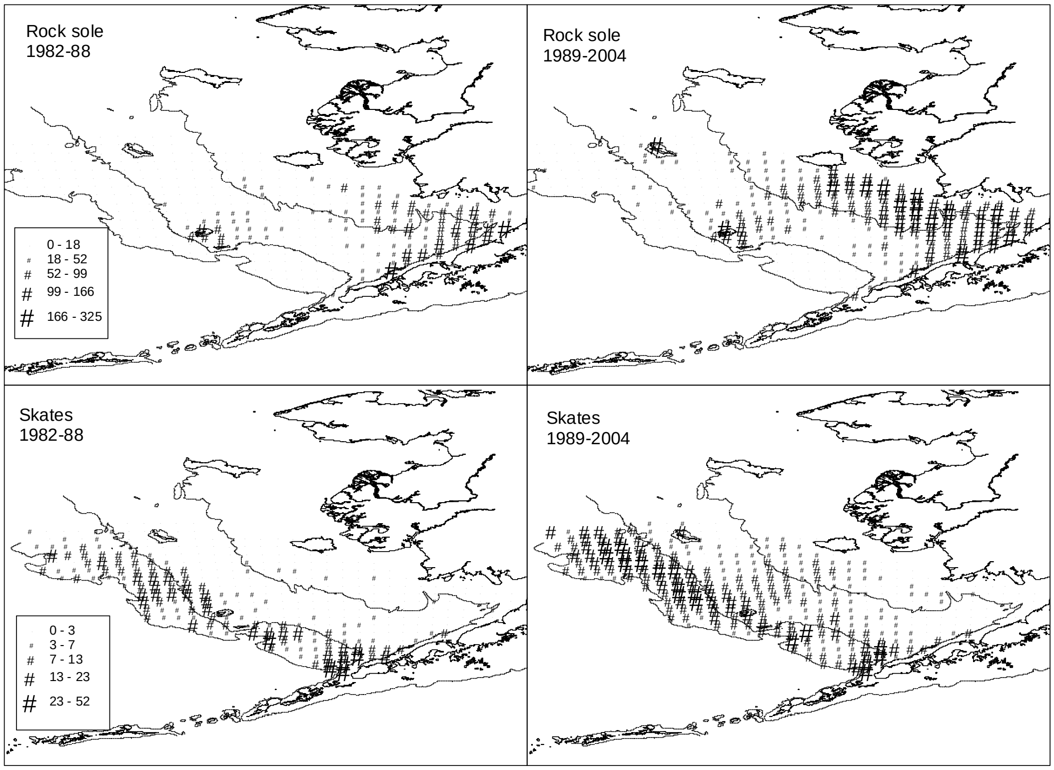


Figure 44. Distributions of relative biomass of rock sole and skates in the eastern Bering Sea from 1982 to 2004 derived from NMFS summer trawl survey data. Relative biomass is expressed as kg/ha. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

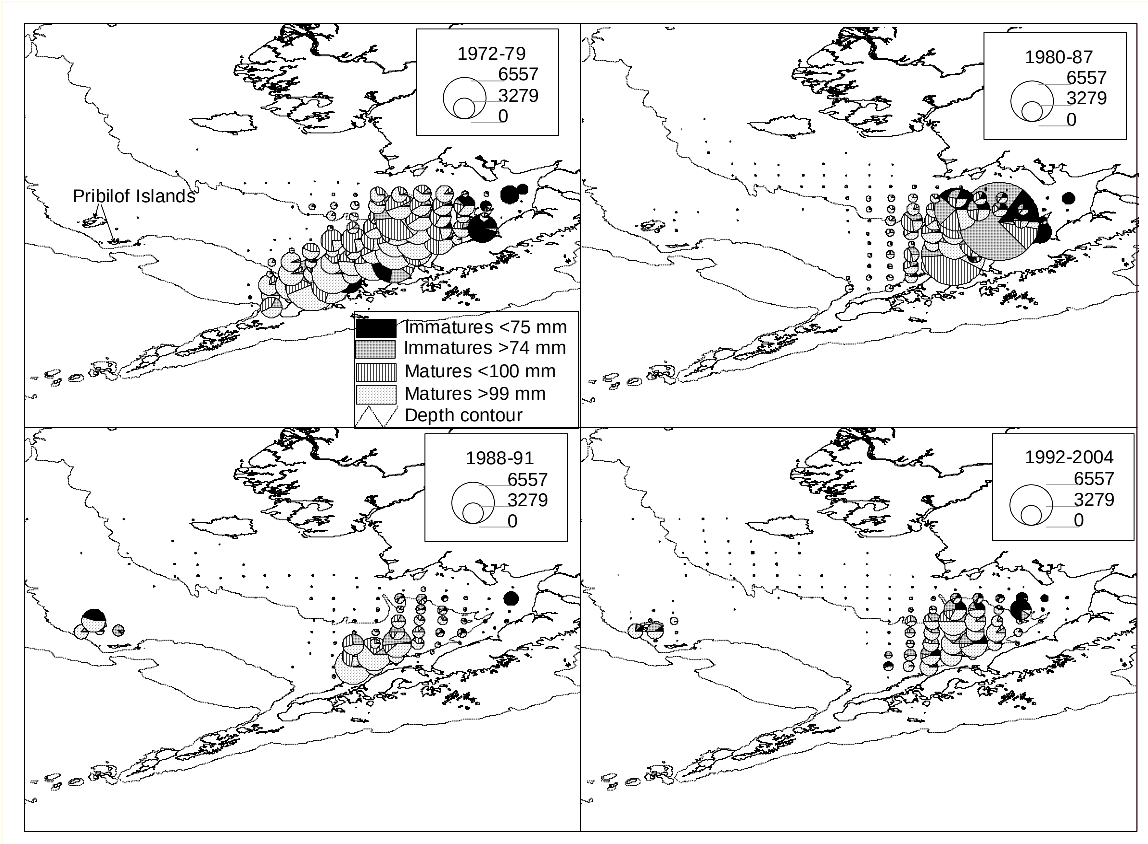


Figure 45. Geographic distributions of immature and mature female red king crabs from 1972 to 2004 in the eastern Bering Sea derived from NMFS summer trawl survey data. The diameter of each pie represents crab density expressed as the number of crabs per square nautical mile. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

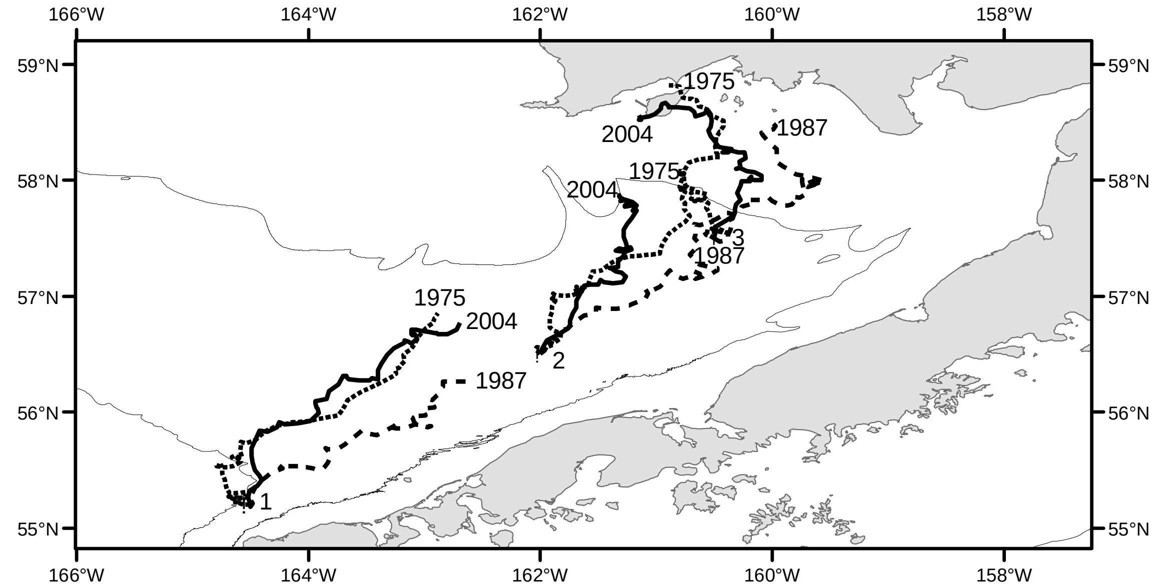


Figure 46. Larval movements after hatching on May 15, 1975, 1987, and 2004 from three different locations for Bristol Bay red king crab during two months. (Source: Zheng and Kruse 2008).

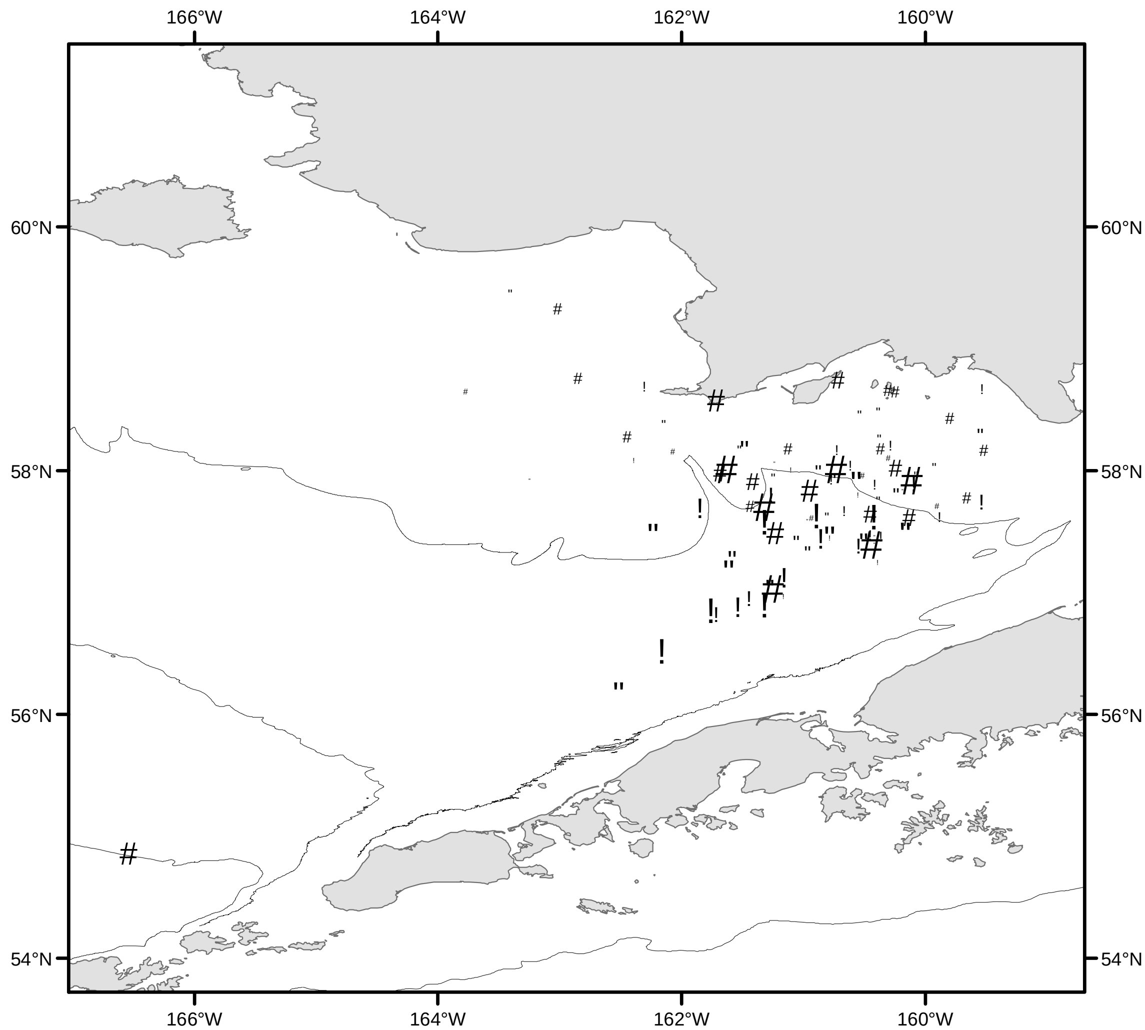


Figure 47. Estimated settling locations from the distribution centers of Bristol Bay mature female red king crabs >99 mm CL during 1967-1999. Hatching dates of April 15, May 15, and June 15 are triangles, squares, and circles, respectively. Symbol sizes are proportional to year-class strength.

2010 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
28 April 2010

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

Preamble
At the time of developing this draft 2010 SAFE report, only survey biomass data through 2009 and fishery data through the 2008/09 season are available. In order to populate the model for the purpose of projecting the 2010/11 OFLs, we set the 2010 survey biomass estimates equal to those of the 2009 survey, and the 2009/10 fishery performance (retained catch, discard plus bycatch losses) equal to the catch components projected in the 2009 SAFE (Rugolo and Turnock 2009). Until the 2010 survey and 2009/10 fishery data are incorporated in the assessment, some of the discussion is taken from the 2009 Tanner crab SAFE. In this draft, the status of the 2009/10 Tanner crab stock can be gauged relative to the overfished status determination criteria in terms of an upper limit on the measure of male mature biomass (MMB) at the time of mating in mid-February 2010.

Status of the 2009/10 Stock
Tanner crab MMB in the 2009 survey declined substantially and even at the time of the survey was below the minimum stock size threshold (MSST=0.5B_{REF}). Under the current plan, MMB projected from the survey to the time of mating in mid-February is gauged against the MSST to determine its status relative to the overfished status criterion. The projection accounts for losses due to natural morality from the survey to the time of mating, in addition to directed and non-directed losses in the 2009/10 fisheries. Although the 2009/10 fishery data are not yet available, we can assess the status of the 2009/10 stock relative to MSST in terms of a projected upper limit on MMB at the time of mating (02/15/10) accounting for losses due to M. Here the term upper limit refers to 2010 projected biomass at the time of mating without fishing mortality. Since the stock will be further depreciated by fishing losses this estimate represents an upper limit.

The ratio of the 2009 survey MMB to B_{REF} is 0.42, thus the stock was below MSST even at survey time and absent further losses from the survey to the time of mating (Rugolo and Turnock 2009). Accounting for fixed losses due to M from the survey to the time of the fishery, the ratio of MMB available to the fishery to B_{REF} is 0.37. In advance of the including the 2009/10 fishery data, assuming zero directed and non-directed fishing losses in 2009/10, the ratio of 2009/10 MMB at mating to B_{REF} would be 0.36. Lastly, assuming that the catch OFLs projected in the 2009 SAFE (Rugolo and Turnock 2009) were realized by the 2009/10 fisheries, the resultant ratio of 2009/10 MMB at mating to B_{REF} would be 0.34. Thus, MMB at mating in mid-February 2010 cannot exceed 0.36B_{REF} and will be lower once fishing losses are incorporated in the projections, but not likely lower than 0.34B_{REF}.

Under the process established by the Crab Plan Team, final recommendation on the status of the 2009/10 EBS Tanner crab stock will occur in September 2010 once the 2009/10 catch data are available. In September 2009, the CPT noted the change in stock status in 2009 relative to 2008 with the projected biomass in February 2010 falling below MSST even under a zero catch harvest strategy. The team recommended to the Council in its report to the SSC in October 2009 that the stock is approaching an overfished condition. The September 24, 2009 letter from the Alaska Regional Office to the NPFMC stated “To comply with section 304(e)(3) of the Magnuson-Stevens Act, the North Pacific Fishery Management Council (Council) has two years from this notification to prepare and implement a rebuilding plan for Tanner crab.” Once the stock losses from the 2009/10 fisheries and M from the survey to mating are incorporated, the calculated MMB at mating in February 2010 will be below the limit that defines an overfished stock.

Executive Summary

In 2009, Tanner crab MMB at the time of the survey was estimated at 34.99 thousand metric tonnes (t). This was a 43.2% decrease in MMB relative to 2008. Legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southern Bristol Bay and northwest of the Pribilof Islands. The total abundance index for legal males decreased 40.3% to 7.9 million crabs between 2008 and 2009. Legal males were distributed 53.3% (4.2 million crabs) east and 46.7% (3.7 million crabs) west of 166^o west longitude which compared to 69.0% and 31.0% respectively in 2008. The abundance index for pre-recruit male crabs (110-137 mm cw) declined 33.7%, and that for small males (<110 mm cw) declined 11.0% relative to 2008. Total male abundance declined 18.7% between 2008 and 2009. Comparison of the male size frequency distributions revealed a dramatic decline in male abundance above 60mm CL between 2008 and 2009 (Figure 12a), a general failure for modes to persist inter-annually (Figures 10a-d), and a relatively increasing percentage of old shell crabs in the mature male stock. A relatively strong recruit mode (20-40mm CL) is apparent in results of the 2009 survey.

Large female (>=85 mm cw) Tanner crab showed a 25.7% decrease relative to 2008, and these were dominated (68.3%) by old shell females. Among all female Tanner crab in 2009, 25.3% were collectively old shell and 71.9% new-hard shell. Small female (<85 mm cw) Tanner crab increased by 21.0% relative to 2008. Total 2009 female abundance increased 11.5% due to increased small female abundance. The total abundance of male and female combined declined 7.8% since 2008. The survey length frequency distributions of female Tanner crab from 2007-2009 showed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually. As seen for male Tanner crab, female abundance above 60mm CL declined sharply between 2008 and 2009, while a strong recruit mode (25-35mm CL) is apparent in 2009 (Figures 11a-d). A significant portion (73.4%) of mature female Tanner crab 75 mm cw and larger in 2009 are comprised of old shell females, and 25.1% of this length group were in the new-hard shell condition class.

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} for OFL-setting is the reference biomass (B_{REF})=83.80 thousand t MMB at the time of mating estimated as the average survey MMB_{mating} from 1969-80 inclusive. 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 B_{REF} as a proxy for B_{MSY}. Here, $F_{OFL}=\gamma M$**.** The 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) for males and females combined.

The value of M is 0.23 for EBS Tanner crab. For this analysis, gamma is set to 1.0. The projected 2010 estimate of MMB at the time of mating is 28.25 thousand t. Relative to B_{REF}, B/B_{REF}=0.34. Under the OFL Control Rule, the 2010/11 F_{OFL}=0.06.

For the 2010/11 Tanner crab fishery, we estimated the Total Catch OFL=2,001.61 t for males and females combined. Total losses to MMB in the 2010/11 Total Catch OFL are 1,764.80 t. Directed and non-directed discard losses to MMB in 2010 are estimated to be 262.20 t and 1,113.76 t, respectively. The retained part of the catch OFL of legal-sized crab is 388.83 t. The retained legal catch would comprise 19.4% of the total MMB losses. A significant component of MMB losses therefore is attributed to non-targeted losses under current fishing practices.

Expected discard losses of female Tanner crab from the 2010/11 groundfish fishery and the directed pot fishery combined was estimated at 236.81 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.11 and 0.06 respectively.

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

Year	MSST	Biomass (MMB)	OFL	TAC [E+W]	Retained Catch	Total Catch
2005/06		35.00		0.73	0.43	1.61
2006/07		52.84		1.35	0.96	3.15
2007/08		59.80		2.55	0.96	3.63
2008/09	41.90	50.80	7.04	1.95	0.88	2.25
2009/10	41.90	28.25[1/]	1.99[2/]	0.61[3/]		

Notes:
1/ Projected 2009/10 MMB at time of mating after extraction of the estimated total catch OFL.
2/ Projected total catch OFL for the 2009/10 fishery.
3/ Eastern District only. No TAC in 2009/10 in Western District.

The 2009/10 stock was below MSST estimated at the time of the 2009 survey. Overfishing did not occur during the 2009/10 fishing year. Once the stock losses from the 2009/10 fisheries and M from the survey to mating are incorporated, the calculated MMB at mating in February 2010 will be below the limit that defines an overfished stock.

A. Summary of Major Changes

There are no major changes to assessment methodology in this 2010 Draft SAFE relative to the 2009 SAFE (Rugolo and Turnock 2009) in determining stock status or estimating the F_{OFL} and the catch components comprising the Total Catch OFL. This assessment is updated in two respects. First, it incorporates the revised bottom trawl survey data from 1976-2009 in which biomass is estimated using measured net widths for each tow. This revision results in differences in biomass estimates relative to those based on the fixed 50 ft net width protocol. Rugolo and Turnock (2009) present the time series of MMB estimated using fixed and measured net widths, and discuss general differences. Secondly, all units of mass are presented in terms of metric tonnes.

B. Responses to SSC and CPT Comments

1. SSC Comments:

October 2009 Meeting:

In their review of the CPT report on the status of BSAI crab stocks and OFLs, the SSC made the following general comments to assessment authors:

- *At the beginning of each SAFE chapter, summarize the SSC and Plan team requests to the author to insure requests are not overlooked.*
- *Each assessment should clearly state what is new and not new from the previous assessment.*
- *Assessment authors should structure their assessment documents following the guidelines established by the crab plan team.*

The authors have attended to each of these comments by the SSC.

The SSC made the following specific comments on the 2009 Tanner crab SAFE report:

1. *The SSC recommends that the forthcoming rebuilding analyses consider the snow crab recommendations when developing rebuilding strategies for this species.*
2. *The SSC recommends that an operational model for Tanner crab be developed to aid in these analyses.*

The authors will attend to the SSC's recommendations on snow crab rebuilding analyses when developing rebuilding strategies for Tanner crab. A length-based Tanner Crab stock assessment model (TCSAM) and projection model was developed and presented to the CPT in March 2010 and the SSC in April 2010. The goal is to promote Tanner crab to a Tier-3 management status, and formulate OFLs based on based the TCSAM. The snow crab stock assessment model (COSAM) and projection model were adapted for Tanner crab. Progress reports will be presented to the CPT and SSC in September 2010 and October 2010 respectively. Given the normal Council review and approval process, a goal is to achieve approval of the TCSAM by the Council in June 2011 and implementation for OFL-setting for the 2011 assessment cycle pertaining to the 2011/12 fisheries.

June 2009 Meeting:

In their review of the Draft 2009 Tanner crab SAFE report, the SSC mad the following general comments concerning EBS Tanner crab SAFE and OFLs:

- *The revised EBS bottom trawl time series was not used in the Tanner crab assessment. This information is important for stock status determination and the SSC recommends use of the revised time series for the final assessment in 2009. The SSC agrees with the CPT and authors that the OFL for this stock should be based on the Tier 4 control rule since no formal assessment has been developed for the entire EBS region. The SSC agrees with the CPT and authors that B_{REF} be based on the average mature male biomass (MMB) for the years 1969-1980, discounted by fishery removals (retained and non-retained mortalities) and natural mortality between the time of survey and mating, and that γ=1.0 and M=0.23. This equates to a B_{REF} of 189.76 million pounds of MMB.*

The SSC made the following specific recommendations to assessment authors:

1. *Use most recent data available, including revised survey data to be included for review in September and revised bycatch data from the groundfish fisheries when those become available.*

The authors agree. The most recent bottom trawl survey data, groundfish fishery bycatch data and directed and non-directed crab pot fishery data are included in this SAFE report and OFL analysis.

2. *By September, 2009, provide complete documentation on data sources and the calculations and assumptions used in the stock assessment for computing OFL. Table headings should clearly and accurately describe the data, including indicating when data includes a handling mortality assumption.*

The authors agree and have addressed the SSC recommendations.

3. *Further an assessment model that incorporates the entire stock area in the next assessment cycle.*

The current stock assessment and OFL-setting Tier-4 analysis incorporates the entire stock area. A length-based Tanner Crab stock assessment model (TCSAM) for the EBS Tanner crab stock is in development. Please see comments above under October 2009 SSC Meeting.

October 2008 Meeting:
In their review of the 2008 Tanner crab SAFE report, the SSC commented concerning EBS Tanner crab SAFE and OFLs:

1. *During the June 2008 meeting, the SSC was presented with an analysis for calculating gamma based on selectivities set equal to values given in the overfishing EA. The most recent three years of data suggest that selectivities in both the directed fishery and pot fisheries differ significantly from those used in the EA and therefore the June 2008 analysis may provide misleading results and should not be used. The SSC therefore concurs with the CPT and author to set gamma=1 for OFL and that* B_{REF} *be estimated as the average male mature biomass (MMB) at the time of mating for the period 1969-1980.*

The authors agree with the SSC comments.

2. CPT Comments:
September 2009 Meeting:
In their review of the 2009 Tanner crab SAFE report, the CPT commented concerning EBS Tanner crab SAFE and OFLs:

1. *The CPT noted the change in stock status from 2008 to 2009 with the projected biomass in February 2010 falling below MSST, even under a zero catch harvest strategy. Thus, the stock is approaching an overfished condition*

The authors concur with this finding.

2. *The CPT suggested that Tanner crab bycatch in the Scallop fishery be included in estimates of total removals in next year's assessment.*

Tanner crab bycatch from the 2006/07, 2007/08 and 2008/09 Scallop fisheries were recently provided. They are not yet included in this draft 2010 SAFE but will be included in future updates.

3. *The CPT considered comparative information on the revised survey dataset compared with the old survey dataset; the old dataset is used in the 2009 assessment. The team noted the OFL and biomass estimates based on these new data will be included in the upcoming rebuilding analyses.*

The OFL and biomass estimates based on the revised bottom trawl survey are included in this assessment.

4. *The Council will receive a letter from NMFS notifying them that the stock is approaching an overfished condition and that a rebuilding plan must be prepared. The team highlighted the importance of a model-based stock assessment to evaluate the inherent trade-offs under rebuilding scenarios. This model development should be the highest priority for crab stock assessments next year.*

Once the stock losses from the 2009/10 fisheries and M from the survey to mating are incorporated, the calculated MMB at mating in February 2010 will be below the limit that defines an overfished stock. A length-based Tanner Crab stock assessment model (TCSAM) for the EBS Tanner crab stock is in development.

5. *The team noted that bycatch considerations are a particular concern with this stock. While snow crab bycatch is best estimated in the snow crab fishery, bycatch in other fisheries could drive an overfishing determination.*

The authors agree. All principal sources of bycatch losses to the stock are included in this assessment and OFL-setting.

<u>May 2009 Meeting</u>:
In their review of the Draft 2009 Tanner crab SAFE report, the CPT made the following comments concerning the EBS bottom trawl survey data and its use in 2009/10 stock assessments and OFL-setting:

- *The CPT recommended using only standard surveys by year as an index. The team discussed the advantages and disadvantages of moving to a time-series of abundance estimates when the reanalysis is not yet complete. Not all assessment authors used the new dataset in the draft assessments presented to the meeting. The assessments that will be presented in September 2009 for each stock will use the dataset that was employed for the May 2009 assessment of that stock. Next year all assessments will use same new dataset for next May's draft assessments.*

The authors addressed this recommendation. This assessment uses the new trawl survey dataset.

<u>September 2008 Meeting</u>:
In their review of the 2008 Tanner crab SAFE report at their September 2008 meeting, the Crab Plan Team commented concerning EBS Tanner crab SAFE and OFLs:

1. *For consistency with Amendment 24, the term "total catch OFL" should consistently be applied only to the total catch of males and females in all fisheries.*

The authors addressed this recommendation. The Total Catch OFL (TC_{OFL}) represents the total losses to male plus female stock biomass resulting from retained catch plus non-directed bycatch and discard losses from all fisheries. The projected male catch OFL is the sum of the retained component of the TC_{OFL} by the directed fisheries plus any directed and non-directed discard losses to legal male biomass.

2. *Based on the assessment, much of the data and information needed to develop a stock assessment model for the entire EBS stock may exist. It's recommended that development of such a model should proceed; the stock assessment model developed for the eastern portion of the EBS Tanner crab stock should be reviewed for adaptation for a model to apply to the full EBS.*

A length-based Tanner Crab stock assessment model (TCSAM) for the EBS Tanner crab stock is in development. Initial results of the TCSAM were presented to the CPT in March 2010. See comments in C.2. Stock Structure.

3. *Future spring stock assessments should provide a full analysis on the choice of gamma and a full evaluation of alternatives relative to the default value, γ=1, and the appropriateness of the default value.*

Per the recommendation of the SSC (October 2008) and consistent with that of the authors, a value of gamma=1.0 is adopted for OFL-setting. Use of a value of gamma greater than unity is unsupported by evidence that this stock can persist in the face of exploitation rates in excess of M. Additional rationale is presented in this document supporting the use of gamma=1.0 for this stock.

4. *The assessment should provide complete documentation on data sources and the calculations and assumptions used in the stock assessment for computing OFL. The total catch OFL should be clearly specified and provided in a table focused on deriving that OFL. Information on sub-dividing the OFL among catch components should be presented clearly.*

The authors agree and have addressed this recommendation.

5. *Research on handling mortality rates needs to be performed to better specify handling mortality rates used in the analysis.*

The authors agree that more reliable estimates of post-release mortality rates on discards in the directed and non-directed pot fisheries and on bycatch in the groundfish trawl fisheries are required for this and all king and Tanner crab stocks under the current NPFMC plan.

6. *The team will revise the terms of reference for assessments to include key management related stock status information consistently.*

The authors agree.

7. *Responses to all comments by the SSC on the May draft of the stock assessment should be clearly addressed and responded to in the September draft.*

This authors have addressed this recommendation.

8. *The next assessment should include a full and reasonably detailed discussion on the pre-1980 data quality issues for both the survey and fishery data.*

The retrospective analysis of the historical NMFS trawl survey database is completed for 1976-2010. This assessment incorporates these new time series data.

D. 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 2009). 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 did he 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 precedent of setting management controls for this stock east and west of 166^{o} 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. Nonetheless, 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 *a posteriori* 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. 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 was 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 and enumerated annually by NMFS 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 those based on the true area-swept calculations using actual net widths spreads for 1976-2009. Survey data in 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 2009 survey. The highest abundance of males and females occurs from 163 to 167 degrees West longitude with the distinction that males also reveal moderate levels of abundance in the area of the Pribilof Islands. Figures 13 and 14 show the abundance by carapace width estimated from the survey for male and female Tanner crab.

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, Figures 4b and 6). LMB data are currently available for 1980-2009. MMB estimates currently date to 1969. Retrospective analysis of the historical NMFS trawl survey data is in progress which will complete the time series record and provide a consistent estimate of stock metrics between 1968 to present. 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) reflects that of the attendant directed fisheries with peak modes in the mid-1960s through mid-1970s and in the early-1990s (Table 5, Figure 5), and collapsed stock status following those modes. MMB at the survey revealed an all-time high of 282.99 thousand t in 1975, and a second peak of 108.34 thousand t in 1991. From late-1990s through 2008, MMB rose at a moderate rate from a low of 10.43 thousand t in 1997 to 73.56 thousand t in 2007 before falling to 34.99 thousand t in 2009. 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.

The legal minimum size of 5.5 in cw (spine tip to spine tip) is equivalent to 138 mm cw measured between the spines. Legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southern Bristol Bay and northwest of the Pribolof Islands (Figure 1). In 2005, the ADF&G stratified the management of the Bering Sea Tanner crab stock into two subareas, east and west of 166°W longitude, hereafter Eastern and Western Districts respectively. The abundance index for legal male Tanner crab for both districts combined was 7.9 million crabs, a 40.3% decrease over 2008. This abundance was distributed between management districts according to 53.3% Eastern and 46.7% Western compared to 69.0% and 31.0%, respectively in 2008. The abundance index (51.5 million crabs) for pre-recruit male crabs (110-137 mm cw) showed a 33.7% decrease, and the abundance of 162.2 million small males (< 110 mm cw) decreased 11.0% relative to 2008 for all areas combined (Figure 9). The 2006 male size-frequency revealed a prominent mode in the 70-75 mm cw range which persisted to 2007 at 90 mm cw (Figures 10a and 10b). However, this mode is absent from the 2008 and 2009 male length frequency distributions and total male abundance was observed to decline 18.7% between 2008 and 2009 (Figures 9, 10d and 12a). Legal-sized males represent only a small portion (3.5%) of total male abundance in 2009. Among all male Tanner crab in 2009, 25.3% were old shell in all categories combined, and 74.2% were comprised of molting, new-soft and new-hard shell (70.2%) categories (collectively, new shell males). Among legal-sized males, 26.6% were old shell all categories combined, 69.0% were new-hard shells. Pre-recruit crab in 2009 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 2009 were seen in southwestern Bristol Bay and the surrounding area of the Pribilof Islands (Figure 1).

The combined Eastern and Western Districts abundance index (23.8 million crabs) of large females ($\geq$ 85 mm cw) showed a 25.7% decrease over 2008, and these were dominated (68.3%) by old shell females. (Figure 9). Among all female Tanner crab in 2009, 25.3% were old shell in all categories combined and 74.7% were comprised of molting, new-soft and new-hard shell (71.9%) categories (collectively, new shell females). Among this new shell female group, 89.8% were immature and 10.2% mature. Of all mature new shell females, 19.3% were barren and 80.7% ovigerous, among which 10.2%, 67.1% and 21.8% brooded ¾ full, ½ full and full clutches, respectively, while the remainder carried partial clutches less than ½ full. The small (<85 mm cw) female Tanner crab abundance estimate in 2009 (152.0 million crab) increased 21.0% relative to 2008. Total 2009 female abundance (175.8 million crab) increased 11.5% from 2008 to 2009, and the total abundance of male and female combined (401.4 million crab) declined 7.8% (Figure 9). Ovigerous females were sparsely distributed from southern Bristol Bay where at relatively highest abundance westward to south of St. Matthew Island (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 2007-2009 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11a-d). The prominent length mode between 65-75 mm cw seen in 2006 did not persist through 2007, 2008 or 2009 but revealed consistently declining abundance through 2009. The mode of mature females in 2008 at 75 mm cw declined in abundance in 2009 and is dominated by old and very old shelled females. A modest mode of new shell recruits is seen in 2009 at 25-30 mm cw, and new shell females dominate the 2009 length frequency distribution below 65 mm cw. A significant portion (73.4%) of mature female Tanner crab 75 mm cw and larger in 2009 are comprised of old shell females, and 25.1% of this length group were in the new-hard shell condition class (Figure 11d). As seen for male Tanner crab, female abundance above 60mm CL declined sharply between 2008 and 2009 (Figure 11d).

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 state of Alaska 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 these 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 long. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168° W long. and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

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 0.43 thousand t retained catch between 2005-2007 (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.

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 trawl fisheries (Table 3). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for trawl fishery bycatch (NPFMC 2008). Total Tanner crab discard and bycatch losses by sex are shown in Table 3 for 1965-2008. 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 trawl fisheries contributed significantly to total bycatch losses, although the combined pot fisheries are the principal source of contemporaneous 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 all pot and trawl fisheries combined to retained catch shifted significantly relative to that between 1980-1996 (Tables 2 and 3). For 2005-2008, the ratio of total male discard losses to retained catch was 4.3, 3.8, 4.6, and 2.4, respectively, and averaged 3.8 (standard error=0.5). The majority of these male losses are sub-legal sized crab, and a principal contributor to these non-retained losses is the directed Tanner crab fishery (Table 7a). This contrasts the pre-closure performance of the domestic fishery (1980-1996) which averaged 1.1 (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 trawl fishery.

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. Estimates of LMB are currently available only for 1980-2008. When the re-analysis of the NMFS trawl survey database is completed, MMB estimates will be available for the time series record, 1968 to present. During 1980-2008, exploitation rate (μ) on LMB was highest in 1981 at 0.54 and fell with stock condition through the mid-1980s. LMB exploitation rate revealed a second prominent mode during 1989-1993, peaking at 0.46 in 1991 and averaging 0.44 (Table 6, Figure 7b). At these rates of exploitation on LMB, the Tanner crab stock did not persist at sustainable or healthy stock levels for even brief periods of time. The pattern of μ on MMB from 1969-2008 reveals two high periods: one associated with the high total catches in 1969-1980; the other coincident with the mode of high catches in the late-1980s through early-1990s. The variability in μ on MMB during the early period (pre-1976) is attributed to early biomass estimates which will be replaced by a new biomass time-series biomass in 2010. Exploitation rates on MMB during the 1990s peaked at 0.44 in 1990, averaged 0.23 between 1986-1997, and closely 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^{o} West 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^{o} 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 are 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 reliable 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 2009) given the close analogues in population dynamic and life-history characteristics between these two species otherwise, where longevity would be at least 20 years. Using 20 years as a proxy for longevity and assuming that this age represents the upper 98.5^{th} 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

We 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). We also examined growth relationships developed by Zheng and Kruse (1999) (Figure 14). Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of Tanner crab in survey data assuming no terminal molt at maturity. Consequently, Somerton's approach did not directly measure molt increments and his findings were confounded by not recognizing that the progression of modal lengths between years was biased as a result that 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

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} for management is the reference biomass (B_{REF})=83.80 thousand t MMB at the time of mating estimated as the average observed MMB_{mating} from the SSC approved time period of 1969-80. In 2009, survey MMB (34.99 thousand t) declined 43.2% relative to 2008 (61.60 thousand t). Thus, even the estimated 2009 survey MMB was below the minimum stock size threshold ($MSST=0.5B_{REF}$). MMB projected to the time of mating in 2010/11 (28.25 thousand t) represents 33.7% of B_{REF} after accounting for projected total losses to MMB in the 2009/10 Total Catch OFL=1.76 thousand t. MMB at mating in 2010 will remain below the benchmark MSST of 41.90 thousand t. The status of the EBS Tanner crab stock in 2010 is projected to be overfished.

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 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 proxy B_{MSY}, or B_{REF}, is commonly 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_t) 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 $\beta < B_t \leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B_t/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_{REF}) 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_{REF}) 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. $B_t/B_{REF} > 1.0$	$F_{OFL} = \gamma \cdot M$
b. $\beta < B_t/B_{REF} \leq 1.0$	$F_{OFL} = \gamma \cdot M\ [(B_t/B_{REF} - \alpha)/(1 - \alpha)]$
c. $B_t/B_{REF} \leq \beta$	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.

Male Mature and Legal Biomass:

Annual estimates of male biomass are derived from the NMFS Eastern Bering Sea summer trawl survey. Two measures are specified: male mature biomass (MMB) and legal male biomass (LMB). From these measures derived at the time of the survey, we estimate MMB and LMB at the time of mating by depreciating survey biomass by the partial natural mortality rate (M) over 8 months from the survey to nominal mating (02/15th) and extracting total catch components (C_{MMB} or C_{LMB}).

$$MMB_{mating} = MMB_{survey}e^{-2M/3} - C_{MMB} \tag{1}$$

$$LMB_{mating} = LMB_{survey}e^{-2M/3} - C_{LMB} \tag{2}$$

Estimating F_{OFL}:

Given MMB_{mating} (or B_t) and the specification of a biomass reference (B_{REF}) proxy for B_{MSY}, the overfishing limit F_{OFL} is found using the OFL algorithm. In the case where, for example, $\beta < B_t/B_{REF} \leq 1.0$, the overfishing limit is estimated, where α=0.1:

$$F_{OFL} = \gamma M\ ((B_t/B_{REF} - 0.1)/(1 - 0.1)) \tag{3}$$

Total Catch OFL and Catch Components:

A total catch overfishing limit (Total Catch OFL) corresponding to the F_{OFL} can be estimated as the product of the annual fishing mortality rate ($1\text{-}e^{-Fofl}$) and the male mature biomass at the time of the fishery ($MMB_{survey}e^{-2M/3}$). The time from survey to the mean fishery period is 8 months.

$$\text{Total Catch OFL} = (1-e^{-Fofl})\ (MMB_{survey}e^{-2M/3}) \tag{4}$$

This total catch overfishing limit includes all retained, plus discard and bycatch losses from the directed fishery and all non-directed fisheries (pot and groundfish trawl). These catch components are defined as:

i. $C_{ret,LMB}$ = retained legal male biomass by the directed fishery
ii. $C_{dir\text{-}dsc,MMB}$ = discard losses to MMB by the directed fishery
iii. $C_{non\text{-}dsc\text{-}pot,MMB}$ = discard losses to MMB by the non-directed pot fisheries
iv. $C_{non\text{-}dsc\text{-}gf,MMB}$ = discard losses to MMB by the non-directed trawl fisheries

Therefore, using these catch components,

$$\text{Total Catch OFL} = C_{ret,LMB} + C_{dir\text{-}dsc,MMB} + C_{non\text{-}dsc\text{-}pot,MMB} + C_{non\text{-}dsc\text{-}gf,MMB} \tag{5}$$

In practice, the catch components i-iv are estimated from past performance in the respective fisheries considered to be most representative of current conditions. Catch components i and iv are co-related, and the magnitude of the discard losses to MMB by the directed fishery is a function of the retained legal male biomass. In this case, $C_{ret,LMB}$ is found by iteration such that the Total Catch OFL (5) equals that estimated in equation (4).

Discard Catches:
Discard losses of mature male biomass by the directed 2009 fishery ($C_{dir\text{-}dsc,MMB\ 09}$) was estimated using data from the most recent three Tanner crab fisheries supplied by D. Pengilly (ADF&G, 08/24/09) (Table 7a). The average ratios of legal and sublegal male and female discards to the average retained catch in the 2006, 2007 and 2008 fisheries are used to project discard losses in the terminal 2010 fishery. Here, $DSC,MMB_{06\text{-}08}$ is the average discarded mature male biomass in the 2006, 2007 and 2008 directed Tanner crab fisheries. $C_{ret,LMB\ 06\text{-}08}$ is the average retained catch in the 2006, 2007 and 2008 directed fisheries, and $C_{ret,LMB\ 10}$ is the projected retained catch in the 2010 fishery. For all pot discards, a post-release handling mortality rate of 50% was used (HM_{pot}=0.50). Directed fishery discard losses to MMB is given by:

$$C_{dir\text{-}dsc,MMB\ 10} = C_{ret,LMB\ 10}\ (DSC,MMB_{06\text{-}08} / C_{ret,LMB\ 06\text{-}08})\ HM_{pot} \qquad (6)$$

Non-directed pot fishery discard losses to male mature biomass ($C_{non\text{-}dsc\text{-}pot,MMB}$) are principally attributed to the EBS snow crab fishery and to the Bristol Bay red king crab fishery to a lesser extent. In this analysis, we used data from the previous three fishing seasons (2006, 2007 and 2008) to estimate of the average ratio of combined Tanner crab mature male discards ($C_{non\text{-}dsc\text{-}pot,MMB\ 06\text{-}08}$) to average snow crab retained catch ($C_{ret,Opilio\ 06\text{-}08}$) (Table 7b). $C_{ret,opilio\ 2010}$ is the projected 2010 retained catch OFL (Turnock, pers. Comm.). Using this ratio, projected non-directed pot fishery discard losses to MMB in the terminal fishery ($C_{non\text{-}dsc\text{-}pot,MMB}$) is given by:

$$C_{non\text{-}dsc\text{-}pot,MMB} = C_{ret,Opilio\ 2010}\ (C_{non\text{-}dsc\text{-}pot,MMB\ 06\text{-}08} / C_{ret,opilio\ 06\text{-}08})\ HM_{pot} \qquad (7)$$

Discard losses to MMB ($C_{non\text{-}dsc\text{-}gf,MMB\ 10}$) resulting from bycatch in the groundfish trawl fisheries was estimated using the average groundfish bycatch of Tanner crab over 2006-08 (Mean $_{06\text{-}08,dsc,gf}$) (Table 7c) supplied by J. Mondragon (ARO, 08/07/09) We assumed that this average (3 y) bycatch of Tanner crab would occur in the terminal 2010 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 bycatch ($Porportion_{male}$) 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 trawl discards, a post-release handling mortality rate of 80% was used (HM_{gf}=0.80). Groundfish trawl fishery discard losses to MMB is given by:

$$C_{non\text{-}dsc\text{-}gf,MMB\ 10} = Mean_{06\text{-}08,dsc,gf}\ Porportion_{male}\ HM_{gf} \qquad (8)$$

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as the ratio of total directed plus non-directed losses to LMB and MMB to respective legal and mature male biomass at the time of the fishery:

$$\mu_{LMB} = \text{Total LMB Losses} / LMB_{fishery} \qquad (9)$$

$$\mu_{MMB} = \text{Total MMB Losses} / MMB_{fishery} \qquad (10)$$

Using the F_{OFL} Control Rule (Figure 8), F_{OFL} is determined based on MMB at time of mating after extraction of the Total Catch OFL. Since the ratio of B/B_{REF} is dependent on the extracted catch and the catch OFL upon the estimated F_{OFL}, the solution for the F_{OFL} and catch OFL is found iteratively based on the relationship of MMB at mating to B_{REF}. The Total Catch OFL includes all sources of fishery-induced removals from the stock (directed retained catch, directed discards, and non-directed pot and trawl bycatch mortalities). Given specification of all component losses, the retained portion of the legal catch is a fishery control set so not to exceed the OFL if the expected non-retained losses are realized.

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 Appendix A, which the SSC reviewed in October 2008 (see B.1. October 2008 SSC Meeting). Fishery selectivity for Tanner crab used in the EA analysis were estimated based on historical fishery performance prior to the 1997 closure. We estimated selectivity for the contemporary Tanner crab fishery following its reopening in 2005 and found that the current selectivity patterns for both the directed and non-directed pot fisheries differed profoundly from those used in the EA analysis. While it's desirable for Tier-4 stocks to employ the $F_{35\%}$ proxy for F_{MSY} where reliable data and understanding on fishery performance exist, the authors and SSC considered it premature to employ this approach for Tanner crab given the changes in the directed and non-directed pot fisheries performance observed from 2005-2007 relative to 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 this assessment and recommended the $F_{35\%}$ not be used in OFL-setting since it could provide misleading results, and to set gamma=1.0. A Tanner crab stock assessment model is being developed in which fishery selectivity will be estimated across the time-series record.

For this analysis, gamma is set to 1.0. Discard mortalities from the directed and non-directed pot fisheries and the groundfish trawl fisheries were included. Even if pot fishery selectivities were equivalent pre-1997 and post-reopening in 2005, 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 equivalently account for non-retained losses. Thus, it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. Further confounding specification of gamma for Tanner crab is the fact that the MMB measure derived in this analysis employs a maturity schedule, whereas the EA simulations employed knife-edge sex-specific maturity at size. 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 maintained itself in dynamic equilibrium over any sustained period, nor persisted in the face of exploitation rates (Table 6, Figures 7and 7b) in excess of M. 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

For the EBS Tanner crab stock and OFL-setting for the terminal 2010/11 fishery, the proxy B_{MSY} is B_{REF}=83.80 thousand t of male mature biomass estimated as the average MMB at mating from 1969-1980 inclusive. The SSC (October 2008) recommended using these 12 y of MMB estimates to specify B_{REF} despite both the author's and CPT's concerns about the availability of survey biomass data prior to 1975. We note that the use of the average 1969-1980 MMB at mating estimates as a proxy for B_{MSY} is confounded by contemporaneous and antecedent high exploitation rates (Table 6, Figure 7a). This B_{REF}

benchmark may underestimate the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries. The authors will revisit the choice of a proxy B_{MSY} once the retrospective analysis of the historical trawl survey is completed and internally consistent estimates of stock metrics are available.

From 1980-2009, the Tanner crab stock collapsed twice resulting in two periods of fishery closures and the imposition of a rebuilding plan by the NPFMC. 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 MSY to the fisheries.

F. Calculation of the 2010/11 OFL

For the 2010/11 Tanner crab fishery, we estimated the Total Catch OFL=2,001.61 t for males and females combined (Table 8). Relative to B_{REF}=83.80 thousand t, projected 2010/11 MMB at mating (28.25 thousand t) represents 33.7% of B_{REF} after accounting for projected total losses to MMB in the 2010/11 Total Catch OFL. Under the OFL Control Rule, the full selection 2010 F_{OFL}=0.06.

Total losses to MMB in the 2010/11 Total Catch OFL are 1,764.80 t. Directed and non-directed discard losses to MMB in 2010 are estimated to be 262.20 t and 1,113.76 t, respectively. The retained part of the catch OFL of legal-sized crab is 388.83 t. The retained legal catch would comprise 19.4% of the total MMB losses. A significant component of MMB losses therefore is attributed to non-targeted losses under current fishing practices.

Expected discard losses of female Tanner crab from the 2010/11 groundfish fishery and the directed pot fishery combined was estimated at 236.81 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.11 and 0.06 respectively.

G. Rebuilding Analyses

The EBS Tanner crab stock is not under a rebuilding plan. Since even the MMB at the time of the 2009 survey fell below the MSST, the calculated MMB at mating in mid-February 2010 will be below the MSST even under a zero catch harvest strategy in 2009/10. The status of the Tanner crab stock in 2010 is projected to be overfished.

In October 2009, the CPT recommended to the Council that the Tanner crab stock is approaching an overfished condition. The finding of an overfished status for this stock in September 2010 will necessitate the development and implementation of a rebuilding plan by 2011 under the provisions of the Magnuson-Stevens Fishery Conservation and Management Act. The September 24, 2009 letter from the Alaska Regional Office to the Council states, "To comply with section 304(e)(3) of the Magnuson-Stevens Act, the North Pacific Fishery Management Council (Council) has two years from this notification to prepare and implement a rebuilding plan for Tanner crab."

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 1969-2010 as inputs. For this stock, the early years (1969-1975) in the survey time series are critical to deriving meaningful biological reference points and threshold stock definitions. An essential requirement to a successful model is a consistent time series of survey population metrics, life-history parameters and biological schedules.

Antecedent analysis of survey data is required 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. This analysis commenced in the Fall 2009 and is ongoing.

I. Economic Status of the Fishery

Figures 18 through 21 summarize BSAI Crab Economic Data Report (EDR) information on participants in Bering Sea Tanner crab fishery. Note that no harvesting or processing data from catcher processors is shown due to the low number of catcher processors participating in this fishery. Figure 18 presents data on catcher vessels' commercial harvest and ex-vessel revenue. Figure 19 shows the number of harvest positions and harvest participants and captain and crew labor payments on catcher vessels. Figure 20 shows the volume of finished pounds resulting from crab production, as reported by shoreside and stationary floating processors, and the estimated first wholesale value of those finished pounds. Figure 21 shows processing man-hours and processing labor payments in the shoreside and stationary floating processor sectors. Refer to the 2010 SAFE introductory chapter for descriptions of these statistics and how they have been derived from EDR data.

Literature Cited

Adams, A. E. and A. J. Paul. 1983. Male parent size, sperm storage and egg production in the Crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). International Journal of Invertebrate Reproduction. 6:181-187.

Aydin, Kerim and Franz Mueter. 2007. The Bering Sea--A dynamic food web perspective. Deep-Sea Research II 54:2501-2525.

Barnard, D. R. 2008. Biodegradable twine report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 08-05, Anchorage.

Barnard, D. R. and R. Burt. 2007. Alaska Department of Fish and Game summary of the 2005/2006 mandatory shellfish observer program database for the rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 07-02, Anchorage.

Barnard, D. R. and R. Burt. 2008. Alaska Department of Fish and Game summary of the 2006/2007 mandatory shellfish observer program database for the rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 08-17, Anchorage. Bowers, F. R., M. Schwenzfeier, S. Coleman, B. J. Failor-Rounds, K. Milani, K. Herring, M.

Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and Westward Region's Shellfish Observer Program, 2006/07. Alaska Department of Fish and Game, Fishery Management Report No. 08-02, Anchorage.

Brown, R. B. and G. C. Powell. 1972. Size at maturity in the male Alaskan Tanner crab, *Chionoecetes bairdi*, as determined by chela allometry, reproductive tract weights, and size of precopulatory males. Journal of the Fisheries Research Board of Canada. 29:423-427.

Byersdorfer, S. C., and D. R. Barnard. 2002. Summary of crab injury assessment and aerial exposure sample results from selected 1998/1999 Bering Sea/Aleutian Islands king and Tanner crab fisheries and the 1999 Pribilof Islands hair crab fishery. Alaska Department of Fish and Game. Regional Information Report 4K02-29.

Carls, M. G. 1989. Influence of cold air exposures on ovigerous red king crab (*Paralithodes camtschatica*) and Tanner (*Chionoecetes bairdi*) crabs and their offspring. Proceedings of the International Symposium on king and Tanner crabs, Anchorage, AK, November 1989.

Conners, M.E., A.B Hollowed, and E. Brown. 2002. Retrospective analysis of Bering Sea bottom trawl surveys: regime shift and ecosystems reorganization. Prog. Oceanogr. 55:209-222.

Donaldson, W .E. and D. M. Hicks. 1977. Technical report to industry on the Kodiak crab population surveys. Results, life history, information, and history of the fishery for Tanner crab. Alaska Dept. Fish and Game, Kodiak Tanner crab research. 46 p.

Donaldson, W. E., and A. A. Adams. 1989. Ethogram of behavior with emphasis on mating for the Tanner crab *Chionoecetes bairdi* Rathbun. Journal of Crustacean Biology. 9:37-53.

Donaldson, W. E., R. T. Cooney, and J. R. Hilsinger. 1981. Growth, age, and size at maturity of Tanner crab *Chionoecetes bairdi* M. J. Rathbun, in the northern Gulf of Alaska. Crustaceana. 40:286-302.

Garth, J. S. 1958. Brachyura of the Pacific Coast of America. Oxyrhyncha. Allen Hancock Pacific Expeditions. 21 (1 and 2). 854 p.

Haynes, E., J. F. Karinen, J. Watson, and D. J. Hopson. 1976. Relation of number of eggs and egg length to carapace width in the brachyuran crabs *Chionoecetes baridi* and *C. opilio* from the southeastern Bering Sea and *C. opilio* from the Gulf of St. Lawrence. J. Fish. Res. Board Can. 33:2592-2595.

Hilsinger, J. R. 1976. Aspects of the reproductive biology of female snow crabs, *Chionoecetes bairdi*, from Prince William Sound and the adjacent Gulf of Alaska. Marine Science Communications. 2:201-225.

Hosie, M. J. and T. F. Gaumer. 1974. Southern range extension of the Baird crab *(Chionoecetes bairdi* Rathbun). Calif. Fish and Game. 60:44-47.

Hunt, G. L. Jr., P. Stabeno, G. Walters, E. Sinclair, R. D. Brodeur, J. M. Napp and N. A Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. Deep-Sea Res. 49: 5821-5853.

ICES. 2002. The effects of Fishing on the Genetic Composition of Living Marine Resources. ICES Council Meeting Documents. Copenhagen.

Incze, L. S., Armstrong, D. A., and S. L. Smith. 1987. Abundance of larval Tanner crabs (*Chionoecetes* spp.) in relation to adult females and regional oceanography of the southeastern Bering Sea. Can. J. Fish. Aquat. Sci. 44:1143-1156.

Incze, L. S., and A. J. Paul. 1983. Grazing and predation as related to energy needs of stage I zoeae of the Tanner crab *Chionoecetes bairdi* (Brachyura, Majidae). Biological Bulletin 165:197-208.

Ivanov, B. G. 1993. An interesting mode of feeding snow crabs, *Chionoecetes* spp.(Crustacea, Decapoda, Majidae), on the ascidian *Halocynthia aurantium*. Zool. Zh. 72:27-33.

Jewett, S. C., and H. M. Feder. 1983. Food of the Tanner Crab *Chionoecetes bairdi* near Kodiak Island, Alaska. J. Crust. Biol. 3(2):196-207.

Karinen, J. F. and D. T. Hoopes. 1971. Occurrence of Tanner crabs (*Chionoecetes* sp.) in the eastern Bering Sea with characteristics intermediate between *C. bairdi* and *C. opilio*. Proc. Natl. Shellfish Assoc. 61:8-9.

Kon, T. 1996. Overview of Tanner crab fisheries around the Japanese Archipelago, p. 13-24. *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, Universityof Alaska Fairbanks.

Lang, G. M., P. A. Livingston, and K. A. Dodd. 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 through 2001. United States Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-158, 230 p.

Litzow, M.A. 2006. Climate shifts and community reorganization in the Gulf of Alaska: how do recent shifts compare with 1976/1977? ICES J. of Mar. Sci. 63:1386-1396.

Livingston, P. A. 1989. Interannual trends in Pacific cod, *Gadus macrocephalus*, predation on three commercially important crab species in the eastern Bering Sea. Fishery Bulletin. 87:807-827.

Livingston, P. A., A. Ward, G. M. Lang, and M. S. Yang. 1993. Groundfish food habitsand predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. NOAA Technical Memorandum, NMFS-AFSC-11, DOC, NOAA, NMFS, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, 192 p.

Lowry, L. F., K. H. Frost, and J. J. Burns. 1980. Feeding of bearded seals in the Bering and Chukchi seas and trophic interaction with Pacific walruses. Arctic 33:330-342.

MacIntosh, R. A., B. G. Stevens, J. A. Haaga, and B. A. Johnson. 1996. Effects of handling and discarding on mortality of Tanner crabs, *Chionoecetes bairdi*. p. 577-590, *In* High Latitude Crabs: Biology, Management, and Economics, , Alaska Sea Grant College Program Report, AK-SG-96-02, University of Alaska Sea Grant Program, Anchorage, AK.

McLaughlin, P. A. and 39 coauthors. 2005. Common and scientific names of aquatic invertebrates from the United States and Canada: crustaceans. American Fisheries Society Special Publication 31. 545 p.

Meyers, T. R., B. Eaton, S. Short, C. Botelho, T. Koeneman, A. Sparks, and F. Morado. 1990. Bitter crab dinoflagellate disease: overview of the causative agent and its importance and distribution in the Alaskan Tanner crab (*Chionoecetes bairdi, C. opilio*) fisheries. p. 405 (abstract only), *In* Proceedings of the International Symposium on King and Tanner Crabs. Lowell Wakefield Fisheries Symposium Series., Alaska Sea Grant Report, 90-04, University of Alaska Fairbanks, Alaska Sea Grant College, Fairbanks.

Munk, J. E., S. A. Payne, and B. G. Stevens. 1996. Timing and duration of the mating and molting season for shallow water Tanner crab (*Chionoecetes bairdi*), p. 341 (abstract only). *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.

Nevisi, A., J. M. Orensanz, A. J. Paul, and D. A. Armstrong. 1996. Radiometric estimation of shell age in *Chionoecetes* spp. from the eastern Bering Sea, and its use to interpret shell condition indices: preliminary results, p. 389-396. *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.

NMFS. 2000. Endangered Species Act Section 7 Consultation - Biological Assessment for listed marine mammals. Activities Considered: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs, DOC, NOAA, July 18, 2000.

NMFS. 2004a. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, P.O. Box 21668, Juneau, AK 99802-1668.

NMFS. 2004b. Alaska Groundfish Fisheries Final Programmatic Supplemental Environmental Impact Statement, DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668. Appx 7300 p.

NPFMC. 1998. Fishery Management Plan for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite, 306, Anchorage, AK 99501.

NPFMC. 1999. Environmental Assessment/Regulatory Impact Review/Initial Regulatory Flexibility analysis for Amendment 11 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite, 306, Anchorage, AK 99501.

NPFMC. 2007. Initial Review Draft Environmental Assessment, Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner crabs to Revise Overfishing Definitions. North Pacific Fishery Management Council, 605 W. 4th Avenue, 306, Anchorage, AK 99501.

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

Ormseth, O. and B. Matta. 2007. Chapter 17: Bering Sea and Aleutian Islands Skates. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage 909-1010 p.

Otto, R. S. 1998. Assessment of the eastern Bering Sea snow crab, *Chionoecetes opilio*, stock under the terminal molting hypothesis, p. 109-124. *In* G. S. Jamieson and A. Campbell, (editors), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Canadian Special Publication of Fisheries and Aquatic Sciences.

Paul, A. J. 1982. Mating frequency and sperm storage as factors affecting egg production in multiparous *Chionoecetes bairdi,* p. 273-281. *In* B. Melteff (editor), Proceedings of the International Symposium on the Genus *Chionoecetes:* Lowell Wakefield Symposium Series, Alaska Sea Grant Report, 82-10. University of Alaska Fairbanks.

Paul, A. J. 1984. Mating frequency and viability of stored sperm in the Tanner crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). Journal of Crustacean Biology. 4:375-381.

Paul, A. J. and J. M. Paul. 1992. Second clutch viability of *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) inseminated only at the maturity molt. Journal of Crustacean Biology. 12:438-441.

Paul, J.M., A.J. Paul, and A. Kimker. 1994. Compensatory feeding capacity of 2 brachyuran crabs, Tanner and Dungeness, after starvation periods like those encountered in pots. Alaska Fish. Res. Bull. 1:184-187.

Paul, A. J. and J. M. Paul. 1996. Observations on mating of multiparous *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) held with different sizes of males and one-clawed males. Journal of Crustacean Biology. 16:295-299.

Rugolo, L, J. Turnock and E. Munk. 2008. 2008 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Report to the North Pacific Fishery Management Council, Crab Plan Team. 59 p.

Quandt, A. 1999. Assessment of fish trap damage on coral reefs around St. Thomas, USVI. Independent Project Report, UVI Spring 1999. 9 p.

Rathbun, M. J. 1924. New species and subspecies of spider crabs. Proceedings of U.S. Nat. Museum. 64:1-5.

Slizkin, A. G. 1990. Tanner crabs *(Chionoecetes opilio*, *C. bairdi*) of the northwest Pacific: distribution, biological peculiarities, and population structure, p. 27-33. *In* Proceedings of the International Symposium on King and Tanner Crabs. Lowell Wakefield Fisheries Symposium Series, Alaska Sea Grant College Program Report 90-04. University of Alaska Fairbanks.

Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Can. J. Fish. Aquat. Sci. 37:1488-1494.

Somerton, D. A. 1981a. Life history and population dynamics of two species of Tanner crab, *Chionoecetes bairdi* and *C. opilio*, in the eastern Bering Sea with implications for the management of the commercial harvest, PhD Thesis, University of Washington, 220 p.

Somerton, D. A. 1981b. Regional variation in the size at maturity of two species of Tanner Crab (*Chionoecetes bairdi* and *C. opilio*) in the eastern Bering Sea, and its use in defining management subareas. Canadian Journal of Fisheries and Aquatic Science. 38:163-174.

Somerton, D. A. and W. S. Meyers. 1983. Fecundity differences between primiparous and multiparous female Alaskan Tanner crab (*Chionoecetes bairdi*). Journal of Crustacean Biology. 3:183-186.

Sparks, A.K. 1982. Observations on the histopathology and probable progression of the disease caused by *Trichomaris invadens* in the Tanner crab, *Chionecetes bairdi*. J. Invertebr. Pathol. 34:184-191.

Stevens, B. G. 2000. Moonlight madness and larval launch pads: tidal synchronization of Mound Formation and hatching by Tanner crab, *Chionoecetes bairdi*. Journal of Shellfish Research. 19:640-641.

Stevens, B. G., and R. A. MacIntosh. 1992. Cruise Results Supplement, Cruise 91-1 Ocean Hope 3: 1991 eastern Bering Sea juvenile red king crab survey, May 24-June 3, 1991., DOC, NOAA, NMFS, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, 13 p.

Tamone, S. L., S. J. Taggart, A. G. Andrews, J. Mondragon, and J. K. Nielsen. 2007. The relationship between circulating ecdysteroids and chela allometry in male Tanner crabs: Evidence for a terminal molt in the genus *Chionoecetes*. J. Crust. Biol. 27:635-642.

Thompson, G. J. Ianelli, M. Dorn, D. Nichol, S. Gaichas, and K. Aydin. 2007. Chapter 2: Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands Area. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, 209-328 p.

Tracy, D. A., and S. C. Byersdorfer. 2000. Summary of crab injury assessment and aerial exposure sample results from selected 1997/1998 Bering Sea/Aleutian Islands king and Tanner crab fisheries and the 1998 Pribilof Islands hair crab fishery. Alaska Department of Fish and Game. Regional Information Report 4K00-52.

Turnock, B. and L. Rugolo. 2008. Stock assessment of eastern Bering Sea snow crab (*Chionoecetes opilio*). Report to the North Pacific Fishery Management Council, Crab Plan Team. 81 p.

Williams, A. B., L. G. Abele, D. L. Felder, H. H. Hobbs, Jr., R. B. Manning, P. A. McLaughlin, and I. Perez Farfante. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. American Fisheries Society Special Publication 17. 77 p.

Zheng, J., G. H. Kruse, and M. C. Murphy. 1998. A length based approach to estimate population abundance of Tanner, *Chionoecetes bairdi*, crab in Bristol Bay, Alaska, p. 97-105. G. S. Jamieson and A. Campbell (editors), *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment. Canadian Special Publication of Fisheries and Aquatic Sciences.

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 *Chionoecetes bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965-2009.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T)					
	US Pot Fishery		Japan	Russia	Total
Year		[Crabs/Pot]			
1965			1.17	0.75	1.92
1966			1.69	0.75	2.44
1967			9.75	3.84	13.60
1968	0.46	0.21	13.59	3.96	18.00
1969	0.46	0.21	19.95	7.08	27.49
1970	0.08	0.03	18.93	6.49	25.49
1971	0.05	0.02	15.90	4.77	20.71
1972	0.11	0.05	16.80		16.90
1973	2.29	1.04	10.74		13.03
1974	3.19	1.50	12.06		15.24
1975	10.12	4.59	7.54		17.65
1976	23.36	10.60	6.66		30.02
1977	30.21	13.70	5.32		35.52
1978	19.28	8.74	1.81		21.09
1979	16.60	7.53	2.40		19.01
1980	13.43	6.11			13.43
1981	4.99	2.26			4.99
1982	2.39	1.09			2.39
1983	0.55	0.25			0.55
1984	1.43	0.65			1.43
1985	0	0			0
1986	0	0			0
1987	1.00	0.45			1.00
1988	3.18	1.43			3.18
1989	11.11	5.04			11.11
1990	18.19	8.25			18.19
1991	14.42	6.54			14.42
1992	15.92	7.22			15.92
1993	7.67	3.48			7.67
1994	3.54	1.60			3.54
1995	1.92	0.87			1.92
1996	0.82	0.37			0.82
1997	0	0			0
1998	0	0			0
1999	0	0			0
2000	0	0			0
2001	0	0			0
2002	0	0			0
2003	0	0			0
2004	0	0			0
2005	0.43	0.00			0.43
2006	0.96	0.44			0.96
2007	0.96	0.43			0.96
2008	0.88	0.40			0.88

Table 3. Eastern Bering Sea *Chionoecetes bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish fisheries, 1965-2008.

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	0.78	0.22	2.79	1.85	3.58	2.07
1966	1.00	0.28	5.06	3.35	6.06	3.63
1967	5.55	1.55	7.88	5.21	13.43	6.77
1968	7.35	2.05	5.98	3.96	13.32	6.01
1969	11.22	3.14	8.78	5.81	20.00	8.95
1970	10.40	2.91	9.76	6.46	20.17	9.37
1971	8.45	2.36	10.95	7.25	19.41	9.61
1972	6.90	1.93	6.29	4.16	13.19	6.09
1973	5.59	1.51	8.60	5.69	14.20	7.21
1974	6.62	1.78	11.91	7.88	18.53	9.66
1975	8.23	2.11	4.61	3.05	12.84	5.16
1976	12.92	3.49	2.00	1.32	14.92	4.81
1977	15.42	4.14	1.35	0.89	16.78	5.04
1978	10.42	2.58	1.55	1.03	11.98	3.61
1979	9.34	2.32	1.24	0.82	10.58	3.14
1980	8.29	1.80	1.02	0.67	9.31	2.47
1981	2.75	0.64	0.71	0.47	3.46	1.11
1982	1.51	0.32	0.22	0.14	1.73	0.47
1983	0.54	0.09	0.32	0.21	0.87	0.31
1984	1.25	0.23	0.31	0.21	1.57	0.43
1985	0.47	0.05	0.19	0.13	0.66	0.17
1986	0.61	0.06	0.31	0.21	0.93	0.27
1987	2.00	0.27	0.31	0.20	2.30	0.47
1988	5.56	0.77	0.22	0.15	5.79	0.92
1989	12.04	1.98	0.32	0.21	12.36	2.20
1990	22.36	3.50	0.45	0.30	22.82	3.80
1991	20.88	3.07	1.22	0.81	22.10	3.88
1992	12.36	1.09	1.33	0.88	13.69	1.97
1993	6.74	1.23	0.85	0.56	7.59	1.79
1994	3.51	1.06	1.01	0.67	4.52	1.73
1995	2.42	1.18	0.73	0.49	3.15	1.67
1996	0.55	0.16	0.77	0.51	1.32	0.67
1997	0.96	0.11	0.57	0.38	1.53	0.49
1998	1.05	0.09	0.45	0.30	1.50	0.39
1999	0.39	0.07	0.30	0.20	0.69	0.28
2000	0.11	0.01	0.36	0.24	0.46	0.25
2001	0.18	0.01	0.57	0.38	0.75	0.38
2002	0.31	0.02	0.35	0.23	0.66	0.25
2003	0.12	0.01	0.20	0.14	0.33	0.15
2004	0.06	0.01	0.32	0.22	0.39	0.22
2005	0.65	0.04	0.30	0.20	0.95	0.23
2006	1.37	0.25	0.35	0.23	1.71	0.48
2007	2.01	0.10	0.33	0.22	2.35	0.33
2008	0.91	0.03	0.26	0.17	1.17	0.20

Table 4. Eastern Bering Sea *Chionoecetes bairdi* total catch in the directed (retained) and non-directed fisheries, 1965-2008.

	Eastern Bering Sea *Chionoecetes bairdi* Total Catch (Retained + Non-Retained) (1000T)		
Year	Male	Female	Total
1965	5.50	2.07	7.57
1966	8.50	3.63	12.13
1967	27.03	6.77	33.79
1968	31.32	6.01	37.34
1969	47.48	8.95	56.43
1970	45.66	9.37	55.03
1971	40.12	9.61	49.73
1972	30.09	6.09	36.18
1973	27.22	7.21	34.43
1974	33.77	9.66	43.43
1975	30.49	5.16	35.65
1976	44.93	4.81	49.74
1977	52.30	5.04	57.34
1978	33.07	3.61	36.68
1979	29.59	3.14	32.73
1980	22.73	2.47	25.21
1981	8.45	1.11	9.56
1982	4.12	0.47	4.59
1983	1.42	0.31	1.72
1984	3.00	0.43	3.43
1985	0.66	0.17	0.84
1986	0.93	0.27	1.19
1987	3.30	0.47	3.77
1988	8.97	0.92	9.88
1989	23.47	2.20	25.67
1990	41.01	3.80	44.81
1991	36.53	3.88	40.41
1992	29.61	1.97	31.58
1993	15.25	1.79	17.04
1994	8.06	1.73	9.79
1995	5.07	1.67	6.74
1996	2.13	0.67	2.81
1997	1.53	0.49	2.02
1998	1.50	0.39	1.89
1999	0.69	0.28	0.96
2000	0.46	0.25	0.71
2001	0.75	0.38	1.14
2002	0.66	0.25	0.90
2003	0.33	0.15	0.48
2004	0.39	0.22	0.61
2005	1.38	0.23	1.61
2006	2.67	0.48	3.15
2007	3.30	0.33	3.63
2008	2.05	0.20	2.25

Table 5. Eastern Bering Sea *Chionoecetes bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1965-2009. (2009/10 MMB mating are based on extraction of 2009/10 catch OFLs).

Eastern Bering Sea *Chionoecetes bairdi* Survey Biomass (1000T)						
	Male Mature Biomass			Legal Male Biomass		
Year	Survey	Fishery	Mating	Survey	Fishery	Mating
1965						
1966						
1967						
1968						
1969	274.40	244.59	187.91			
1970	68.86	61.38	13.41			
1971						
1972						
1973	94.55	84.28	53.88			
1974	180.00	160.45	120.64			
1975	282.99	252.25	212.27			
1976	151.60	135.13	85.12			
1977	129.63	115.54	58.90			
1978	79.18	70.58	34.86			
1979	48.14	42.91	11.71			
1980	95.65	85.26	59.32	30.96	27.59	13.13
1981	55.51	49.48	39.17	10.40	9.27	3.93
1982	46.84	41.75	36.06	6.75	6.02	3.40
1983	27.22	24.27	21.94	4.40	3.92	3.22
1984	23.18	20.67	16.89	6.40	5.71	4.06
1985	11.01	9.81	8.78	3.81	3.40	3.27
1986	13.74	12.25	10.86	2.50	2.23	2.14
1987	26.76	23.85	19.66	5.79	5.16	3.97
1988	65.02	57.96	46.81	16.12	14.37	10.65
1989	105.65	94.18	67.16	32.41	28.89	16.69
1990	103.60	92.34	47.86	45.50	40.55	20.84
1991	108.34	96.57	56.41	35.15	31.33	15.73
1992	104.33	93.00	59.89	39.59	35.29	18.04
1993	58.76	52.38	35.16	18.80	16.76	8.46
1994	40.12	35.76	26.36	15.21	13.56	9.51
1995	29.62	26.40	20.34	9.47	8.44	6.20
1996	24.28	21.64	18.70	8.61	7.68	6.57
1997	10.43	9.30	7.42	3.32	2.96	2.85
1998	9.99	8.91	7.07	2.02	1.80	1.73
1999	12.80	11.41	10.29	2.14	1.91	1.84
2000	15.93	14.20	13.20	4.39	3.91	3.77
2001	17.79	15.86	14.51	5.90	5.26	5.06
2002	17.06	15.21	13.98	6.14	5.47	5.27
2003	23.19	20.67	19.56	6.61	5.89	5.67
2004	24.73	22.04	20.83	4.83	4.31	4.15
2005	42.40	37.80	34.99	10.28	9.16	8.39
2006	64.72	57.69	52.84	12.77	11.38	9.99
2007	73.56	65.57	59.80	10.48	9.34	8.03
2008	61.60	54.91	50.80	14.49	12.91	11.55
2009	34.99	31.19	28.25	7.03	6.26	5.32

Table 6. Eastern Bering Sea *Chionoecetes bairdi* fishery exploitation rate on male mature biomass (MMB) and legal mature biomass (LMB), 1965-2008. 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
1965		
1966		
1967		
1968		
1969	0.19	
1970	0.74	
1971		
1972		
1973	0.32	
1974	0.21	
1975	0.12	
1976	0.33	
1977	0.45	
1978	0.47	
1979	0.69	
1980	0.27	0.49
1981	0.17	0.54
1982	0.10	0.40
1983	0.06	0.14
1984	0.14	0.25
1985	0.07	0.00
1986	0.08	0.00
1987	0.14	0.19
1988	0.15	0.22
1989	0.25	0.38
1990	0.44	0.45
1991	0.38	0.46
1992	0.32	0.45
1993	0.29	0.46
1994	0.23	0.26
1995	0.19	0.23
1996	0.10	0.11
1997	0.16	0
1998	0.17	0
1999	0.06	0
2000	0.03	0
2001	0.05	0
2002	0.04	0
2003	0.02	0
2004	0.02	0
2005	0.04	0.05
2006	0.05	0.08
2007	0.05	0.10
2008	0.04	0.07

Table 7. Data used to estimate discard and bycatch losses in the terminal 2009/10 OFL fishery: (a) average Tanner crab fishery performance, (b) Tanner crab discards in the snow and red king crab pot fisheries and snow crab retained catch, and (c) 2006-08 Tanner crab bycatch in the EBS groundfish fisheries.

(a)

Average Observer Fishery Data
EBS Tanner Crab Directed Fishery
[2006/07, 2007/08, 2008/09]

		1000T	Ratio:
Discard:			
	S.Legal ♂:	1.23	1.32
	Legal ♂:	0.03	0.03
	All ♀:	0.15	0.16
Retained:		0.93	1.0
	Total:	2.34	

(b)

Tanner Crab Non-Directed Pot Fishery Discards
(Combined Opilio + RKC Pot Fisheries)

Year	Opilio Retained (1000T)		Bairdi Discard	Ratio
2006/07	16.49		1.49	0.09
2007/08	28.59		1.93	0.07
2008/09	26.56		1.39	0.05
2009/10	22.91	*		
			Average:	0.07
			Projected Bairdi Discard (1000T):	1.60

* Projected retained catch OFL for 2009/10 @ 0.75F35%.

(c)

Trawl Fishery Tanner Crab Bycatch
(Male + Female Combined)

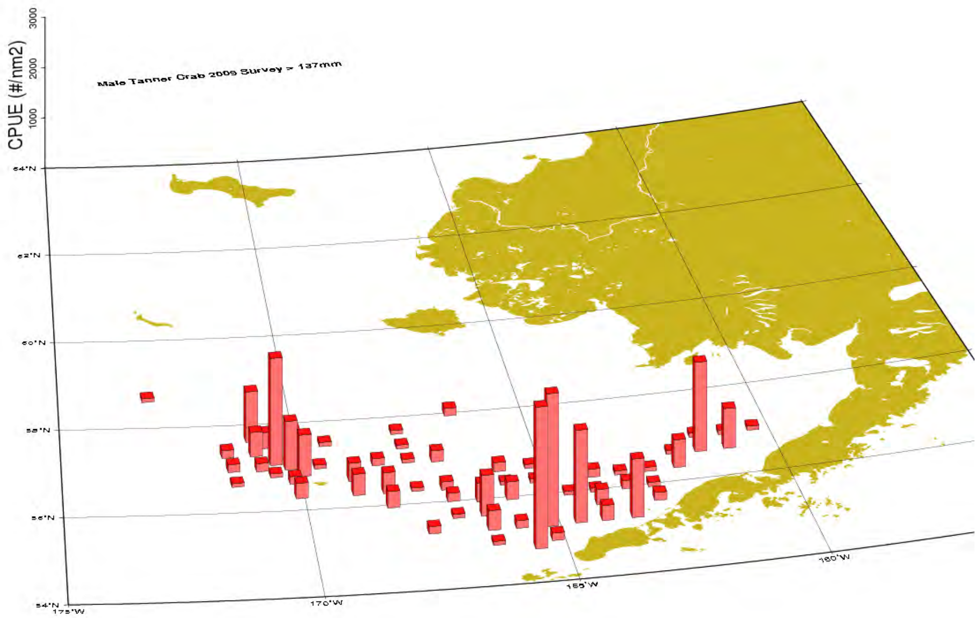
Year		Bycatch (1000T)
2006		0.72
2007		0.69
2008		0.53
	Average:	0.65

Table 8. Catch overfishing limits, stock and fishery metrics for the 2010/11 Estern Bering Sea *C. bairdi* fishery. (B_{REF}=mean 1969-1980 MMB at the time of mating, inclusive; µ on MMB is Total Catch OFL/MMB at the time of the fishery).

2010/11 Eastern Bering Sea *Chionoecetes bairdi*
Catch OFL, Stock and Fishery Metrics

Metrics (1000T):	
B_{REF}:	83.80
MMB @ Mating:	28.25
B/B_{REF}:	0.34
F_{OFL}:	0.06
Catch Components (1000T):	
Total ♂ Catch OFL:	1.76
Directed Discard Losses MMB:	0.26
Non-Directed Discard Losses MMB:	1.11
Retained Part of Total ♂ Catch OFL:	0.39
Discard + Bycatch Losses ♀:	0.24
Total ♂ Catch OFL + ♀ Losses:	2.00
Rates:	
µ on MMB @ Fishery:	0.057

B_{REF}=mean 1969-80 MMB @ mating as proxy for B_{MSY}.



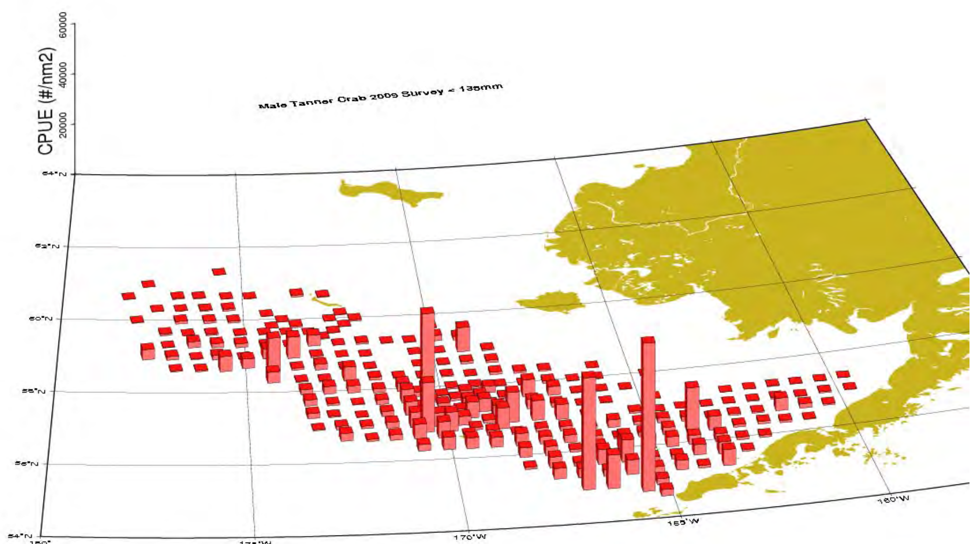


Figure 1. Distribution and abundance of legal (>= 138 mm cw) and sublegal (< 138 mm cw) male Tanner crab in the summer 2009 NMFS EBS trawl survey.

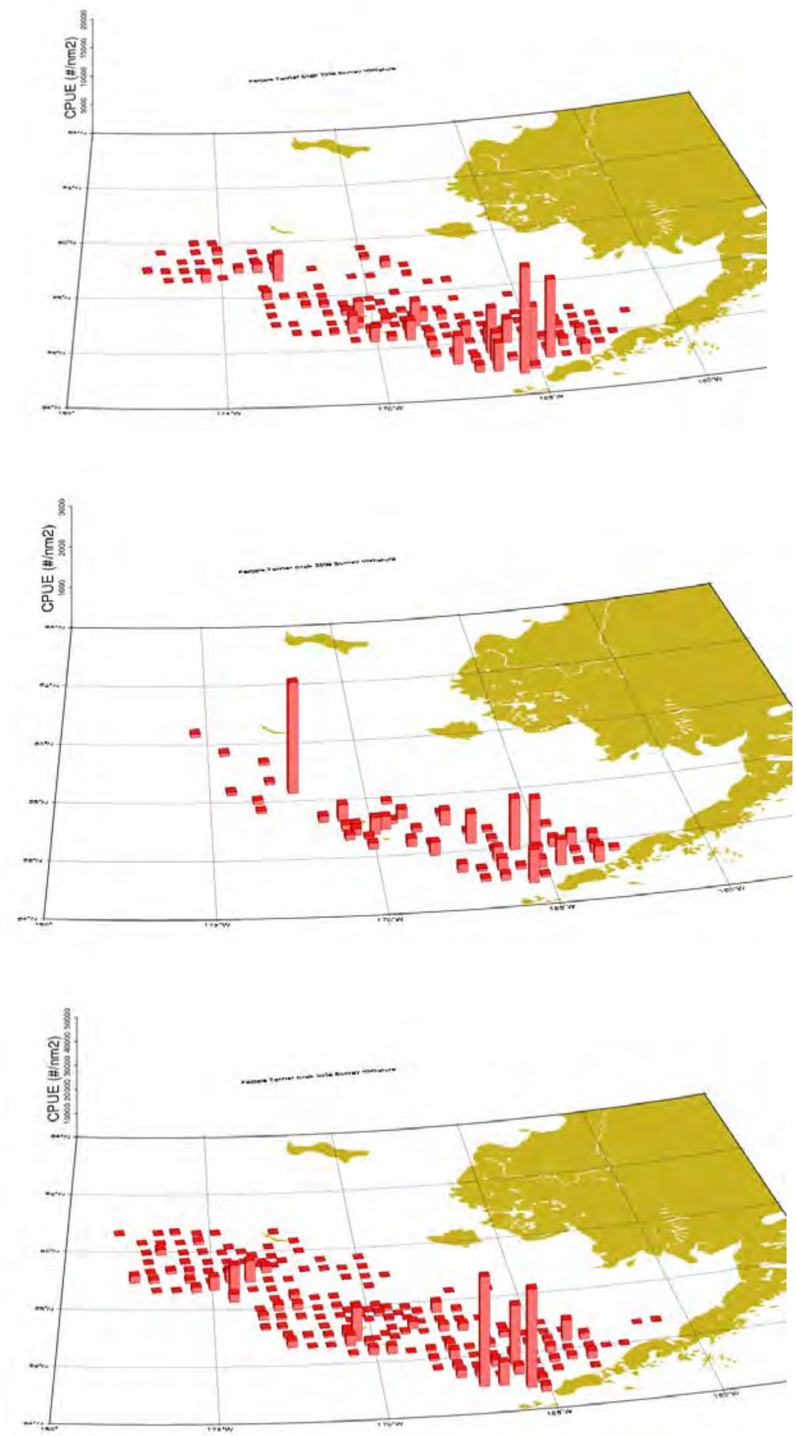


Figure 2. Distribution and abundance of ovigerous, barren mature, and immature female Tanner crab in the summer 2009 NMFS EBS trawl survey.

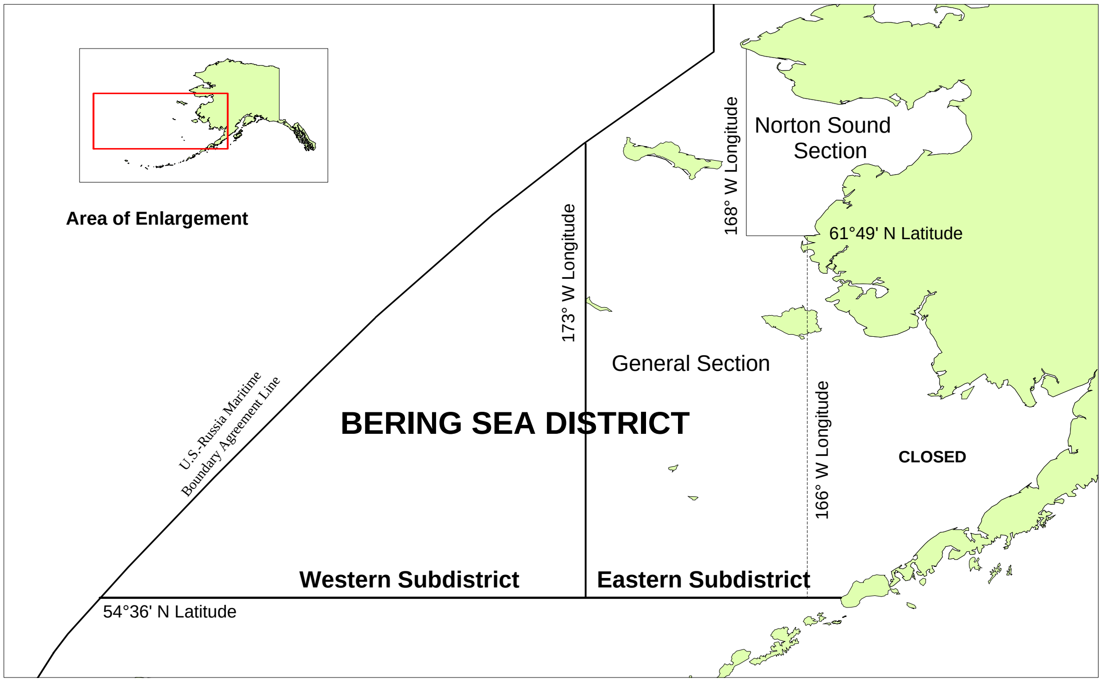
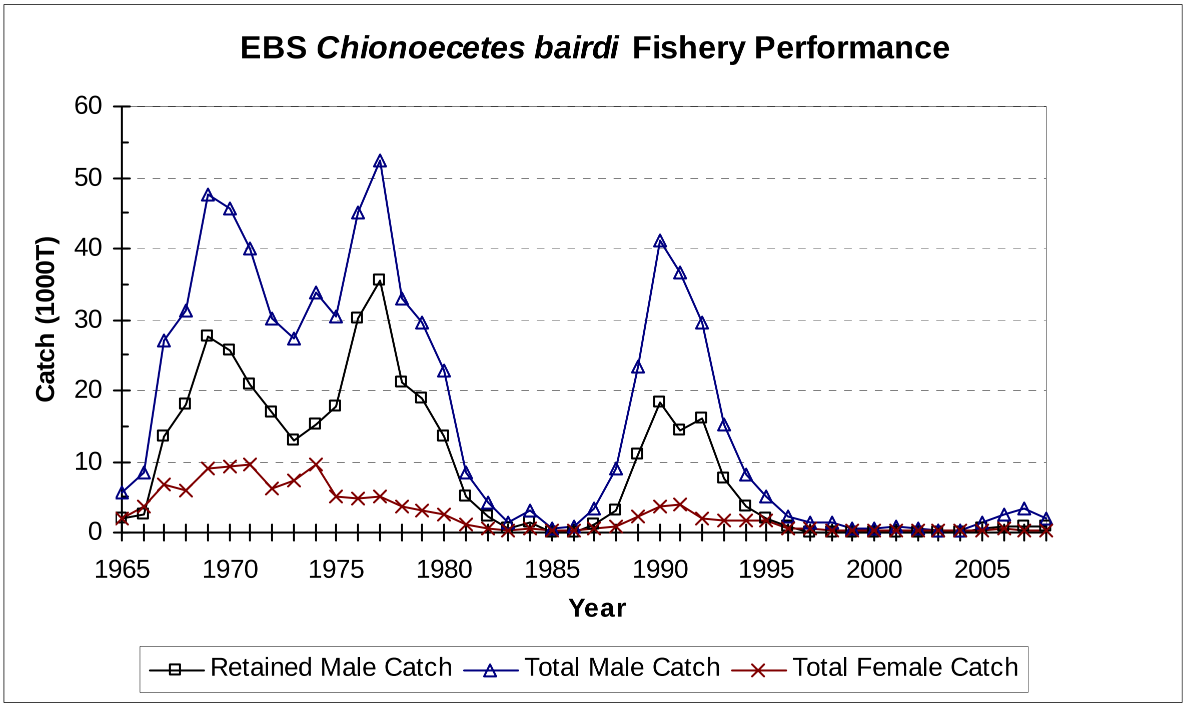


Figure 3. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)



(b)

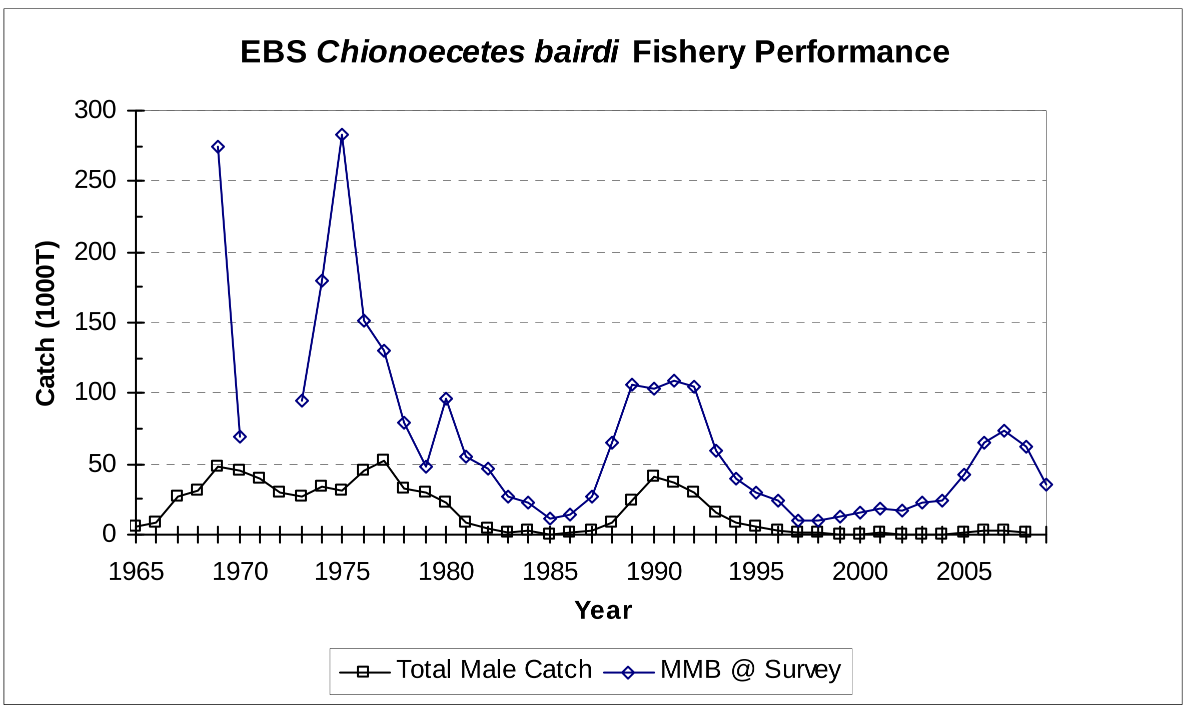


Figure 4. Eastern Bering Sea *Chionoecetes bairdi* retained male catch, total (retained + bycatch) male catch and total female catch (a), and total male catch vs male mature biomass at the time of the survey (b), 1965-2009.

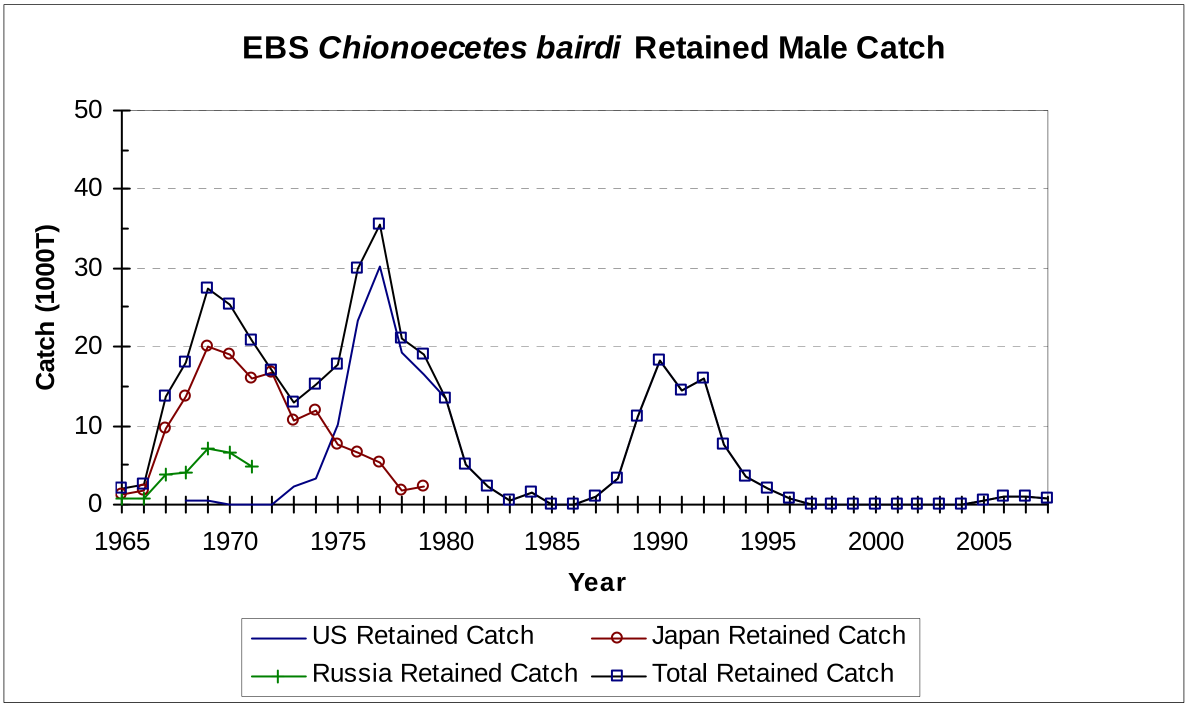


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965-2009.

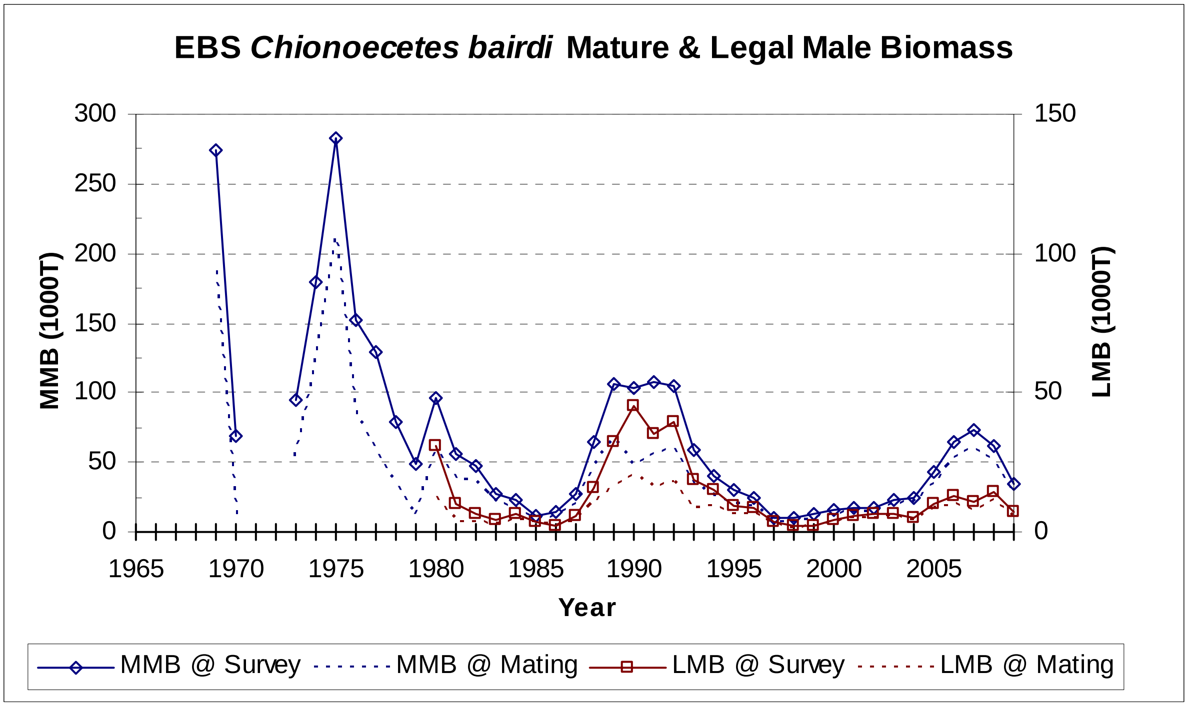
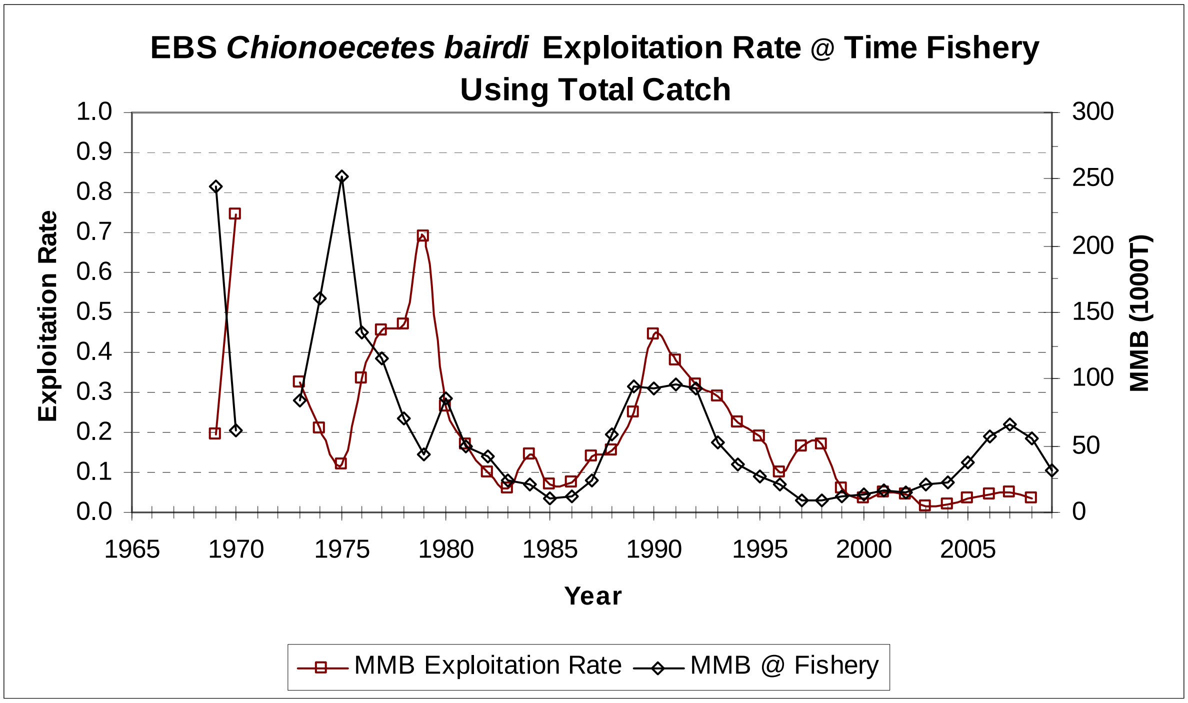


Figure 6. Eastern Bering Sea *Chionoecetes bairdi* mature and legal male biomass at time of the survey and subsequent mating, 1965-2009. (Note: 2009/10 MMB and LMB at time of mating are estimates based on extraction of respective 2009/10 catch OFLs).

(a)



(b)

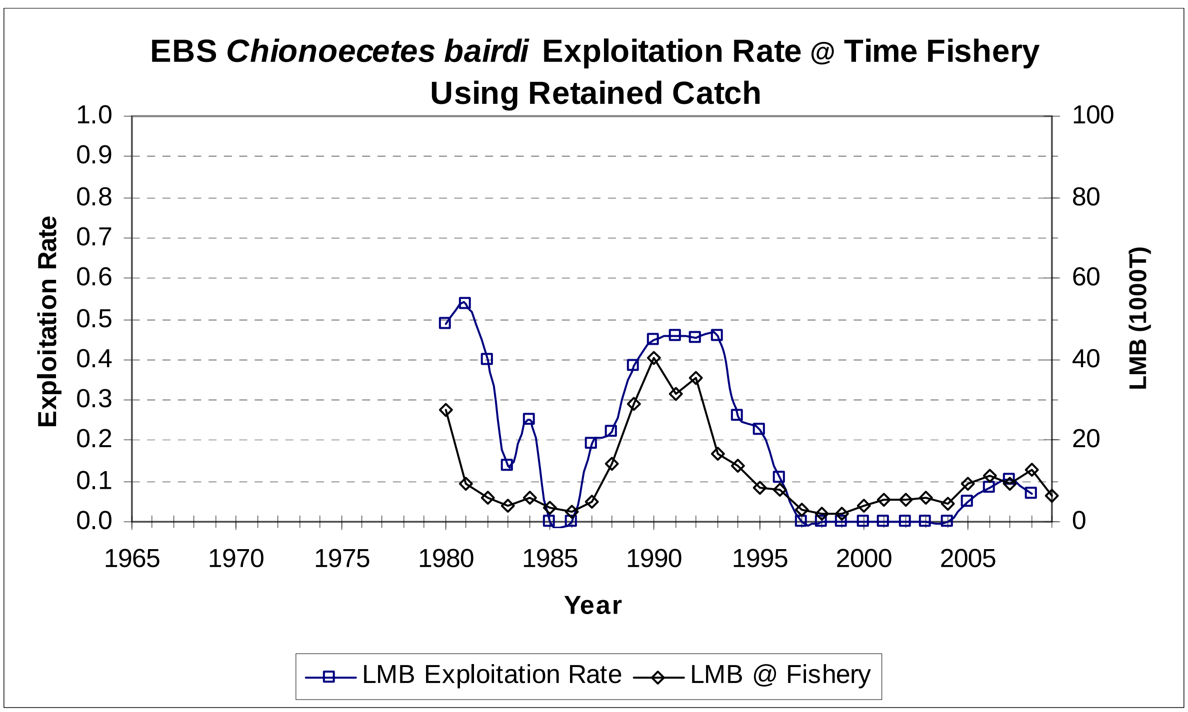


Figure 7. Eastern Bering Sea *Chionoecetes bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1965-2009.

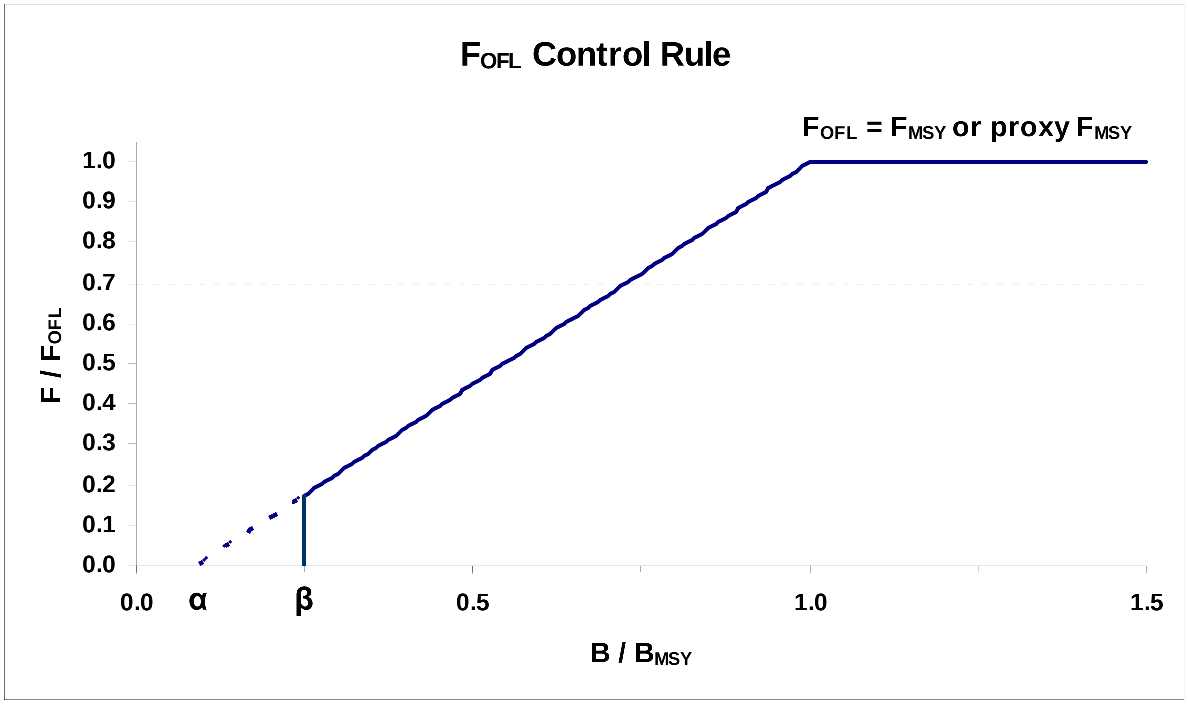


Figure 8. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

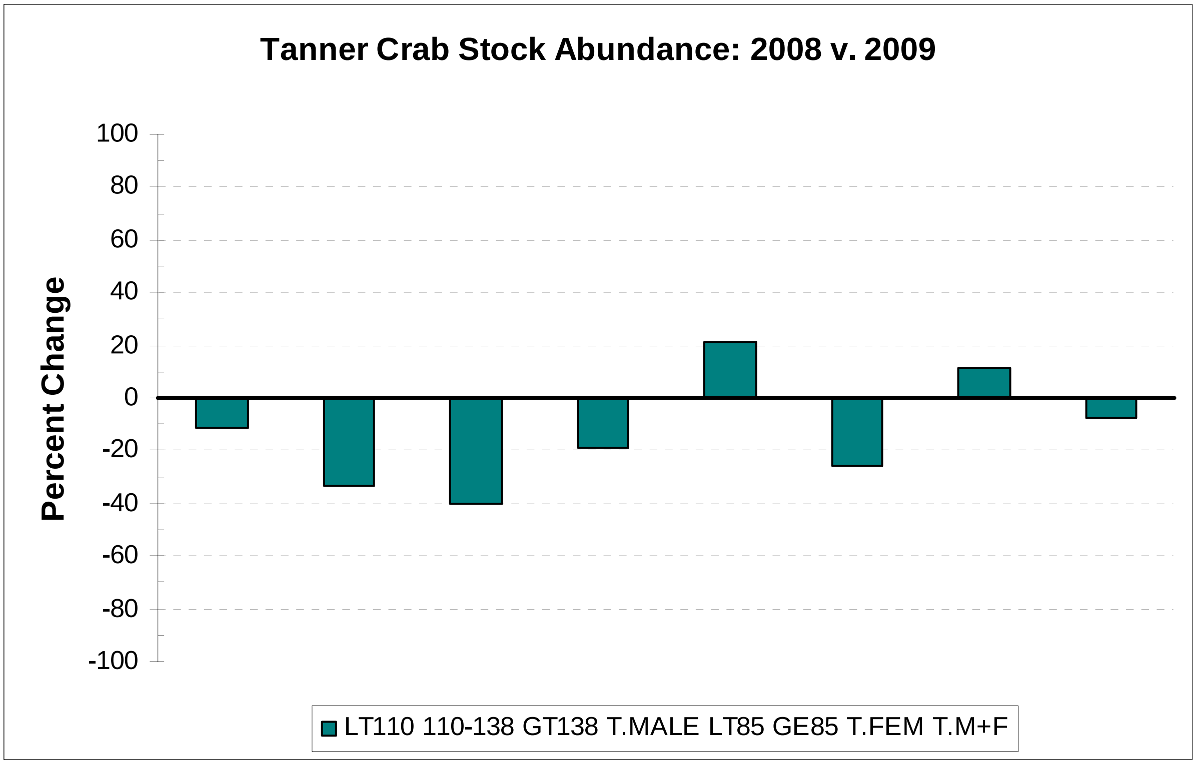
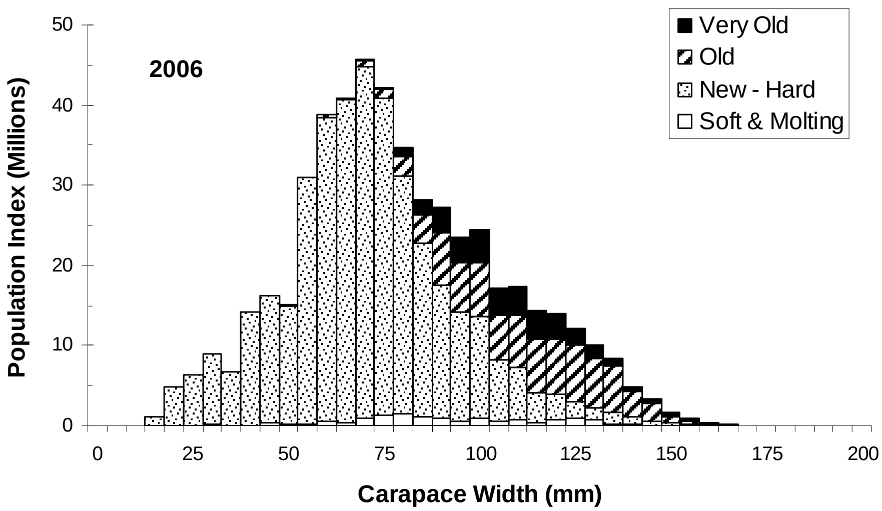


Figure 9. Percent change in Tanner crab stock abundance between 2008 and 2009 for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.

(a)



(b)

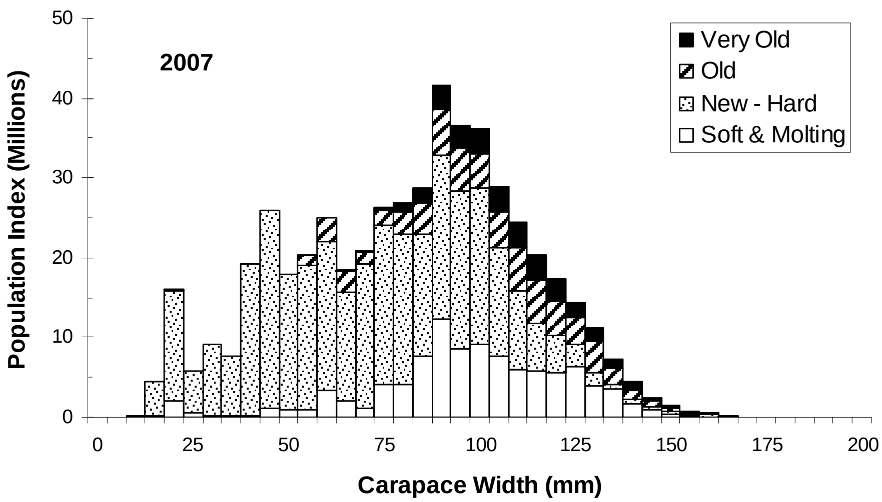
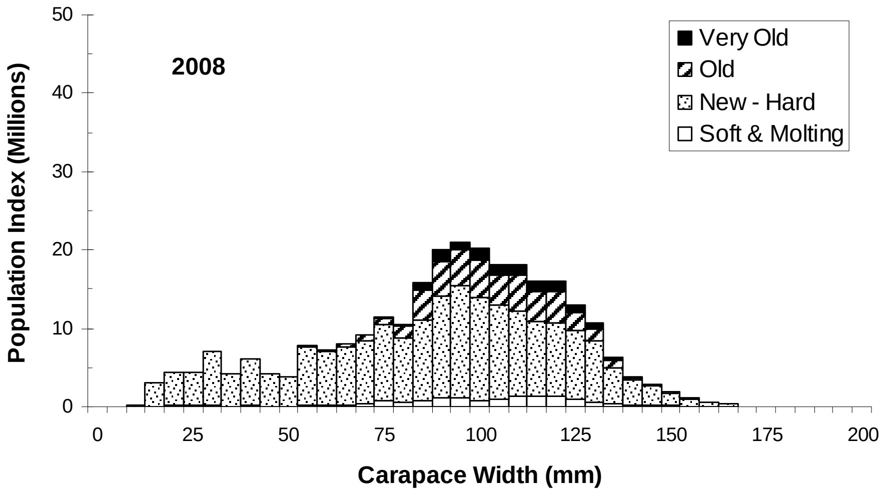


Figure 10 (a-b). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2007.

(a)



(b)

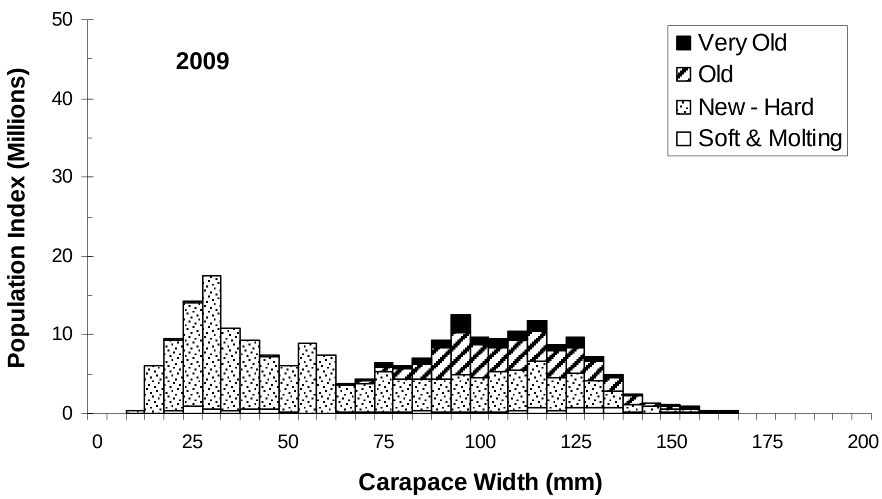
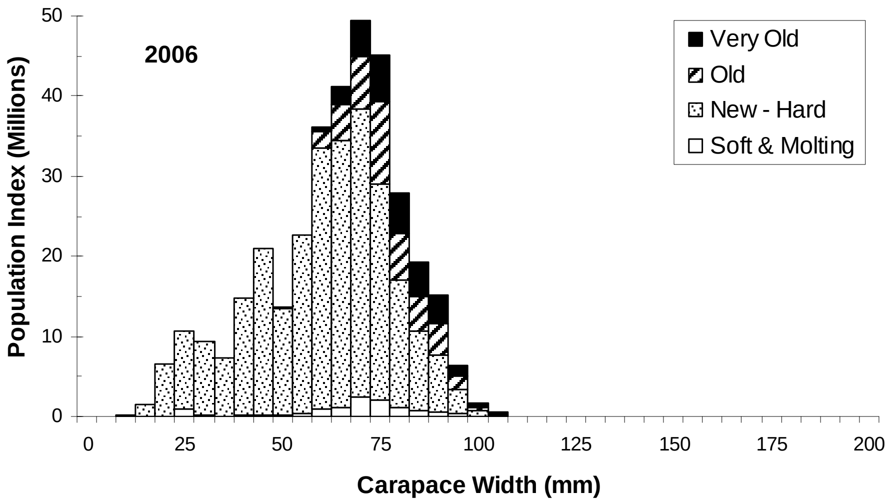


Figure 10 (c-d). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008-2009.

(a)



(b)

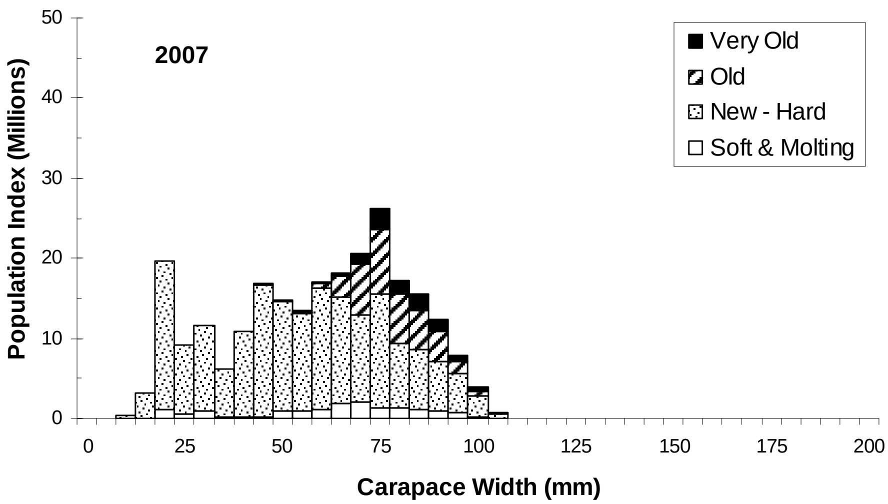
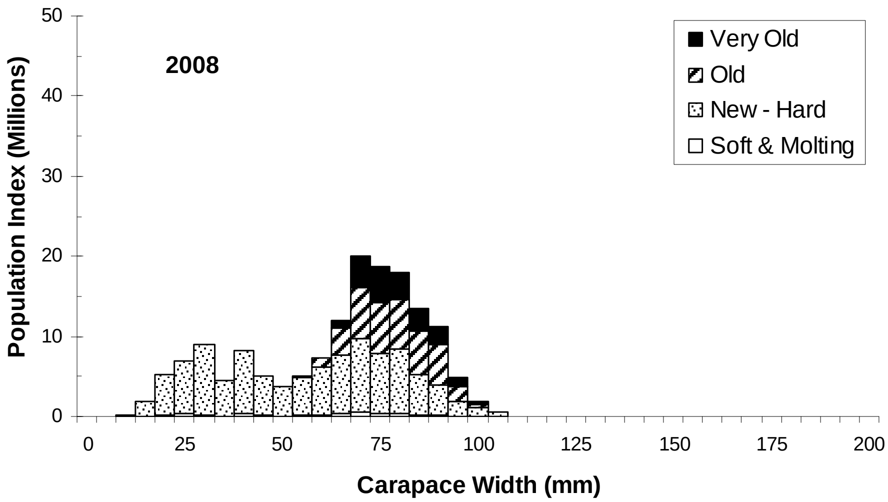


Figure 11 (a-b). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2007.

(a)



(b)

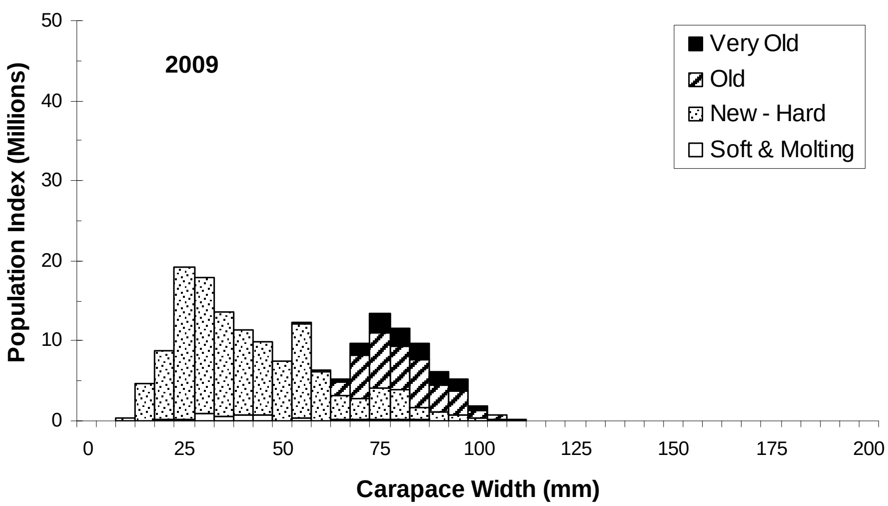
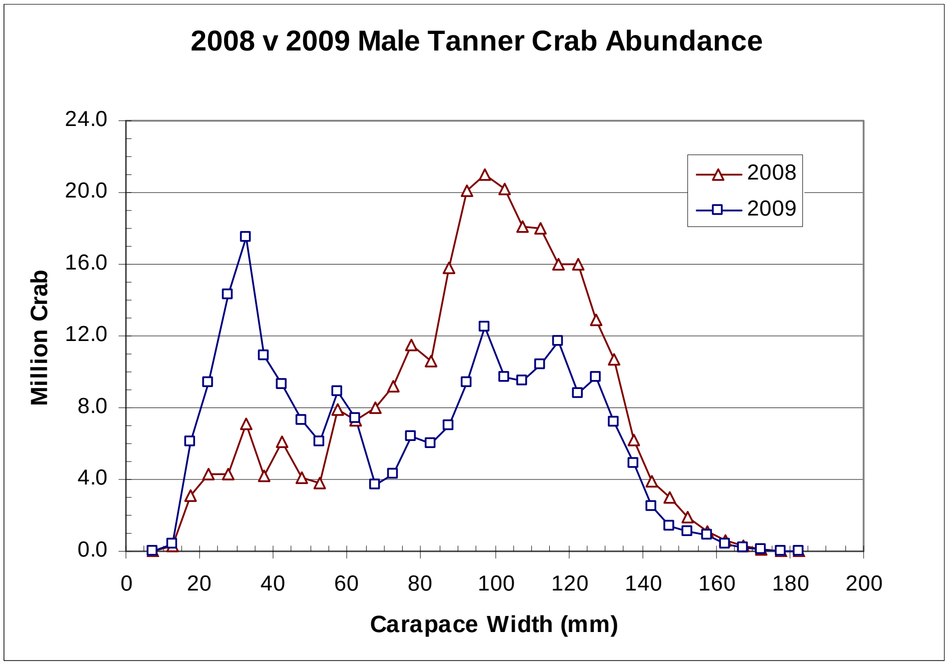


Figure 11 (c-d). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008-2009.

(a)



(b)

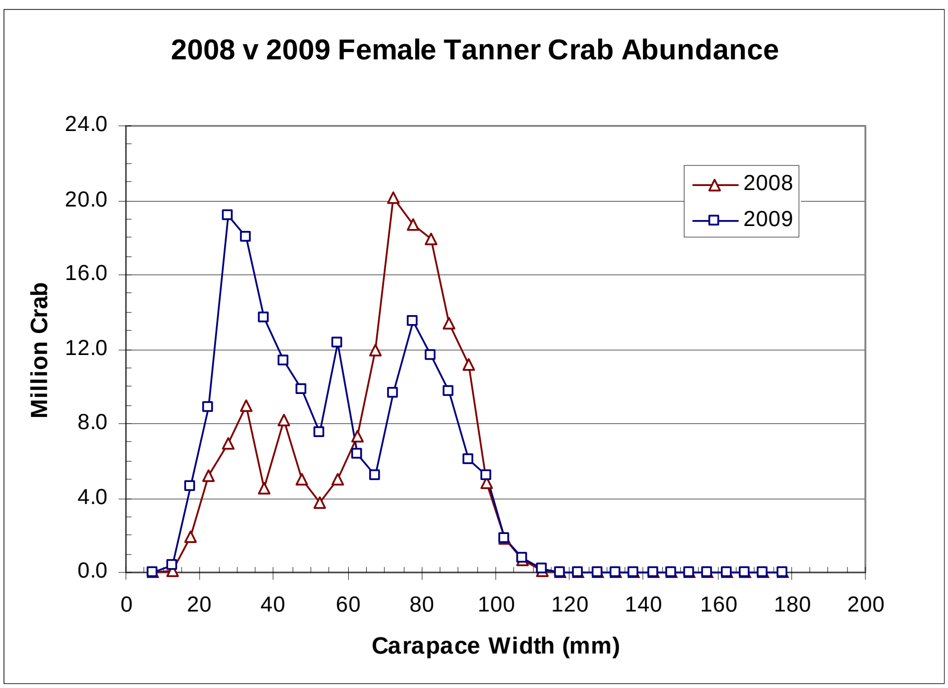


Figure 12. Male (a) and female (b) Eastern Bering Sea *Chionoecetes bairdi* total abundance in 2008 and 2009 by 5 mm carapace width.

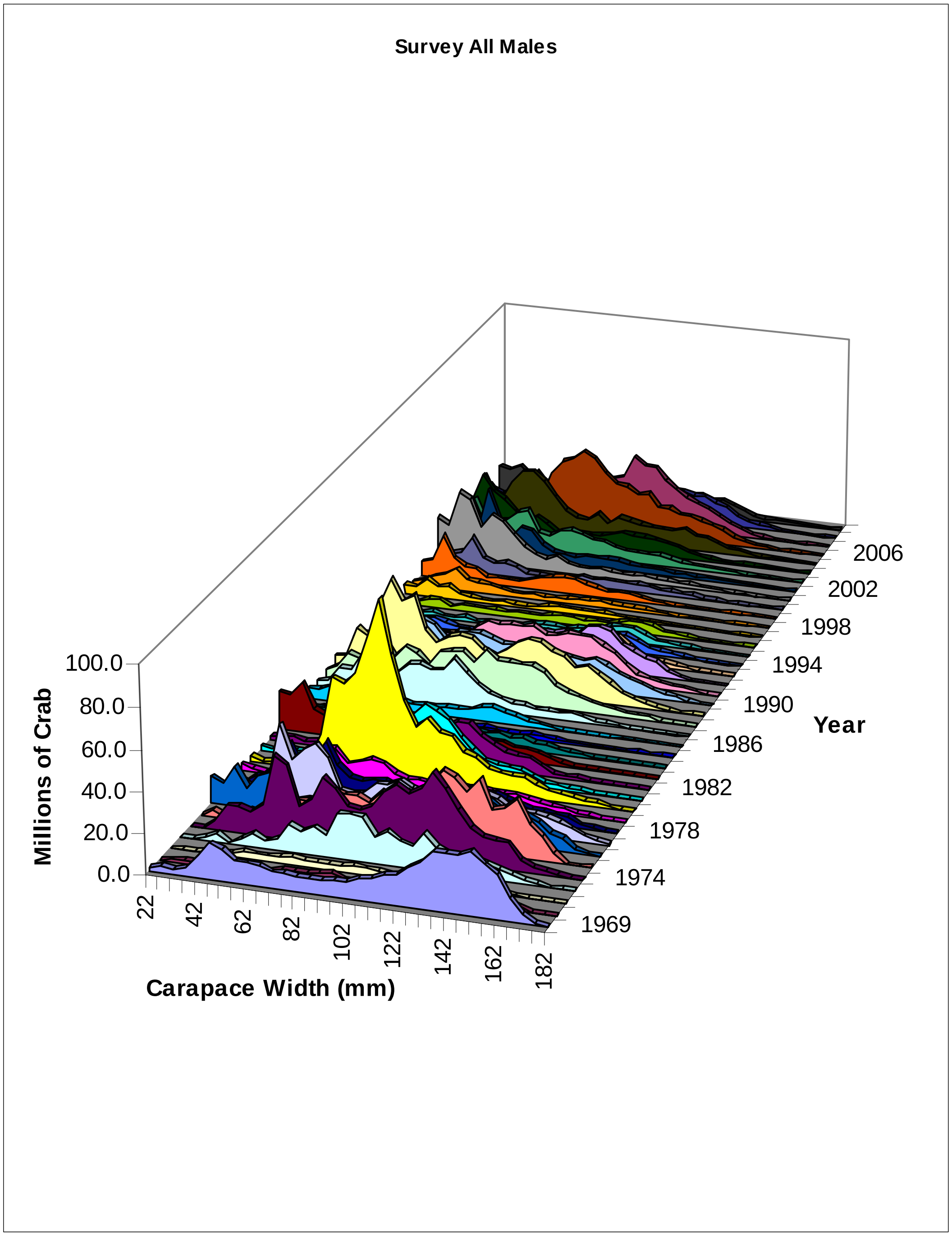


Figure 13. Observed survey numbers (millions of crab) by carapace width and year for male Tanner crab.

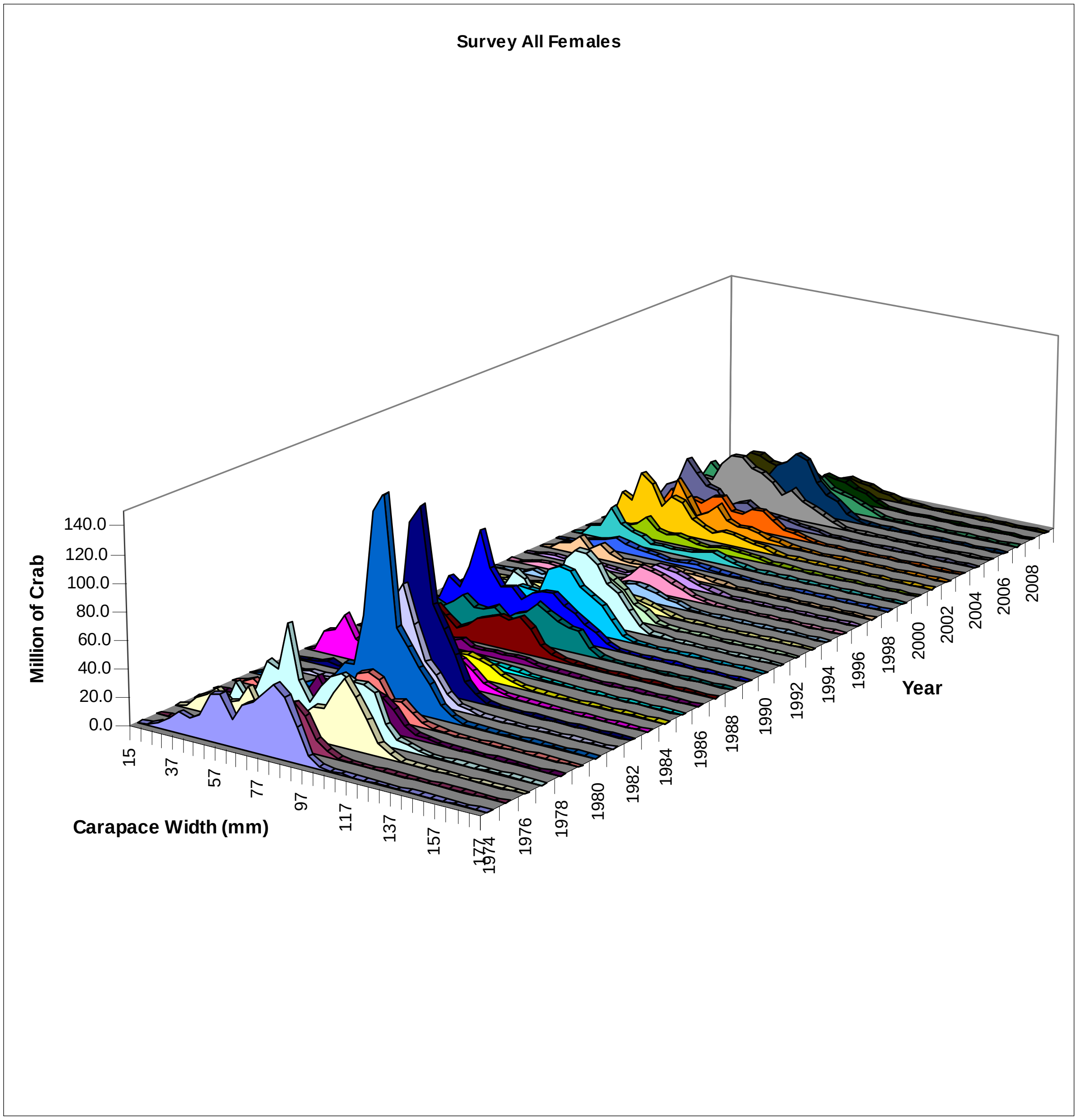


Figure 14. Observed survey numbers (millions of crab) by carapace width and year for female Tanner crab.

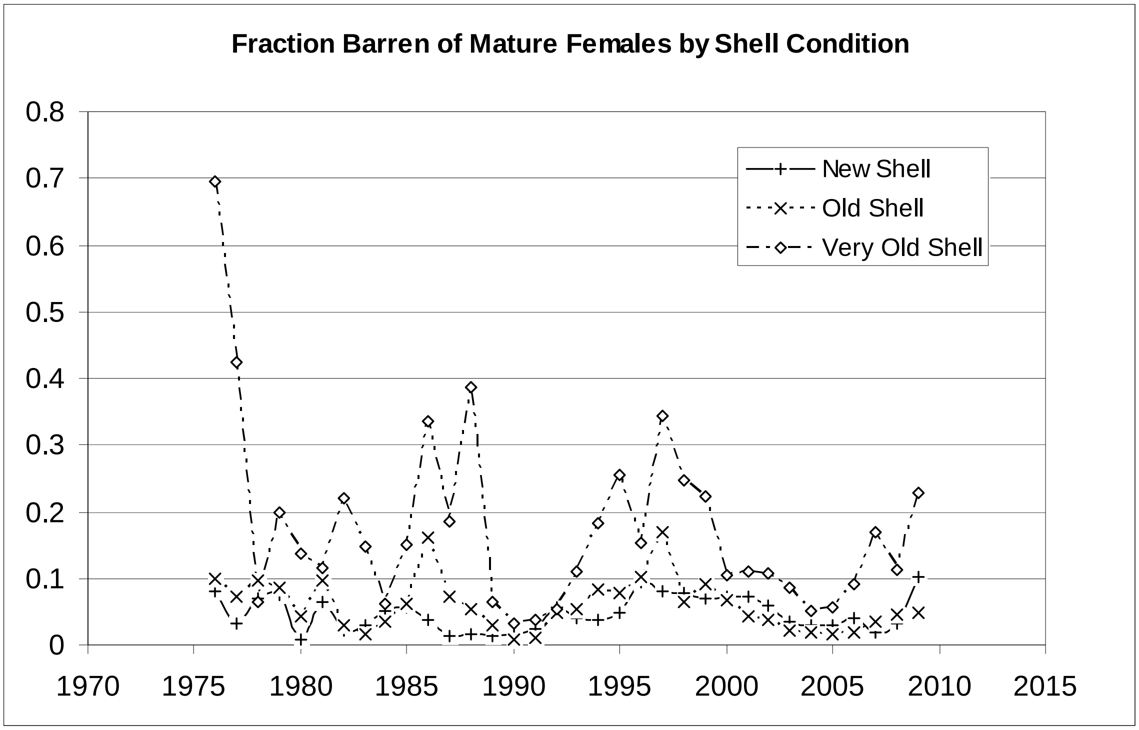


Figure 15. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976 to 2009.

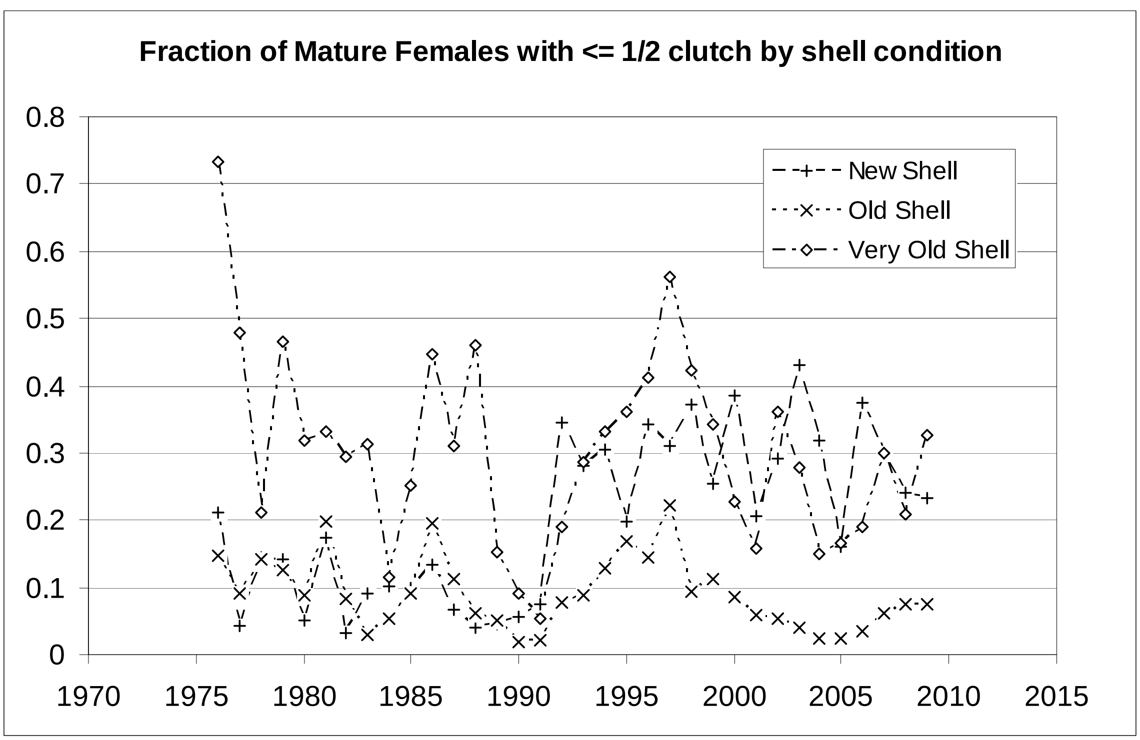


Figure 16. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976 to 2009.

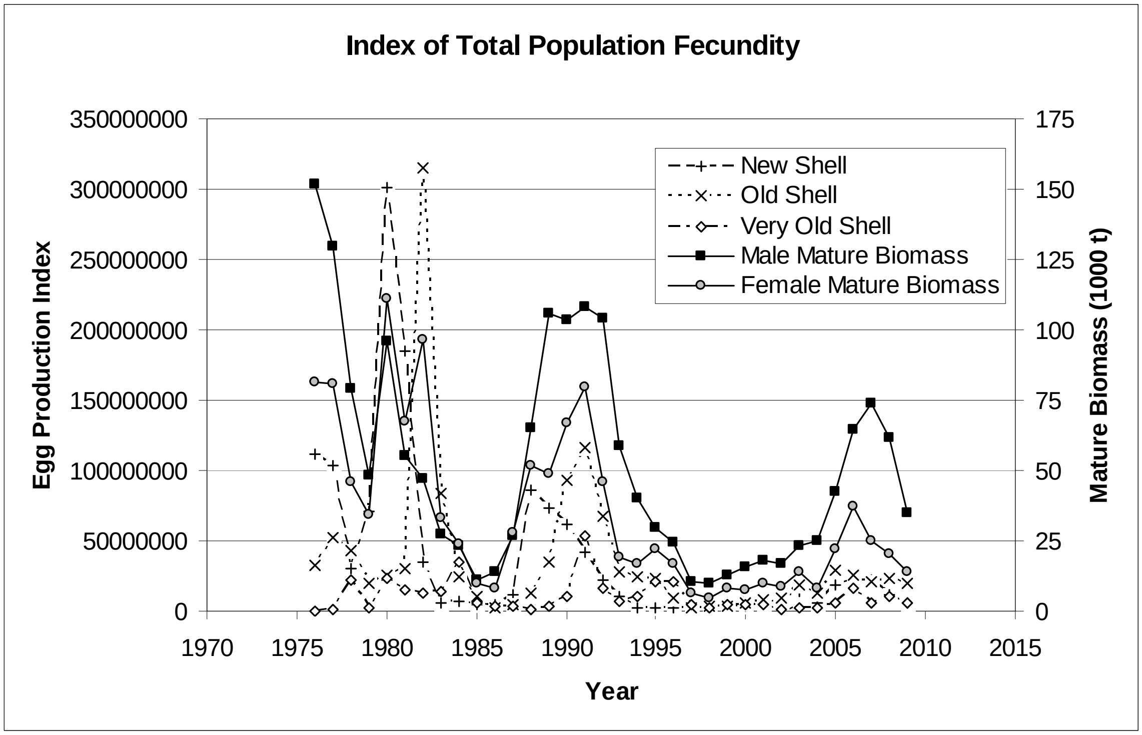


Figure 17. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976 to 2009.

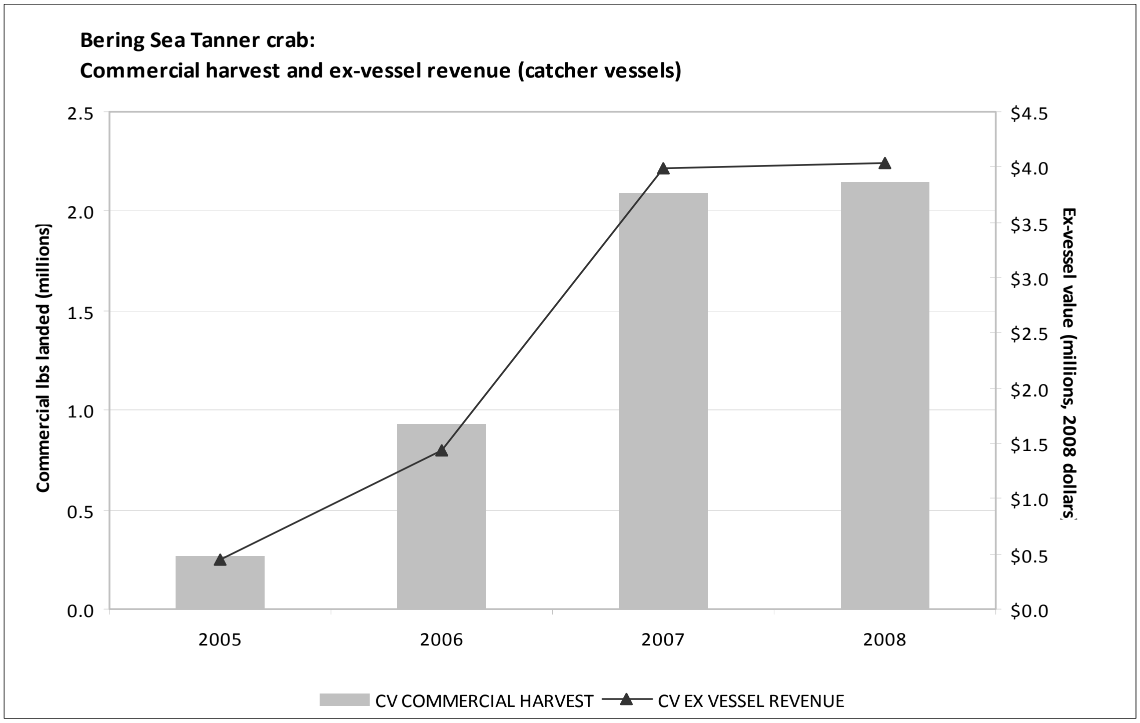


Figure 18. Bering Sea Tanner crab commercial harvest and ex-vessel revenue (catcher vessels).

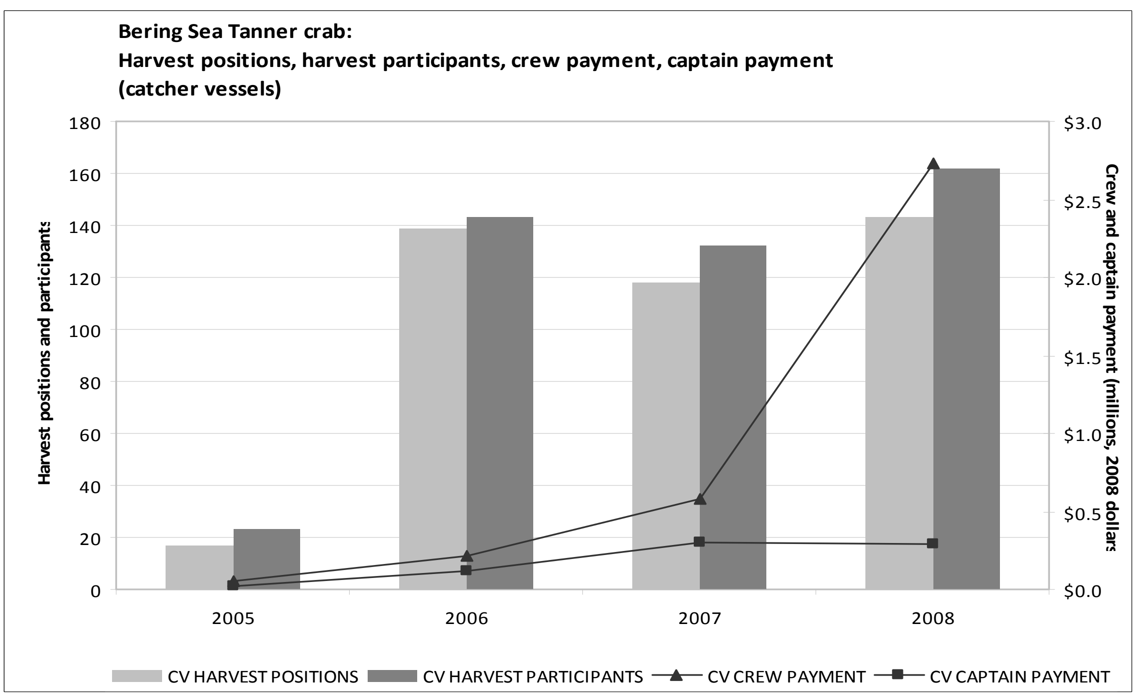


Figure 19. Bering Sea Tanner crab harvest employment and compensation (catcher vessels).

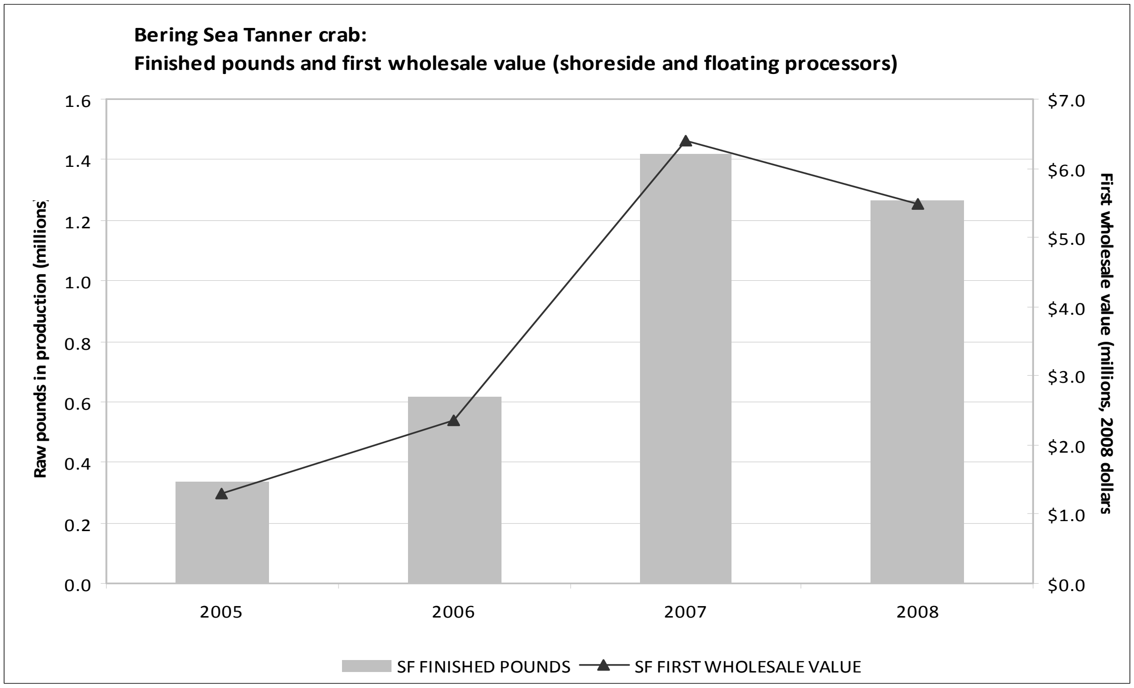


Figure 20. Bering Sea Tanner crab finished production volume and first wholesale value (shoreside and floating processors).

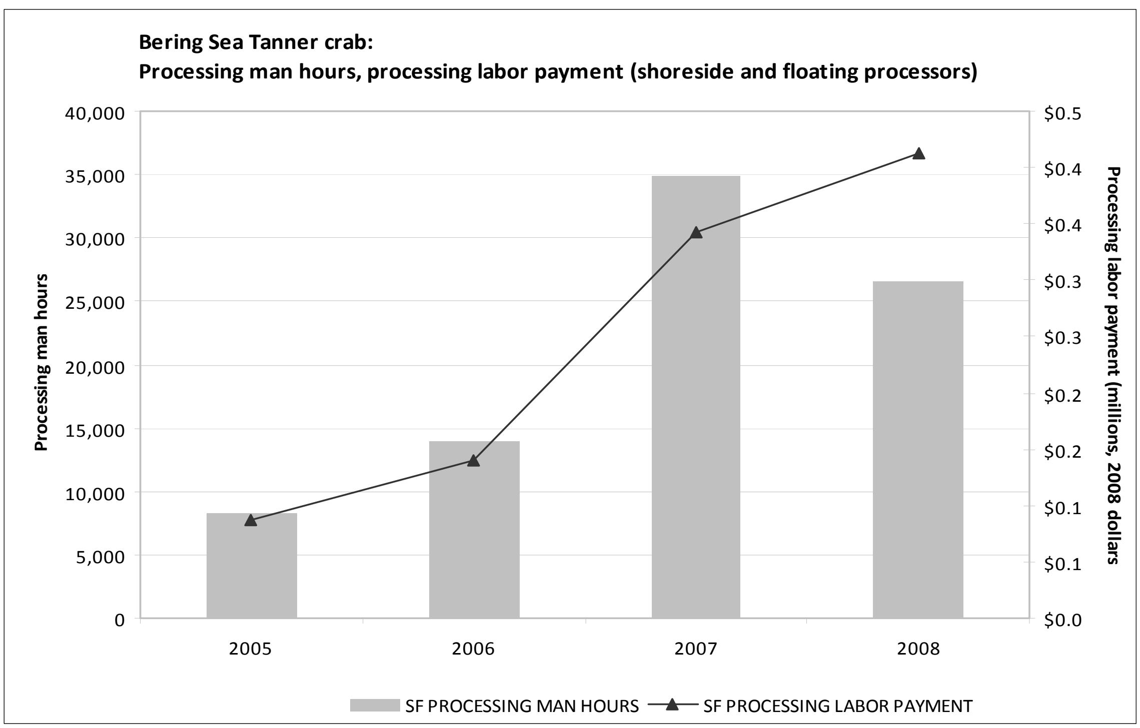


Figure 21. Bering Sea Tanner crab processing labor employment and compensation (shoreside and floating processors).

Appendix A. Feasibility study: estimation of eastern Bering Sea Tanner crab OFL using $F_{35\%}$ and estimated fishery selectivities

The calculation of the OFL in this study follows the method proposed by the SSC at their June 2008 meeting. The SSC recommended using fishery selectivities taken from the Environmental Assessment (EA) on new OFL definitions for EBS crab stocks to derive an $F_{35\%}$ proxy for F_{MSY} (Figure A-5) due to the lack of recent data on selectivities. The F_{MSY} proxy was recommended as a scaler multiple of the instantaneous mortality rate (M) derived as $F_{35\%}$ / M and estimated as 2.1 x M from the analysis presented in June 2008. The same method is used here, except that new fishery selectivity curves are estimated from the most recent year of fishery data and $F_{35\%}$ is calculated using these newly estimated fishery selectivities. The F_{MSY} proxy for the control rule would be:

$$\text{Proxy } F_{MSY} = \gamma M \tag{1}$$

The SSC proposed that gamma might be estimated as $F_{35\%}$ / M, therefore,

$$\text{Proxy } F_{MSY} = (F_{35\%} / M) \cdot M = F_{35\%} \tag{2}$$

Under this formulation, the use of $F_{35\%}$ as the F_{MSY} proxy in the control rule is equivalent to using γ, where γ is estimated as $F_{35\%}$ / M. As recommended by the SSC, this value of $F_{35\%}$ is used with the estimated fishery selectivities estimate the OFL. Thus, γ is specific to the $F_{35\%}$ used in the ratio $F_{35\%}$ / M, and it cannot be used without those fishery selectivities, for example in a simple multiplication on M and mature male biomass to estimate the total catch OFL.

The observer data from the 2006/7 and the 2007/8 fishery seasons were not available for analysis in June 2008 so the fishery selectivities used in the EA analysis for new OFL definitions were used in the June 2008 SSC presentation. However, the last two years of fishery data indicate a change in selectivity and an increase in the discarding in the directed Tanner crab fishery. Discard and retained selectivities were estimated using the length frequency of the observed catch from the 2007/8 season as well as the ratio of discarded to retained numbers of crab (Figure A-1 and Table A-2) and the predicted catch length frequency and numbers (discard and retained) using the 2007 survey abundance by length projected forward to the time of the fishery. The discard fishery selectivities were used along with trawl selectivities to estimate bycatch in the snow crab and trawl fisheries (Figure A-2). $F_{35\%}$ was then determined base on the estimated fishery selectivities and the OFL calculated. Two fishery selectivity scenarios were estimated, one with retained selectivity at 1.0 for the 140-145 mm cw length bin and then dropping to 0.5 for larger sizes (Figure A-1 and Table A-2), and scenario 2 were retained selectivity was 1.0 for all crab > 140mm cw (Figure A-4 and Table A-2). The scenario with retained selectivity at 1.0 for all crab larger than 140 mm cw did not fit the length frequency of the catch as well and also did not fit the ratio of discard to retained numbers as well as the scenario with retained selectivity at 0.5 at > 145 mm cw (Figures A-3 and A-5).

The discard fishery selectivities were estimated differently for each scenario to fit the total length frequency and the ratio of retained and discarded numbers in the 2007/8 fishery using the 2007 survey length frequency projected forward. The current Tanner crab fishery may not be targeting specifically on Tanner crab, which results in the drop in selectivity at larger sizes fitting the fishery data better than selectivity of 1.0 at larger sizes.

The 2008 survey abundance by length was projected forward to estimate catch and MMB using $F_{35\%}$ and the estimated fishery selectivities (Table A-1). The total catch OFL for scenario 1 (0.5 selectivity size>145 mm cw) was 7.30 thousand t with a retained directed fishery catch of 2.39 thousand t. The total catch OFL for scenario 2 (1.0 selectivity size>140 mm cw) was 7.11 thousand t with a retained directed fishery catch of 2.36 thousand t. The total catch OFL with F=M was 6.97 thousand t with a retained directed fishery catch of 2.14 thousand t.

Table A-1. Total male catch OFL (million pounds) using $F_{35\%}$ and 2008 survey numbers by length and mature biomass at mating. Ratio of numbers of discard to retained was 4.09 in the 2007/8 fishery. Scenario 1 ratio in the fitting was 4.37, for the selectivity=1.0 ratio was 5.05.

Metric:	Scenario 1	Scenario 2
	Retained sel >145mm = 0.5	Retained sel >140 mm = 1.0
Directed Legal Catch	5.62	5.57
Retained Directed Legal Catch	5.27	5.21
Directed Discard	7.13	6.75
Non-Directed Discard (snow crab + groundfish trawl)	3.35	3.36
Total Male Catch OFL	16.10	15.67
MMB	106.03	106.47
B_{REF}	178.2	178.2
MMB/ B_{REF} (%)	59.49	59.75
Directed $F_{35\%}$	0.585	0.411
Directed Control Rule F 2008/09	0.322	0.227
F Snow Crab Fishery	0.105	0.09

Table A-2. Estimated retained and discard selectivity. Discard selectivity estimated as a logistic function with slope 0.17 and size at 50% selected 120 mm cw from 95 mm cw to 135 mm cw. Value at 135-140 mm fixed at 0.5, and discard selectivity 0 after 140 mm cw. Values of retained selectivity set at 1 and 140-145 mm cw other values (0.5) estimated to fit the length frequency of the catch and the split in catch between retained and discarded.

	Scenario 1		Scenario 2	
CW (mm)	Retained	Discard	Retained	Discard
97.5	0	0.014064	0	0.032295
102.5	0	0.032295	0	0.072426
107.5	0	0.072426	0	0.154465
112.5	0	0.154465	0	0.299433
117.5	0	0.299433	0	0.5
122.5	0	0.5	0	0.700567
127.5	0	0.700567	0	0.845535
132.5	0	0.845535	0	1
137.5	0.5	0.5	0.5	0.5
142.5	1	0	1	0
147.5	0.5	0	1	0
152.5	0.5	0	1	0
157.5	0.5	0	1	0
162.5	0.5	0	1	0
167.5	0.5	0	1	0
172.5	0.5	0	1	0
177.5	0.5	0	1	0

Table A-3. Fishery selectivities for discard and retained males by shell condition used in the EA analysis.

	Discard		Retained	
CW (mm)	New	Old	New	Old
97.5	0.097	0.053	0	0
102.5	0.098	0.053	0	0
107.5	0.158	0.055	0	0
112.5	0.302	0.096	0	0
117.5	0.327	0.121	0	0
122.5	0.482	0.124	0	0
127.5	0.701	0.138	0	0
132.5	0.955	0.2	0	0
137.5	0.5	0.16	0.5	0.16
142.5	0	0	1	0.317
147.5	0	0	1	0.317
152.5	0	0	1	0.317
157.5	0	0	1	0.317
162.5	0	0	1	0.317
167.5	0	0	1	0.317

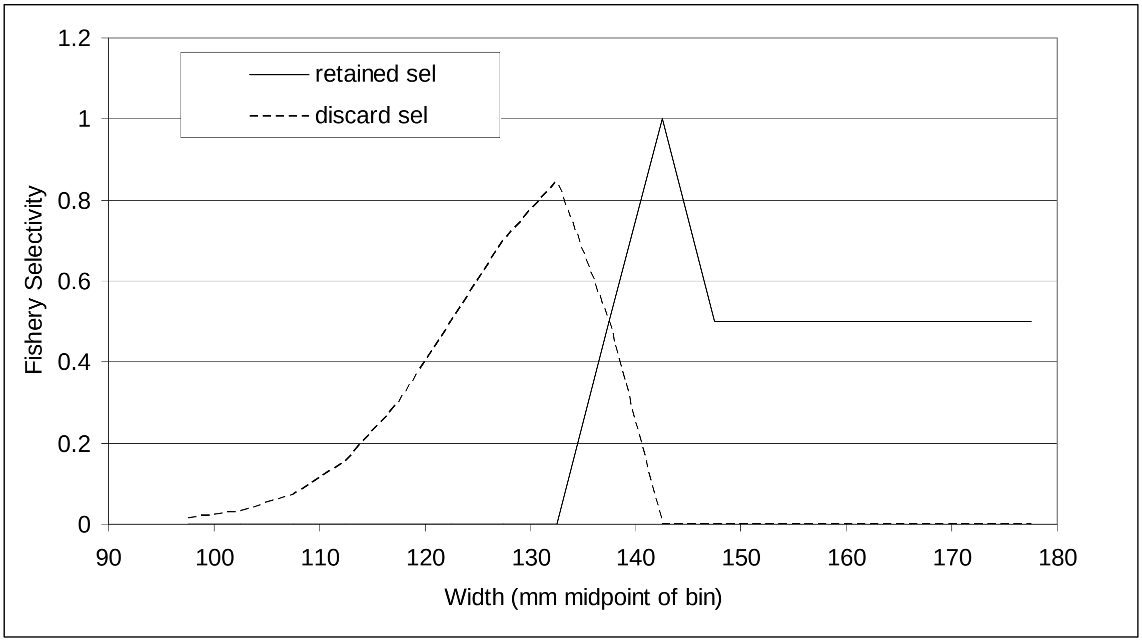


Figure A-1. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery before discard mortality is applied.

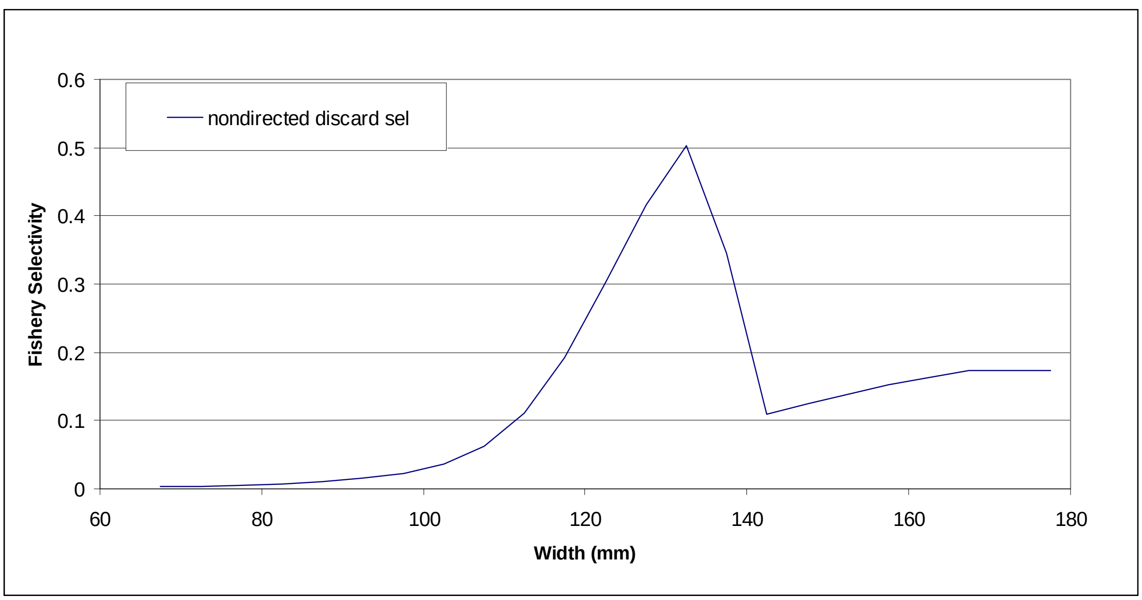


Figure A-2. Non-directed discard fishery selectivities with 50% mortality in the snow crab fishery and 80% mortality from trawl fisheries. The directed Tanner crab discard selectivity was used for snow crab fishery discards. Selectivity for the trawl discard is from the EA on overfishing analysis.

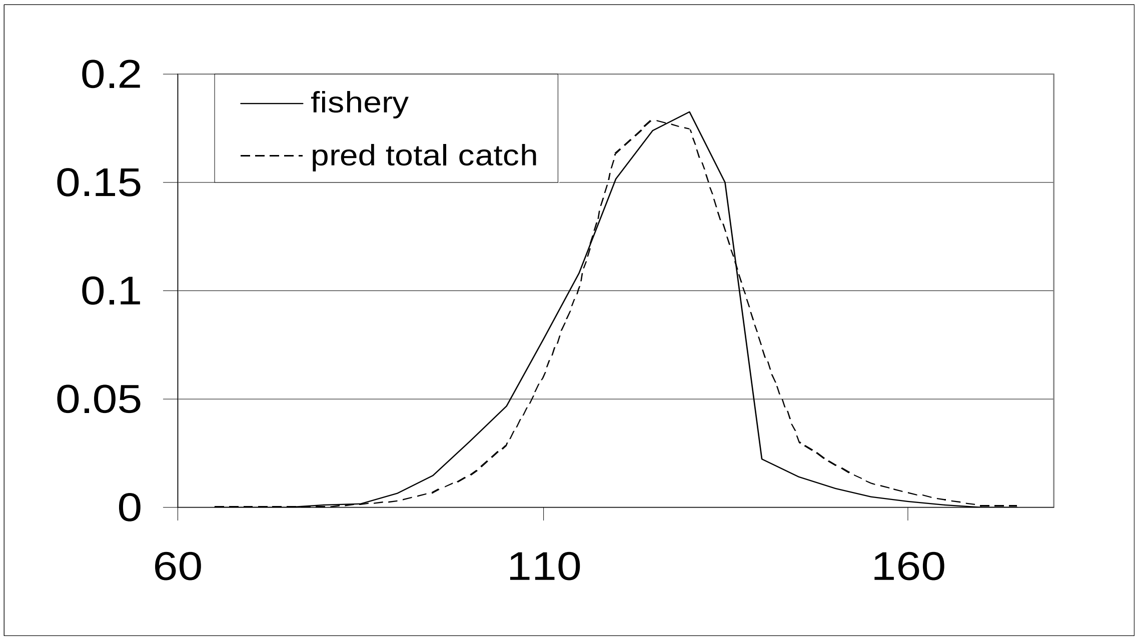


Figure A-3. Length frequency of total directed Tanner fishery catch (fishery) and predicted total directed Tanner fishery catch with estimated discard and retained fishery selectivities (Figure A-1) using the 2007 survey data and 2007/8 fishery observer data.

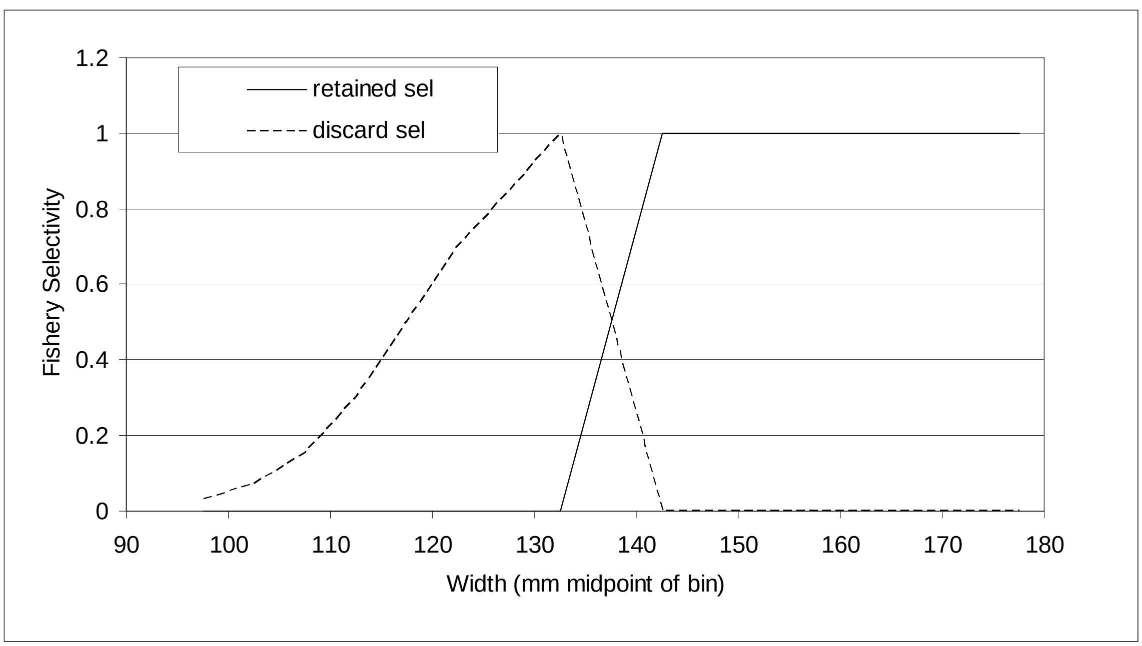


Figure A-4. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery (before discard mortality is applied), with retained selectivity of crab >140 mm cw fixed at 1.0.

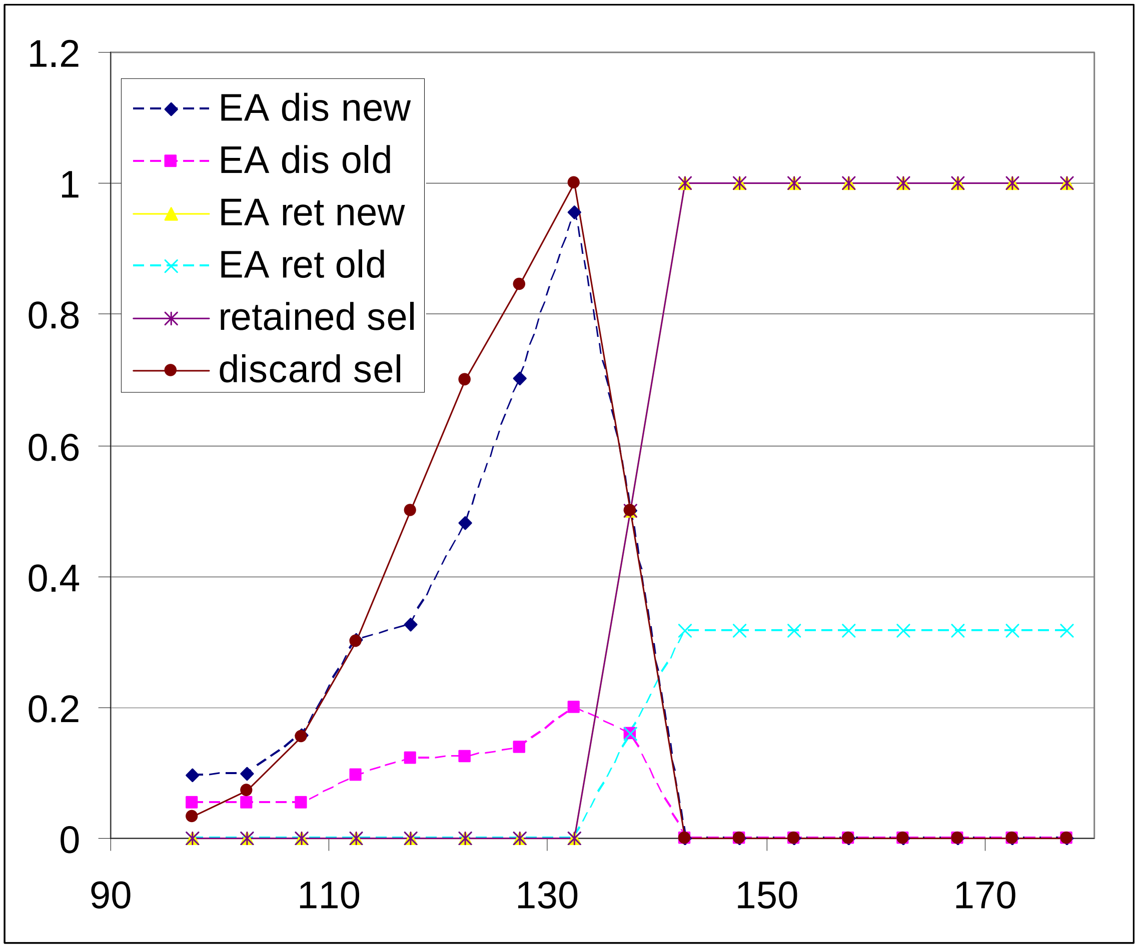


Figure A-5. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery shell condition combined, before discard mortality is applied. Selectivities on discard and retained split by new and old shell from the EA analysis.

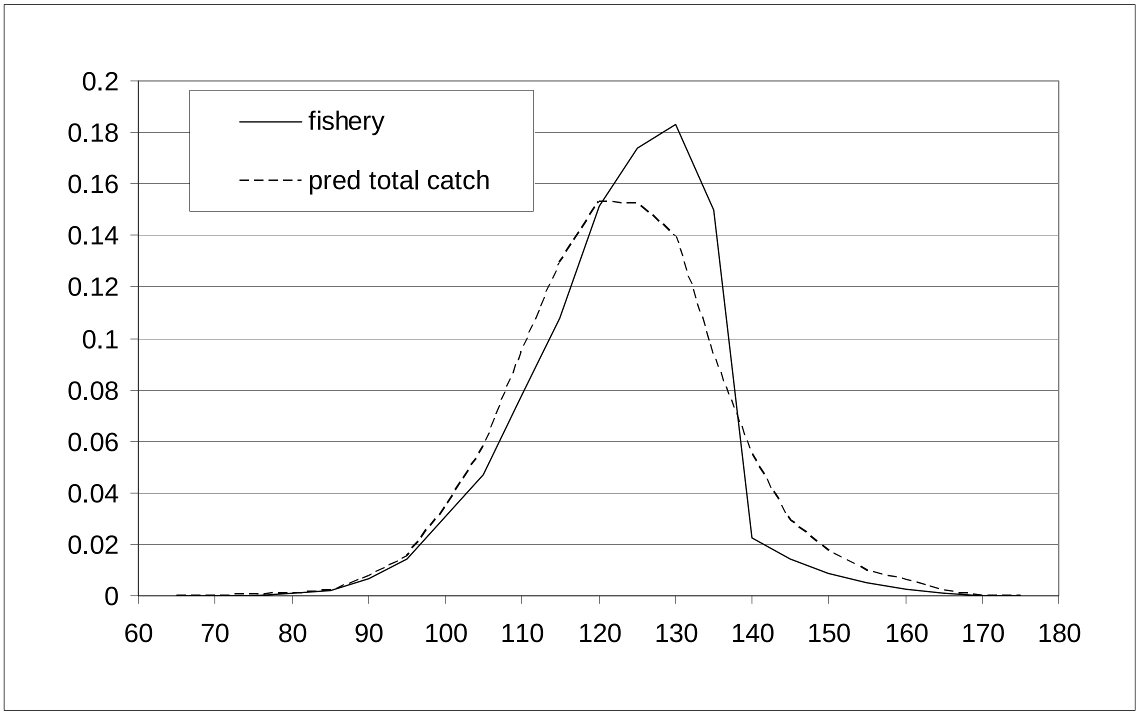


Figure A-6. Fit to total catch length frequency using retained selectivity at 1.0.

DRAFT

2010 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Red King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

R.J. Foy
Alaska Fisheries Science Center
NOAA Fisheries

Executive Summary

Major changes to this DRAFT 2010 stock assessment include removal of ecosystem chapter, and conversion of units to metric tons. Highlighted sections will be updated when new data is received before the SAFE document is finalized in September 2010.

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 near XXX t.
3. Stock biomass: Stock biomass in recent years has decreased since the 2007 survey with a substantial decrease in all size classes in XXX.
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
2007/08	1,964	6,663[A]	0	0	6.8	
2008/09	1,991	5,017[B]	0	0	9.5	1,506
2009/10	XXX	2,023[C]	XXX	XXX	XXX	227
2010/11		XXX[D]				XXX

All units are in tons of crabs and the OFL is a total catch OFL for each year. The stock was above MSST in 2008/09 and is hence not overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
B – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
C – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
D – Based on survey data available to the Crab Plan Team in September 2010

6. Basis for OFL:

Year	Tier	B_{MSY} t	Current MMB_{mating} t	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}
2009/10	4b	3,983	2,023	0.51	1.0	1991/1992-2008/2009	0.18

7. Rebuilding analyses results summary: not applicable

Summary of Major Changes:

Major changes to this DRAFT 2010 stock assessment include removal of ecosystem chapter, and conversion of units to metric tons. Highlighted sections will be updated when new data is received before the SAFE document is finalized in September 2010.

1. Management: There were no major changes to the 2009/2010 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series was updated with 2009/2010 data.
3. Assessment methodology: There were no changes to assessment methodology. A draft catch and survey model was developed in 2010 and is presented as a separate document.
4. Assessment results: The projected MMB and subsequent OFL declined substantially in this assessment. Total catch in 2008/2009 was 0.021 t.

Responses to SSC and CPT Comments

SSC comments June 2009:

General remarks pertinent to this assessment

- *As reiterated from our June 2008 report, "future stock assessments should provide analyses to support the choice of γ…" in Tier 4. Currently, analysts have used and the Crab Plan Team and the SSC have supported a value of 1 for γ in the calculation $F_{OFL} = \gamma M$, in which M is natural mortality, which results in a proxy for F_{MSY}. The SSC recommends that analysts provide rationale for the selection of $\gamma=1$. The value of 1 for γ is the default value used in Tier 5 for groundfish and should be conservative for crab stocks, since only the legal male component of the adult stock is harvested. However, analysis in the Environmental Assessment for Amendment 24 to revise overfishing definitions for crab showed that values of γ between 2 and 3 might be appropriate for F_{msy} estimation for some Bering Sea crab stocks. Therefore, it is desirable to investigate whether alternative approaches can be developed. Some suggestions for doing this will be forthcoming from the crab data weighting and stock assessment workshop held in Seattle during the May Crab Plan Team meeting. A report from that workshop will be available in time for the September Crab Plan Team meeting.*

- *The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number of years that are common across groups of species or areas.*

Specific remarks pertinent to this assessment

The SSC agrees with the Plan Team recommendations for management of Pribilof Islands Red King Crab under Tier 4, setting $\gamma=1$, $M=0.18$, using the 1991 - 2009 period to determine the average mature male biomass as a proxy for B_{MSY}, once the 2009 bottom trawl survey results for this area are available. The SSC appreciates the inclusion of estimates of B_{MSY} proxies for the two time periods, 1980 – 2009 and 1991-2009, and looks forward to the results of the final analysis in October. The Plan Team's rationale for beginning the time series at 1991 was based on the observation that red king crab were relatively uncommon in the area prior to 1991. The SSC would like to see this *rationale included in the final SAFE report. The SSC also looks forward to seeing the implementation of the catch-survey analysis in next year's iteration of the assessment.*

The SSC notes that there is a possibility that the abundance trends of red king crab are related to those of blue king crab, in that red king crab may be replacing blue king crab in the Pribilof Islands area. Given this possibility, it would be valuable to include interactions between these crab species as a factor in any future development of population dynamics models. This might take the form of a single king crab model with partitioning of size class abundances between the two species, or of two separate models with a factor in each to account for the interaction.

In regards to ecosystem considerations, the SSC would like to see consideration given to time trends in the abundance and potential influence of major fish predators, including arrowtooth flounder. Also, the SSC suggests that calculations of the impact of pot gear on the substrate should be based on the area inhabited by the Pribilof Islands red king crab population, rather than the entire area of the Bering Sea shelf.

Responses to CPT Comments: The choice for gamma was discussed at the May 13-14, 2009 assessment workshop with guidance that will be used for the May 2010 assessment cycle. The discussion for specific shifts in recruitment has occurred briefly in previous meetings. This will be a focused topic in 2010. Rationale for using the 1991 time series was included in the assessment. The particulars of the CSA model are included in this SAFE for discussion and recommendation of the CPT for specific analyses so that the model can be implemented in 2010. Options to include interactions between blue and red king crab in the Pribilofs will be considered as catch-survey models are developed. Expanded ecosystem sections were not considered during this assessment cycle to focus efforts on model development, ACL implementation, and survey data. A general Ecosystems Chapter will be developed for May 2010 for all crab stocks.

<u>SSC comments October 2009:</u>

General remarks pertinent to this assessment

The SSC offers these general comments to all stock assessment authors: (1) at the beginning of each SAFE chapter, summarize the SSC and Plan team requests to the author (and the response to each) to assure that these requests are not overlooked, especially as the SSC has been examining crab stock assessments spread over multiple Council meetings per year, and (2) each assessment should clearly state what is new and not new from the previous assessment. (3) All assessment authors should structure their assessment documents following the guidelines established by the crab plan team.

Specific remarks pertinent to this assessment

none

Responses to CPT Comments: The SSC and CPT comments are included, new information is clearly stated, and the new SAFE guidelines have been followed.

CPT comments May 2009:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The team agreed with the author's recommendation for the basis for the B_{msy} proxy as well as for the model parameters.

Responses to CPT Comments:

None

CPT comments September 2009:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

- *In the next assessment the Team recommends the authors add confidence intervals to graphs, even just on one group to show the relative variability. Stock size variability in the survey biomass estimates provided a good argument for not basing the OFL on the most recent year.*

Responses to CPT Comments: CIs to be added to graphs.

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).

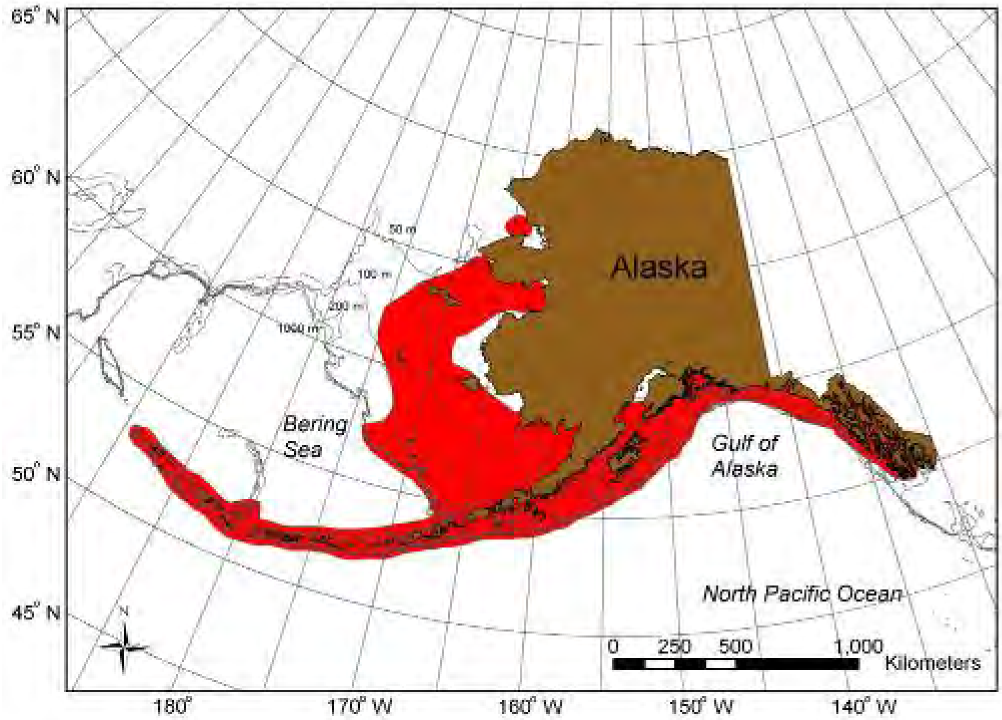


Figure 1. Red king crab distribution.

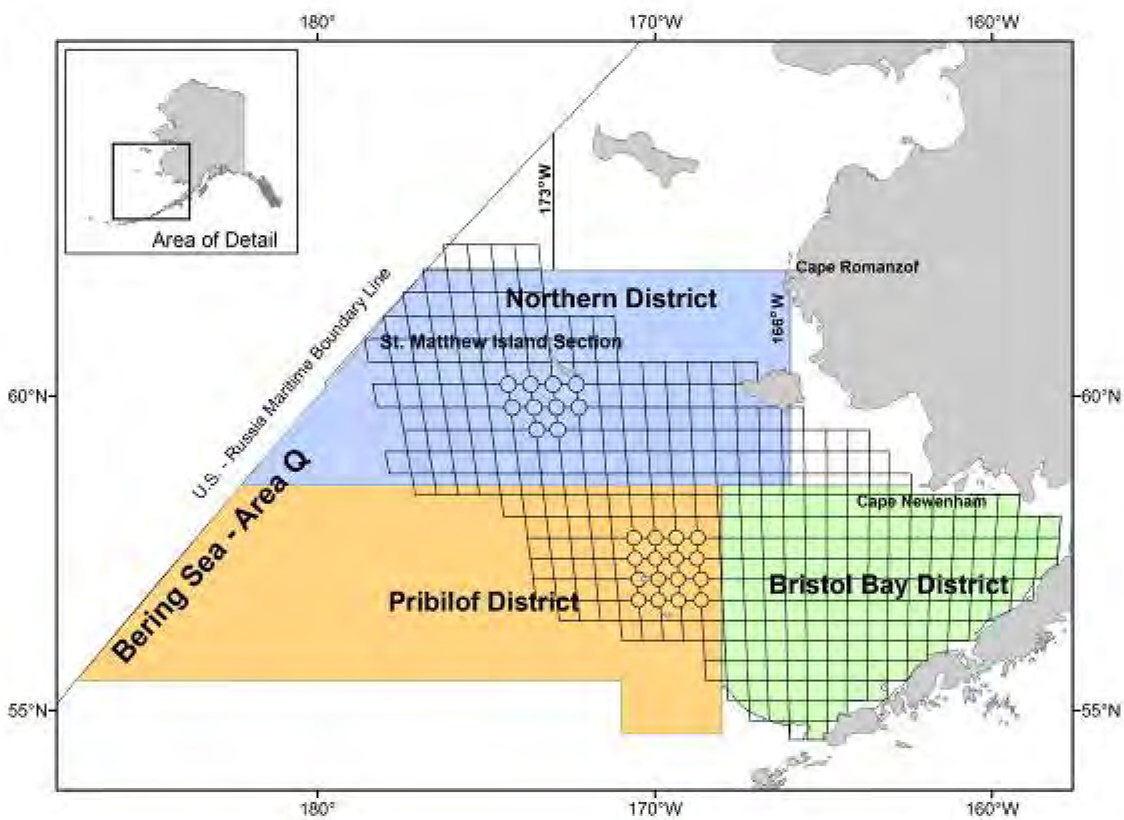


Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

3. **Stock structure** - Stock structure of red king crabs in the North Pacific is largely unknown.

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. 2008 for complete management history).

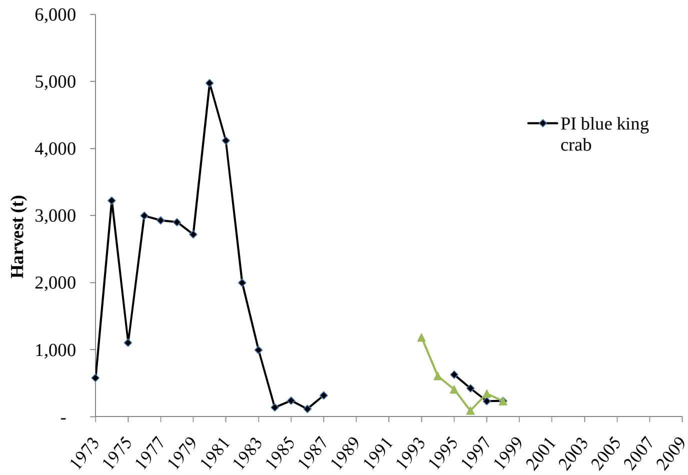


Figure 3. Historical harvests and GHLs for Pribilof Island red king crab (Bowers et al. 2007).

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.

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area

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 2010 and the standard groundfish discards time series data updated through XXX were used in this assessment. The crab fishery retained and discard catch time series was updated with 2009/2010 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 2009/2010 fishing season.

Table 1. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2008; D. Pengilly, ADF&G, personal communications).

Year	Catch (count)	Catch (t)	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	11
1994/1995	167,520	607	6
1995/1996	110,834	407	3
1996/1997	25,383	91	<1
1997/1998	90,641	343	3
1998/1999	68,129	231	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

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, 1993-2007/08 (Bowers et al. 2008)

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
1999-2009/10	Fishery Closed			

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 (lbs) 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 (see equation 1: males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * \text{CL(mm)}^{B} \qquad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \qquad (2)$$

Finally, weights were the product of average weight, CPUE, and total pot lifts in the fishery. The total weight in g was then converted to lbs by dividing the gram weight by 453.6 g/lb. 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 2008/2009, XXX t of legal males were incidentally caught in the crab fisheries (Table 3).

<u>Groundfish pot, trawl, and hook and line fisheries</u>

The 2009/2010 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 2009 to June 2010. 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. Current efforts are underway to provide data on a more fine spatial scale to correct this error. To estimate sex ratios for 2010 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 3).

In 2009/2010, XXX t of male and female red king crab were caught in groundfish fisheries which is 0.01 more than the 0.016 million lb estimate of non-retained crab catch in 2007/2008 pot, trawl, and hook and line groundfish fisheries. The catch was mostly in non-pelagic trawls (73%) followed by pot (23%) and longline (4%) fisheries. The targeted species in these fisheries were yellowfin sole (40%), Pacific cod (34%), flathead sole (16%), and rock sole (9%).

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. 2008; 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	1.01	11.40	10.40	6.82
1999/2000	1.30	0.00	8.21	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	0.19	1.75	4.53	24.72
2006/2007	1.19	0.15	1.06	6.99	21.35
2007/2008	0.87	0.06	0.10	1.92	2.76
2008/2009	0.10	0.00	0.00	1.64	6.94
2009/2010	XXX	XXX	XXX	XXX	XXX

c. Catch-at-length: NA

d. Survey biomass:
The 2010 NOAA Fisheries EBS bottom trawl survey results (Chilton et al. in press) are included in this SAFE report. 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.

Proportion mature = $1/(1 + (5.842 * 10^{14}) * e^{(CL(mm) * -0.288)}$ (3)

Historical survey data are available from 1980 to the present when surveyand data analyses were standardized (Table 4, Figure 6).

Table 4. Pribilof Islands District red king crab abundance, mature biomass, and legal male biomass (t), and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Total males @ survey t	Total females @ survey t
1980/1981	2,640	1,764	2,640		
1981/1982	2,640	2,127	2,640		
1982/1983	1,352	1,175	1,352		
1983/1984	349	308	318		
1984/1985	367	327	304		
1985/1986	100	86	100		
1986/1987	122	109	122		
1987/1988	41	36	41		
1988/1989	127	113	36		
1989/1990	1,411	1,252	803		
1990/1991	1,089	966	59		
1991/1992	3,679	3,239	1,111		
1992/1993	3,089	2,640	2,368		
1993/1994	7,638	5,525	7,130		
1994/1995	7,412	5,956	6,559		
1995/1996	3,860	3,007	3,470		
1996/1997	2,009	1,687	1,982		
1997/1998	5,262	4,314	4,881		
1998/1999	2,300	1,783	1,719		
1999/2000	9	0	9		
2000/2001	3,960	3,506	3,520		
2001/2002	7,911	7,008	5,221		
2002/2003	6,749	5,983	6,731		
2003/2004	5,012	4,436	4,921		
2004/2005	3,878	3,438	3,878		
2005/2006	1,352	1,179	1,338		
2006/2007	7,099	6,278	6,790		
2007/2008	7,521	6,663	7,248	7,716	2,717
2008/2009	5,665	5,017	5,280	6,241	3,452
2009/2010	2,463	2,023	2,114	2,522	553
2010/2011	XXX	XXX	XXX	XXX	XXX

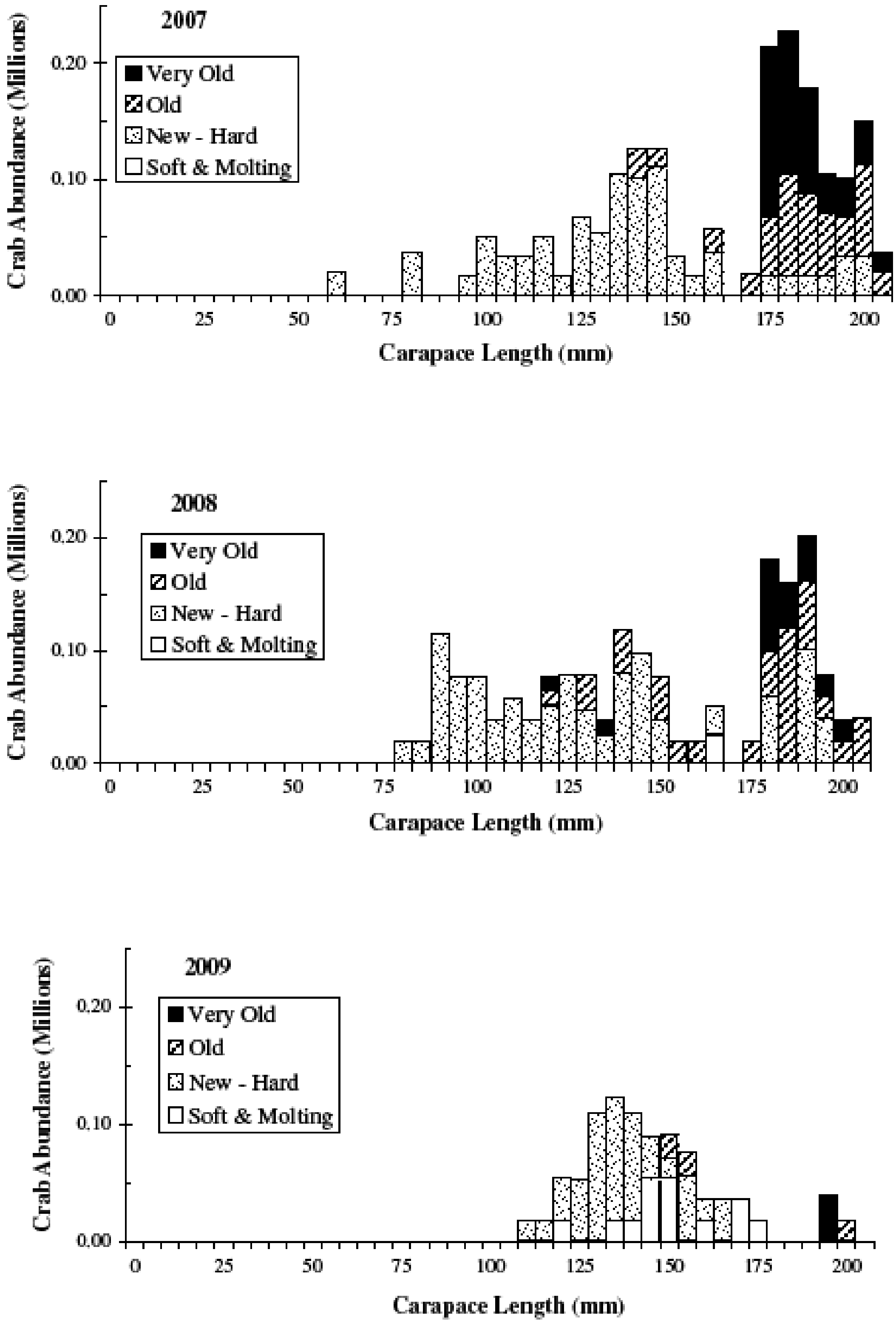


Figure 5. Distribution of Pribilof Island red king crab in 5 mm length bins by shell condition for the last 3 surveys.

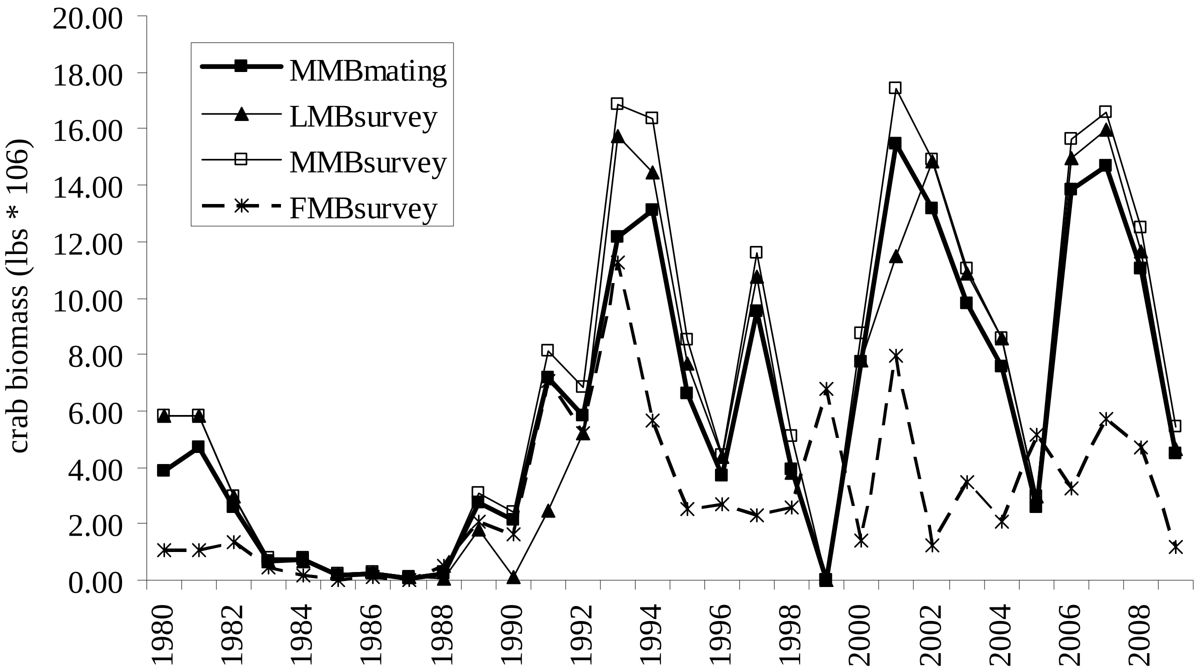


Figure 6. Historical trends of Pribilof Island red king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

Red king crab were caught at 7 of the 41 stations in the Pribilof District high-density sampling area in 2009 (Chilton et al. in press, Figure 7). The density of legal-sized males caught at a station ranged from 66 to 1,745 crab/nmi^2. Legal-sized male red king crab were caught at 6 stations in the Pribilof District and were estimated at 0.7 ± 0.9 million crab (Figure 8). Pre-recruit males were encountered at 2 of the 41 stations with an abundance estimate of 0.3 ± 0.4 million crab. Thirty percent of the legal-sized males were in molting or softshell condition while 53% were evaluated as new hardshell crabs and 17% as oldshell and very oldshell condition crabs. The 2009 size-frequency for red king crab males shows a decrease in the number of oldshell and very oldshell legal-sized males in comparison to the 2007 and 2008 shell conditions. The 2009 abundance estimate of large red king crab females was 0.3 ± 0.4 million crab. Thirteen percent of the total female red king crab caught were immature while 65% of the mature females were brooding uneyed embryos, 12% had eyed embryos, and 23% were barren or had empty egg cases.

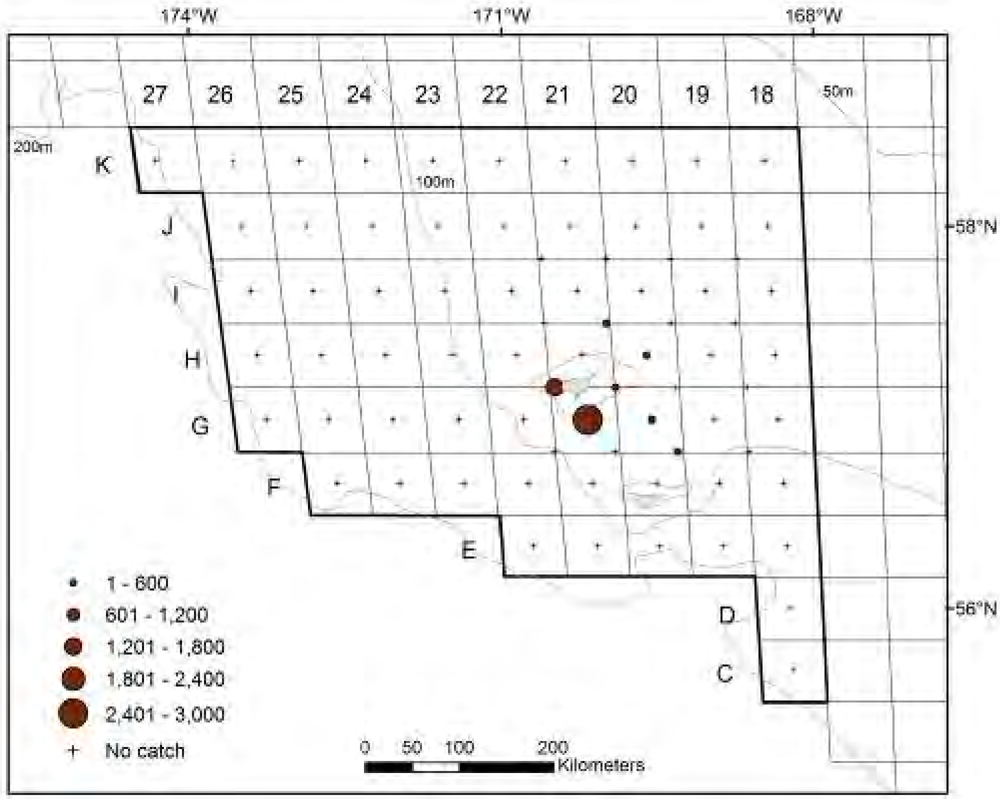


Figure 7. Total density (number/nm^2) of red king crab in the Pribilof District in the 2009 EBS bottom trawl survey.

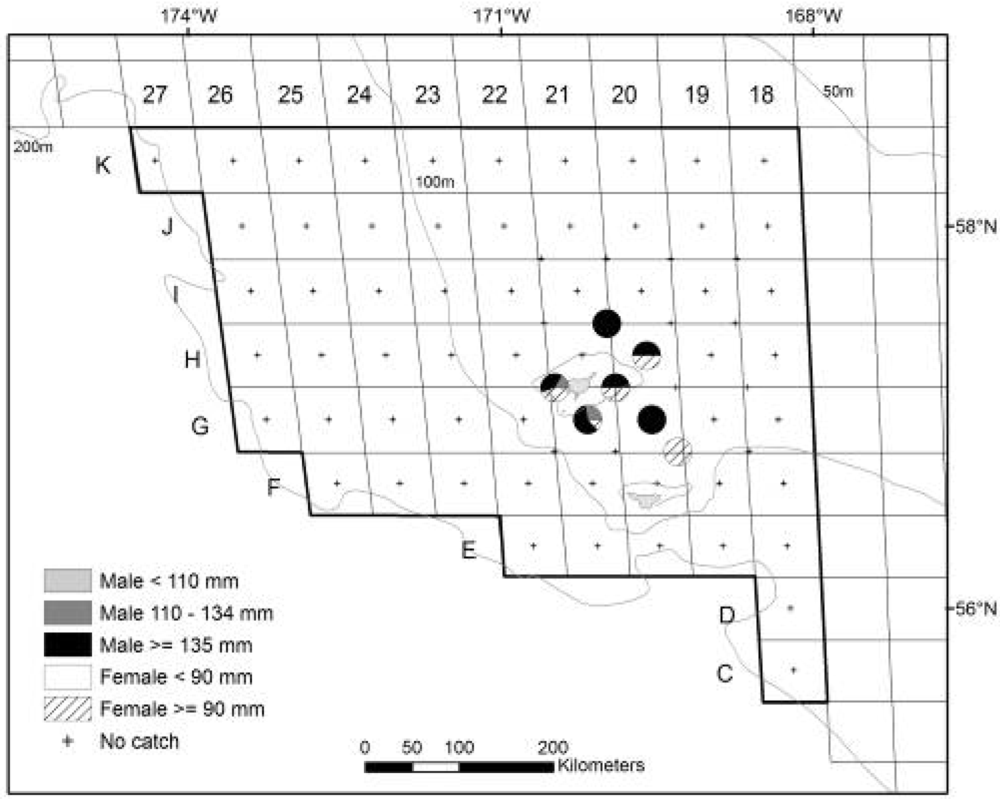


Figure 8. 2009 EBS bottom trawl survey size class distribution of red king crab in the Pribilof District.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and has been developed as a separate document for potential inclusion in the 2011 stock assessment cycle.

Calculation of the OFL

1. Based on available data, the authors, the Crab Plan Team, and the Science and Statistical Committee all recommend that this stock should be classified as a Tier 4 stock 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 9). 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.

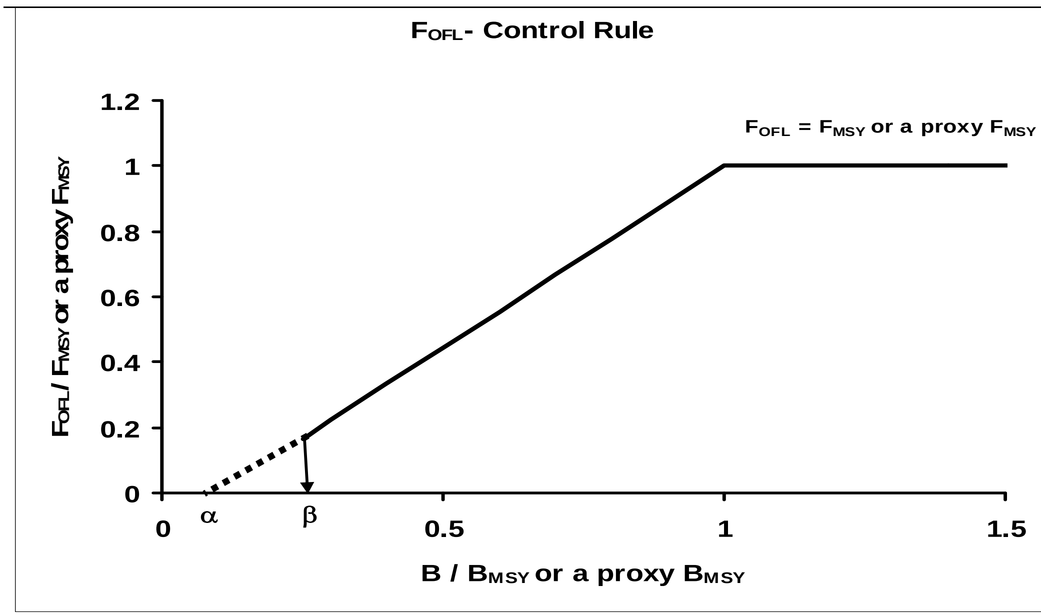


Figure 9. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

3. OFL specification:
   a. In the Tier 4 OFL-setting approach, the “total catch OFL” and the “retained catch OFL” are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained

catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure 8) 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_{MSY}^{prox} for the 2009 assessment was calculated as 1) 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. 2) the average MMB_{mating} for the entire survey period 1980 to current.

b. The MMB_{Mating} projection is based on application of M from the 2010 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:

$$\mu_{LMB} = [\text{Total LMB retained and non-retained catch}] / LMB_{Fishery} \quad (9)$$

$$\mu_{MMB} = [\text{Total MMB retained and non-retained catch}] / MMB_{Fishery} \quad (10)$$

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL
2007/08	1,964	6,663[A]	0	0	6.8	
2008/09	1,991	5,017[B]	0	0	9.5	1,506
2009/10	XXX	2,023[C]	XXX	XXX	XXX	227
2010/11		XXX[D]				XXX

All units are in tons of crabs and the OFL is a total catch OFL for each year. The stock was above MSST in 2008/09 and is hence not overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
B – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
C – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
D – Based on survey data available to the Crab Plan Team in September 2010

4. Recommendations:
   For 2009/2010, two levels of B_{MSY}^{prox} were defined. $B_{MSY}^{prox}{}_1$=3,983 t of MMB_{mating} derived as the mean of 1991/1992 to 2008/2009 and is recommended by the authors, CPT and SSC. $B_{MSY}^{prox}{}_2$=2,758 t derived mean of 1980/1981 to 2008/2009 for comparison purposes. The stock demonstrated highly variable levels of MMB_{mating} 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.

   Male mature biomass at the time of mating for 2009/2010 is estimated at 2, 023 and 1,950 t for $B_{MSY}^{prox}{}_1$ and $B_{MSY}^{prox}{}_2$ options, respectively. The B/B_{MSY}^{prox} ratios and F_{OFLs} corresponding to the two biomass reference options are, respectively, [$B/B_{MSY}^{prox}{}_1$=0.51, F_{OFL}=0.18] and [$B/B_{MSY}^{prox}{}_2$=0.71, F_{OFL}=0.18]. For both biomass reference options B/B_{MSY}^{prox} is < 1, therefore the stock status level is a (equation 5). For the 2009/2010 fishery, total catch OFLs were estimated at 227 and 331 t of crab and legal male catch OFLs were estimated at 154 and 227 t of crab for options 1 and 2 respectively. The projected exploitation rates based on full retained catches up to the OFL for LMB and $MMB_{fishery}$ are: 0.09 and 0.07 for B_{MSY}^{prox} option 1 and 0.12 and 0.11 for B_{MSY}^{prox} option 2.

   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.

Literature Cited

ADFG. 1998. Annual management report for the shellfish fisheries of the westward region, 1997. Alaska Department of Fish and Game, Regional Information Report. 4K98-39, 308 p.

Barnard, D.R. and R. Burt. 2007. Alaska Department of Fish and Game summary of the 2005/2006 mandatory shellfish observer program database for the rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 07-02, Anchorage.

Barnard, D.R. and R. Burt. 2008. Alaska Department of Fish and Game summary of the 2006/2007 mandatory shellfish observer program database for the rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 08-17, Anchorage.

Bell, M. C. 2006. Review of Alaska crab overfishing definitions: Report to University of Miami Independent System for peer reviews. April 24-28, 2006 Seattle, Washington, 35 p.

Bowers, F. R., M. Schwenzfeier, S. Coleman, B. J. Failor-Rounds, K. Milani, K. Herring, M. Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2006/07. Alaska Department of Fish and Game, Fishery Management Report. No. 08-02, 230 p.

Boyle, L, and M. Schwenzfeier. 2002. Alaska's mandatory shellfish observer program, 1988-2000, p. 693-704. *In* A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley and D. Woodby (editors), Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant College Program, Report No. AK-SG-02-01, University of Alaska, Fairbanks, AK.

Bright, D. B. 1967. Life histories of the king crab, *Paralithodes camtschatica*, and the "Tanner" crab, *Chionoecetes bairdi*, in Cook Inlet, Alaska. Ph.D. Thesis, University of Southern California.

Chilton, E.A., C.E. Armistead, R.J. Foy, and L. Rugolo. In press. The 2008 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-XXX, 195 p.

Feder, H.M., and S.C. Jewett. 1981. Feeding interactions in the eastern Bering Sea with emphasis on the benthos, p. 1229-1261 *In* D.W. Hood and J.A. Calder (editors.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, Office of Marine Pollution and Assessment.

Gish, R. K. 2006. The 2005 Pribilof District king crab survey. Alaska Department of Fish and Game, Fishery Management Report. No. 06-60, 49 p.

Haflinger, K. 1981. A survey of benthic infaunal communities of the Southeastern Bering Sea shelf, p. 1091-1104. *In* Hood and Calder (editors), The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2. Office Mar. Pol. Assess., NOAA. University of Washington Wash. Press, Seattle, WA.

Ianelli, J.N.S. Barbeaux, T. Honkalehto, S. Kotwicki, K. Aydin and N. Williamson. 2007. Chapter 1: Eastern Bering Sea walleye Pollock. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, p. 41-138.

Jensen, G.C. 1995. Pacific Coast Crabs and Shrimps. Sea Challengers, Monterey, California, 87p.

Jewett, S.C., and C.P. Onuf. 1988. Habitat suitability index models: red king crab. Biological Report, 82(10.153), U.S. Fish and Wildlife Service, 34 p.

Jørstad, K.E., E. Farestveit, H. Rudra, A-L. Agnalt, and S. Olsen. 2002. Studies on red king crab (*Paralithodes camtschaticus*) introduced to the Barents Sea, p. 425-438. *In* A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley and D. Woodby (editors), Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant College Program Report No. AK-SG-02-01, University of Alaska, Fairbanks, AK.

Lang, G.M., P.A. Livingston, and K.A. Dodd. 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 through 2001. United States Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-158, 230 p.

Livingston, P. A., A. Ward, G. M. Lang, and M.S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. United States Department of Commerce, NOAA Technical Memorandum. NMFD-AFSC-11, 192 p.

Livingston, P.A. 1989. Interannual trends in Pacific cod, *Gadus macrocephalus*, predation on three commercially important crab species in the Eastern Bering Sea. Fishery Bulletin 87:807-827.

Loher, T. and D.A. Armstrong. 2005. Historical changes in the abundance and distribution of ovigerous red king crabs (*Paralithodes camtschaticus*) in Bristol Bay (Alaska), and potential relationship with bottom temperature. Fisheries Oceanography 14:292-306.

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

Lovvorn, J.R., L.W. Cooper, M.L. Brooks, C.C. De Ruyck, J.K. Bump, and J.M. Grebmeier. 2005. Organic matter pathways to zooplankton and benthos under pack ice in late winter and open water in late summer in the north-central Bering Sea. Marine Ecology Progress Series 291:135-150.

Marukawa, H. 1933. Biological and fishery research on Japanese king crab *Paralithodes camtschatica* (Tilesius). Fish. Exp. Stn, Tokyo 4:1-152.

Matsuura, S. and Takeshita, K. 1990. Longevity of red king crab, *Paralithodes camtschatica*, revealed by long-term rearing study, p. 65-90. *In* B. Melteff (editor) International Symposium on King and Tanner crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

McLaughlin, P. A. and J. F. Herberd. 1961. Stomach contents of the Bering Sea king crab. International North Pacific Commission, Bulletin 5:5-8.

NMFS. 2000. Endangered Species Act Section 7 Consultation – Biological Assessment: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. National Marine Fisheries Service, Alaska Region, 14 p.

NMFS. 2002. Endangered Species Act Section 7 Consultation – Biological Assessment: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. National Marine Fisheries Service, Alaska Region, 59 p.

NMFS. 2004. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, Alaska Region

NPFMC (North Pacific Fishery Management Council). 1994. Environmental Assessment/Regulatory Impact/Review/Initial Regulatory Flexibility analysis for

Amendment 21a to the Fishery Management Plan for Bering Sea and Aleutian Islands Groundfish. Anchorage, Alaska.

NPFMC (North Pacific Fishery Management Council). 1998. Fishery Management Plan for the Bering Sea/Aleutian Islands king and Tanner crabs. Anchorage, Alaska 105 p.

NPFMC (North Pacific Fishery Management Council). 2003. Environmental Assessment for Amendment 17 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands: A rebuilding plan for the Pribilof Islands blue king crab stock. Anchorage, Alaska 87 p.

NPFMC (North Pacific Fishery Management Council). 2008. Environmental Assessment for Amendment 24 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands: to revise overfishing definitions. Anchorage, Alaska 194 p.

Ormseth, O. and B. Matta. 2007. Chapter 17: Bering Sea and Aleutian Islands Skates. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage 909-1010 p.

Otto R.S., R.A. MacIntosh, and P.A. Cummiskey. 1990. Fecundity and other reproductive parameters of female red king crab (*Paralithodes camtschatica*) in Bristol Bay and Norton Sound, Alaska, p. 65-90 *In* B. Melteff (editor) Proceedings of the International Symposium on King and Tanner crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

Overland, J.E. and P.J. Stabeno. 2004. Is the climate of the Bering Sea warming and affecting the ecosystem? EOS 85:309-316.

Powell G.C. and R.B. Nickerson. 1965. Reproduction of king crabs, *Paralithodes camtschatica* (Tilesius). Journal of Fisheries Research Board of Canada 22:101-111.

Powell, G.C. 1967. Growth of king crabs in the vicinity of Kodiak Island, Alaska. Informational Leaflet 92, Alaska Department of Fish and Game, 58 p.

Schumacher, J.D., N.A. Bond, R.D. Brodeur, P.A. Livingston, J.M. Napp, and P.J. Stabeno. 2003. Climate change in the southeastern Bering Sea and some consequences for biota, p. 17-40. *In* G. Hempel and K. Sherman (editors.) Large Marine Ecosystems of the World-Trends in Exploitation, Protection and Research. Elsevier Science, Amsterdam.

Shirley, S. M. and T. C. Shirley. 1989. Interannual variability in density, timing and survival of Alaskan red king crab *Paralithodes camtschatica* larvae. Marine Ecology Progress Series 54:51-59.

Shirley, T. C., S. M. Shirley, and S. Korn. 1990. Incubation period, molting and growth of female red king crabs: effects of temperature, p. 51-63. *In* B. Melteff (editor) Proceedings of the International Symposium on King and Tanner Crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

Siddeek, M.S.M, L. J. Watson, S. F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data, p. 51-75. *In* A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley and D. Woodby (editors), Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant College Program Report No. AK-SG-02-01, University of Alaska, Fairbanks, AK.

Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Canadian Journal of Fisheries and Aquatic Science 37: 1488-1494.

Sparks, A.K. and J.F. Morado. 1985. A preliminary report on the diseases of Alaska king crabs, p. 333-339. *In* B.R. Melteff (editor), Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program Report No. 85-12, University of Alaska, Anchorage, AK.

Sparks, A.K. and J.F. Morado. 1997. Some diseases of northeastern Pacific commercial crabs. Journal of Shellfish Research 16:321.

Stevens, B.B. 1990. Temperature-dependent growth of juvenile red king crab (*Paralithodes camtschatica*), and its effects on size-at-age and subsequent recruitment in the eastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences 47:1307-1317.

Stevens, B.G. and K. M. Swiney. 2007b. Growth of female red king crabs *Paralithodes camtshaticus* during pubertal, primiparous, and multiparous molts. Alaska Fisheries Research Bulletin 12:263-270.

Stevens, B.G. and K.M. Swiney. 2007a. Hatch timing, incubation period, and reproductive cycle for primiparous and multiparous red king crab *Paralithodes camtschaticus*. Journal of Crustacean Biology 27:37-48.

Thompson, G. J. Ianelli, M. Dorn, D. Nichol, S. Gaichas, and K. Aydin. 2007. Chapter 2: Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands Area. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, 209-328 p.

Tyler, A.V. and G.H. Kruse. 1996. Conceptual modeling of brood strength of red king crabs in the Bristol Bay region of the Bering Sea, p. 511-543. *In* High Latitude Crabs: Biology, Management, and Economics. Alaska Sea Grant College Program Report No. 96-02, University of Alaska, Fairbanks, AK.

Wang, M., C. Ladd, J. Overland, P. Stabeno, N. Bond, and S. Salo. Eastern Bering Sea Climate-FOCI. 2008, p. 106-113. *In* J. Boldt (editor) Appendix C: Ecosystem Considerations for 2008. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, AK.

Weber, D. D. 1967. Growth of the immature king crab Paralithodes camtschatica (Tilesius). Bulletin No. 21, North Pacific Commission, 53 p.

Weber, D.D. 1974. Observations on growth of southeastern Bering Sea king crab, *Paralithodes camtschatica*, from a tag-recovery study, 1955-65. Data Report 86, National Marine Fisheries Service, 122 p.

Wilderbuer, T.K. D.G. Nichol and J. Ianelli. Chapter 4: Yellowfin sole. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage 447-512 p.

Zheng, J. and G. H. Kruse. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science 57:438-451.

Zheng, J. M.C. Murphy, and G.H. Kruse. 1995. A length-based population model and stock-recruitment relationships for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska. Canadian Journal of Fisheries and Aquatic Science 52:1229-1246.

DRAFT

2010 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

R.J. Foy
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA

Executive Summary

Major changes to this DRAFT 2010 stock assessment include removal of ecosystem chapter, and conversion of units to metric tons hereafter referred to as tons (t). Highlighted sections will be updated when new data is received before the SAFE document is finalized in September 2010.

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 XXX t.
3. Stock biomass: Stock biomass in recent years was decreasing between the 1995 and 2008 survey, however, there was an increase in most size classes in XXX.
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
2007/08	2,105	304[A]	0	0	2.3	
2008/09	2,041	113[B]	0	0	0.5	1.8
2009/10	XXX	513[C]	0	0	XXX	1.8
2010/11		XXX [D]				XXX

All units are tons of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2008/09 and is hence overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
B – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
C – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
D – Based on survey data available to the Crab Plan Team in September 2010

6. Basis for 2010/2011 OFL projection:

Year	Tier	B_{MSY} t	Current MMB_{mating} t	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}
20010/11	4c	4,209	513	0.12	1.0	1980/1981-1984/1985 & 1990/1990-1997/1998	0.18

7. 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 with preliminary review of the environmental assessment on the proposed FMP revision in April 2010 and initial review scheduled for October 2010.

Summary of Major Changes:
Major changes to this DRAFT 2010 stock assessment include removal of ecosystem chapter, and conversion of units to metric tons. Highlighted sections will be updated when new data is received before the SAFE document is finalized in September 2010.

1. Management: There were no major changes to the 2009/2010 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series was updated with 2009/2010 data.
3. Assessment methodology: There were no changes to assessment methodology. A draft catch and survey model was developed in 2010 and is presented as a separate document.
4. Assessment results: The projected MMB increased in this assessment but remained below the MSST. Therefore, the OFL remained low with no directed fishery. Total catch in 2008/2009 was XXX t.

Responses to SSC and CPT Comments

<u>SSC comments June 2009:</u>

General remarks pertinent to this assessment

- *As reiterated from our June 2008 report, "future stock assessments should provide analyses to support the choice of γ…" in Tier 4. Currently, analysts have used and the Crab Plan Team and the SSC have supported a value of 1 for γ in the calculation $F_{OFL} = \gamma M$, in which M is natural mortality, which results in a proxy for F_{MSY}. The SSC recommends that analysts provide rationale for the selection of $\gamma=1$. The value of 1 for γ is the default value used in Tier 5 for groundfish and should be conservative for crab stocks, since only the legal male component of the adult stock is harvested. However, analysis in the Environmental Assessment for Amendment 24 to revise overfishing definitions for crab showed that values of γ between 2 and 3 might be appropriate for F_{msy} estimation for some Bering Sea crab stocks. Therefore, it is desirable to investigate whether alternative approaches can be developed. Some suggestions for doing this will be forthcoming from the crab data weighting and stock assessment workshop held in Seattle during the May Crab Plan Team meeting. A report from that workshop will be available in time for the September Crab Plan Team meeting.*

- *The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number of years that are common across groups of species or areas.*

Specific remarks pertinent to this assessment

The SSC agrees with the Plan Team recommendation for management of Pribilof Islands Blue King Crab under Tier 4 with γ=1, M=0.18 using the 1980 -1984 and 1990-1997 time periods to determine the average MMB as a proxy for B_{MSY}, estimated as 9.01 million pounds. The SSC appreciates seeing the written justification in the SAFE omission of the 1985-1989 period because it may not represent the productive potential of the current stock.

This stock was declared overfished in 2002 and, even though there has not been any directed fishing since 1999, the stock has continued to decline and it is unlikely that it will be rebuilt by the end of the rebuilding plan 10 year horizon in 2012. Recognizing that a new rebuilding plan will be needed, and that additional protective measures could be taken, the SSC commends the Plan Team for considering 5 alternatives (listed in the September 2008 plan team minutes) to reduce bycatch of blue king crab, four of which pertained to closing areas to all targeted groundfish harvest or just to directed Pacific cod harvest, whereas the fifth was to modify pot gear for Pacific cod. If the Council initiates a review of these alternatives, the SSC requests that the analysts identify expected bycatch reductions that might be accrued. The SSC also encourages additional observer coverage as appropriate to improve monitoring of blue king crab bycatch. While the Plan Team suggested not considering item 5 above, the SSC suggests that use of a slick ramp for Pacific cod pots to make entry into a pot difficult for king crab could be considered.

In regards to a revised rebuilding plan, the SSC recommends that the time frame for estimation of B_{REF} be reconsidered in terms of potential environmental changes that may have altered the potential productivity of the population. The SSC also requests that when a revised rebuilding plan is developed, it include an analysis examining information on stock separation from the St. Matthew Island blue king crab stock and the possibility of competitive or predation interactions with Pribilof Islands red king crab.

Responses to SSC Comments: The choice for gamma was discussed at the May 13-14, 2009 assessment workshop with guidance that will be used for the May 2010 assessment cycle. The discussion for specific shifts in recruitment has occurred briefly in previous meetings. This will be a focused topic in 2010. Options to include alternative for rebuilding plan bycatch reduction in the Pribilofs will be considered as additional rebuilding scenarios are developed. In addition the time period for B_{REF} will be reconsidered.

<u>SSC comments October 2009:</u>

General remarks pertinent to this assessment

The SSC offers these general comments to all stock assessment authors: (1) at the beginning of each SAFE chapter, summarize the SSC and Plan team requests to the author (and the response to each) to assure that these requests are not overlooked, especially as the SSC has been examining crab stock assessments spread over multiple Council meetings per year, and (2) each assessment should *clearly state what is new and not new from the previous assessment. (3) All assessment authors should structure their assessment documents following the guidelines established by the crab plan team.*

Specific remarks pertinent to this assessment
none

Responses to CPT Comments: The SSC and CPT comments are included, new information is clearly stated, and the new SAFE guidelines have been followed.

<u>CPT comments May 2009:</u>
General remarks pertinent to this assessment
none
Specific remarks pertinent to this assessment
The team agreed with the author's recommendation for the basis for the B_{msy} proxy as well as for the model parameters.
Responses to CPT Comments:
none

<u>CPT comments September 2009:</u>
General remarks pertinent to this assessment
none

Specific remarks pertinent to this assessment

- *The team requests the author evaluate more specifically the spatial areas of the bycatch in 2008/09 particularly the hook and line catch and the Pacific cod fishery.*

Responses to CPT Comments: A full analysis of spatial and temporal bycatch is being completed for the PIBKC rebuilding plan.

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).

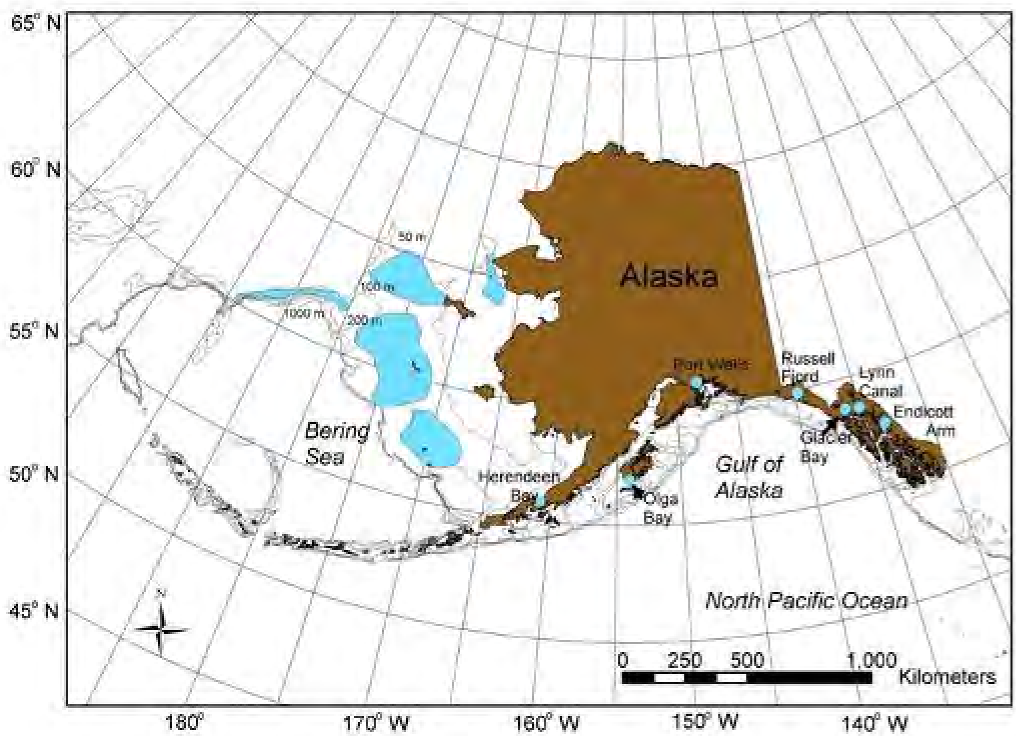


Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

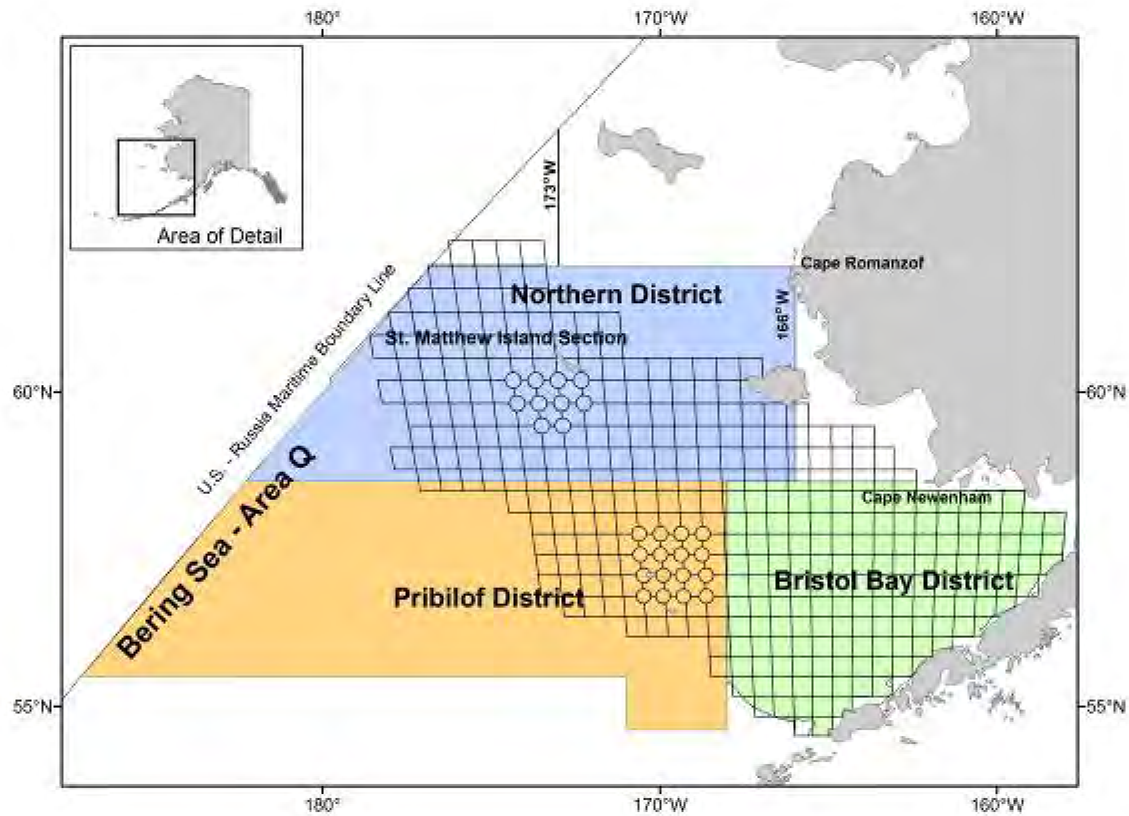


Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

3. **Stock structure** - Stock structure of blue king crabs in the North Pacific is largely unknown.

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 3). Landings increased during the 1970s and peaked at a harvest of 4,990 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).

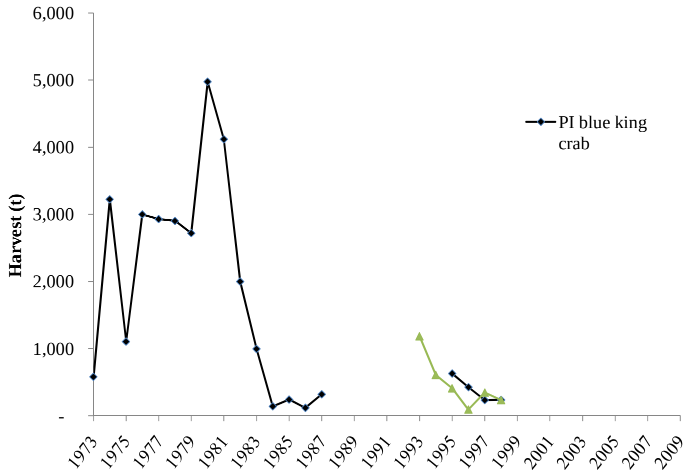


Figure 3. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2007).

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.

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area. Trawl fishing is prohibited year-round in this zone.

Blue king crab in the Pribilof District can occur as bycatch in the following crab fisheries: the eastern Bering Sea snow crab (*Chionocetes opilio*), the eastern Bering Sea Tanner crab (*chionocetes 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 2010 and the standard groundfish discards time series data updated through XXX were used in this assessment. The crab fishery retained and discard catch time series was updated with 2009/2010 data.

2. a. Total catch:
   <u>Crab pot fisheries</u>
   Retained pot fishery catches (live and deadloss landings data) are provided for 1973/1974 to 2009/2010 (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 2009/2010 fishing season

Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2008; 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

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 (lbs) 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 (see equation 3: males: A=0.000329, B=3.175; females: A=0.114389, B=1.9192), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 4).

$$\text{Weight (g)} = A * CL(mm)^B \tag{1}$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \tag{2}$$

Finally, weights were the product of average weight, CPUE, and total pot lifts in the fishery. The total weight in g was then converted to lbs by dividing the gram weight by 453.6 g/lb. 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 3, Bowers et al. 2008) 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 2008/2009, Pribilof blue king crab were not incidentally caught in any crab fishery (Table 2).

<u>Groundfish pot, trawl, and hook and line fisheries</u>

The 2009/2010 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 2008 to June 2010. 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. Current efforts are underway to provide data on a more fine spatial scale to correct this error. To estimate sex ratios for 2010 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 2009/2010, XXX t of male and female blue king crab were caught in groundfish fisheries. The catch was mostly in non-pelagic trawls (77%) and longline (23%) fisheries. The targeted species in these fisheries were yellowfin sole (77%), and Pacific cod (23%).

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. (Bowers et al. 2008; 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	0.03	4.96
1992/1993	0.00	0.00	0.00	0.44	48.63
1993/1994	0.00	0.00	0.00	0.00	27.39
1994/1995	0.00	0.00	0.00	0.02	5.48
1995/1996	0.00	0.00	0.00	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	0.03	0.18	1.07
2006/2007	0.00	0.00	0.05	0.07	0.06
2007/2008	0.00	0.00	0.07	2.00	0.11
2008/2009	0.00	0.00	0.00	0.07	0.38
2009/2010	XXX	XXX	XXX	XXX	XXX

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 3, Figure 5). Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock (Figure 6). Weight (equation 1) and maturity (equation 3) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass (t).

$$\text{Proportion mature} = 1/(1 + (3.726 * 10^{15}) * e^{(CL(mm) * -0.332)} \quad (3)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 3).

Table 3. Pribilof Islands District blue king crab abundance, mature biomass, and legal male biomass (t), and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Total males @ survey t	Total females @ survey t
1980/1981	14,801	8,151	12,701		
1981/1982	14,601	8,831	12,501		
1982/1983	7,688	4,822	6,609		
1983/1984	5,221	3,633	3,928		
1984/1985	2,232	1,837	1,801		
1985/1986	1,139	771	875		
1986/1987	1,288	1,025	1,270		
1987/1988	2,390	1,801	2,250		
1988/1989	635	562	630		
1989/1990	916	812	721		
1990/1991	2,799	2,481	1,039		
1991/1992	3,992	3,511	2,508		
1992/1993	4,159	3,651	2,499		
1993/1994	3,960	3,497	2,622		
1994/1995	2,830	2,508	2,100		
1995/1996	7,480	6,006	5,779		
1996/1997	4,509	3,574	3,461		
1997/1998	2,771	2,218	2,250		
1998/1999	3,062	2,477	2,472		
1999/2000	1,692	1,497	1,329		
2000/2001	1,878	1,665	1,529		
2001/2002	1,438	1,275	1,261		
2002/2003	617	544	585		
2003/2004	608	540	581		
2004/2005	132	118	50		
2005/2006	345	308	345		
2006/2007	177	154	127		
2007/2008	345	304	186	463	295
2008/2009	132	113	45	259	789
2009/2010	581	513	168	685	635
2010/2011	XXX	XXX	XXX	XXX	XXX

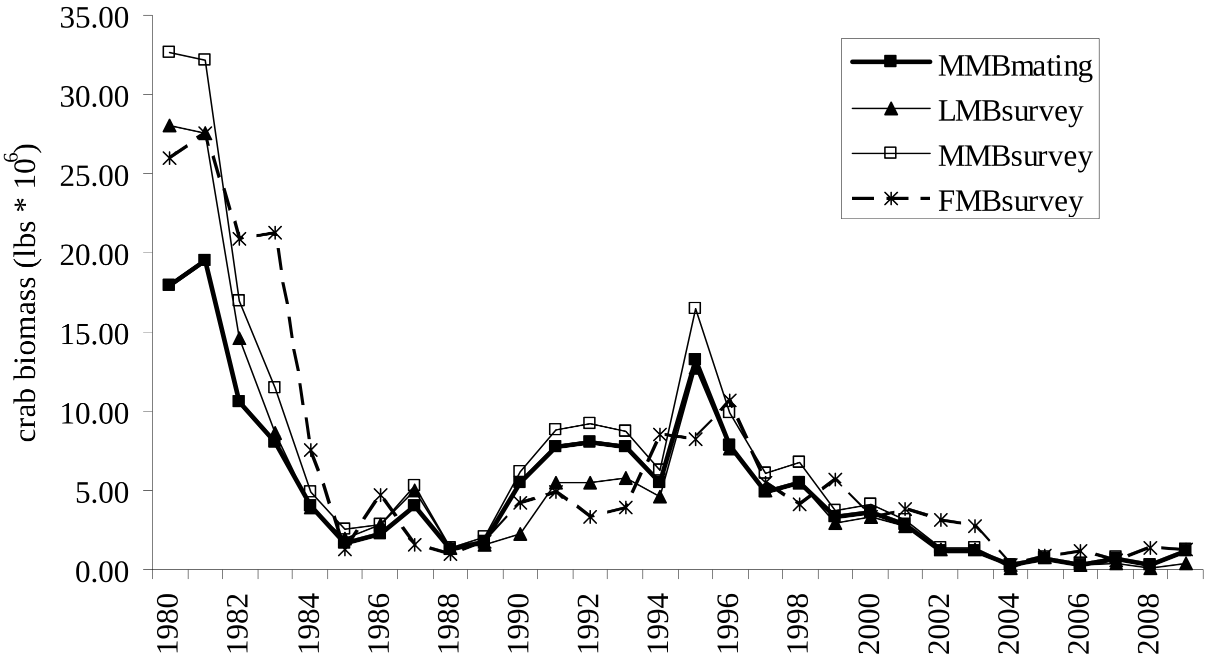


Figure 5. Historical trends of Pribilof Island blue king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

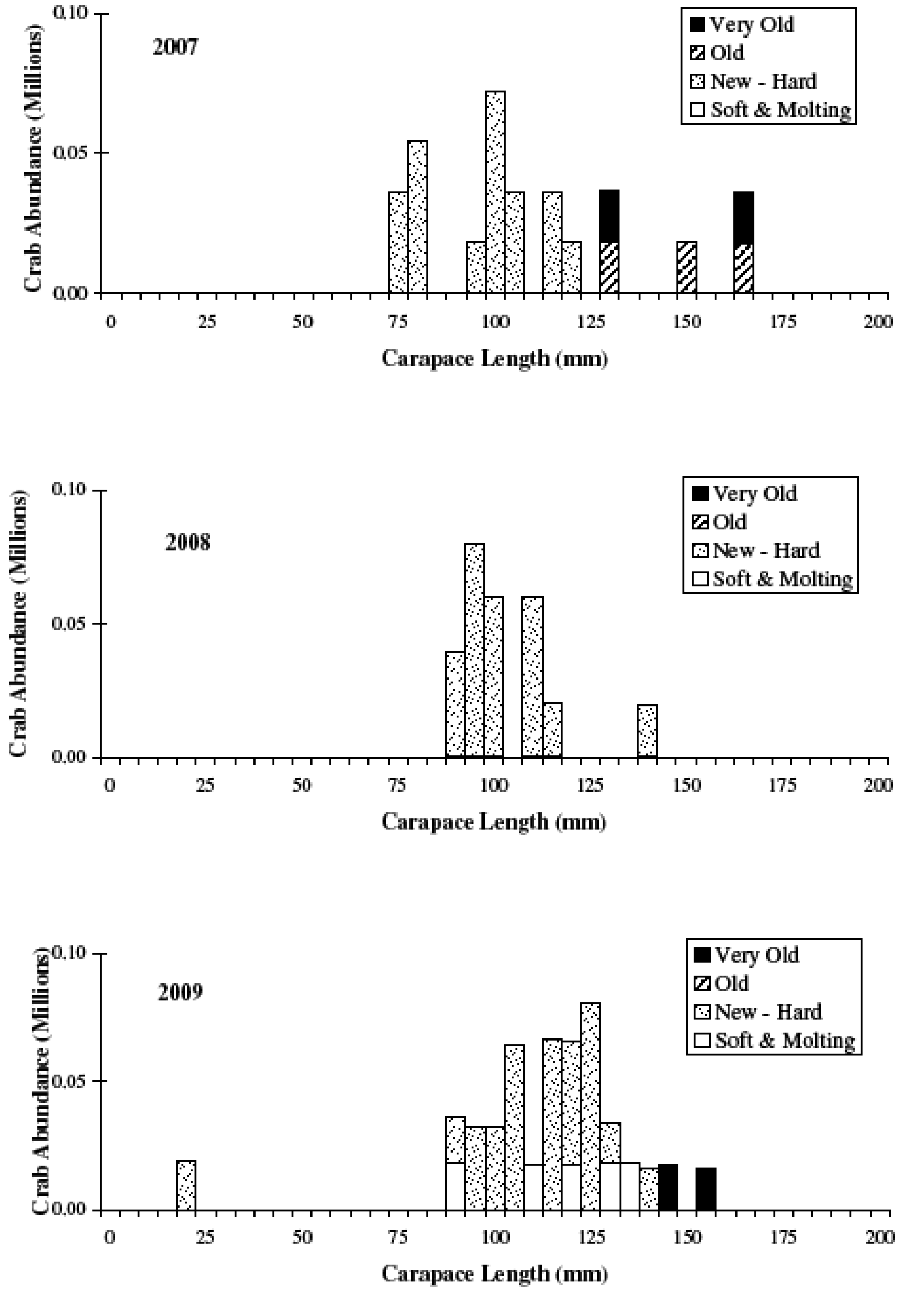


Figure 6. Distribution of Pribilof Island blue king crab in 5 mm length bins by shell condition for the last 3 surveys.

In 2009, Pribilof Island District blue king crab were observed in 6 of the 41 stations in the Pribilof District, all of which were in the high-density sampling area (Chilton et al. in press, Figure 7). Legal-sized males were caught at three stations east of St. Paul Island, with a density ranging from 73 to 131 crab/nmi^2. The 2009 abundance estimate of legal-sized males was 0.07 ± 0.08 million crab, representing 15% of the total male abundance and below the average of 0.56 million crab for the previous 20 years (Figure 8). Only 4 legal-sized male blue king crab were captured on the survey: one in molting or softshell condition and one in new hardshell condition, while two were in very oldshell condition. Large female blue king crab were caught at three stations in the Pribilof District with an abundance estimate of 0.6 ± 0.9 million crab representing 95% of the total female abundance. Fourteen of the 29 large female blue king crab sampled during the survey were brooding uneyed or eyed embryos. Among sampled mature females, 24% were new hardshell crab all with newly extruded embryos while 76% were oldshell females of which 24% were brooding eyed embryos and 52% had empty egg cases.

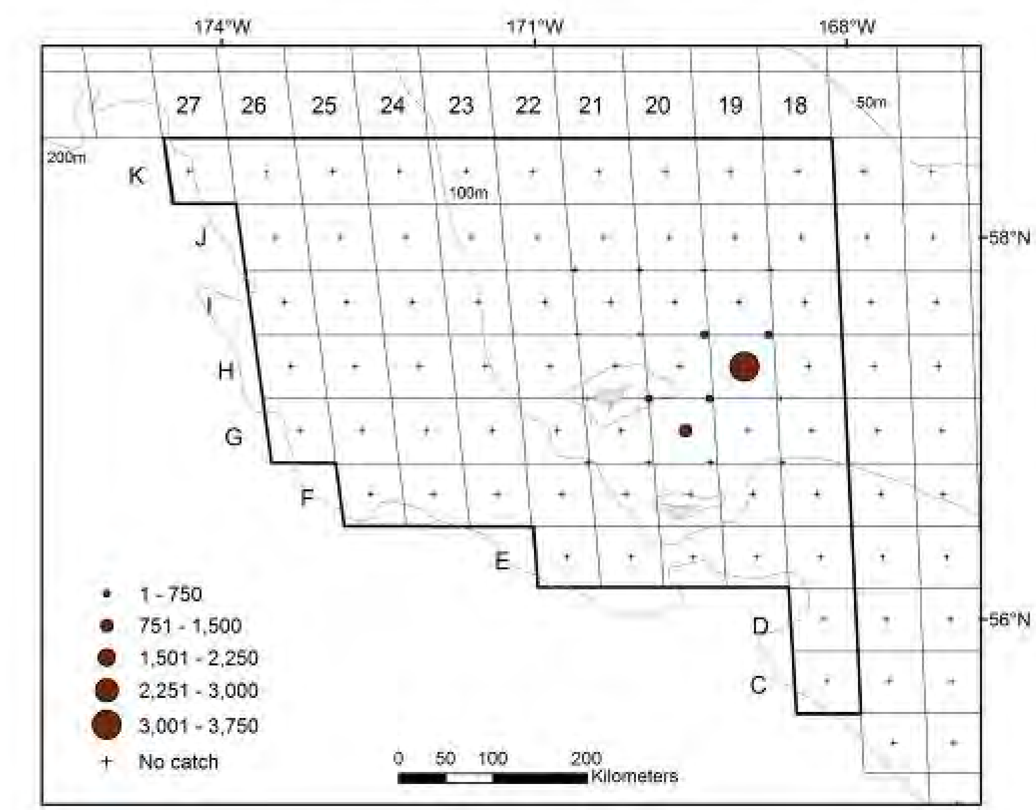


Figure 7. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2009 EBS bottom trawl survey.

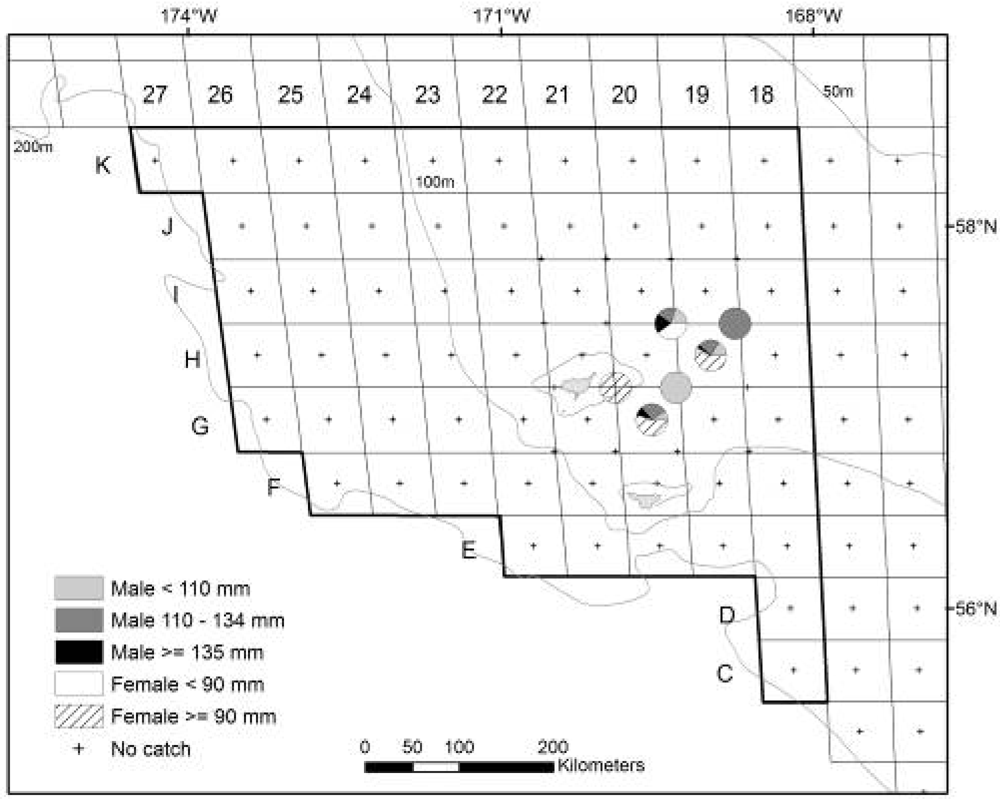


Figure 8. 2009 EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and has been developed as a separate document for potential inclusion in the 2011 stock assessment cycle.

Calculation of the OFL

1. Based on available data, the authors, the Crab Plan Team, and the Science and Statistical Committee all recommend that this stock should be classified as a Tier 4 stock 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 9). 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.

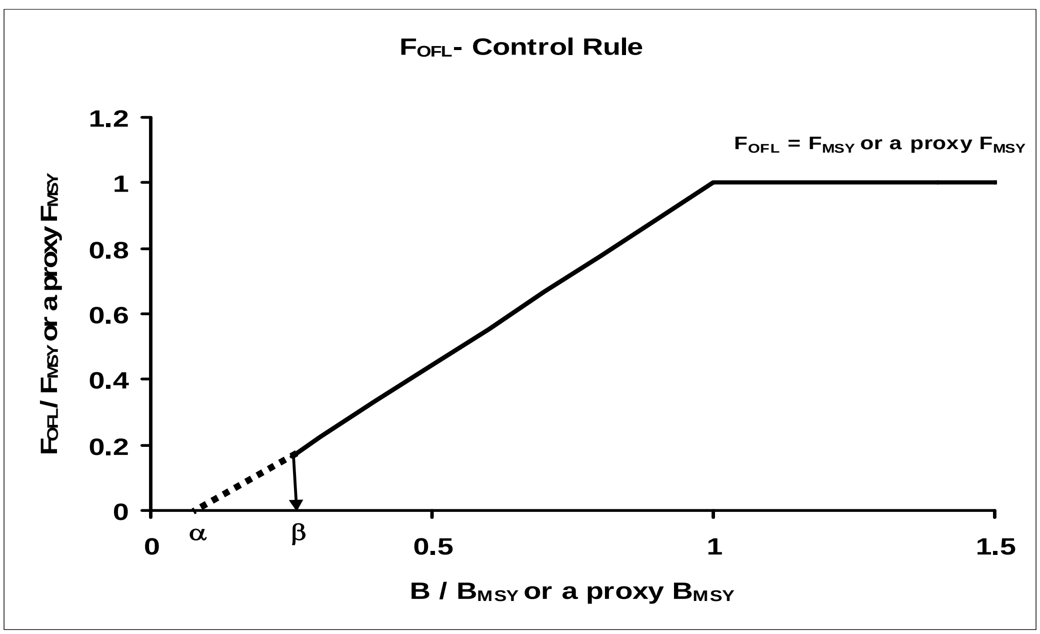


Figure 9. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

3. OFL specification:

   a. In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch

OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure 9) where Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

Stock Status Level:	F_{OFL}:	
a. $B/B_{MSY}^{prox} > 1.0$	$F_{OFL} = \gamma \cdot M$	(4)
b. $\beta < B/B_{MSY}^{prox} \leq 1.0$	$F_{OFL} = \gamma \cdot M\ [(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(5)
c. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$	(6)

B_{MSY}^{prox} for the 2009 assessment was calculated as 1) 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 and 2) the average MMB_{mating} for the entire survey period 1980 to current.

b. The MMB_{Mating} projection is based on application of M from the 2010 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:

μ_{LMB} = [Total LMB retained and non-retained catch] / $LMB_{Fishery}$ (9)

μ_{MMB} = [Total MMB retained and non-retained catch] / $MMB_{Fishery}$ (10)

Year	**MSST**	**Biomass (MMB_{mating})**	**TAC**	**Retained Catch**	**Total Catch**	**OFL**
2007/08	2,105	304[A]	0	0	2.3	
2008/09	2,041	113[B]	0	0	0.5	1.8
2009/10	XXX	513[C]	XXX	XXX	XXX	1.8
2010/11		XXX [D]				XXX

All units are tons of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2008/09 and is hence overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
B – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
C – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
D – Based on survey data available to the Crab Plan Team in September 2010

4. Recommendations:
   For 2009/2010, two levels of B_{MSY}^{prox} were defined. $B_{MSY}^{prox}{}_1$=4,209 t of MMB_{mating} derived as the mean MMB from 1980 to 1984 and 1990 to 1997 and is recommended by the authors, CPT and SSC. $B_{MSY}^{prox}{}_2$=2,368 t derived mean of 1980 to 2008 to assess the use of the entire time series. 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.

   Male mature biomass at the time of mating for 2009/2010 is estimated at 513 t for both $B_{MSY}^{prox}{}_1$ and $B_{MSY}^{prox}{}_2$ options. The B/B_{MSY}^{prox} ratios and F_{OFLs} corresponding to the two biomass reference options are, respectively, [$B/B_{MSY}^{prox}{}_1$=0.12, F_{OFL}=0.00] and [$B/B_{MSY}^{prox}{}_2$=0.22, F_{OFL}=0.00]. For both biomass reference options B/B_{MSY}^{prox} is $< \beta$, therefore the stock status level is c, $F_{directed} = 0$, and $F_{OFL} \leq F_{MSY}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008). The preferred alternative was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/2006 which was 1.8 t. This period was after a targeted fishery and did not include the most recent 2006/2007 and 2007/2008 changes to the groundfish fishery that led to increased blue king crab bycatch.

Rebuilding Analyses

Under the current rebuilding plan, this stock has to recover to the B_{MSY} proxy in 2011/12 and 2012/13 to be defined as rebuilt. As the 2008/09 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. A new rebuilding plan was initiated and is presented as a separate document.

Literature Cited

Alaska Department of Fish and Game (ADF&G). 2006. 2006-2008 commercial king and tanner crab fishing regulations. Alaska Department of Fish and Game, Juneau, AK. 160 pp.

Alaska Department of Fish and Game (ADF&G). 2008. Annual Management Report for the Commercial and Subsistence Shellfish Fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2006/07. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries, Fishery Management Report 08-02, Kodiak.

Armstrong, D.A., J.L. Armstrong, G. Jensen, R. Palacios, and G. Williams. 1987. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 67:1-278.

Armstrong, D.A., J.L. Armstrong, R. Palacios, G. Jensen, and G. Williams. 1985. Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands. Pp. 211-229 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Blau, F. S. 1997. Alaska king crabs: wildlife notebook series. Alaska Department of Fish and Game. http://www.adfg.state.ak.us/pubs/notebook/shellfsh/kingcrab.php, last accessed April 8, 2008.

Chilton, E.A., C.E. Armistead, and R.J. Foy. In press. The 2009 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-XXX, 96 p.

Feder, H., K. McCumby and A.J. Paul. 1980. The Food of Post-larval King Crab, *Paralithodes camtschatica*, in Kachemak Bay, Alaska (Decapoda, Lithodidae). Crustaceana, 39(3): 315-318.

Feder, H.M., and S.C. Jewett. 1981. Feeding interactions in the eastern Bering Sea with emphasis on the benthos. Pages 1229-1261 *in*: Hood, D.W. and J.A. Calder (eds.). The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, Office of Marine Pollution and Assessment.

Hawkes, C.R., T.R. Myers, and T.C. Shirley. 1985. The prevalence of the rhizocephalan *Briarosaccus callosus* Boschma, a parasite in blue king crabs, *Paralithodes platypus*, of southeastern Alaska. *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks. Pp. 353-364.

High, W.L., and Worlund, D.D. 1979. Escape of king crab, *Paralithodes camtschatica*, from derelict pots. NOAA Tech. Rep. No. NMFS SSRF-734.

Jensen, G.C., and D. A. Armstrong. 1989. Biennial reproductive cycle of blue king crab, *Paralithodes platypus*, at the Pribilof Islands, Alaska and comparison to a congener, *P. catschatica*. Can. J. Fish. Aquat. Sci., 46:932-940.

Jensen, G.C., D.A. Armstrong and G. Williams. 1985. Reproductive biology of the blue king crab, Paralithodes platypus, in the Pribilof Islands. Pp. 109-122 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Livingston, P.A., and B.J. Goiney, Jr. 1993. Food habits of North Pacific marine fishes: a review and selected bibliography. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-54, 81 p.

Mueter, F.J. and M.A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecological Applications 18:309–320.

Nakanishi, T. 1987. Rearing Condition of Eggs, Larvae and Post-Larvae of King Crab. Bull. Jap. Sea Reg. Fish. Res. Lab. 37: 57-161.

NMFS. 2005. APPENDIX F.3. ESSENTIAL FISH HABITAT ASSESSMENT REPORT for the Bering Sea and Aleutian Islands King and Tanner Crabs. NOAA Fisheries, Juneau, AK. 35pp.

NPFMC (North Pacific Fishery Management Council). 2003. Environmental assessment for amendment 17 to the fishery management plan for the king and tanner crab fisheries in the Bering Sea/Aleutian Islands a rebuilding plan for the Pribilof Islands blue king crab stock. North Pacific Fishery Management Council Anchorage, 101 pp.

NPFMC (North Pacific Fishery Management Council). 2008. Environmental Assessment for Amendment 24 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands: to revise overfishing definitions. Anchorage, Alaska 194 p.

NPFMC. 2008. Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2008 Crab SAFE. North Pacific Fishery Management Council Anchorage, 259pp.

Otto, R.S and P.A. Cummiskey. 1990. Growth of adult male blue king crab (*Paralithodes platypus*). pp 245-258 *in:* Proceeding of the the International Symposium on King and Tanner Crabs:, Alaska Sea Grant Report No 90-04, University of Alaska, Fairbanks, AK.

Palacios, R., D.A. Armstrong, J.L. Armstrong, and G. Williams. 1985. Community analysis applied to characterization of blue king crab habitat around the Pribilof Islands. Pp. 193-209 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Paul, A. J. and J. M. Paul. 1980. The Effect of Early Starvation on Later Feeding Success of King Crab Zoeae. J. Exp. Mar. Bio. Ecol., 44: 247-251.

Selin, N.I., and Fedotov, P.A. 1996. Vertical distribution and some biological characteristics of the blue king crab *Paralithodes platypus* in the northwestern Bering Sea. Mar. Biol. 22: 386-390.

Shirley, S.M., T. C. Shirley and T. E. Myers. 1985. Hymolymph studies of the blue (*Paralithodes platypus*) and golden (*Lithodes aequispina*) king crab parasitized by the rhizocephalan barnacle *Briarosaccus callosus*. *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks. Pp. 341-352.

Siddeek, M.S.M., L.J. Watson, S.F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data. pp 51-75 *in:* Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant Report No 02-01, University of Alaska, Fairbanks, AK.

Somerton, D.A. 1985. The disjunct distribution of blue king crab, *Paralithodes platypus*, in Alaska: some hypotheses. Pp. 13-21 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Somerton, D.A., and R. A. MacIntosh. 1983. The size at sexual maturity of blue king crab, *Paralithodes platypus*, in Alaska. Fishery Bulletin, 81(3):621-628.

Somerton, D.A., and R. A. MacIntosh. 1985. Reproductive biology of the female blue king crab *Paralithodes platypus* near the Pribilof Islands, Alaska. J. Crustacean Biology, 5(3): 365-376.

Sparks, A.K., and J.F. Morado. 1985. A preliminary report on the diseases of Alaska king crabs. in: Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No. 85-12, University of Alaska Fairbanks. Pp. 333-339.

Stevens, B. G. and K. M. Swiney. 2005. Post-settlement effects of habitat type and predator size on cannibalism of glaucothoe and juveniles of red king crab *Paralithodes camtschaticus*. J. Exp. Mar. Bio. Ecol. 321(1): 1-11.

Stevens, B.S. 2006a. Embryo development and morphometry in the blue king crab *Paralithodes platypus* studied by using image and cluster analysis. J. Shellfish Res., 25(2):569-576.

Stevens, B.S. 2006b. Timing and duration of larval hatching for blue king crab *Paralithodes platypus* Brandt, 1850 held in the laboratory. J. Crustacean Biology, 26(4):495-502.

Stevens, B.S., S.L. Persselin and J.A. Matweyou. 2008. Survival of blue king crab *Paralithodes platypus* Brandt, 1850, larvae in cultivation: effects of diet, temperature and rearing density. Aquaculture Res., 39:390-397.

Zheng, J., and D. Pengilly. 2003. Evaluation of alternative rebuilding strategies for Pribilof Islands blue king crabs. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 5J03-10, Juneau.

Zheng, J., and Kruse, G. H. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science, 57: 438–451.

Zheng, J., M.C. Murphy and G.H. Kruse. 1997. Application of a catch-survey analysis to blue king crab stocks near Pribilof and St. Matthew Islands. Alaska Fish. Res. Bull. 4(1):62-74.

St. Matthew Blue King Crab Stock Assessment in Spring 2010

Jie Zheng[1], Robert Foy[2], and David Barnard[3]

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

[2]National Marine Fisheries Service
Alaska Fisheries Science Center
Kodiak Fisheries Research Center
301 Research Court, Kodiak, AK 99615-7400

[3]Alaska Department of Fish and Game
Division of Commercial Fisheries
211 Mission Road, Kodiak, AK 99615-6399

Executive Summary

1. Stock: Blue king crab, *Paralithodes platypus*, St. Matthew Island, Alaska.
2. Catches: the directed fishery was closed from 1999 to 2008 and re-opened during 2009/10 with a retained catch of 0.461 million lbs. Trawl bycatch fluctuated over time and was 0.0134 million lbs in 2008/09.
3. Stock biomass: the stock abundance and biomass have an upward trend during recent year, and mature male biomass was above the B_{MSY} proxy in 2009.
4. Recruitment: estimated recruitment trends up during recent years and recent recruitments are close to historical high levels.
5. Management performance:

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		5.3[A]	closed	closed	0.47	
2006/07		7.1[B]	closed	closed	0.66	
2007/08		9.7[C]	closed	closed	0.35	
2008/09	4.0	10.74[D]	closed	closed	0.20	1.63 (retained)
2009/10	4.0	12.47[E]	1.167	0.461		1.72 total male catch

The stock was above MSST in 2009/10 and is hence not overfished. Overfishing did not occur during the 2009/10 fishing year.

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2006
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2007
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2008
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2009
E – Model forecast based on the 2009 assessment under the assumption that the 2009/10 catch equals to the OFL. This value will be updated during the September 2010 assessment when the 2010 survey data and the 2009/10 catch data become available.

6. Basis for the OFL:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2008/09	4a	7.387	10.743	1.454	$0.18yr^{-1}$	1989/90-2008/09	$0.18yr^{-1}$
2009/10	4a	6.952	12.732	1.832	$0.18yr^{-1}$	1989/90-2009/10	$0.18yr^{-1}$

7. A summary of the results of any rebuilding analyses: the stock has been rebuilt.

A. Summary of Major Changes in 2010

1. Areas-swept for the NMFS surveys has been re-estimated and trawl survey abundances have been re-estimated, which are similar to those estimates in 2009.
2. Survey CVs for survey biomass were used to compute likelihood values.
3. The likelihood values for biomass and proportion data were computed separately.
4. Survey CVs were added to a table and the confidence intervals were plotted with the estimated abundances.
5. Male trawl bycatch was estimated and included in the OFL.

B. Responses to SSC and CPT Comments

Response to CPT Comments (from May 2009)

"1) The model should continue to be refined for review at the May 2010 CPT meeting to allow this stock to be considered for Tier 3. 2) Bycatch data in all fisheries must be compiled to generate a total catch OFL. Note this MUST be done for the September 2009 assessment for a total catch OFL in the 2009/10 fishery. 3) Confidence intervals are needed on model output as well as CVs for survey data. The assessment needs to include figures showing data and fits to these data for both pot and trawl surveys including confidence intervals on data and model results. 4) The assessment should also examine the sensitivity of the weighting choices employed in the model to examine relative influence on results [e.g. conducting the assessment using each of the two indices of abundance in turn (pot and trawl survey)]. New recommendations include the following. 5) Include separate likelihood components for the total number of crab and the breakdown to size-class to address lack of independence in the residuals evident in the bubble plots. 6) Report the number of parameters used in each of the model scenarios. 7) Justify how

changes in molting probability affect model results. 8) Use the existing model and conduct a simulation to determine how the stock would, hypothetically, respond to fishing at the proxy for Fmsy as an exercise to inform Bmsy."

Items (1), (3), (4), (6) and (7) were addressed in the SAFE report in May 2009. Due to time constraint, these items were not examined in the report. Items (2) and (5) were addressed in this report. Male trawl bycatches were included in the model and separate likelihood components for biomass and size compositions were computed. Item (8) may be addressed in the future reports.

Response to CPT Comments (from September 2009)

"1) The model should continue to be refined for review at the May 2010 CPT meeting to allow this stock to be considered for Tier 3.

2) Bycatch data in all fisheries must be compiled to generate a total catch OFL. Note this was only done for total (male) catch OFL in the 2009/10 fishery. The model should be modified in the future to allow for the total catch OFL to include both males and females."

Male trawl bycatch data were incorporated into the model in the report. Due to space distribution, trawl surveys do not measure the female abundance very well. Future work may address the female abundance estimation.

Response to SSC Comments specific to this assessment (from June 2009 and October 2009)

"In summary, these are: (1) towards possible future Tier 3 designation, continue model refinements for review at the May 2010 Crab Plan Team meeting; (2) include bycatch in the estimation model, so that a total male catch OFL can be estimated and, ultimately, total male and female catch OFL; (3) include confidence intervals on model output and CVs for surveys; (4) examine the sensitivity of weighting choices; (5) include separate likelihood components for total number of crab and breakdown to size classes; (6) report the number of parameters for each model scenario; (7) justify how changes in molting probability affect model results; and (8) run the model to determine how the stock might respond at a F_{MSY} *proxy to inform* B_{MSY}*."*

Items (1), (3), (4), (6) and (7) were addressed in the SAFE report in May 2009. Due to time constraint, these items were not examined in the report. Items (2) and (5) were addressed in this report. Male trawl bycatches were included in the model and separate likelihood components for biomass and size compositions were computed. Item (8) may be addressed in the future reports.

C. Introduction

Blue king crab, *Paralithodes platypus* (Brant 1850), are sporadically distributed throughout their range in the North Pacific Ocean from Hokkaido, Japan to southeastern Alaska. 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 cold water areas of the Gulf of Alaska at Olga Bay- Kodiak Island and at Port Wells- Prince William Sound, Russell Fjord, Glacier Bay, Lynn Canal, and Endicott Arm- Southeast Alaska (Figure 1) (Somerton 1985). Adult blue king crab are found at depths less than 180 meters and in average bottom water temperatures of 0.6° C (NPFMC 1998). The St. Matthew Island Section for blue king crab is within the Northern District of the Bering Sea king crab registration area (Area Q2) and includes the waters north of the latitude of Cape Newenham (58°39’ N. lat.) and south of the latitude of Cape Romanzof (61°49’ N. lat.) (Figure 2) (Bowers et al. 2008).

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). These two stocks are managed separately based on different life history characteristics and exploitation by the fishery.

D. Catch History

Fisheries

The St. Matthew Island 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. The fishing seasons were generally short, lasting less than a month (Table 1). From 1986 to 1990 the fishery was fairly stable, harvesting a mean of 1.252 million pounds by <70 vessels (Table 2). The mean catch increased to 3.297 million pounds during 1991-1998. Participation increased from 68 vessels in 1991 to 174 vessels in 1992. After 1992, the St. Matthew and Pribilof Islands blue king crab fisheries were opened concurrently, dividing vessel effort between the two fisheries and initially stabilizing vessel participation at about 90 vessels. To reduce total fishing effort and improve manageability of the relatively small allowable harvests, maximum limits of 60 pots and 75 pots were set in 1993 for vessels <38.1 m and ≥38.1 m, respectively. Those limits reduced the number of pots registered by a third from 1992 to 1993 (Bowers et al. 2008). However, the number of potlifts in the fishery increased slightly because the season length doubled and pot turnover rates increased. During 1996-1998 participation increased to an average of 123 vessels per year and the average number of potlifts increased 54% from 1992 (Bowers et al. 2008).

This fishery was declared overfished and closed in 1999 when the stock size 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 1998). 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 St. Matthew Island blue king crab stock. The rebuilding plan included a harvest strategy established in regulation by the Alaska Board of Fisheries and area closures to control bycatch as well as gear modifications and an area closure for habitat protection. Since 1999, the abundance estimates calculated from the National Marine Fisheries Service (NMFS) annual eastern Bering Sea shelf survey data have not met the rebuilding plan's harvest strategy threshold or minimum TAC, although 2006 and 2007 abundance estimates, 11.2 and 15.6 million pounds respectively, were above MSST and the stock is considered rebuilding (Bowers et al. 2008). The fishery was closed during 1999-2008 and re-opened in 2009.

Zheng and Kruse (2002) hypothesized a high level of natural mortality in the St. Matthew blue king crab stock 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 nearshore pot survey, as well as the low numbers across all male crab size groups caught in the eastern Bering Sea NMFS annual trawl survey from 1999 to 2005. Watson (2005) has found similar trends in the population estimates for St. Matthew blue king crab based on the 1995-2004 ADF&G pot survey conducted triennially in the St. Matthew Island district.

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 both the St. Matthew blue king crab fishery and the eastern Bering Sea snow crab fishery. The St. Matthew Island golden king crab fishery, the third commercial crab fishery in that area, is executed in areas with depths deeper than blue king crab distribution. Discard mortality rates have been established by the NPFMC (1999) as either species or fishery specific. Bycatch mortality rates for all crab species were set at 80% in trawl fisheries, 40% in dredge fisheries, 20% in fixed gear fisheries, and 8% in king crab pot fisheries (NPFMC 2006). A higher bycatch mortality rate for the directed pot fishery was used for development of the current ADF&G harvest strategy, and we assumed the directed crab fishery mortality rate to be 20% for blue king crab in this report.

Harvest Strategy

Subject to the federal overfishing limits, the current TAC is determined based on the state harvest strategy (**5 AAC 34.917**), which was adopted by the BOF in March 2000 as part of a rebuilding plan developed for the stock (NPFMC 2000) and modified in 2009. The harvest strategy has three components for determining the TAC:

- A threshold of 2.9-million pounds of mature male biomass,
- An exploitation rate on mature male abundance that is a function of mature male biomass,
- A 40% cap on the harvest of legal males, and

Mature male biomass (MMB) is defined for the harvest strategy as the biomass of males ≥105-mm carapace length (CL) in July. When MMB is below the 2.9-million-pound threshold of the State’s harvest strategy, the stock is closed to commercial fishing. When the stock is above that threshold, an exploitation rate on mature male abundance (defined for management purposes as the abundance of all males ≥105-mm CL) is determined as a function of MMB. The exploitation rate on mature male abundance increases linearly from 10% when MMB = 2.9-million pounds to 20% when MMB = 11.6-million pounds. For MMB >11.6-million pounds, the exploitation rate remains at 20%. Application of the mature male exploitation rate to mature male abundance determines the targeted number of legal-sized males for commercial harvest. Minimum legal size is 5.5-in carapace width (CW), but 120-mm CL is used as a proxy for the size limit in stock-assessment computations. To protect from excessive harvest of the legal-sized component of the mature male stock, the targeted number of legal-sized males for commercial harvest is capped at 40% of the estimated legal-sized male abundance.

Besides the directed commercial fishery, some St. Matthew Island blue king crab have been caught in the eastern Bering Sea snow crab fishery and groundfish trawl fisheries.

E. Data

Fishery Catch Data

Vessel numbers, potlifts, catches in number and weight and CPUE for the directed pot fishery are summarized in Table 2. In this report, total annual retained catches (including deadloss) were used in the catch-survey analysis.

Trawl Survey Data

NMFS has conducted annual summer trawl surveys of St. Matthew Island blue king crab since 1978. The survey stations used to assess the St. Matthew Island blue king crab stock are located within the St. Matthew Island Section of the ADF&G Northern District. From 1978 to 1982 40 stations centered in 20 X 20 nm (37.04 X 37.04 km) cells were sampled in a total area of 16,040 nm^2. From 1983 to 2009, 2 strata were identified with low and high density of stations. The low-density strata consisted of 28 stations within a 11,228 nm^2 area and the high density strata consisted of 29 stations in a 7,619 nm^2 area. Total area calculations for each stock management unit uses an area of 401 nm^2 for each 20 X 20 nm cell due to a spherical projection of the grid surface in an area as large as the EBS.

The fishing gear used from 1978 to 1980 was a 400-mesh Eastern otter trawl with an effective path width of 12.19 m, and in 1981 was an 83-112 trawl towed by the R/V *Chapman* with an effective path width of 18 m. From 1982 to 2009 a standardized 83-112 Eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope (Acuna and Lauth 2008) was used and net width was measured from net mensuration equipment during each tow. Each tow was approximately 0.5 h in duration and 1.5 nm (2.8 km) in length at a speed of 3 knots (1.54 m/sec) (Stauffer 2004). Fishing power was assumed to be equal between vessels if more than one vessel was used.

Crab density (number/nm^2) was estimated at each station for pre-recruit 1 (105-119 mm CL), pre-recruit 2 (90-104 mm CL), recruit (newshell 120-133 mm CL), and post recruit (oldshell ≥120 mm CL and newshell ≥134 mm CL) males. The area swept by the trawl was calculated as the product of the distance traveled while the net had bottom contact by the effective width. Distance traveled by the trawl was determined from ship positions recorded at the beginning and end of each tow using LORAN or GPS equipment. Total crab population abundance within the St. Matthew Island Section management unit was estimated by averaging crab densities among all stations, multiplying by the total area of the strata, and then adding strata within the management unit. Variance was estimated by summing the estimated variances for individual strata weighted by squared area of each stratum in each year. Stage-specific area-swept survey abundance estimates that were entered into the catch-survey model are summarized in Table 3 and Figure 3.

Pot Survey Data

ADF&G performed a triennial pot survey for St. Matthew Island blue king crab in 1995, 1998, 2001, 2004 and 2007 (Watson 2008), which is able to sample from areas of important habitat for blue king crab, particularly females, that the NMFS trawl survey cannot sample from. The pot surveys were usually conducted during late July and August with a chartered commercial crab pot vessel. The 2007 survey station grid encompassed the 2,850 nmi^2 area between 59º30' - 60º30' N. latitude and 172º00' - 174º00' W. longitude and contained 141 primary stations and 24 secondary stations (Figure 4, Watson 2008). Watson (2008) described the detailed survey design, pot structures and biological sampling.

Ninety-six stations were fished in common in each of the five surveys (Figure 5, Watson 2008). Among all stations fished in each survey year, the peak catch of legal male blue king crab declined from a high of 256 crabs in 1995 to a low of 57 crabs in 2004 and increased to 119 crabs in 2007 (Figure 6). The peak catch of sublegal male crabs also declined, from a high of 167 crabs in 1995 to a low of 37 crabs in 2004 and increased to 86 crabs in 2007 (Figure 7). Peak catches of females mirrored that observed for male crabs, with a peak catch of 590 crabs in 1995 declining to a low of 50 crabs in 2004; in 2007, however, the peak catch rebounded to 490 crabs (Figure 8). The CPUE indices from these 96 stations (Table 4) were used in the catch-survey analysis.

F. Analytical Approach

Main Assumptions for the Model

A list of main assumptions for the model:

(1) Natural mortality is constant over time and stages except for 1999, which was estimated separately in the model for scenarios (1)-(3). For scenarios with a fixed natural mortality value, it was estimated with a maximum age of 25 and the 1% rule (Zheng 2005).

(2) Survey selectivities are a function of stage and are constant over time.

(3) Growth is a function of stage and does not change over time.

(4) Molting probability is a function of stage and changes over time with a random walk process.

(5) A fishing season for the directed fishery is short.

(6) Handling mortality was assumed to be 0.2 and bycatch selectivities were assumed to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s, which are similar to bycatch selectivities estimated for Bristol Bay red king crab (Zheng and Siddeek 2008).

(7) A 20% shell error was assumed for classifying recruits.

(8) Trawl survey catchability was set to be 1.0 for legal males when fixed in the model.

(9) Male crab are mature at sizes $\geq$105 mm CL.

(10) Area-swept estimates of biomass had a log-normal error structure.

Model Description

A four-stage catch-survey analysis (CSA) is principally similar to a full length-based analysis (Zheng et al. 1995) with the major difference being coarser length groups for the CSA. Because of large size categories, the CSA is particularly useful for a small stock with low survey catches each year. Currently, a four-stage CSA is used to assess abundance and prescribe fishery quotas for the St. Matthew Island blue king crab fishery.

Only male crab abundance is modeled by the CSA because the analysis requires commercial catch data and only males may be retained by the fishery. Male crab abundance was divided into four groups: prerecruit-2s ($P2$), prerecruit-1s ($P1$), recruits (R), and postrecruits (P). To be of legal size, St. Matthew Island male king crab must be ≥140 mm carapace width (regulatory measurement), corresponding to males ≥120 mm carapace length (CL). The average growth increment per molt is about 14 mm CL for adult male blue king crab (Otto and Cummiskey 1990). We categorized St. Matthew Island male blue king crab into $P2$ (90-104 mm CL), $P1$ (105-119 mm CL), R (newshell 120-133 mm CL), and P (oldshell ≥120 mm CL and newshell ≥134 mm CL).

For each stage of crab, the molting portions of crab "grow" into different stages based on a growth matrix, and the non-molting portions of crab remain in the same stage or become postrecruits. The model links the crab abundances in four stages in year t+1 to the abundances and catch in the previous year through natural mortality, molting probability, and the growth matrix:

$$
\begin{aligned}
P2_t^b &= (P2_t\, e^{-0.5M} - hc2_t\, e^{-(0.5-y_t)M_t})\, e^{-0.5M_t - st_2 Ft_t - sf_2 Ff_t}(1 - sp_2\, Ho_t\, h),\\
P1_t^b &= (P1_t\, e^{-0.5M_t} - hc1_t\, e^{-(0.5-y_t)M_t})\, e^{-0.5M_t - st_1 Ft_t - sf_1 Ff_t}(1 - sp_1\, Ho_t\, h),\\
P2_{t+1} &= P2_t^b[(1 - m2_t) + m2_t\; G_{P2,P2}] + N_{t+1},\\
P1_{t+1} &= P1_t^b[(1 - m1_t) + m1_t\; G_{P1,P1}] + P2_t^b\; m2_t\; G_{P2,P1},\\
R_{t+1} &= P2_t^b\, m2_t\; G_{P2,R} + P1_t^b\, m1_t\; G_{P1,R},\\
P_{t+1} &= [(P_t + R_t)e^{-0.5M_t} - rc_t\, e^{-(0.5-y_t)M_t}]e^{-0.5M_t - Ft_t - Ff_t}(1 - Ho_t\, h),
\end{aligned}
\qquad (1)
$$

Where $P2_t^b$ and $P1_t^b$ are prerecruit-2 and prerecruit-1 abundances after handling mortality in year t, $hc2_t$ and $hc1_t$ are pot bycatches for prerecruit-2s and prerecruit-1s, st_2, st_1, sf_2, sf_1, sp_2, and sp_1 are selectivities for prerecruit-2s and precruit-1s bycatches from groundfish trawling, groundfish fixed gear, and directed pot fisheries, Ho_t is the bycatch mortality rate from other crab fisheries, h is handling mortality rate, N_t is new crab entering the model in year t, $m2_t$ and $m1_t$ are molting probabilities for prerecruit-2s and prerecruit-1s in year t, $G_{i,j}$ is a growth matrix containing the proportions of molting crab growing from stage *i* to stage *j*, M_t is natural mortality in year *t*, rc_t is estimated commercial catch in year *t*, and y_t is the time lag from the survey to the mid-point of the fishery in year *t*. By definition, all recruits become postrecruits in the following year.

The retained catch is estimated to be

$$rc_t = (P_t + R_t)hr, \qquad (2)$$

Where *hr* is legal harvest rate at the survey time. The pot bycatches from the directed fishery are

$$\begin{aligned} hc2_t &= sp_2\, hr\, P2_t\, h, \\ hc1_t &= sp_1\, hr\, P1_t\, h. \end{aligned} \qquad (3)$$

The bycatches from the groundfish fisheries are computed as

$$\begin{aligned} tc2_t &= (P2_t\, e^{-0.5M_t} - hc2_t\, e^{-(0.5-y_t)M_t})(1-e^{-st_2\, Ft_t}), \\ tc1_t &= (P1_t\, e^{-0.5M_t} - hc1_t\, e^{-(0.5-y_t)M_t})(1-e^{-st_1\, Ft_t}), \\ tc_t &= [(P_t + R_t)e^{-0.5M_t} - rc_t\, e^{-(0.5-y_t)M_t}](1-e^{-Ft_t}), \\ fc2_t &= (P2_t\, e^{-0.5M_t} - hc2_t\, e^{-(0.5-y_t)M_t})(1-e^{-sf_2\, Ff_2}), \\ fc1_t &= (P1_t\, e^{-0.5M_t} - hc1_t\, e^{-(0.5-y_t)M_t})(1-e^{-sf_1\, Ff_1}), \\ fc_t &= [(P_t + R_t)e^{-0.5M_t} - rc_t\, e^{-(0.5-y_t)M_t}](1-e^{-Ff_t}), \end{aligned} \qquad (4)$$

Where $tc2_t$, $tc1_t$, tc_t, $fc2_t$, $fc1_t$ and fc_t are crab bycatches of precruit-2s, prerecruit-1s, and legals from the trawl and fixed gear fisheries.

Four sets of selectivities were used in the model: trawl survey, pot survey, groundfish trawl bycatch and fixed gear bycatch. These selectivities were described by a logistic function with different sets of parameters ϕ and ω:

$$S_l = \frac{1}{1+e^{-\phi(l-\omega)}}. \qquad (5)$$

S_l was scaled to be 1.0 for all legal males.

We modeled molting probability for prerecruit-1s, $m1_t$, as a random walk process:

$$m1_{t+1} = m1_t\, e^{\eta_t}, \qquad (6)$$

where η_t are independent, normally distributed random variables with a mean of zero. This allows us to model the changes in molting probability under a constraint condition.

Parameters Estimated Independently

Five scenarios of the model were developed for St. Matthew Island blue king crab, depending on parameters estimated independently and conditionally. In scenarios (1) and (4), both *M* for 1978-1998 and 2000-2009 and *Q* were fixed (estimated independently) and *M* for 1999 was independently estimated for scenario (1) and fixed for scenario (4); in model scenarios (2) and (5), *M* was estimated conditionally whereas *Q* was fixed and *M* was constant for the whole time series for scenario (5) and a different *M* value was independently estimated for 1999 for scenario (2); and in model scenario (3), *Q* was estimated conditionally and *M* was fixed for 1978-1998 and 2000-2009 and estimated for 1999:

	Scenario				
	(1)	(2)	(3)	(4)	(5)
M for 1978-1998, 2000-2009	0.18	Estimate	0.18	0.18	Estimate
M for 1999	Estimate	Estimate	Estimate	0.18	Same as above
Q	1.0	1.0	Estimate	1.0	1.0

The independently-estimated *Q* is 1. To reduce the number of parameters estimated, we used the ratio (1.44) of *m*1 to *m*2 from tagging data to estimate *m*2 from *m*1. The growth matrix was estimated from tagging data (Table 5; Otto and Cummiskey 1990). We assumed that the relative frequencies of length groups from the first-year trawl survey data approximate the true relative frequencies. Thus, we did not need to conditionally estimate length-specific abundance for the first year. Handling mortality rate was assumed to be 0.2, and to be 0.0 and 0.5 in a sensitivity study. Observer coverage was very limited for the directed fishery, and only 1-3 out of 90-131 vessels were covered from 1995 to 1998 (Moore et al. 2000). Due to limited observer data, fishery selectivities of pre-recruits 2 and 1 in the directed pot fishery were assumed to be 0.4 and 0.6 relative to legal crab, respectively, based on the results of the Bristol Bay red king crab stock assessment (Zheng and Siddeek 2008).

Natural Mortality

The estimate of natural mortality for all species of king crab 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). Siddeek et al. (2002) reexamined tagging experiments conducted around St. Matthew Island in 1995 and 1998 to estimate natural mortality (*M*). Based on a multinomial likelihood *M* estimator using returned tag data, values of *Z* (annual instantaneous total mortality) for both male and female blue king crab ranged from 0.65 to 0.74 assuming that *M* and SR (initial tagging survival/recapture ratio) did not vary by sex. Using the combined sexes returned tag data (80-157 mm CL) from the 1995 tagging experiment, the mean estimate of *M* = 0.19.

One other natural mortality estimate has been reported for St. Matthew Island blue king crab based on tagging data. Values ranged from 0.19 to 2.04 with a mean estimate of 0.81 for adult male blue king crab (105-139 mm CL) (Otto and Cummiskey 1990).

The independently-estimated *M* is 0.18 in this report, based on a maximum age of 25 and the 1% rule (Zheng 2005).

Length-weight Relationships

Based on 136 samples collected in 1978 to 1981 from St. Matthew Island (Somerton and MacIntosh 1983b), the carapace length (mm)-weight (g) relationship for blue king crab males (range = 59-147 mm) is described by the equation:

$$W = 0.000329 * CL^{3.175}, \qquad (7)$$

Somerton and MacIntosh (1983b) compared the carapace size-weight relationship of blue king crab males collected in the Bering Sea and found no statistical difference between St. Matthew Island and the Pribilof Islands stocks. Recent samples collected from both the Pribilof Islands and St. Matthew Island area in 2006 and 2007 on the annual AFSC eastern Bering Sea shelf trawl survey provide an updated carapace length-weight relationship for male blue king crab (n = 172, range = 57-172 mm) described by the equation: $W = 0.0005257 * CL^{3.1040800}$. The carapace size-weight relationship for blue king crab ovigerous females is: $W = 0.114389 * CL^{1.919200}$ and non-ovigerous females is: $W = 0.035988 * CL^{2.155575}$.

Sizes at Maturity

Blue king crab males do not have a specific morphometric indication of maturity. Earlier studies exploring the relationship of the major chela height measurement to the carapace length (CL) of an individual crab as a measurement of male maturity did not produce statistically sound results, although one study reports males from St. Matthew Island were considered mature at 77 mm CL based on this relationship (Somerton and MacIntosh 1983a). St. Matthew Island blue king crab males were found to produce spermatophores at the 50-59 mm CL size range, which indicates these crab are reaching sexual maturity at a smaller size than estimated using chela height morphology (Paul et al. 1991). ADF&G considers males mature at carapace length of $\geq$ 105 mm when estimating total mature biomass (TMB) to determine guideline harvest levels (GHL). Size at functional maturity used by the North Pacific Fishery Management Council

(NPFMC 1998) in fishery management for blue king crab males in the St. Matthew district is 105 mm carapace length.

Blue king crab females in the St. Matthew Island area are considered mature at 80.6 mm CL based on 50% maturity estimates determined by the presence of eggs or empty egg cases (Somerton and MacIntosh 1983a). They are biennial spawners, with a 14-15 month period of embryonic development, and are less fecund but with larger sized eggs (1.2 mm) than red king crab females (Somerton and MacIntosh 1985, Jensen and Armstrong 1989). Molting is necessary for egg extrusion, thus the intermolt period is two years for blue king crab females. Somerton and MacIntosh (1985) suggested that blue king crab females live longer and have larger sized eggs than red king crab females as a reproductive strategy to compensate for their biennial spawning cycle. Reproductive studies on Pribilof Island blue king crab females supports a biennial reproduction cycle for large multiparous females but found smaller, primiparous (first year of maturity) females were often able to reproduce in two consecutive years (Jensen and Armstrong 1989).

Parameters Estimated Conditionally

Estimated parameters include natural mortality, molting probabilities, catchabilities, selectivities, fishing mortalities, bycatch fishing mortalities, *M* in 1999, crab entering the model for the first time each year except the first, and total abundance in the first year (Tables 6-8). Depending on the model scenario, *M* and *Q* may be estimated conditionally (Table 6).

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

$$Rf = \prod_{l=1}^{L}\prod_{t=1}^{T}\frac{\left\{\exp\left[-\frac{(p_{l,t}-\hat{p}_{l,t})^2}{2\sigma^2}\right]+0.01\right\}}{\sqrt{2\pi\sigma^2}}, \qquad (8)$$

$$\sigma^2 = \left[\hat{p}_{l,t}(1-\hat{p}_{l,t})+0.01\right]/n,$$

where

L is the number of stage groups,

T is the number of years,

$p_{l,t}$ is observed proportions of stage l and year t,

$\hat{p}_{l,t}$ is estimated proportions of stage *l* and year *t*, and

n is the effective sample size, which was estimated to be 50% of observed sample sizes with a maximum cap of 100.

The weighted negative log-likelihood functions are:

$$Length\ compositions: \quad -\sum_i \ln(RF_i)\ ,$$

$$Biomasses\ other\ than\ survey: \quad \lambda_j \sum_t \left[\ln(C_t / \hat{C}_t)^2\right],$$

$$NMFS\ survey\ biomass: \quad \sum_t \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))\right],$$

$$Pot\ survey\ biomass\ index: \lambda_p \sum_t \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))\right],$$

$$R\ variation: \quad \lambda_R \sum [\ln(R\ deviations)^2]\ ,$$

$$Fishing\ mortality\ deviations: \quad \lambda_s \sum \left[\ln(F\ deviations)^2\right],$$

$$Molting\ probability\ deviations: \quad \lambda_m \sum \left[\ln(Molting\ probability\ deviations)^2\right].$$

Weighting factors are set as: λ_j=100 (retained catch) and 2 (trawl bycatch), λ_p = 0.2, λ_R=0.1, λ_s=0.1, and λ_m=20. Using AD Model Builder (Otter Research Ltd. 1994), we estimated parameters using the quasi-Newton method to minimize –Ln(L).

G. Model Results

Abundance and Parameter Estimates

Estimated natural mortality and trawl survey catchability and likelihood values for different scenarios are compared in Table 6, and estimated parameters with scenario (1) are summarized in Tables 7 and 8, and estimated abundance, recruitment to the model and mature male biomass are summarized in Table 8. Estimated abundance and biomass among five scenarios differed mainly during the late 1970s, late 1990s and recent years (Figure 9). Scenario (2) resulted in the lowest negative log likelihood value, and scenario (4) had the highest negative log likelihood (Table 6). The Chi-Square test was used to compare scenarios with different numbers of degrees of freedom. Scenario (2) outperformed scenarios (1) with p-value of 0.1. With a p-value of 0.05, scenario (1) is the best model, and scenario (4) is the worst one. All scenarios indicate an increasing abundance and biomass since 1999, and estimated legal abundance and mature male biomass in 2009 were the highest values since 1999 (Figure 9; Table

8). Scenarios (2) and (5) fitted the pot survey index better than the other three scenarios (Table 6).

The model fitted the trawl survey biomass very well (Figure 10). Among 33 data points, only one data point is outside of the 95% confidence interval. The CV for pot survey biomass appears to be underestimated. Three out of 5 data points are outside of the estimated 95% confidence interval of pot survey biomass index (Figure 10). A weight of 0.2 was used for the pot biomass likelihood, effectively increasing the pot survey biomass CV.

Handling mortality may also affect abundance estimates. Handling mortality reduces future recruitment to fisheries by reducing both prerecruit abundance and spawning biomass. Besides mortality, handling may also produce sublethal effects on crab, such as reduced growth (Kruse 1993). 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, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs (Moore et al. 2000). But observer data were extremely limited for the St. Matthew Island blue king crab directed pot fishery. We assumed fishery selectivities to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s and handling mortality rate to be 0.2, based on the results for Bristol Bay red king crab (Zheng and Siddeek 2008). Although estimated recruitment to the model is affected by handling mortality, handling mortality rates ranging from 0 to 50% do not affect legal male abundance and mature male biomass estimates much (Zheng et al. 2008).

Observed and model estimated retained catch and trawl bycatch biomasses were very close to each other (Figures 11 and 12). The highest catches occurred during early 1980s and the fishery was closed during 1999-2008. Estimated bycatch biomass from the directed fishery was small, relative to the retained catch (Figure 11).

The model fit the length composition data well for summer trawl survey and groundfish bycatches (Figures 13 and 14). No bias was seen from these residual plots. However, bias occurred for fitting of length composition data of pot survey: all recruits have negative residuals and all post-recruits have positive residuals (Figure 13). The model cannot account for the large proportion of recruits from pot surveys; this could be caused by large shell errors when classifying recruits and post-recruits.

Legal harvest rate was defined as the ratio of retained catch to estimated legal abundance adjusted by natural mortality to the midpoint of each fishing season. Estimated legal harvest rates were very high during 1982-1985, above 50% (Figure 15). The fishery has been closed since 1999.

likelihood profiles for estimated legal male abundance and mature male biomass in 2009 are illustrated in Figure 16. The 95% confidence intervals for legal male abundance are 1.371 million to 2.653 million of crabs. The 95% confidence intervals for mature male biomass in 2009 with the assumed fishing mortality of 0.18 are 8.605 million lbs to 17.444 million lbs.

Retrospective Analyses

Two kinds of retrospective analyses are presented in this report: (1) historical results and (2) the 2009 model 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. Assuming the estimates in 2009 as the baseline values, we can also evaluate how well the model had done in the past. The 2009 model results are based on leaving one year's data out at a time to evaluate how well the current model performs with less data.

Before 2008, the baseline scenario was scenario (2), which has been used to set the catch quota for more than 10 years. In 2008 and 2009, scenario (1) was used to set the federal OFL. Therefore, the historical results consisted of the model results from scenario (2) before 2008 and scenario (1) for 2008 and 2009, and the assessments made before 2009 came from slightly different area-swept estimates of trawl survey data because areas-swept were re-estimated for all trawl surveys in 2009. Legal male abundance and mature male biomass were slightly overestimated historically during the last 10 years (crab SAFE 2009).

The 2010 model results are compared in Figure 17 for scenario (1). Because of relatively low legal abundance from the trawl survey data during the early and mid 2000s, the estimated legal males and mature male biomass during the terminal years tended to be higher during this period than those estimated with the terminal year of 2009 for scenario (1). The bias was very small except during 2000-2003.

The 2009 model fit the survey abundance by stage directly while the 2010 model computes separate likelihood values for biomass and length composition data. The abundance and biomass estimates have the same trend over time but the exact values differ slightly, especially during the mid 1990s (Figure 18).

H. *Calculation of the OFL*

The St. Matthew Island blue king crab stock has been recommended for placement in Tier 4 (NPFMC 2007). For Tier 4 stocks, abundance estimates are available, but complete population parameters are not available for computer simulation studies and spawning biomass per recruit analyses needed for Tier 3 stocks. Average of estimated biomasses for a certain period is used to develop B_{MSY} proxy for Tier 4 stocks. We evaluated averages of mature male biomasses from four periods for a B_{MSY} proxy: 1978-2009, 1983-1998, 1983-2010, and 1989-2009 (Figure 19). The CPT selected $\gamma = 1$ for determining overfishing limits for 2008 and 2009.

Estimated B_{MSY} proxy:

Based on average during 1978-2009: 7.693 million lbs

Based on average during 1983-1998: 7.272 million lbs

Based on average during 1983-2009: 6.507 million lbs

Based on average during 1989-2009: 6.952 million lbs

The OFL is estimated by the F_{MSY} proxy, B_{MSY} proxy, and estimated male abundance and biomass:

$$F_{OFL} = \gamma M, \quad when\, B/B_{MSY} > 1, \qquad (a)$$
$$F_{OFL} = \gamma M\,(B/B_{MSY} - 0.1)/0.9, \quad when\, 0.25 < B/B_{MSY} \le 1, \quad (b)$$
$$F_{OFL} = bycatch\, mortality\, \&\, directed\ fishery\, F = 0, \quad when\, B/B_{MSY} \le 0.25, \quad (c)$$

$$OFL = [1 - \exp(-F_{OFL})]\exp(-lag\, M)[R\, w_R + P\, w_P + h\,(sp_2\, P2\, w_{P2} + sp1 P1\ w_{P1})],$$

where *lag* is the time lag from the July 1 to the start of the pot fishery, *P2*, *P1*, *R*, and *P* are estimated pre-recruits 2, pre-recruits 1, recruits and post-recruits in the terminal year, *w* is the mean weight, *h* is a handling mortality rate assumed to be 0.2, and sp_2 and sp_1 are selectivities for pre-recruits 2 and pre-recruits 1. With the choice of M = 0.18 and γ = 1 by the CPT, F_{OFL} =0.18, and these estimates are:

γ = 1:	0.180
Retained OFL:	1.448 million lbs
Total male OFL:	1.655 million lbs

Estimated mature male biomass in 2009 was 12.732 million lbs under the target level of γ = 1. The mean bycatch of the last five years was used to set trawl bycatch levels for OFL. The estimated mature male biomass in 2009 would exceed all six B_{MSY} proxies even after adjusting the catch should directed fishing be allowed in 2009. Year classes after the 1976/77 regime shift (Overland et al. 1999) were about to reach the mature population after 1982, so two of the three periods used to estimate B_{MSY} proxy started in 1983. The stock collapsed and was at a low level during the early and mid 2000s, so this period might reasonably be excluded from estimating the B_{MSY} proxy, resulting in use of the period of 1983-1998. The CPT suggested a period of 1989-2009. The period of 1978-2009 includes all data. For a given model scenario, the averages from the three periods were not greatly different.

The high abundance estimate for 2009 was primarily caused by the relatively good trawl survey abundance of prerecruit-2s in 2006 and 2008, very high trawl survey abundance of prerecuti-1s and prerecruit-2s in 2007 and 2009, and high trawl survey abundance of postrecruits in 2008, and high pot survey abundance in 2007. The stock is estimated to have been above the B_{MSY} proxy for two years.

I. Ecosystem Considerations

Ecosystem Effects on Stock

Prey Availability/Abundance Trends

Early juvenile and larval *Paralithodes* spp. are planktotrophic, actively feeding on diatoms, nauplii and copepods (Paul et al. 1979, Abrunhosa and Kittaka 1997). Blue king crab larvae are described as obligate plankton feeders (Otto 2006). Zheng and Kruse (2000) found a relationship between periods of weak year class strength in blue king crab stocks in the eastern Bering Sea and decadal climate shifts, which exhibit strong winter Aleutian lows with periods with an unstable water columns due to vertical mixing. These winter Aleutian lows may prevent diatom growth, such as *Thalassiosira* spp., that are rich in nutrients and are important prey for early stages of larval blue king crab.

Recently settled blue king crab juveniles switch from a planktivorous diet to benthic prey such as echinoderms (including sea stars, sea urchins and sand dollars), mollusks (bivalves and snails), and polychaetes, as well as other crustaceans including crab. Invertebrates accounted for 23% of the total demersal animal biomass of 15.4 million tons estimated for the eastern Bering Sea shelf. The 2007 biomass of invertebrates was composed primarily of crustaceans minus commercially important crab and shrimp species (1.4 million t), echinoderms (1.3 million t), and crab (1.3 million t) (Acuna and Lauth 2008).

Predator Population Trends

Since it is difficult to distinguish between red and blue king crab as prey items without the whole carapace, there is no predator information specific to blue king crab in data published by the AFSC food habitats laboratory. Pacific cod, Pacific halibut and skate stomachs contained small amounts of unidentified king crab collected from the eastern Bering Sea annual summer shelf survey (Lang et al. 2005).

The 2007 abundance estimate for Pacific cod in the eastern Bering Sea shelf was 423,703 metric tons, with the highest catch rate of Pacific cod occurring in the northwestern part of the eastern Bering Sea shelf. Biomass estimates of Pacific cod have been declining, although there has been an increase in population size indicating an increase in a number of smaller sized fish and suggesting the emergence of a strong year class (Acuna and Lauth 2008).

The International Pacific Halibut Commission predicts low levels of recruitment and even lower estimates of productivity for Pacific halibut in the St. Matthew Island area, resulting in a 2008 harvest level below the optimal rate of 20% (IPHC 2008). Low commercial and survey catch rates support a general decline in abundance estimates of Pacific halibut in the eastern Bering Sea (Clarke 2008).

Paralithodid species are especially vulnerable as adults when in the soft shell state just after the molting process (Loher et al. 1998) and as recently settled juveniles. Numerous planktivorous fishes prey on *Paralithodid* larvae (Livingston et al. 1993, Wespestad et al. 1994).

Changes in Habitat Quality

Table 9 lists the potential ecosystem effects by changes in habitat quality. According to Somerton (1985), blue king crab (BKC) have a restricted distribution in Alaska waters, occurring in isolated populations that are thought to be relicts from a former, broader distribution (Figure 1). The general rise in water temperature that has occurred during the present inter-glacial period is thought to be the primary factor in shaping their distribution into these isolated refuges. Somerton (1985) hypothesized that the isolated distribution of BKC could be due to three mechanisms that might come into play, either singly or in combination, following an increase in temperature: reproductive interference, competitive displacement and predatory exclusion. Due to these restricted and discrete isolated populations of BKC, they are particularly susceptible to any perturbations during critical life history stages and to their critical habitats. An increase in temperature, ocean acidification, and oil mishaps could affect their survival, reproductive success, distribution, habitat quality, recruitment success, year class strength, and predator or prey distribution.

Early life history studies of blue king crab around the Pribilof Islands during the spring of 1983 and 1984 by Armstrong et al. (1985) have demonstrated that larvae hatch in mid to late April. Although the average current patterns in the southeastern Bering Sea show a general northwest direction and slow speeds along the shelf breaks near the islands, for the local scale of the Pribilof and presumably St. Matthew Island there must be current patterns and eddies that will retain the larvae nearshore to enhance settlement to the preferred but limited refuge in the area. Armstrong et al. (1985) also pointed out that in certain years it would be probable that anomalous events could occur that would transport larvae well beyond the Pribilof Islands, resulting in settlement into unfavorable habitats and very low survival.

Juvenile blue king crab (<30 mm carapace length) are known to occur predominately along nearshore rocky and shell hash (a mixture of broken bivalve and gastropod shells) habitats near the Pribilof Islands, and these habitats are considered vital refuge from predation and for successful recruitment (Palacios et al. 1985). Shell hash is a key material for refuge and thus the survival of blue king crab is ultimately linked to certain mollusk species that are abundant within the species assemblage that characterize the BKC juvenile habitat along the Pribilof Islands (Armstrong et al. 1985). The preferred shelltype epibenthic substrate for juvenile BKC was composed primarily of four species of bivalves (*Serripies groenlandicus*, *Spisula polynyma*, *Chlamys sp.*, *Modiolus modiolus*), and large neptunid gastropods. Shells of this type were usually intact or in large pieces and usually covered with dense epiphytic growth including feathery bryozoans, barnacles, anemones, and ascidians.

Male and female adult blue king crab along the Pribilof Islands had a high occurrence offshore on deeper, mud-sand substrates. In August of 1998, ovigerous females occurred in high abundance and dominated all catches (99% females, almost all ovigerous) along mostly rocky habitats in nearshore waters sampled during St Matthew Island pot surveys (Blau and Watson 1999). A high percentage of mature blue king crabs also occurred in the vicinity of St. Matthew Island during a trawl survey in 1983 (NMFS 1984) and have not been located anywhere else in the Bering Sea (Armstrong et al. 1985, Palacios et al. 1985, Moore et al. 1998). The high incidence of ovigerous females during the 1998 pot survey occurred at depths from 7 to 20 fathoms in mostly rocky habitats and CPUE (number of crab per pot) ranged from 10 at 7 fm to 146 at 8 fm, whereas CPUE of all males at those depths was <2. The nearshore rocky habitats of St Matthew Island are very important habitat for ovigerous females during the summer and fall months. Nearshore dive surveys along St. Matthew Island by the Alaska Department of Fish & Game (ADF&G) have not revealed juvenile blue king crab nor have their habitat associations been described (Blau 2000).

Recently several studies have investigated the effects of temperature on embryonic development, hatch timing, respiration, and larval survival of BKC (Stevens 2006a, Stevens 2006b, Stevens et al. 2008). This research will aid in understanding the impacts of climate change, especially seawater warming, on BKC production.

Due to their restricted distribution along the Pribilof and St Mathews Islands, blue king crab are considered highly vulnerable to oil mishaps (Armstrong et al. 1987). There have been numerous studies that have investigated the potential impacts of oil on blue king crab along the Pribilof Islands (Armstrong et al. 1983, Armstrong et al. 1987, Laevastu et al. 1985). The life history stages considered most vulnerable are the larval stages since they are in the water column and would follow the same currents as the oil. The restricted distribution of early juveniles on and in substrates such as shellhash and gravel/cobble that are limited to the Pribilof Islands (compared to hundreds of km in all directions) underscores the unique habitat required by this species. The high concentrations and dominance by ovigerous females that occur in nearshore waters during the summer and fall would be at great risk during an oil mishap for St. Matthew and the Pribilof Islands. If oil reaches these islands the impact on BKC could be great depending on a variety of biological and physical factors (Laevastu et al. 1985).

Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects (M. Sigler, AFSC NOAA Fisheries, pers. comm.). These effects have been measured as decreased pH of the water, as well as measurable increases in dissolved inorganic carbon over a large section of the northeastern Pacific suspected to be a problem in surface water affecting calcifying planktonic organisms in the northeast Pacific Ocean (R. Feely, NOAA PMEL, pers. comm.). Some investigators believe that the effects of decreased calcification in microscopic algae and animals could impact food webs and, combined with other climatic changes in salinity, temperature and upwelled nutrients, could substantially alter the biodiversity and productivity of the ocean (Orr et al. 2005). A recent trial laboratory study has shown a 15% reduction in growth and 67% reduction in survival when pH was reduced 0.5 units (Litzow et al., trial data, AFSC NOAA Fisheries). Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival. Current studies underway will investigate the effect pH has on survival, growth, and morphology of larval and juvenile blue and red king crab (K. Swiney, NMFS/AFSC/Kodiak Lab, pers. comm.).

Disease

Diseases that may infect *Paralithodid* species include a herpes-type viral disease of the bladder, a pansporoblastic microsporidian (*Thelohania* sp.), and a parasitic rhizocephalan (*Briarosaccus* sp.) which feeds on female egg clutches (Sparks and Morado 1997).

Fishery Effects on the Ecosystem

The St. Matthew blue king crab commercial fishery has been closed since 1999. Non-retained blue king crab such as females and sub-legal males may have been caught in previous directed fishing for St. Matthew blue king crab and eastern Bering Sea snow crab commercial fisheries (see bycatch in directed fishery section).

Seapens or seawhips, corals, anemones, and sponges are species groups in the eastern Bering Sea considered as Habitat Areas of Particular Concern (HAPC), which are defined as living substrates in shallow or deep waters, although not many corals (gorgonians, soft corals and stony corals) are encountered on the EBS shelf. Relative CPUE from EBS shelf survey data 1982-2007 is available for these species groups but the survey gear is not appropriate for effective sampling of these types of organisms and survey results provide imprecise abundance information. Since most of the eastern Bering Sea survey stations are repeated from survey to survey, apparent decreases in abundance for many of the slow growing HAPC organisms could result from repeated trawling of these areas by the survey (Lauth 2007).

J. Acknowledgments

We thank Doug Woodby and Douglas Pengilly of ADF&G for reviewing the earlier draft of this report. The study was funded, in part, by cooperative agreement from the National

Oceanic and Atmospheric Administration (NOAA). The views expressed are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

K. References

Abrunhosa, F.A. and J.K. Kittaka. 1997. Functional morphology of mouthparts and foregut of the last zoea, glaucothoe and first juvenile of the king crabs *Paralithodes camtschaticus, P. brevipes and P. platypus.* Fisheries Sci. 63(6):923-930.

Acuna, E. and R. R. Lauth. 2008. Results of the 2007 eastern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-181, 195 pp.

Armstrong, D.A., L.S. Incze, J.L. Armstrong, D.L. Wencker, and B.R. Dumbauld. 1983. Distribution and Abundance of Decapod Crustacean Larvae in the Southeast Bering Sea with Emphasis on Commercial Species. Final Report of Principal Investigators for the Year Ending 1983, RU 609. USDOC, NOAA, OCSEAP, Office of Marine Pollution Assessment, 406 pp.

Armstrong, D. A., R. Palacios, G. Williams, G. C. Jensen, and W. Pearson. 1985. Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands. Pages 211-230 *in* Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program Report 85-12. University of Alaska Fairbanks.

Armstrong, D.A., J.L. Armstrong, G. Jensen, R. Palaios, and G. Williams. 1987. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands. Final report on 1983-1984 data. Contract No. 83-ABC-00066 from OCSEAP/OMPA. School of Fisheries WH-10 University of Washington Seattle, WA 98195.

Blau, S. F. 2000. Nearshore blue king crab survey St. Matthew Island, 1999. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K00-42 Kodiak, Alaska.

Blau, S.F. and L.J. Watson. 1999. St. Matthew Island blue king crab survey, 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K99-66, Kodiak, Alaska.

Bowers, F.R., M. Schwenzfeier, S. Coleman, B. Failor-Rounds, K. Milani, K. Herring, M. Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the westward region's shellfish observer program, 2006/07. Alaska Department of Fish and Game, Fishery Management Report No. 08-02, Anchorage. 230 pp.

Clarke, W., G. and S. R. Hare. 2008. Assessment of the Pacific halibut stock at the end of 2007. p. 27. International Pacific Halibut Commission, Seattle, WA.

International Pacific Halibut Commission. 2008. Summary of 2008 International Pacific Halibut Commission annual meeting, p.7. International Pacific Halibut Commission, Seattle, WA.

Jensen, G. C. and D. A. Armstrong. 1989. Biennial reproduction cycle of blue king crab, *Paralithodes platypus*, at the Pribilof Islands, Alaska, and comparison to a congener, *P. camtschatica*. Can. J. Fish. Aquat. Sci. 46:932-940.

Kruse, G.H. 1993. Biological perspectives on crab management in Alaska. Pages 355-384 *in*: G.H. Kruse, D.M. Eggers, R.J. Marasco, C. Pautzke & T.J. Quinn II (eds.), Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. University of Alaska Fairbanks, Alaska Sea Grant Rep. 93-02.

Lang, G. M., P. A. Livingston, and K.A. Dodd. 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 to 2001. U. S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-158. 230 pp.

Lauth, R. R. 2007. HAPC biota- Bering Sea. *In* J. Bolt (editor) Appendix C. Ecosystems Considerations for 2008. North Pacific Fishery Management Council, Anchorage, Alaska.

Laevastu, T., R. Marasco, N. Bax, F. Fredkin, F. Fukuhara, A. Gallagher, T. Honkalehto, J. Ingraham, P. Livingston, R. Miyahara, and N. Pola. 1985. Evaluation of the effects of oil development on the commercial fisheries in the eastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 36(1):1-48.

Livingston, P.A., Ward, A., Lang, G.M. and Yang, M-S. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-AFSC-11,192 pp.

Loher, T., Hill, P.S., Harrington, G. and Cassano, E. 1998. "Management of Bristol Bay red king crab: a critical intersections approach to fisheries management." Rev. Fish. Sci.6(3):169-251.

Moore, H., L.C. Byrne, and D.E. Connolly. 1998. Alaska Department of Fish and Game summary of the 1997 mandatory shellfish observer program database. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 4K98-50 Kodiak, Alaska.

Moore, H., L.C. Byrne, and D. Connolly. 2000. Alaska Department of Fish and Game summary of the 1998 mandatory shellfish observer program database. Alaska Dept. Fish and Game, Commercial Fisheries Division, Reg. Inf. Rep. 4J00-21, Kodiak. 146 pp.

National Marine Fisheries Service. 1984. Cruise results, cruise no. 83-01 charter vessel *Valiant*. National Marine Fisheries Service, Northwest and Alaska Fisheries Science Center, Seattle.

North Pacific Fishery Management Council (NPFMC). 1998. Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs. North Pacific Fishery Management Council, Anchorage, Alaska.

North Pacific Fishery Management Council (NPFMC). 1999. Environmental assessment/Regulatory Impact review/initial regulatory flexibility analysis for Amendment 11 to the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner crabs. North Pacific Fishery Management Council, Anchorage, Alaska.

North Pacific Fishery Management Coucil (NPFMC). 2000. Environmental assessment/regulatory impact review/initial regulatory flexibility analysis for proposed Amendment 15 to the Fishery Management Plan for king and Tanner crab fisheries in the Bering Sea/Aleutian Islands and regulatory amendment to the Fishery Management Plan for the groundfish fishery of the Bering Sea and Aleutian Islands area: A rebuilding plan for the St. Matthew blue king crab stock. North Pacific Fishery Management Council, Anchorage, AK. Draft report.

North Pacific Fishery Management Council (NPFMC). 2006. Bering Sea Habitat Conservation: Evaluating the need for possible protection measures for St. Matthew blue king crab and eastern Bering Sea snow crab. North Pacific Fishery Management Council, Anchorage, Alaska. 42 pp.

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

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R. Feely, A.Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. G. Najjar, Gian-Kasper Plattner, K. B. Rodgers, C. L. Sabine, Jorge L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdell, Marie-France Weirig, Y. Yamanaka and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437: 681-686.

Otter Research Ltd. 1994. An introduction to AD Model Builder: for use in nonlinear modeling and statistics. Otter Research Ltd., Nanaimo, British Columbia.

Otto, R.S. 1990. An overview of eastern Bering Sea king and Tanner crab fisheries. Pages 9-26 *in* Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Program Report 90-4.

Otto, R.S. 2006. A review of worldwide fisheries for lithodid crabs (Decapoda: Anomura: Lithodidae) and their fluctuations. Biology of Anomura II (A.Asakura, editor), Crustacean Research, Special Number 6:167-185, 2006.

Otto, R.S., and P.A. Cummiskey. 1990. Growth of adult male blue crab (*Paralithodes platypus*). In: Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Rep. 90-4, pp. 245-258.

Paul, A.J., Paul, J.M., Shoemaker, P.A. and Feder, H.M. 1979. Prey concentrations and feeding response in laboratory-reared stage-one zoeae of king crab, snow crab, and pink shrimp. Trans. Am. Fish. Soc. 108: 440-443.

Paul, J. M., A. J. Paul, R. S. Otto, and R. A. MacIntosh. 1991. Spermatophore presence in relation to carapace length for eastern Bering Sea blue king crab (*Paralithodes platypus*, Brandt, 1850) and red king crab (*P. camtschaticus* (Tilesius, 1815)). J. Shellfish Res. 10(1):157-163.

Palacios, R., D. A. Armstrong, J. L. Armstrong, and G. Williams. 1985. Community analysis applied to characterization of blue king crab habitat around the Pribilof Islands. Pages 193-209 *in* Proceedings of the international king crab symposium. Alaska Sea Grant Program Report 85-12, University of Alaska Fairbanks.

Siddeek, M. S. M., L. J. Watson, S. F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data. Pages 51-75 *in* Crabs in cold water regions: Biology, management, and economics. Alaska Sea Grant College Program Report 02-01, University of Alaska Fairbanks.

Somerton, D.A. 1985. The disjunct distribution of blue king crab, *Paralithodes platypus*, in Alaska: some hypotheses. Pages 13-21 *in* Proceedings of the international king crab symposium. Alaska Sea Grant Program Report 85-12, University of Alaska Fairbanks.

Somerton, D. A. and R. A. MacIntosh. 1983a. The size at sexual maturity of blue king crab, *Paralithodes platypus*, in Alaska. Fish Bull. U.S. 81:621-628.

Somerton, D. A. and R. A. MacIntosh. 1983b. Weight-size relationships for three populations in Alaska of the blue king crab, *Paralithodes platypus* (Brandt, 1850) (Decapoda, Lithodidae). Crustaceana 45(2):169-175.

Somerton, D. A. and R. A. MacIntosh. 1985. Reproductive biology of the female blue king crab *Paralithodes platypus* near the Pribilof Islands, Alaska. J. Crust. Biol. 5:365-376.

Sparks, A. K. and J. F. Morado. 1997. Some diseases of northeastern Pacific commercial crabs. J. Shellfish Res. 16(1):321.

Stauffer, G. 2004. NOAA protocols for groundfish bottom trawl surveys of the nation's fishery resources. U.S. Dep. Commerce, NOAA Tech. Memo. NMFSF/SPO-65.

Stevens, B.G. 2006a. Embryonic development and morphometry in the blue king crab, *Paralithodes platypus*, studied by image and cluster analysis. J. Shellfish Res. 25(2):569-576.

Stevens, B.G. 2006b. Timing and duration of larval hatching for blue king crab *Paralithodes platypus*, held in the laboratory. J. Crust. Biol. 26(4):495-502.

Stevens, B.G., S. Persselin, and J. Matweyou. 2008. Survival of blue king crab larvae, *Paralithodes platypus,* in cultivation: Effects of diet, temperature, and density. Aquaculture Res. 39:390-397.

Watson, L.J. 2005. The 2004 triennial St. Matthew Island blue king crab survey and comparisons to the 1995, 1998, and 2001 survey. Alaska Department of Fish and Game Fishery Management report 05-22.

Watson, L. J. 2008. The 2007 triennial St. Matthew Island blue king crab survey and comparisons to historic surveys. Alaska Department of Fish and Game, Fishery Management Report No. 08-XX, Anchorage. In press.

Wespestad, V.G., Livingston, P.A. and Reeves, J.E. 1994. Juvenile sockeye salmon (*Oncorhynchus nerka*) predation on Bering Sea red king crab (*Paralithodes camtschaticus*) larvae as a cause of recruitment variation. ICEC C.M. 1994/R:10, Copenhagen, 10 pp.

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

Zheng, J. and G. H. Kruse. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES J. Mar. Sci. 57(2): 438-451.

Zheng, J., and G.H. Kruse. 2002. Assessment and management of crab stocks under uncertainty of massive die-offs and rapid changes in survey catchability. Pages 367-384 *In* A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

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

Zheng, J., M.C. Murphy, and G.H. Kruse. 1997. Application of catch-survey analysis to blue king crab stocks near Pribilof and St. Matthew Islands. Alaska Fish. Res. Bull. 4:62-74.

Zheng, J. and M.S.M. Siddeek. 2008. Bristol Bay red king crab stock assessment in fall 2008. A draft report for the crab SAFE reports.

Table 1. Harvest level, economic performance and season length summary for the Saint Matthew Island Section commercial blue king crab fishery, 1983 -2006/07 (Bowers et al., 2008).

		Value		Season Length	
Season	GHL/TAC[a]	Ex-vessel[b]	Total[c]	Days	Dates
1983	8	$3.00	$25.80	17	08/20-09/06
1984	2.0-4.0	$1.75	$6.50	7	09/01-09/08
1985	0.9-1.9	$1.60	$3.80	5	09/01-09/06
1986	0.2-0.5	$3.20	$3.20	5	09/01-09/06
1987	0.6-1.3	$2.85	$3.10	4	09/01-09/05
1988	0.7-1.5	$3.10	$4.00	4	09/01-09/05
1989	1.7	$2.90	$3.50	3[d]	09/01-09/04
1990	1.9	$3.35	$5.70	6	09/01-09/07
1991	3.2	$2.80	$9.00	4	09/16-09/20
1992	3.1	$3.00	$7.40	3[d]	09/04-09/07
1993	4.4	$3.23	$9.70	6	09/15-09/21
1994	3.0	$4.00	$15.00	7	09/15-09/22
1995	2.4	$2.32	$7.10	5	09/15-09/20
1996	4.3	$2.20	$6.70	8	09/15-09/23
1997	5.0	$2.21	$9.80	7	09/15-09/22
1998	4.0[e]	$1.87	$5.34	11	09/15-09/26
1999-2006/07			FISHERY CLOSED		

[a]Guideline harvest level in millions of pounds. Total allowable catch for IFQ beginning in 2005.

[b]Average price per pound.

[c]Millions of dollars.

[d]Actual length - 60 hours.

[e]General fishery only.

Table 2**.** Saint Matthew Island Section commercial blue king crab fishery data, 1977 - 2006/07 (Bowers et al., 2008).

	Number of				Number of Pots		Percent	Average			
Season	Vessels	Landings	Crabs[a]	Harvest[a,b]	Registered	Pulled	Recruits	Weight[b]	CPUE[c]	Length[d]	Deadloss[b]
1977	10	24	281,665	1,202,066	NA	17,370	7	4.3	16	130.4	129,148
1978	22	70	436,126	1,984,251	NA	43,754	NA	4.5	10	132.2	116,037
1979	18	25	52,966	210,819	NA	9,877	81	4.0	5	128.8	128.8
1980	CONFIDENTIAL										
1981	31	119	1,045,619	4,627,761	NA	58,550	NA	4.4	18	NA	53,355
1982	96	269	1,935,886	8,844,789	NA	165,618	20	4.6	12	135.1	142,973
1983	164	235	1,931,990	9,454,323	38,000	133,944	27	4.8	14	137.2	828,994
1984	90	169	841,017	3,764,592	14,800	73,320	34	4.5	11	135.5	31,983
1985	79	103	441,479	2,200,781	13,000	47,748	9	5.0	9	139	2,613
1986	38	43	219,548	1,003,162	5,600	22,073	10	4.6	10	134.3	32,560
1987	61	62	227,447	1,039,779	9,370	28,230	5	4.6	8	134.1	600
1988	46	46	302,098	1,325,185	7,780	23,058	65	4.4	30	133.3	10,160
1989	69	69	247,641	1,166,258	11,983	30,803	9	4.7	8	134.6	3,754
1990	31	38	391,405	1,725,349	6,000	26,264	4	4.4	15	134.3	17,416
1991	68	69	726,519	3,372,066	13,100	37,104	12	4.6	20	134.1	216,459
1992	174	179	545,222	2,475,916	17,400	56,630	9	4.6	10	134.1	1,836
1993	92	136	630,353	3,003,089	5,895	58,647	6	4.8	11	135.4	3,168
1994	87	133	827,015	3,764,262	5,685	60,860	60	4.6	14	133.3	46,699
1995	90	111	666,905	3,166,093	5,970	48,560	45	4.8	14	135	90,191
1996	122	189	660,665	3,078,959	8,010	91,085	47	4.7	7	134.6	36,892
1997	117	166	939,822	4,649,660	7,650	81,117	31	4.9	12	139.5	209,490
1998	131	255	612,440	2,869,655	8,561	89,500	46	4.7	7	135.8	15,107
1999-2006/07	FISHERY CLOSED										

[a]Deadloss included.
[b]In pounds.
[c]Number of legal crabs per pot lift.
[d]Carapace length in millimeters.
NA = Not available.

Table 3. NMFS EBS summer trawl survey area-swept estimates of abundance (million of crab) and associated CV for 4 length groups. In this and subsequent tables, P2 is an abbreviation for the prerecruit 2 length group; P1 = prerecruit 1, R = recruits, and P = postrecruits.

Year	P2	P1	R	P	Matures	Legals	Total bio.	CV
1978	2.384	2.268	1.182	0.582	4.032	1.764	16.081	0.394
1979	2.939	2.225	1.821	0.402	4.448	2.223	18.128	0.404
1980	2.539	2.456	1.495	1.371	5.322	2.867	21.937	0.506
1981	0.477	1.233	0.970	1.376	3.579	2.346	14.141	0.402
1982	1.713	2.495	3.123	2.864	8.482	5.987	34.222	0.343
1983	1.078	1.663	1.395	1.968	5.027	3.363	20.611	0.297
1984	0.410	0.499	0.769	0.709	1.977	1.478	8.156	0.184
1985	0.381	0.376	0.489	0.635	1.500	1.124	6.455	0.210
1986	0.206	0.457	0.179	0.198	0.833	0.377	3.037	0.386
1987	0.325	0.631	0.477	0.238	1.346	0.715	4.881	0.291
1988	0.410	0.816	0.505	0.452	1.772	0.957	6.648	0.251
1989	2.164	1.158	0.886	0.906	2.951	1.792	13.771	0.271
1990	1.053	1.031	1.075	1.263	3.370	2.338	14.314	0.274
1991	1.135	1.680	1.306	0.930	3.916	2.236	15.059	0.249
1992	1.074	1.382	1.184	1.107	3.672	2.291	14.748	0.200
1993	1.521	1.828	1.459	1.818	5.104	3.276	21.110	0.169
1994	0.883	1.298	1.183	1.074	3.555	2.257	14.090	0.176
1995	1.025	1.188	0.910	0.831	2.929	1.741	11.828	0.178
1996	1.238	1.891	1.466	1.598	4.956	3.064	19.726	0.240
1997	1.165	2.228	2.056	1.733	6.017	3.789	23.179	0.337
1998	0.660	1.661	1.249	1.600	4.510	2.849	17.565	0.355
1999	0.223	0.222	0.164	0.393	0.780	0.558	3.469	0.182
2000	0.282	0.285	0.292	0.449	1.025	0.740	4.437	0.310
2001	0.419	0.502	0.324	0.614	1.440	0.938	6.123	0.246
2002	0.111	0.230	0.161	0.479	0.870	0.640	3.749	0.321
2003	0.449	0.280	0.157	0.308	0.745	0.465	3.477	0.335
2004	0.247	0.184	0.252	0.310	0.746	0.562	3.292	0.304
2005	0.319	0.310	0.258	0.243	0.811	0.501	3.372	0.370
2006	0.917	0.642	0.682	0.558	1.882	1.240	8.166	0.333
2007	2.518	2.020	0.681	0.512	3.212	1.193	13.574	0.384
2008	1.352	0.801	0.529	0.927	2.257	1.457	10.565	0.284
2009	1.573	2.161	0.597	0.813	3.571	1.410	13.754	0.256

Table 4. Crabs per pot lift for the pot surveys from the common 96 stations performed during the 1995-2007 ADF&G triennial St. Matthew Island blue king crab pot survey.

Year	P2	P1	R	P
1995	1.919	3.198	3.214	3.708
1998	0.964	2.763	3.906	4.898
2001	1.266	1.737	2.378	3.109
2004	1.719	0.453	0.299	0.826
2007	0.500	2.721	2.773	2.063

Table 5. Growth matrix for St. Matthew Island blue king crab.

	Growth Matrix (*G*): From Prerecruit-2s	Prerecruit-1s
Prerecruit-2s	0.11	0.00
Prerecruit-1s	0.83	0.11
Recruits	0.06	0.83
Postrecruits	0.00	0.06

Table 6. Negative log likelihood values for a catch-survey analysis of St. Matthew Island blue king crab with data from 1978 to 2009. Five scenarios of the model are (1) fixed M = 0.18 and Q=1 with 2 *Ms*, (2) fixed Q = 1 and estimating M with 2 *Ms*, (3) fixed M = 0.18 and estimating Q with 2 *Ms*, (4) fixed M = 0.18 for the whole time series and Q=1, (5) fixed Q = 1 and estimating M for the whole time series. An M value is estimated for 1999 with the "2 *Ms*" scenario. A value of "fix" indicates that it is fixed in the model.

	Model Scenario				
Parameter	(1)	(2)	(3)	(4)	(5)
Natural mortality for years other than 1999	fix	0.245	fix	fix	0.286
Natural mortality in 1999	1.416	1.298	1.451	fix	0.286
Trawl survey catchability (Q)	fix	fix	0.921	fix	fix
Negative log likelihood components					
Trawl survey niomass	15.520	15.534	15.633	20.661	21.100
Pot survey biomass	12.250	10.777	12.230	12.664	10.205
Retained catch biomass	1.071	1.112	1.016	1.472	1.362
Trawl bycatch biomass	0.177	0.173	0.223	0.130	0.139
Fixed gear bycatch biomass	0.079	0.084	0.079	0.079	0.089
Trawl survey length composition	-196.66	-195.74	-197.13	-193.20	-193.72
Pot survey length composition	-38.304	-40.062	-38.146	-34.058	-39.238
Trawl bycatch length composition	-15.877	-15.900	-15.888	-15.797	-15.860
Fixed gear bycatch length composition	-45.941	-46.391	-46.013	-44.871	-45.267
Other penalty	14.901	14.791	14.809	15.853	15.846
Total	-252.78	-255.62	-253.18	-237.06	-245.35
Total number of parameters	145	146	146	144	145

Table 7. Summary of parameter estimates (excluding molting and recruitment in the next table) for scenario (1).

Parameter	Value	Std. deviation	Parameter	Value	Std. deviation	Parameter	Value	Std. deviation
M99	1.4163	0.2106	F_mean	-4.9521	0.1991	F_trawl	-9.0000	0.0009
mo0	0.5224	0.0949	F_ret78	3.5303	0.2445	F_tr92	-0.1302	1.0783
Mo12	1.0000	0.0001	F_ret79	1.1616	0.2369	F_tr93	1.4963	0.6220
qp1	0.1311	0.0421	F_ret80	0.5152	0.2282	F_tr94	-0.2167	1.1932
qp2	98.6240	2.7928	F_ret81	3.7978	0.2192	F_tr95	0.6672	0.7803
q	0.2455	0.0302	F_ret82	4.4918	0.2153	F_tr96	-1.7311	2.4217
ps1	0.1323	0.0196	F_ret83	5.0307	0.2180	F_tr97	-1.7956	2.5446
ps2	110.8000	2.6130	F_ret84	4.6811	0.2260	F_tr98	-1.1767	2.8082
Log_N_{76}	6.9423	0.1142	F_ret85	4.4243	0.2406	F_tr99	-0.7712	2.8829
tr_qp1	0.1873	0.1164	F_ret86	3.7180	0.2428	F_tr00	-0.7977	2.7794
tr_qp2	120.7600	5.9401	F_ret86	3.5717	0.2358	F_tr01	-0.8193	2.6692
fi_qp1	0.1012	0.0183	F_ret87	3.6207	0.2302	F_tr02	1.9532	0.7014
fi_qp2	125.5400	3.7419	F_ret88	3.2293	0.2260	F_tr03	2.0435	0.6828
			F_ret89	3.5963	0.2241	F_tr04	-0.0777	1.7477
			F_ret90	4.0431	0.2214	F_tr05	-1.2066	2.7920
			F_ret91	3.6741	0.2193	F_tr06	2.2510	0.6127
			F_ret92	3.8163	0.2181	F_tr07	-0.8291	1.9247
			F_ret93	4.1395	0.2176	F_tr08	-0.3553	1.2771
			F_ret94	3.8760	0.2195	F_fixed	-8.2124	0.5745
			F_ret95	3.8191	0.2205	F_fix92	0.2238	0.8625
			F_ret96	4.1479	0.2260	F_fix93	-2.6924	2.6649
			F_ret97	3.8662	0.2563	F_fix94	-2.3445	2.4394
			F_ret98	-6.5092	1.8581	F_fix95	-2.0031	1.9911
			F_ret99	-6.6193	1.8434	F_fix96	-2.7756	2.6971
			F_ret00	-6.7239	1.8295	F_fix97	-1.5805	1.6017
			F_ret01	-6.7453	1.8268	F_fix98	0.3224	1.0108
			F_ret02	-6.7623	1.8252	F_fix99	1.7088	0.8347
			F_ret03	-6.8134	1.8193	F_fix00	-1.6996	3.0118
			F_ret04	-6.9173	1.8069	F_fix01	1.0160	0.8913
			F_ret05	-7.0455	1.7917	F_fix02	0.2866	1.0641
			F_ret06	-7.3010	1.7634	F_fix03	1.0884	0.8737
			F_ret07	-7.5310	1.7394	F_fix04	0.5728	0.9601
			F_ret08	-7.7825	1.7151	F_fix05	0.3823	0.9799
						F_fix06	1.0745	0.8351
						F_fix07	4.5593	0.7444
						F_fix08	1.8609	0.7681

Table 8. Estimated recruits to the model (Model R), abundance (P2, P1, R, P, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-

recruit-1s (Molt1) for model scenario (1) fixing *M* and *Q*. Recruits and abundance are in million of crab and biomass is in million lbs. *F* = *M* (0.18) for 2009.

Year	Model R	P2	P1	R	P	Legals	Matures	Bio215	Molt1
1978	NA	0.955	2.647	1.104	0.955	2.059	4.706	11.458	0.522
1979	4.288	4.707	1.492	0.958	1.414	2.372	3.864	12.302	0.658
1980	3.138	4.766	2.657	0.833	1.985	2.818	5.476	17.021	0.692
1981	0.383	1.911	3.136	1.438	2.417	3.855	6.991	17.570	0.742
1982	1.436	1.966	1.822	1.630	2.453	4.083	5.905	12.122	0.757
1983	0.610	1.126	1.461	0.973	1.859	2.832	4.293	6.525	0.762
1984	0.416	0.702	0.924	0.750	0.819	1.568	2.492	4.567	0.752
1985	1.035	1.221	0.589	0.475	0.631	1.106	1.695	3.522	0.781
1986	1.042	1.341	0.779	0.347	0.524	0.871	1.650	4.139	0.816
1987	1.194	1.494	0.916	0.481	0.570	1.051	1.966	5.011	0.831
1988	0.998	1.317	1.039	0.574	0.714	1.289	2.327	5.940	0.829
1989	2.427	2.709	0.964	0.634	0.862	1.496	2.460	6.874	0.809
1990	1.799	2.424	1.720	0.638	1.078	1.716	3.436	8.770	0.795
1991	1.540	2.121	1.719	1.016	1.166	2.182	3.901	9.000	0.778
1992	1.736	2.266	1.536	0.970	1.262	2.232	3.768	9.677	0.760
1993	1.918	2.517	1.573	0.870	1.455	2.326	3.898	9.847	0.764
1994	1.741	2.398	1.709	0.899	1.449	2.348	4.057	9.320	0.780
1995	2.374	2.969	1.675	0.974	1.299	2.273	3.949	9.639	0.779
1996	1.222	1.965	1.979	0.985	1.395	2.380	4.359	10.719	0.757
1997	1.178	1.701	1.529	1.076	1.495	2.571	4.100	9.414	0.684
1998	0.755	1.294	1.260	0.749	1.398	2.147	3.407	3.391	0.631
1999	0.386	0.520	0.288	0.164	0.340	0.504	0.792	2.655	0.614
2000	0.475	0.672	0.330	0.138	0.429	0.568	0.898	3.075	0.579
2001	0.704	0.976	0.403	0.152	0.484	0.636	1.039	3.516	0.344
2002	0.111	0.676	0.466	0.113	0.538	0.651	1.117	3.770	0.314
2003	0.477	0.884	0.428	0.112	0.550	0.662	1.090	3.743	0.406
2004	0.101	0.572	0.477	0.139	0.561	0.700	1.177	3.980	0.517
2005	1.043	1.301	0.420	0.186	0.596	0.782	1.202	4.169	0.648
2006	1.587	2.047	0.733	0.231	0.667	0.898	1.631	5.275	0.667
2007	1.992	2.687	1.195	0.407	0.773	1.180	2.374	7.138	0.539
2008	3.254	4.420	1.519	0.516	0.992	1.509	3.028	9.278	0.530
2009	1.629	3.581	2.293	0.675	1.298	1.973	4.266	12.732	0.522

Table 9. Ecosystem effects on the St. Matthew Island blue king crab stock. Changes in habitat quality.

Ecosystem effects on St. Matthew Island blue king crab stocks			
Indicator	Observation	Interpretation	Evaluation
Changes in Habitat Quality			
EFH-HAPC	Rocky/shellhash nearshore habitats are critical habitat/vital refuge for juveniles in the Pribilof Islands. Ovigerous females dominate nearshore rocky habitats during the warmer months.	Effects on population dynamics of mollusk species that compose the shellhash and associated epiphytes, such as oil mishaps, coastal development, and dredging.	Concern
Temperature regime	Experimental studies.- temperature effects on hatch timing, embryonic development, larval growth and survival.	Lower temperatures delay development, hatch timing, and growth. Higher temperatures may increase all of the above and decrease survival.	Concern
Ocean Acidification	Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects.	Lab studies have shown a ~15% reduction in growth and ~67% reduction in survival when pH was reduced 0.5 units. Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival.	Concern
Oil exploration	Restricted distribution makes them vulnerable to oil mishaps.	Oil mishap would impact planktonic larvae the most. Juveniles in shallow water nearshore habitats would be impacted. As well as ovigerous females that occur in shallower warmer water during the summer and fall.	Concern
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability. Concern.
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability and recruitment in year class strength	Possible concern

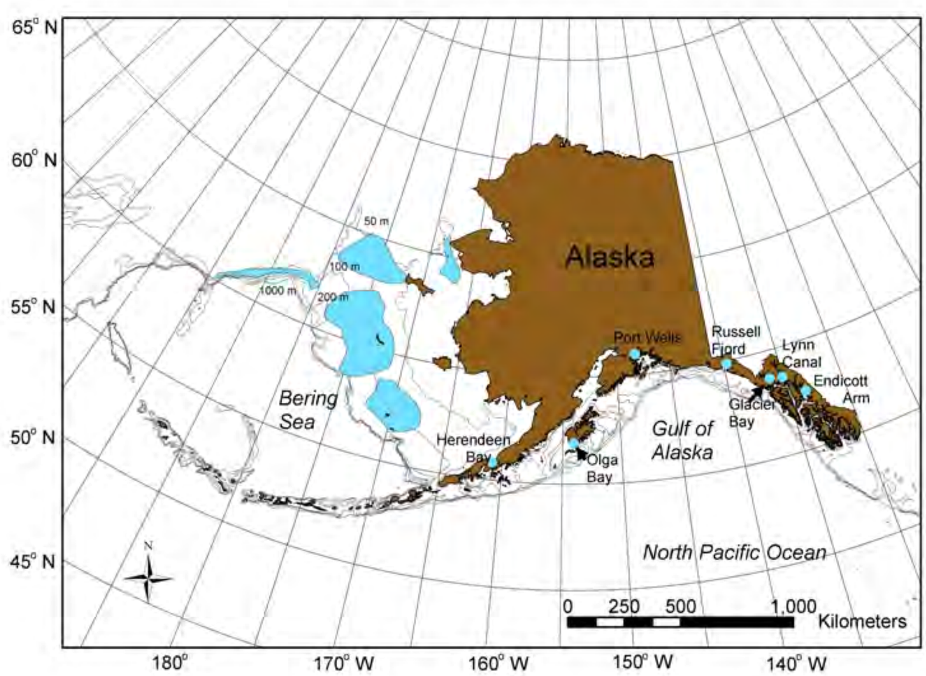


Figure 1. Distribution map of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters.

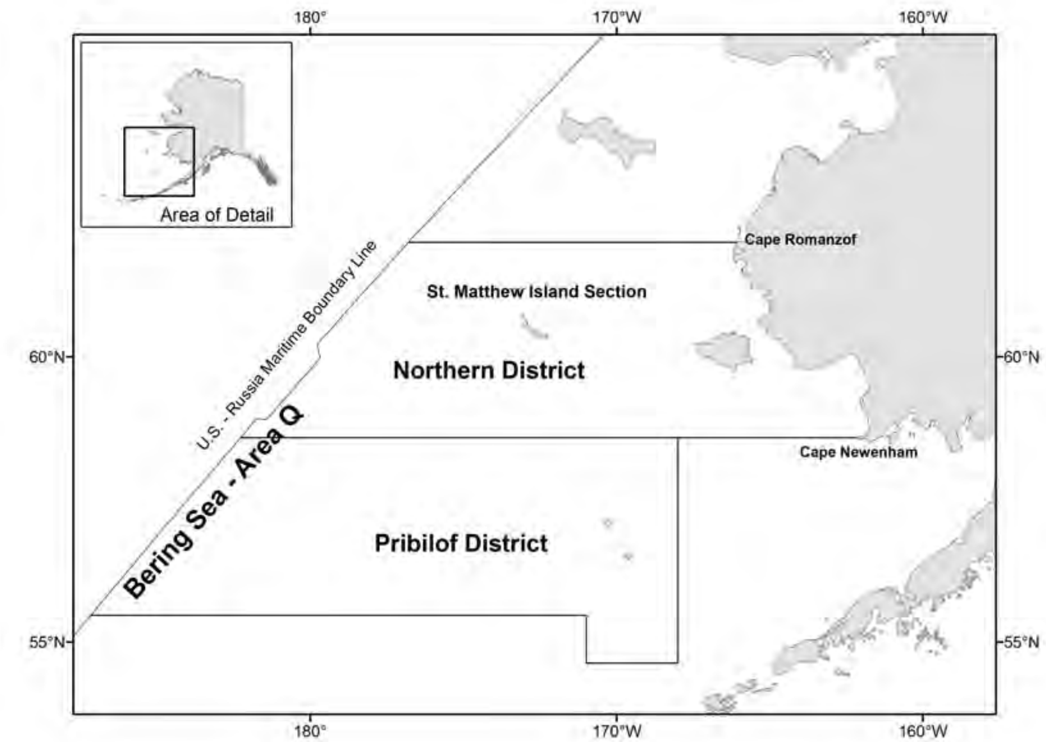


Figure 2. King crab Registration Area Q (Bering Sea).

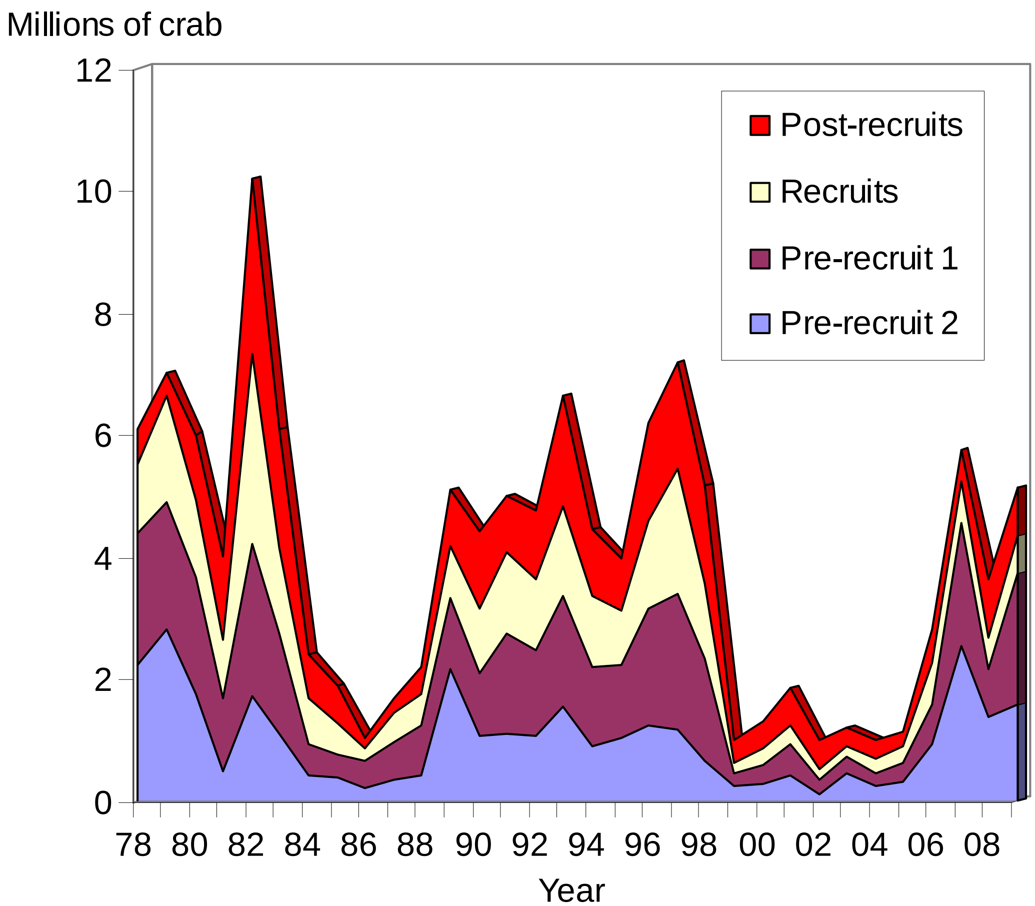


Figure 3. Area-swept abundance estimates from trawl surveys from 1978 to 2009 for St. Matthew Island blue king crab.

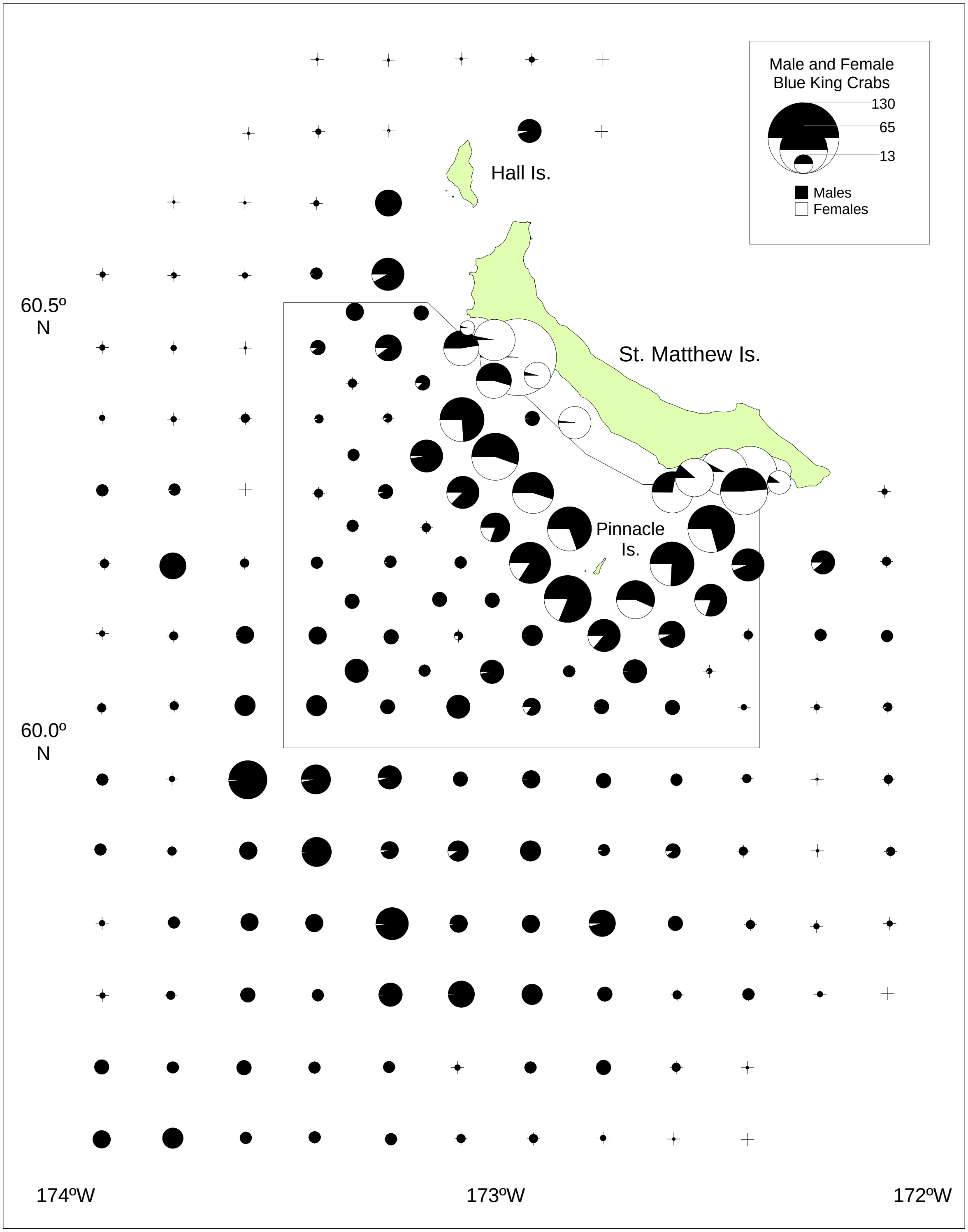


Figure 4. Male and female blue king crab catch per unit effort (CPUE) by station in the 2007 St. Matthew Island survey. (Source: Watson 2008).

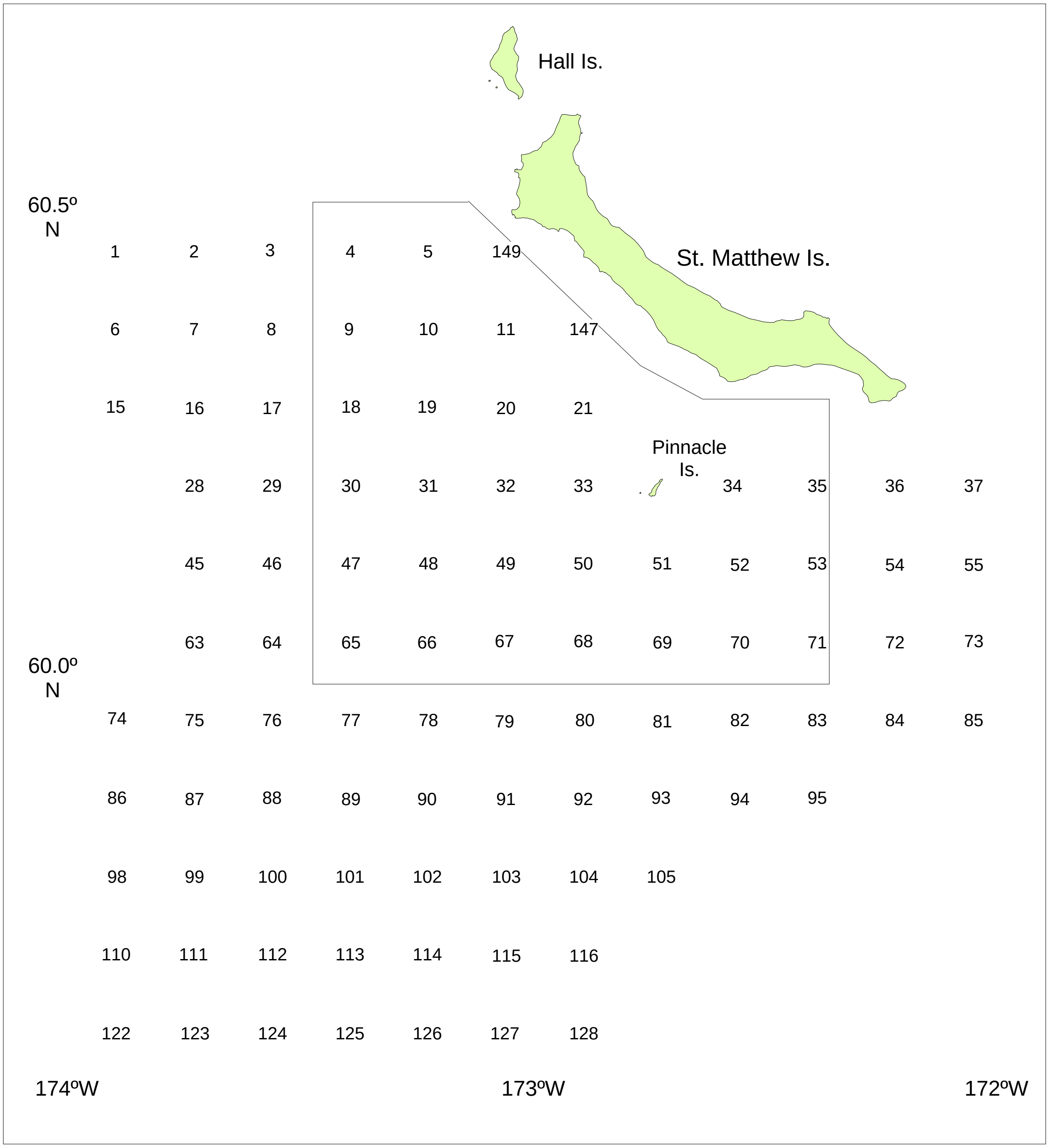


Figure 5. Location of the 96 stations fished in common during the five triennial St. Matthew Island blue king crab surveys, 1995 - 2007. (Source: Watson 2008).

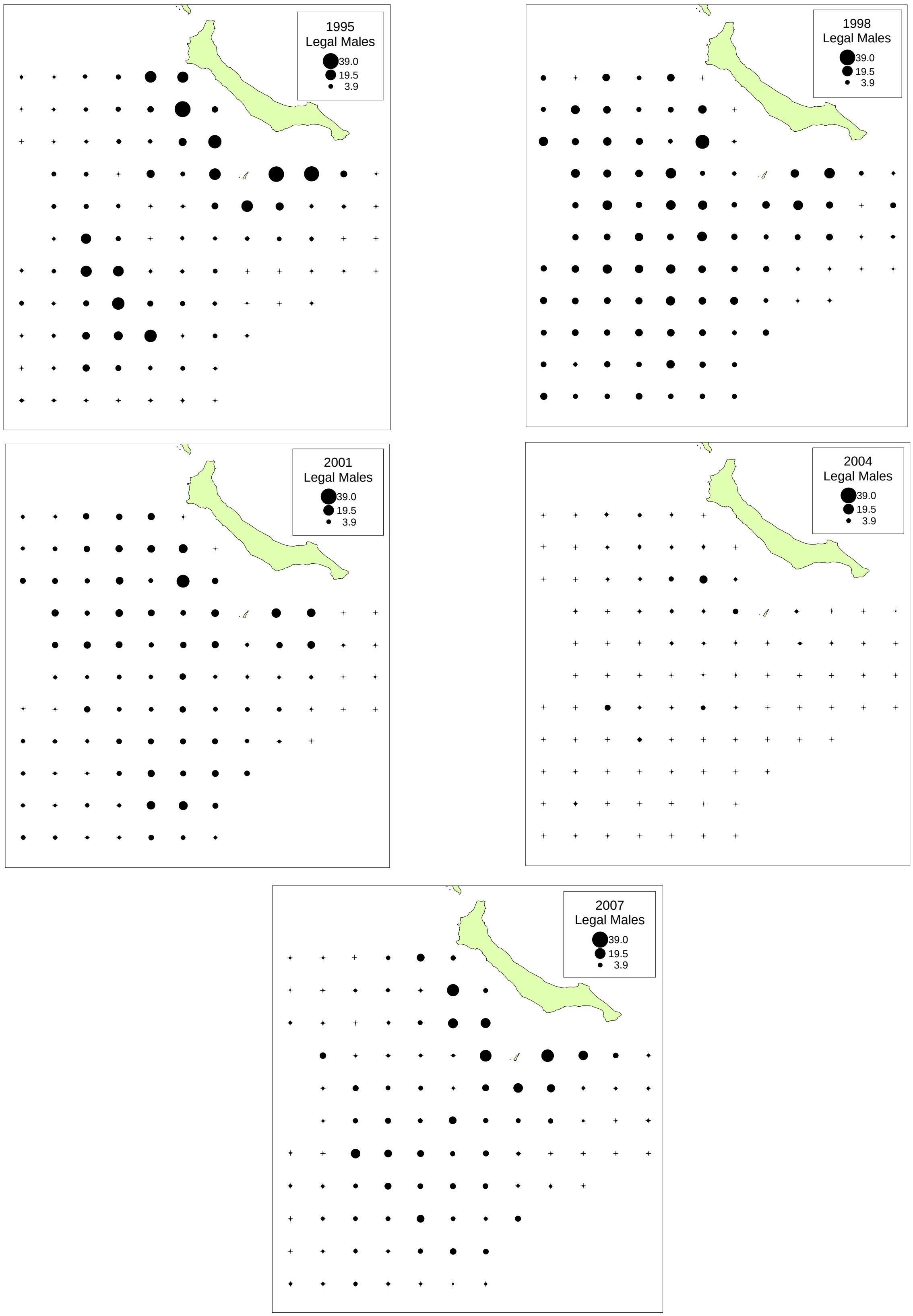


Figure 6. Legal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

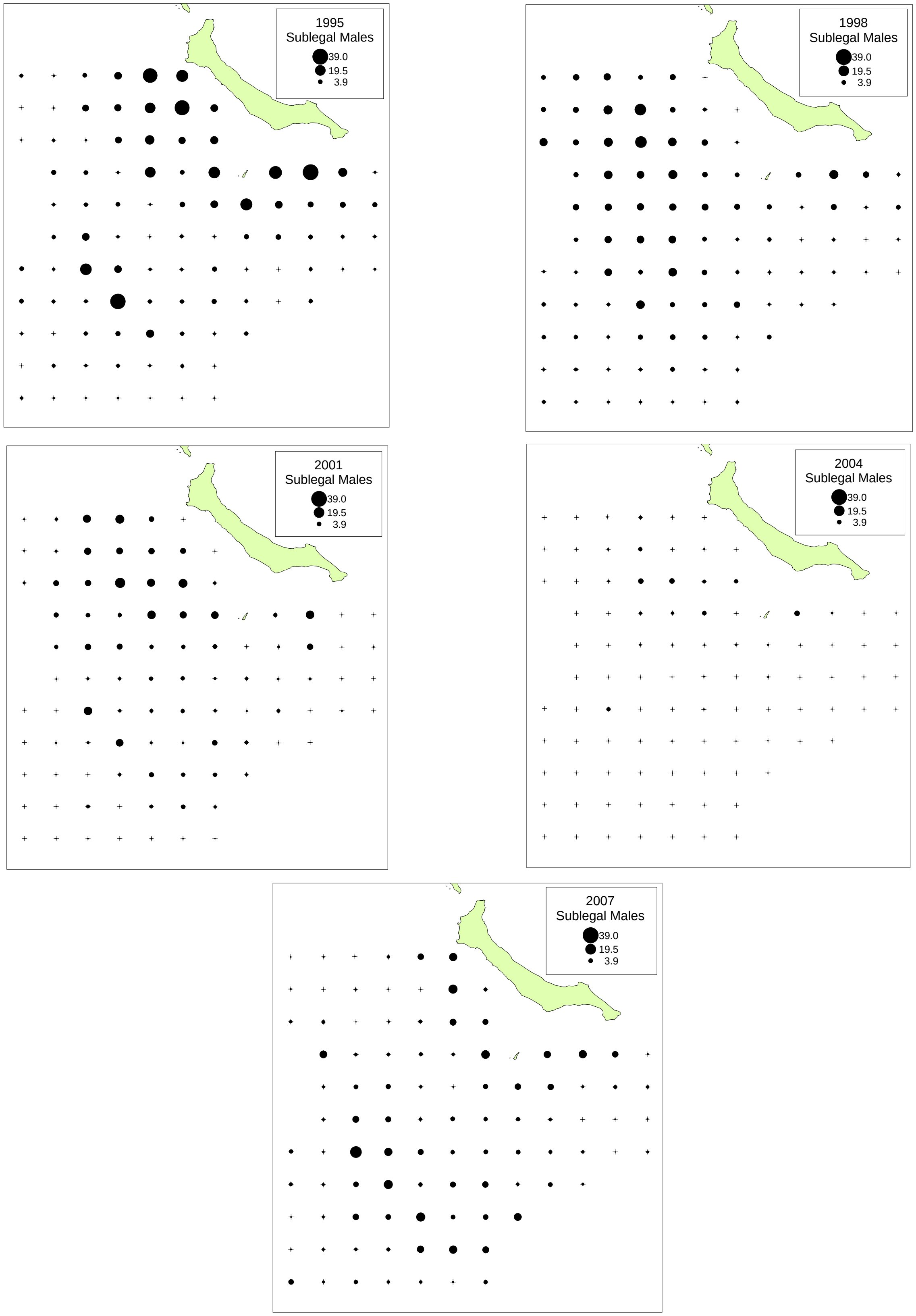


Figure 7. Sublegal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

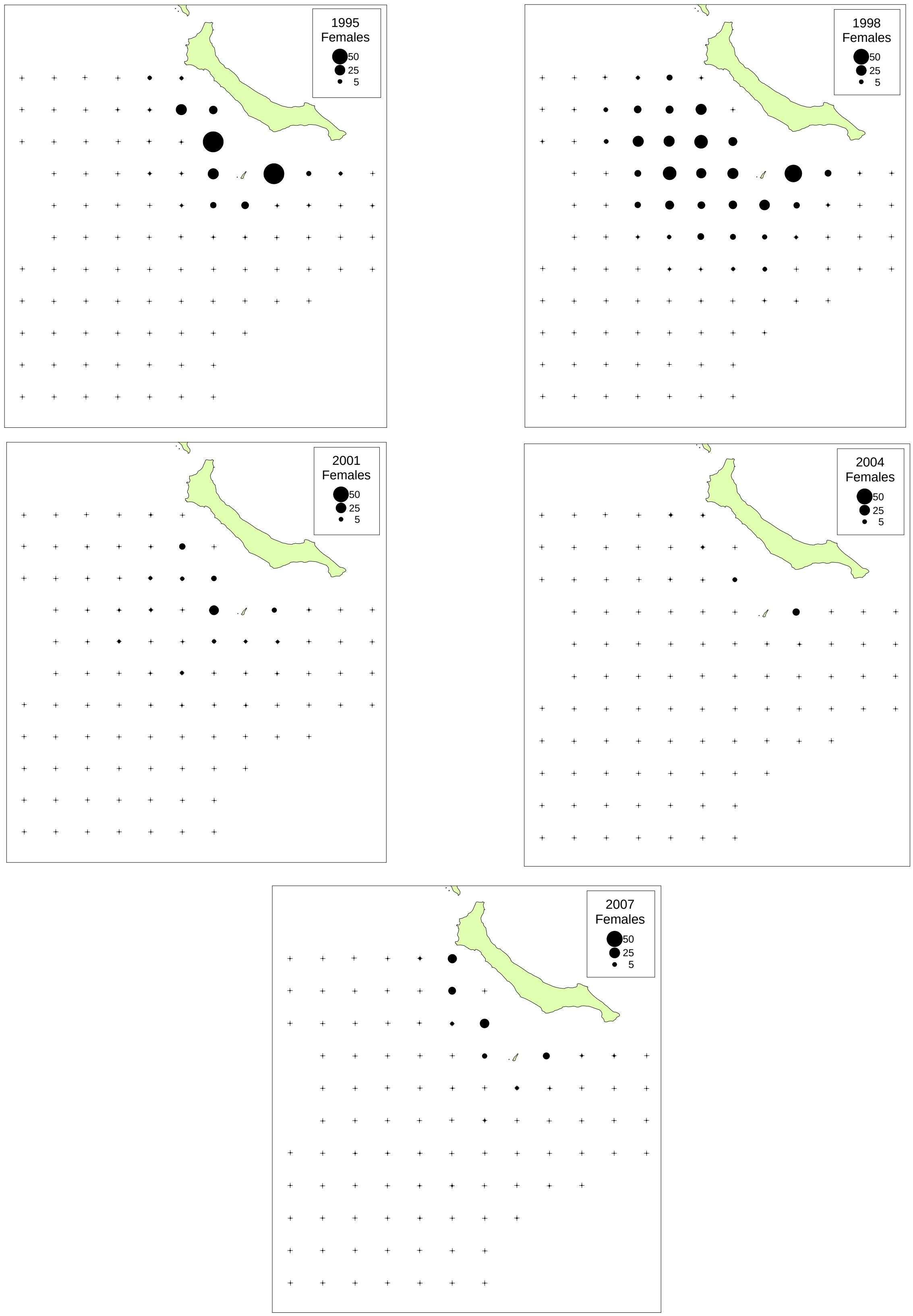


Figure 8. Female blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

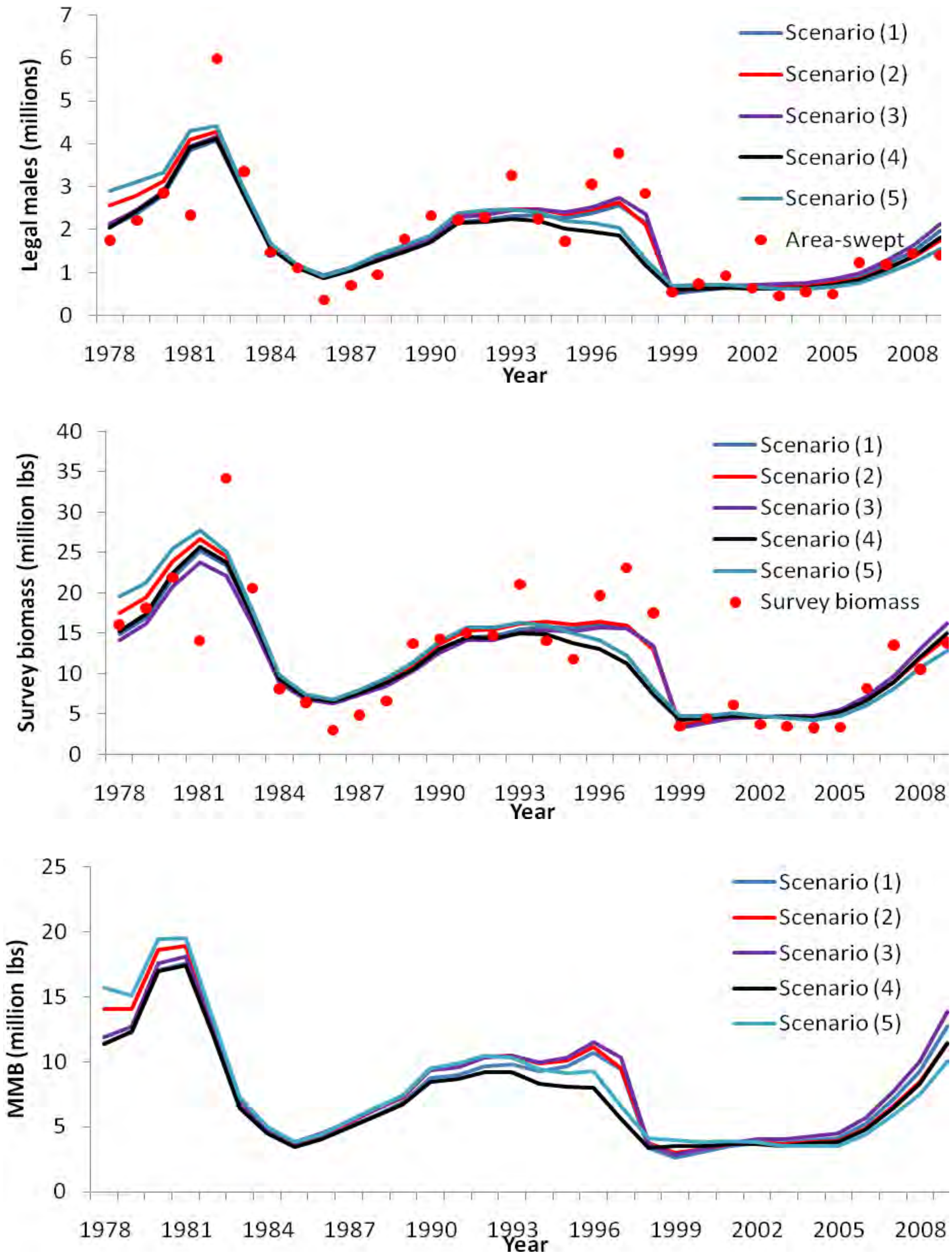


Figure 9. Comparison of legal abundance, survey biomass, and mature male biomass estimates with five scenarios of the catch-survey analysis and trawl survey abundance.

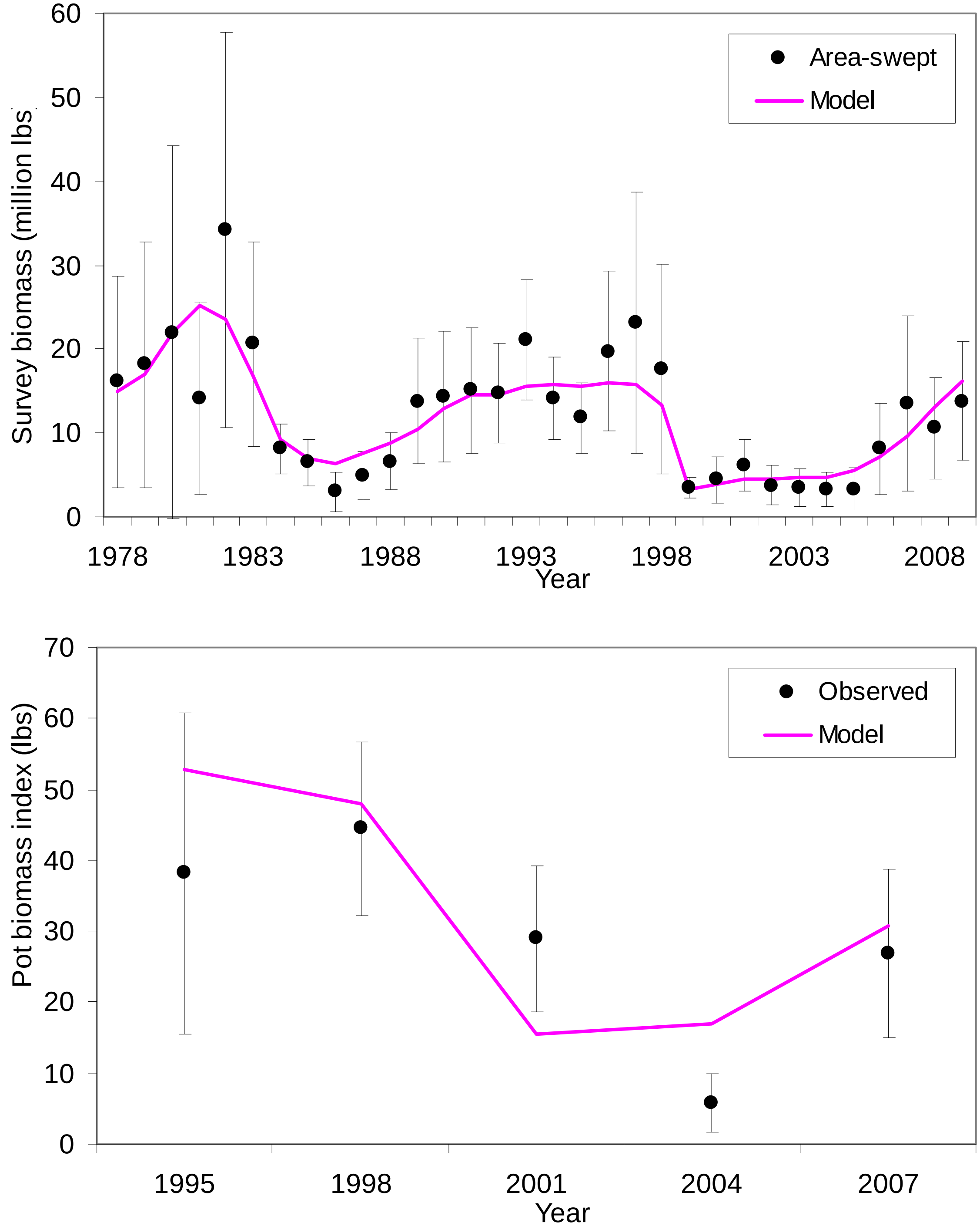


Figure 10. Comparison of trawl and pot survey biomass with 95% confidence intervals to model estimates with scenario (1).

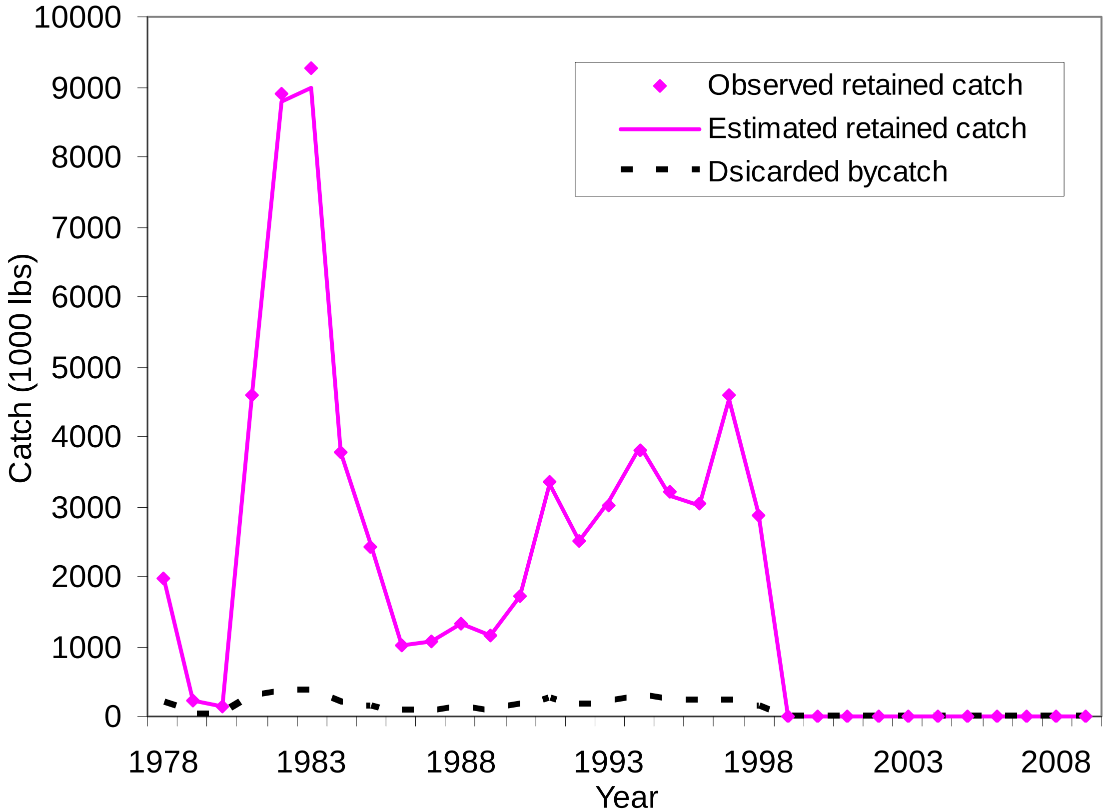
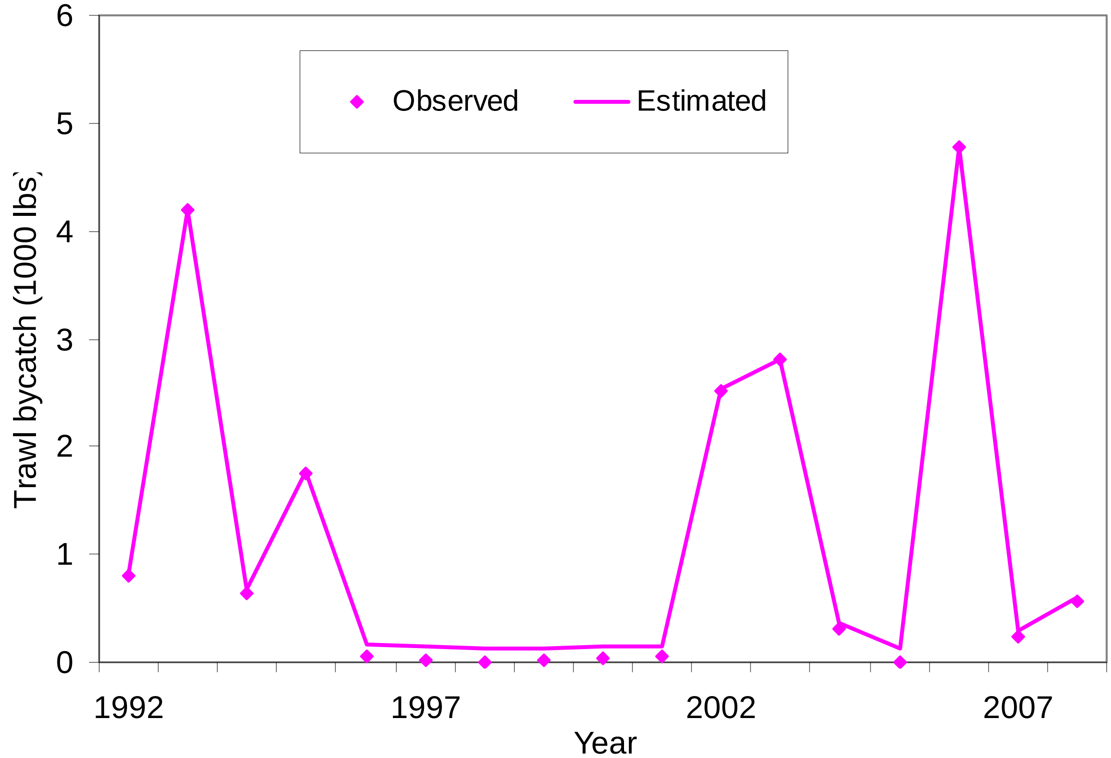


Figure 11. Comparison of observed and estimated retained catch and bycatch from the directed pot fishery with scenario (1).



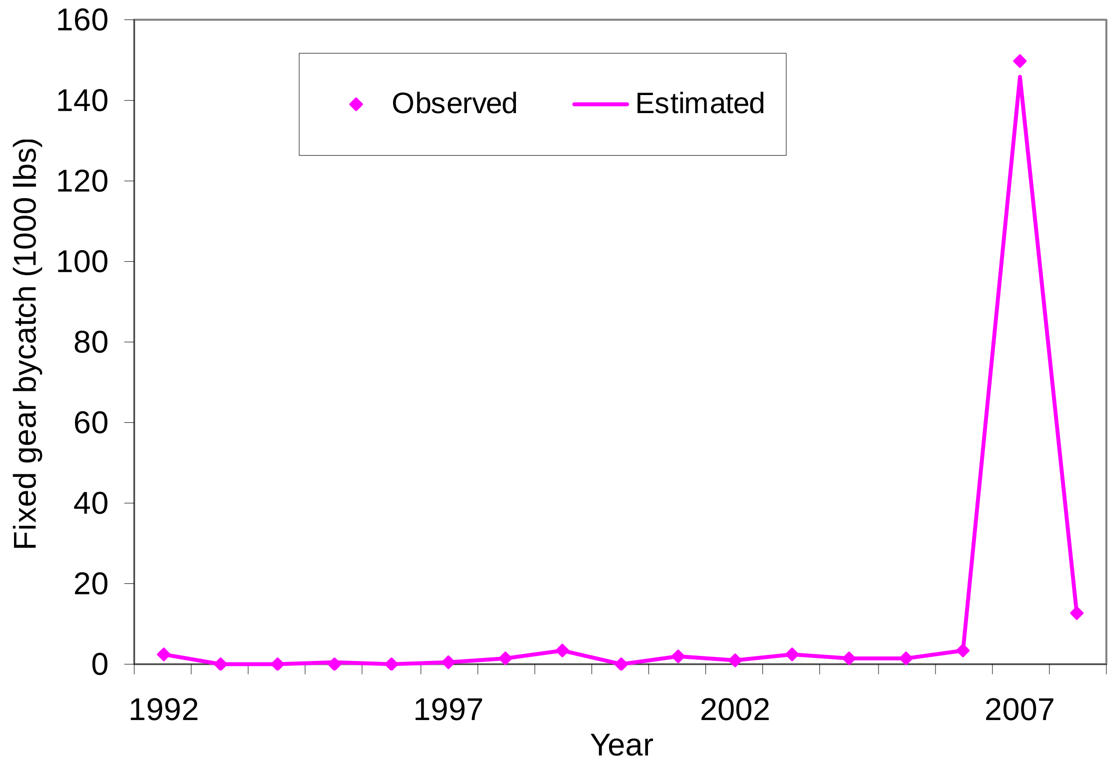
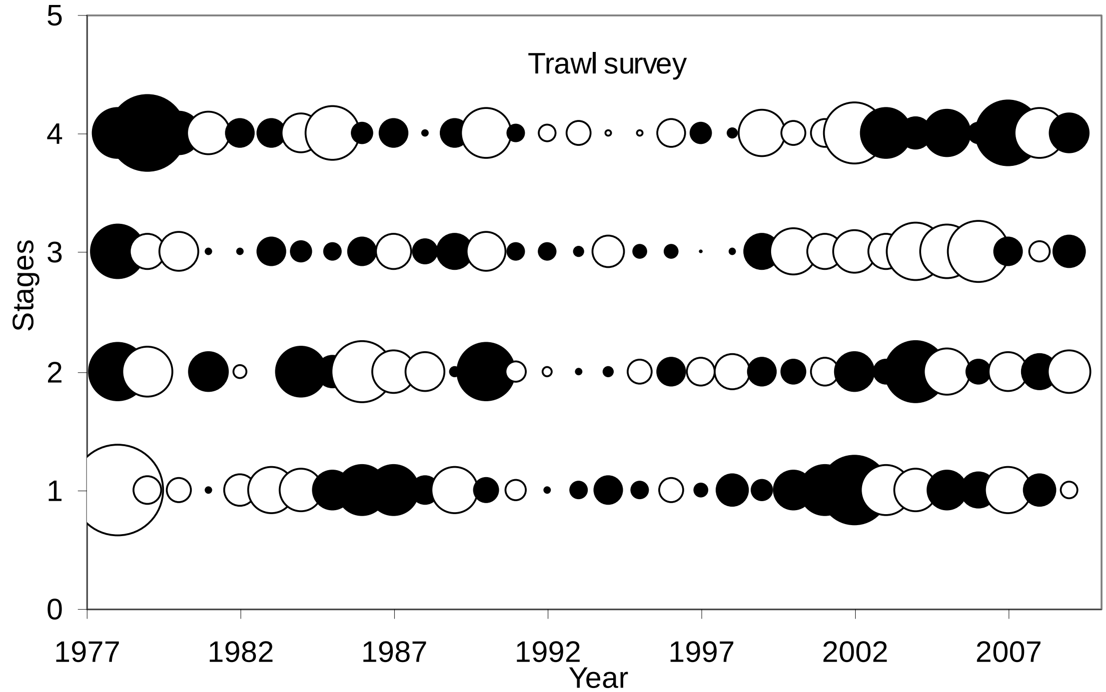


Figure 12. Comparison of observed and estimated bycatches of St. Matthew Island blue king crab from groundfish trawl fisheries and fixed gear fisheries with scenario (1).



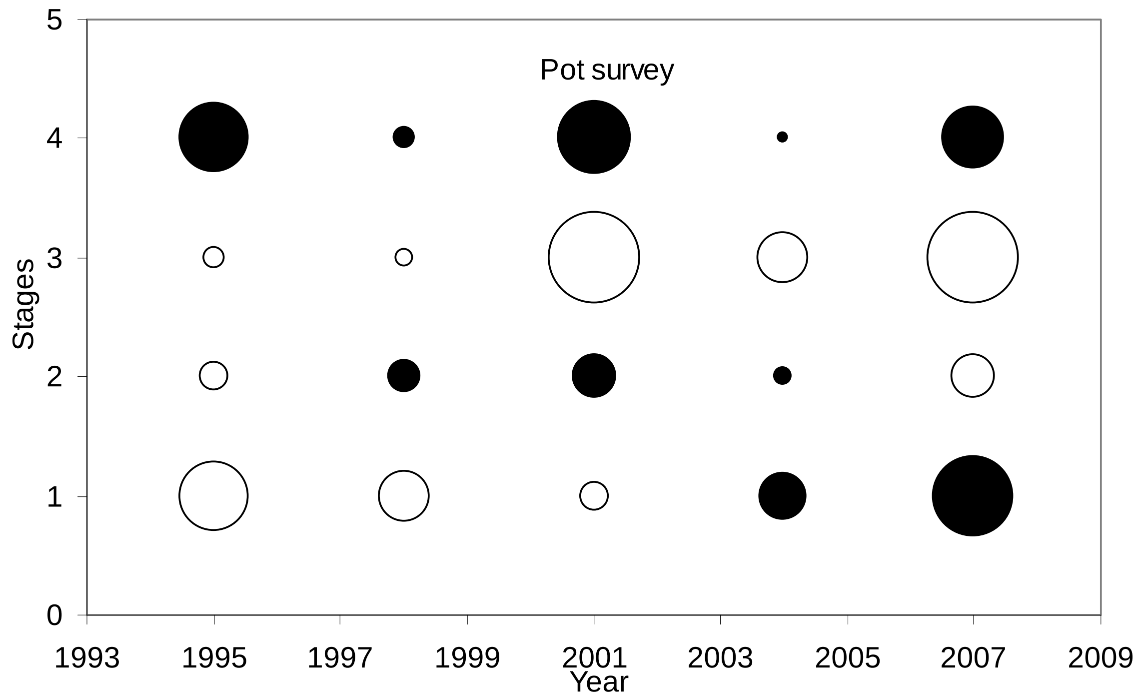


Figure 13. Residuals of different stages (1 pre-recruits 2, 2 pre-recruits 1, 3 recruits, and 4 post-recruits) for trawl (upper plot) and pot surveys (lower plot) with scenario (1). Solid circles are positive residuals, and open circles are negative residuals.

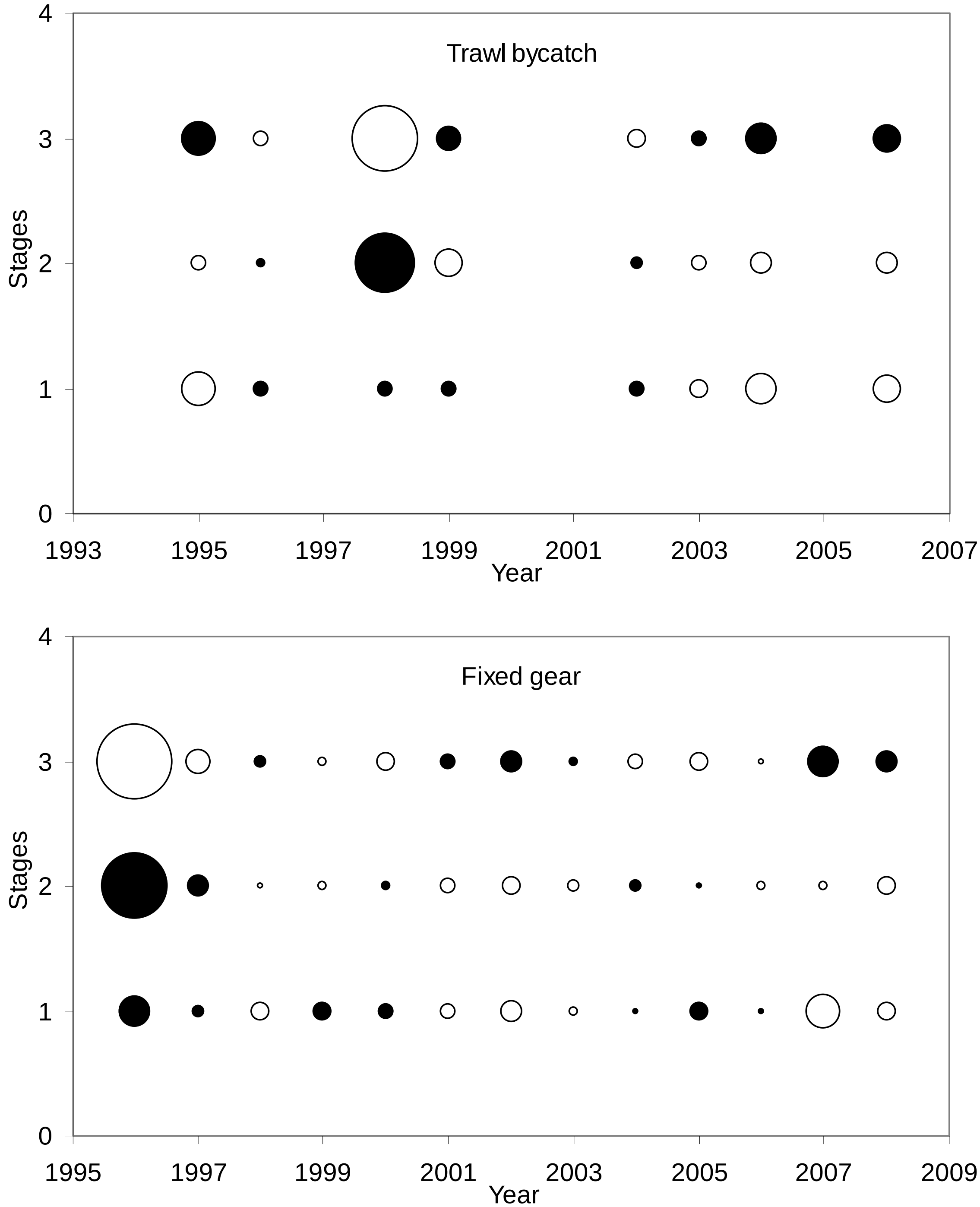


Figure 14. Residuals for different stages (1 pre-recruits 2, 2 pre-recruits 1, 3 recruits, and 4 post-recruits) for blue king crab bycatches in the groundfish trawl and fixed gear fisheries with scenario (1). Solid circles are positive residuals, and open circles are negative residuals.

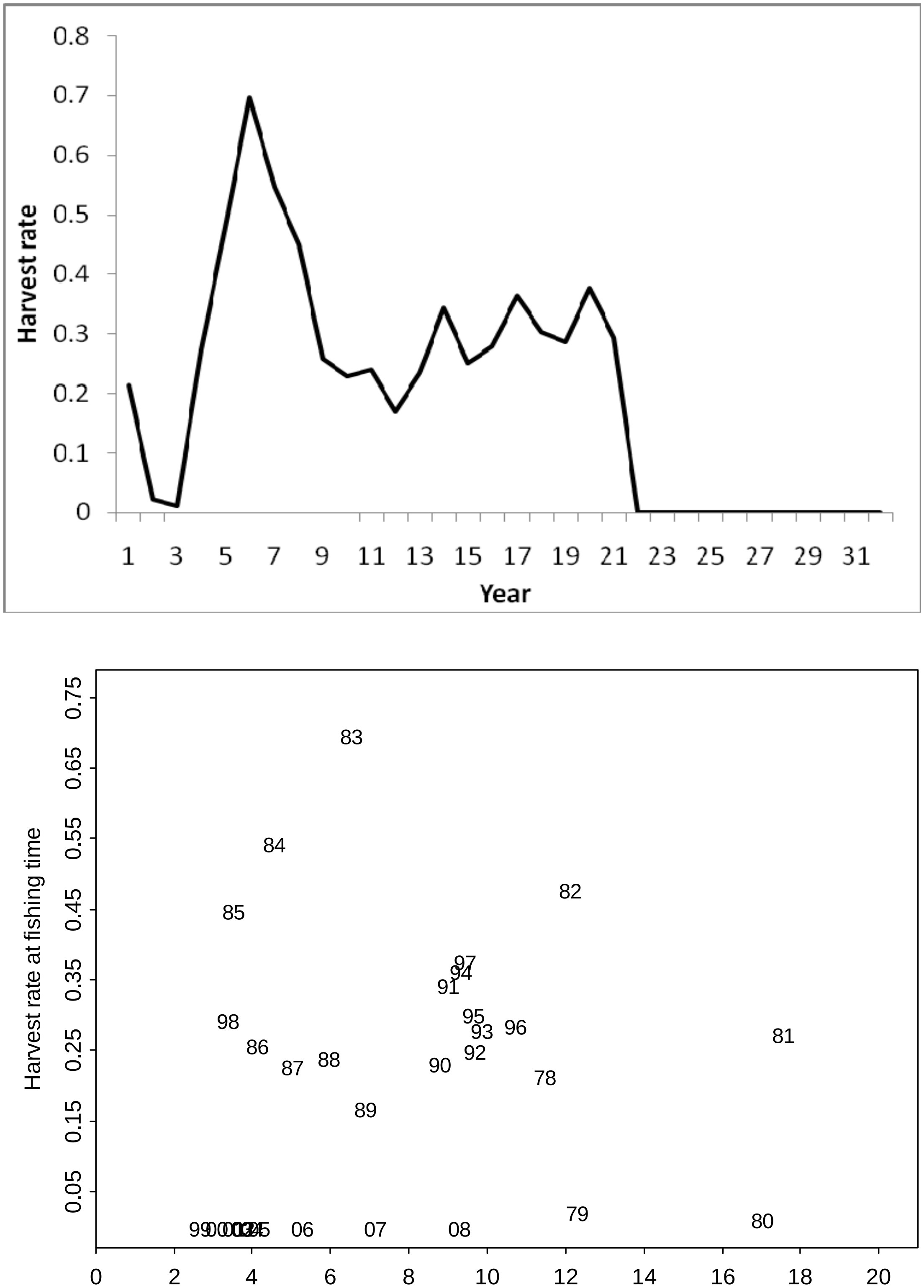


Figure 15. Estimated harvest rates at fishing time (upper plot) and relationship between harvest rate and mature male biomass (lower plot) of St. Matthew Island blue king crab with scenario (1) of fixed *M*=0.18 and *Q*=1.0.

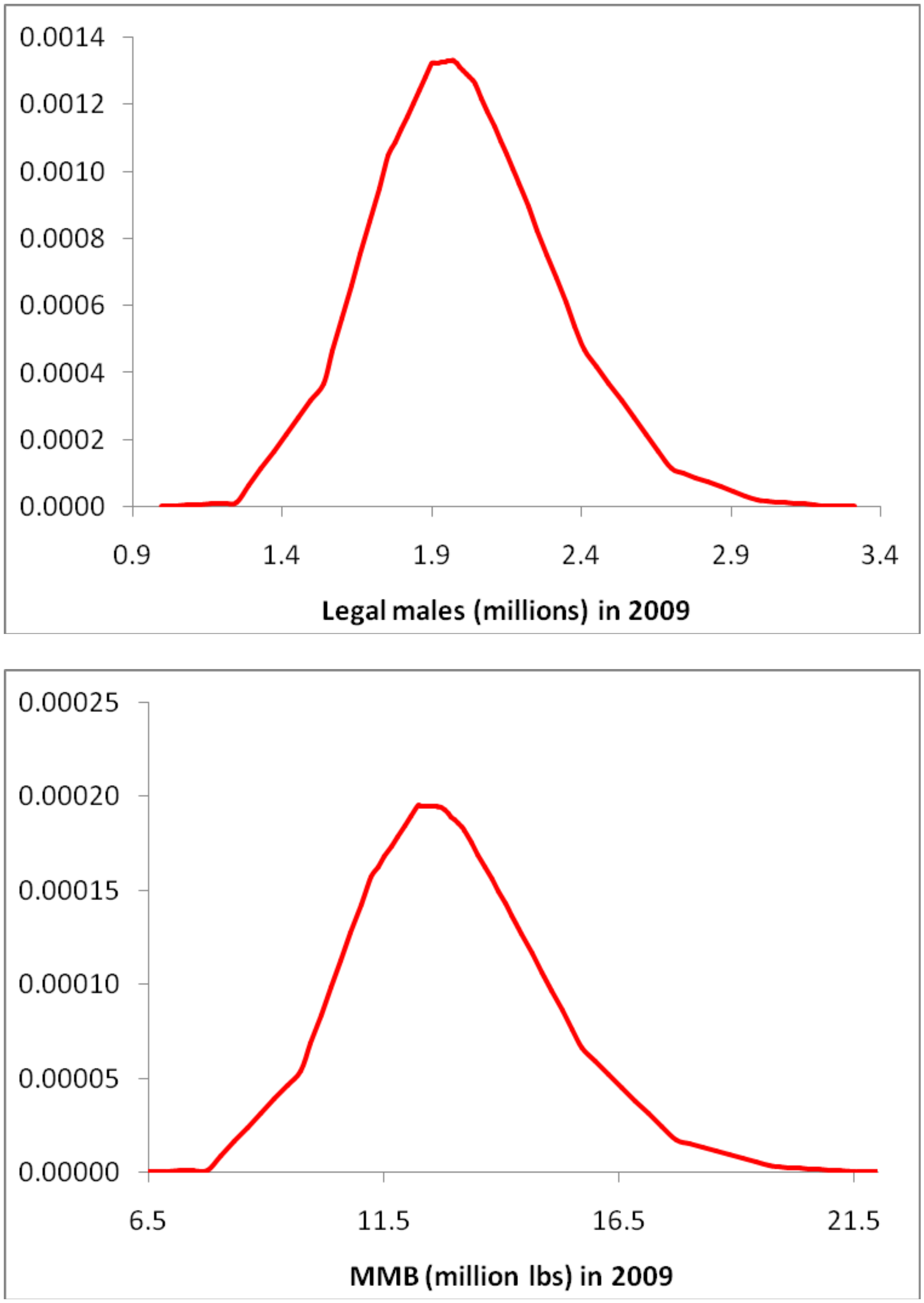


Figure 16. Likelihood profiles for estimated legal male abundance and mature male biomass in 2009 with scenario 1.

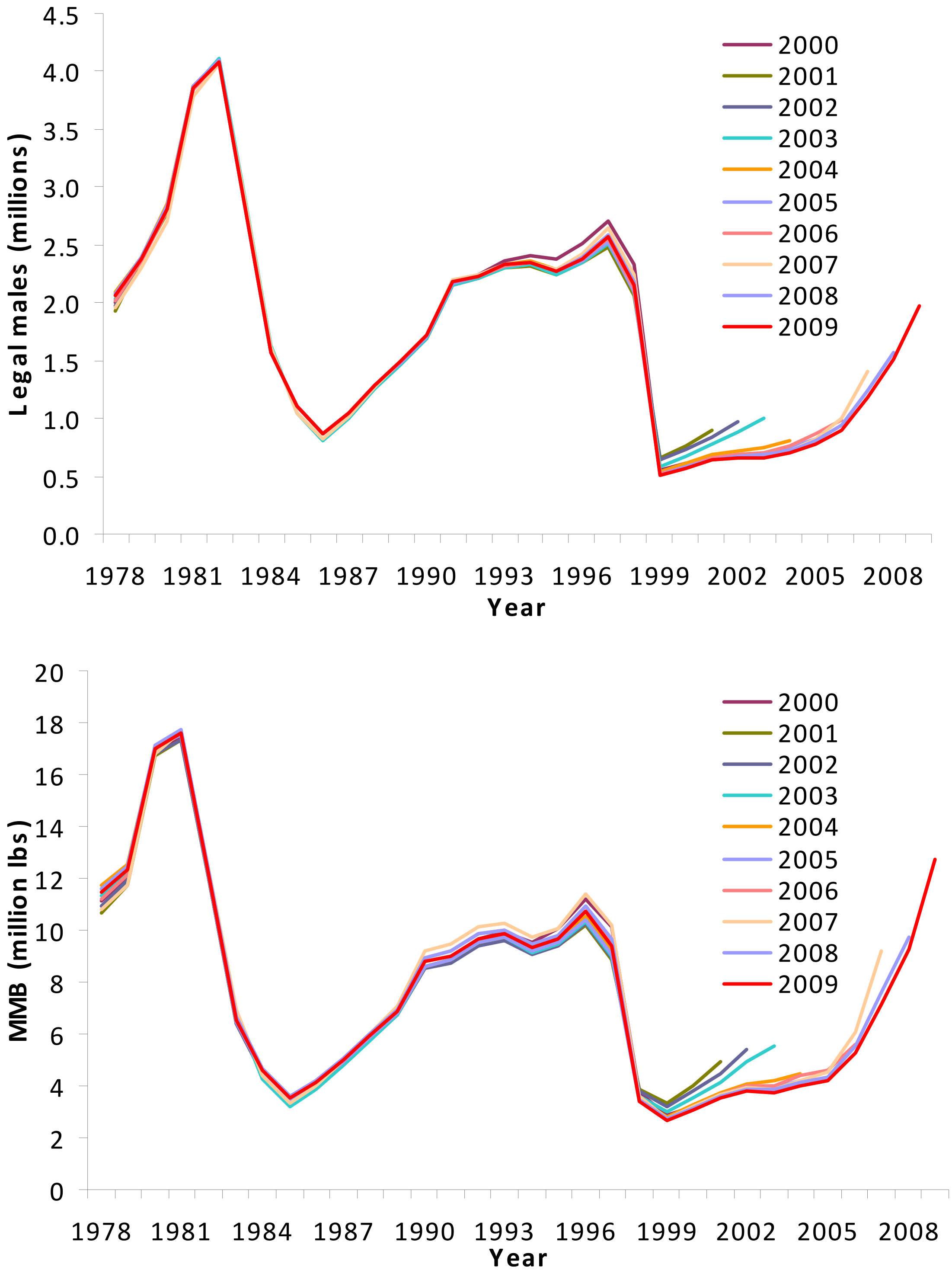


Figure 17. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2009 made with terminal years 2000-2009. These are results of the 2010 model with a fixed *M*=0.18 and *Q*=1.0 (scenario 1). Legend shows the year in which the assessment was conducted.

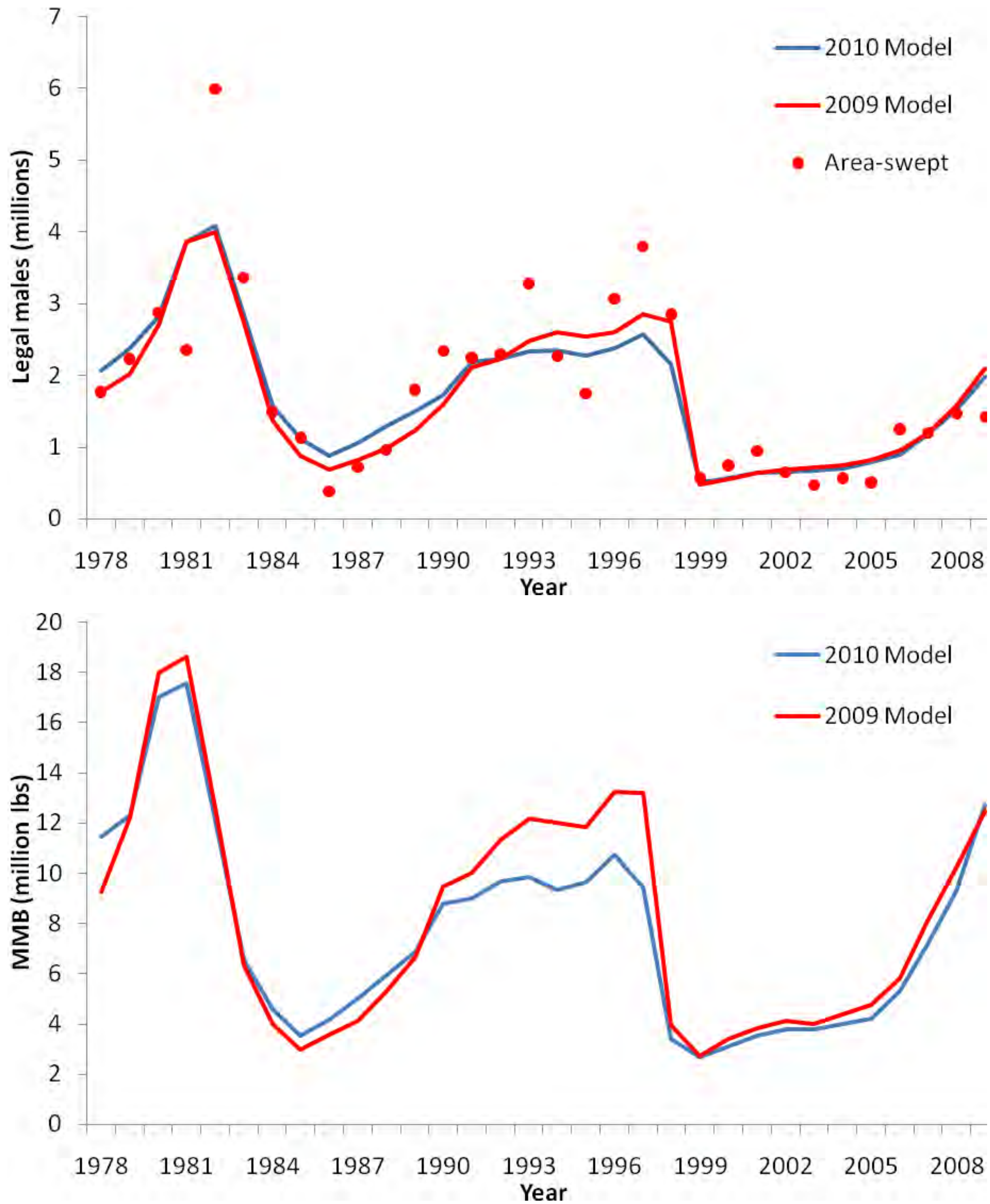


Figure 18. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2009 made with the 2009 and 2010 model with scenario (1).

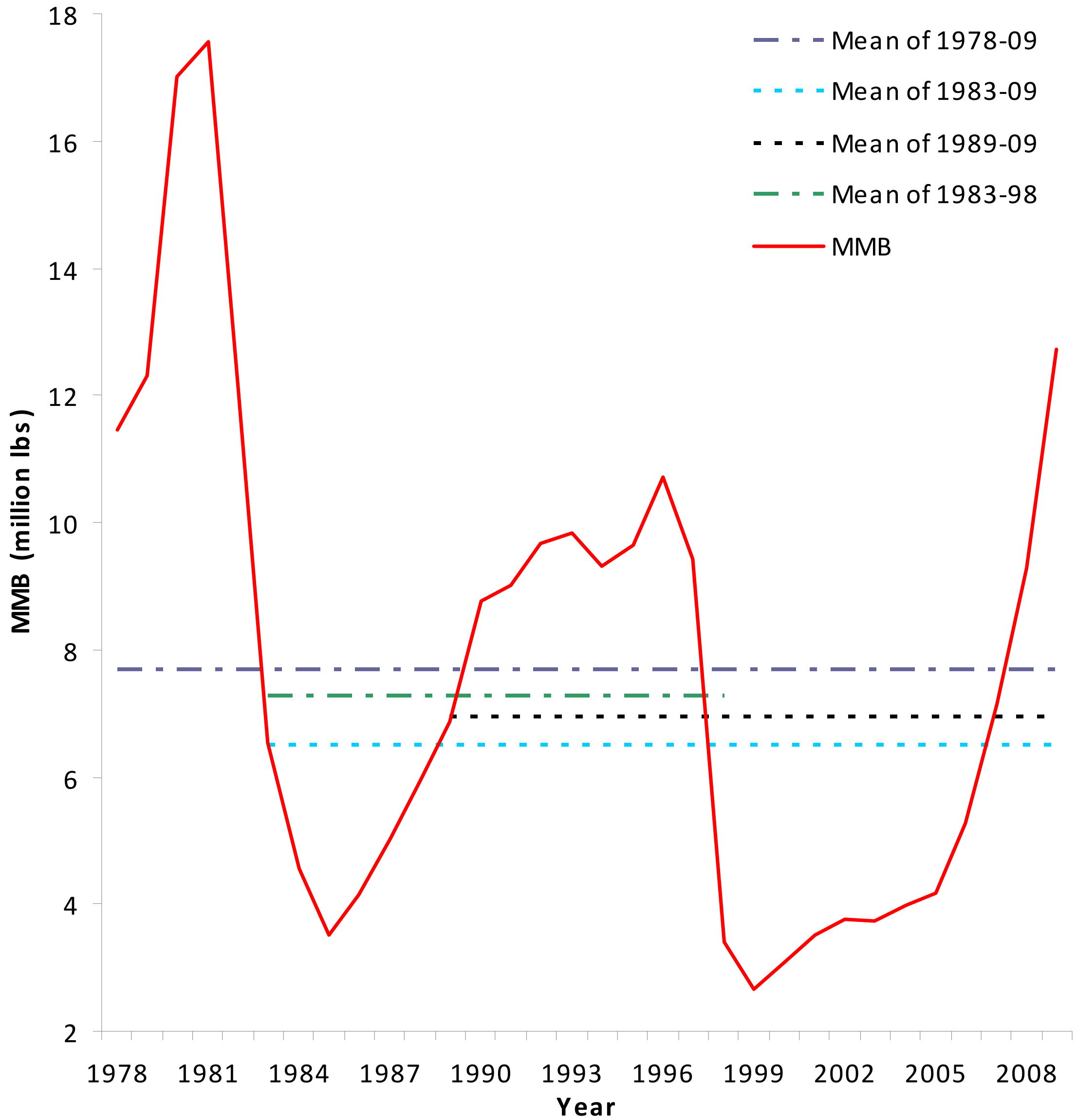


Figure 19. Comparison of estimated mean mature male biomasses during different periods for St. Matthew Island blue king crab. The model was with a fixed M=0.18 and Q=1.0 (scenario 1). $\gamma = 1$ was used for the 2009 fishery to project mature male biomass in 2009.

Norton Sound Red King Crab Stock Assessment in Spring 2010

Jie Zheng[1], Hamachan Hamazaki[2] and Joyce K. Soong[3]
Alaska Department of Fish and Game
Commercial Fisheries Division
[1]P.O. Box 115526, Juneau, AK 99811-5526
Phone : 907-465-6102
Email : Jie.Zheng@alaska.gov
[2]333 Raspberry Rd., Anchorage, AK 99518-1565
Phone: 907-267-2158
Email: Hamachan.Hamazaki@alaska.gov
[3]P.O. Box 1148, Nome, AK 99762
Phone: 907-443-5167
Email: Joyce.Soong@alaska.gov

Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. 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 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. 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.

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL
2005/06		3.89	0.37	0.40		
2006/07		3.62	0.45	0.45		
2007/08		4.40	0.32	0.31		
2008/09	1.78[a]	5.24[a]	0.41	0.39	TBD	0.68[a]
2009/10	1.54[b]	5.83[b]	0.38	0.40	TBD	0.71[b]
2010/11	1.56	5.44				0.73

[a] calculated from the assessment model agreed on by the Crab Plan Team in May 2008.
[b] calculated from the assessment model agreed on by the Crab Plan Team in May 2009.

6. Basis for the OFL. Biomass quantities are in millions of pounds.

Year	**Tier**	**B_{MSY}**	**Current MMB**	**B/B_{MSY} (MMB)**	**F_{OFL}**	**Years to define B_{MSY}**	**Natural Mortality**
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	5.44	1.7	0.18	1983-2010	0.18

[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; $\gamma = 1$.

For comparison, an assessment for 2010 using the 2009 model is presented below. The OFL for this scenario is estimated as 0.8621 million pounds (retained catch).

Year	**Tier**	**B_{MSY}**	**Current MMB**	**B/B_{MSY} (MMB)**	**F_{OFL}**	**Years to define B_{MSY}**	**Natural Mortality**
2010/11	4a	3.07[a]	6.37	2.1	0.18	1983-2010	0.18

[a] BMSY and MMB calculated from the assessment model agreed on by the Crab Plan Team in May 2009; $\gamma = 1$.

An alternative OFL determination is presented below based on a tier 5 formulation, which requires selection of a range of years that are representative of the production potential of the stock. Two such ranges are offered for comparison purposes: the period prior to the current conservative harvest strategy (1977-1990), or the full period from the beginning of the fishery to the most recent year (1977-2009). The second period is not very representative of the production potential due to conservative harvest constraints of state management. Average catches for those periods are provided in the table below. Biomass quantities are in millions of pounds.

Year	**Tier**	**Years to define average catch (OFL)**	**OFL**	**Natural Mortality**
2010	5	1977-1990	0.803	0.18
2010	5	1977-2009	0.498[a]	0.18

[a]Average does not include 1991 when the fishery was closed due to lack of staff.

A. *Summary of Major Changes in 2010*

1. Changes to the management of the fishery**:** None.
2. Changes to the input data
    a. The model was updated with new data from the 2010 winter pot survey, 2009 summer commercial fishery, and 2009/2010 winter commercial and subsistence catch.
3. Changes to the assessment methodology:
    a. Bycatch from the directed summer pot fishery was estimated and included.
    b. Maximum effective sample size for commercial catch and winter surveys were set to be 100 from the previous value of 200.
    c. Weight for fishing effort was set to 20 from the previous value of 5.
4. Changes to the assessment results. These are tabularized in item 6 of the Executive Summary, above.

B. *Response to SSC and CPT Comments*

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

    a. CPT, May 2009: *"The timing for final assessments for Tier 5 stocks should be done annually in May and only brought back to the CPT as an agenda item in September should there be new information over the summer and/or modification to CPT recommendations from the SSC."*

    Response: N/A

    b. SSC, June 2009: *"As reiterated from our June 2008 report, "future stock assessments should provide analyses to support the choice of γ" in Tier 4. Currently, analysts have used, and the Crab Plan Team and the SSC have supported, a value of 1 for γ in the calculation FOFL = γ M, in which M is natural mortality, which results in a proxy for FMSY. The SSC recommends that analysts provide rationale for the selection of γ. The value of 1 for γ is the default value used in Tier 5 for groundfish and should be conservative for crab stocks, since only the legal male component of the adult stock is harvested. However, analysis in the Environmental Assessment for Amendment 24 to revise overfishing definitions for crab showed that values of γ between 2 and 3 might be appropriate for Fmsy estimation for some Bering Sea crab stocks. Therefore, it is desirable to investigate whether alternative approaches can be developed. Some suggestions for doing this will be forthcoming from the crab data weighting and stock assessment workshop, held in Seattle during the May Crab Plan Team meeting. A report from that workshop will be available in time for the September Crab Plan Team meeting."*

Response: The CPT selected $\gamma = 1$ for this stock in May 2009. No rationale has been further developed.

c. SSC, June 2009: *"The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number a number of years that are common across groups of species or areas."*

Response: The stock assessment authors have not addressed this question yet this year and does not recall a larger discussion on this by the CPT as whole.

d. CPT, September 2009: None.

e. SSC, October 2009: *"The SSC offers these general comments to all stock assessment authors: (1) at the beginning of each SAFE chapter, summarize the SSC and Plan team requests to the author (and response to each) to assure that these requests are not overlooked, … and (2) each assessment should clearly state what is new and not new from the previous assessment. (3) All assessment authors should structure their assessment documents following the guidelines established by the crab plan team."*

Response: Item 1 is done. For item 2, what is new is stated, and what is not new is made clear by following the new report guidelines. For item 3, this is partly done, with further revisions to the specified structure to be completed as time allows.

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

a. SSC Comments (from June 2009)

"1. The assessment model from the previous year should be included in the current assessment in order to evaluate the impact of changes made to the model, and to have those results as a fallback option if the current model is unsuitable and rejected for OFL-determination."

Response: Done (see Executive Summary item 6 and Figure 11).

"*2. In this assessment, stock losses due to natural mortality and retained catch are considered. Mortalities due to directed fishery discards and non-directed bycatch are not included; thus, handling mortality is explicitly set equal to zero. In the absence of observer data on discards and bycatch, the assessment should include a sensitivity analysis as to a plausible range of nonretained mortalities. Also, the approach used in the Bristol Bay red king crab assessment for estimating discarded catch in the directed fishery should be investigated, with the results compared to those from the zero non-retained mortality assumption."*

Response: Bycatches were estimated in the 2010 model with a handling mortality rate set = 0.2.

"3. The assessment should be updated for September 2009, with the 2008/09 retained catch, in order to determine if overfishing was occurring in 2008/09."

Response: Updated retained catch data and OFL are given in the executive summary. No overfishing occurred in 2008/09.

"4. Further analysis of the retrospective pattern in the assessment should be performed given concerns regarding the consistent pattern indicating an overestimate of biomass, compared to the trawl survey."

Response: Done. The same patterns occur. The reasons are explained in the report.

"*5. The assessment should include an assumed bycatch and discard mortality."*

Response: Done.

"The CPT also requested, and the SSC concurs, that subsequent assessments include an OFL calculation based on Tier 5. However, 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. In particular, the SSC requests that likelihood profiles on natural mortality be included in the 2010 assessment, to re-examine the results when bycatch mortality and discard are included in the model."

Response: Average catch during two periods was estimated and tier 5 calculations are presented. Likelihood profile for M is plotted in Figure 2, and the maximum likelihood occurs with M = 0.34.

"*Several sentences appear to be remnants from the earlier version and should be fixed. For example:*

1. *Page 15 2nd paragraph. The author should clarify that the information available for the assessment has changed since the publication of Zheng et al. 1998. The conclusions made in 1998, may not reflect the conclusions that would be made with the current model under different assumptions of the baseline natural mortality rate.*

2. *Page 17, first full paragraph, last sentence. This sentence appears to be in conflict with the recommendation for setting gamma = 1.*"

Response: Item 1 is now addressed with a caveat. For item 2, the sentence has been removed.

b. Response to SSC Comments (from October 2009)

"The SSC reiterates two Crab Plan Team suggestions for future assessments. First, there should be further analysis of the retrospective pattern in the assessment given concerns regarding the consistent pattern indicating an overestimate of biomass compared to the trawl survey. Second, future assessments should include an assumed bycatch and discard mortality."

Response: Response is the same as to comments 2 and 4 from June 2009 SSC minutes.

c. CPT Comments (from May 2009)

1. *"…the CPT's preferred model from the previous year's assessment should be included in the suite of scenarios examined for the new assessment, in order to evaluate the impact of the changes in assessment methodology."*

   Response: Response is the same as to comment 1 from June 2009 SSC minutes.

2. *"The CPT discussed the justification for the zero handling mortality rate employed and questioned the justification as described in the assessment. The author assumed the only source of handling mortality is temperature-related freezing, but the team finds this assumption to be invalid. The team discussed additional mortality due to physical handling. The team recommends sensitivity tests be conducted next year based on plausible levels of handling mortality (use Bristol Bay red king crab as a benchmark). In the absence of any observer data on bycatch for this fishery, one suggestion was to estimate a fixed catch discard (e.g. 10-20% of retained) for comparison against the assumption of zero handling mortality."*

   Response: Length proportion data observed during 1986-1994 were used to estimate bycatch selectivities, which were used with annual harvest rates to estimate annual bycatch. See equation (4).

3. *"The current assessment uses M=0.30yr-1 versus 0.18yr-1 last year). The CPT discussed the validity of this change in M, noting that the likelihood profile for M in the assessment document does not fully justify this modification. If the assessment is using the argument that the likelihood profile is flat, then M should be based on Y axis scale, and not a visual evaluation of the profile. The CPT also disagreed with the assumption that the maximum age is 15 years, which is implicit in a natural mortality rate of 0.30yr-1."*

   "The team discussed the likelihood profiles of M presented in the assessment (Figure 2) and did not consider the rate of 0.30 to be adequately supported by either profile. The author argued that the likelihood profiles are essentially flat

beyond M=0.30 and that constituted justification for the choice. The team observed that such a finding must be evaluated on the basis of the change in log likelihood units equivalent to a 95% confidence interval on the Y-axis. Inspection of the change in M within approximately 2 log likelihood units for either profile did not support the assertion that M=0.30. The team requested that the author provide a comprehensive rationale for the selecting M from the log likelihood profile and a more informative discussion of model sensitivity to varying values of M."

Response: Figure 2 includes Y axis scale showing 2 log likelihood limits; however, *M* is assumed to be 0.18 per CPT request.

4. *"The author supported the choice of M=0.30 based on longevity. The author assumed that longevity (Tmax) for Norton Sound red king crab was 15 y. For the unexploited stock, a Tmax=15 y under a 1% rule corresponds to a M=0.30, viz 15 represents the 99th percentile of the age distribution of a virgin stock. Tmax=25 y previously used corresponds to a M=0.18 under a 1% rule."*

   "The author's assumed Tmax=15 y was based on mark-recapture results on Norton Sound red king crab. Here, 15 y = the approximate mean age at tagging (7-8 y) plus the maximum years at large of a recovered tag (7 y). The team noted that the maximum recovery period (7 y) depended on the underlying the mark-recapture program to provide crab at maximum age which was not evaluated. The team noted that the estimated 15 y age only represents a minimum estimate of Tmax by definition – e.g., observations are not on an unexploited stock and adequacy of the markrecapture program to provide recoveries 17-18 y at large. The team was concerned that the strong pattern exhibited by results of the retrospective analysis indicates that model results may be upward biased.

   Response: Tagging data was not used to estimate *M* for this year's assessment.

5. *The team discussed the estimated selectivity for small crab, noting that selectivity on small animals changed with M, but with flat selectivity for M < ~0.29yr-1. It was also unexpected to see estimates of MMB and legal males increase with decreasing M below ~M=0.30yr-1. The team noted that additional information should be included in the assessment to better understand parameter estimation as currently specified in model. Also, the assessment should include the previous year's OFL and catch for determination of overfishing."*

   Response: With *M* fixed at 0.18, trawl survey selectivity is estimated to be 1 for all crab. The OFL for 2009 was 0.7125 million pounds (retained), whereas the retained catch was 0.4173 million pounds.

6. *"The current assessment uses a gamma value of 0.6. The CPT noted that insufficient justification was given for a gamma different from 1.0. It was further noted that the author chose to modify Fmsy proxy to 0.18yr-1 (which is equivalent*

to the previous M value and a gamma of 1.0) without a clear justification. Author should provide strong justifications for rejecting the calculated F35."

Response: Gamma is now set equal to 1 as requested in the next CPT comment.

7. *"The CPT discussed the choice of model parameters, did not agree with the listed rationale for M and gamma, raised the possibility that model itself is mis-specified, and could consequently not support the author's preferred scenario. The CPT requested a revised assessment be presented. The revised assessment should be based on M = 0.18yr-1 and gamma = 1. The revised assessment was presented on Friday of the CPT meeting and is included in the draft SAFE report for May 2009."*

   Response: Gamma is now set equal to 1 as requested.

8. *"Next year's assessment should explore the implications of including bycatch and discard estimates in the assessment and also include the total catch for the year to date and compare this against the model assumptions of catch."*

   Response: Done. Effects of including bycatch mortalities are included. Total catches for each of the 3 fisheries as well as bycatch estimates for each year are given in Table 7. Size composition residuals for the summer fishery catches are shown in Figure 5.

9. *"The subsequent assessment should include a Tier 5 calculation."*

   Response: Done.

d. CPT Comments (from September 2009): none

C. Introduction

1. Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.
2. General Distribution: Norton Sound red king crab form 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 summer. The same surveys show that they are consistently abundant offshore of Nome. Red king crab generally show a migration pattern between deeper offshore waters during molting/feeding and inshore shallow waters during the mating period. Timing of the inshore mating migration is unknown. Scant data exists about mating location in the nearshore area. They are assumed to mate during March-June. Offshore migration is considered to begin in May-July. Trawl surveys during 1976-2006 show that crab distribution is dynamic. While crabs have always been abundant near shore in front of Nome, more 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).

   Summer Commercial Fishery

   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 involving approximately 10 fishers harvesting 2,400 crabs on average annually during 1978-2007 (Soong 2007).

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. 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. The GHL for the summer fishery is set in three levels: (1) estimated legal biomass < 1.5 million lbs: legal harvest rate = 0%; (2) estimated legal biomass ranges from 1.5 to 2.5 million lbs: legal harvest rate ≤ 5%; and (3) estimated legal biomass >2.5 million lbs: legal harvest rate ≤ 10%.

D. Data

1. Summary of new information:
    a. The model was updated with new data from the 2010 winter pot survey, 2009 summer commercial fishery, and 2009/2010 winter commercial and subsistence fisheries.
2. Available survey, catch, and tagging data are summarized in Table 2. The National Marine Fisheries Service (NMFS) conducted trawl surveys every 3 years from 1976 to 1991 (Stevens and MacIntosh 1986), and ADF&G conducted five trawl surveys during 1996-2008 (Soong 2008). 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 (10X10 nmi) 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 (Table 3) from the length of each soft-shell crab (assumed to have molted within the past 2 months). Four summer pot surveys were conducted by ADF&G (Table 2), and total male crab abundances were estimated using Petersen mark-and-recapture methods (Brannian 1987). ADF&G also conducted 25 winter pot surveys during 1980-2009 and one preseason pot survey in the summer of 1995 (Table 2); total crab abundances were not estimated for these pot surveys because of unreliable catch per unit effort (CPUE) data due to changing environmental conditions over time and a lack of tagging data. For all pot surveys, length and shell condition compositions were estimated.

Red king crab catches from the summer fishery were sampled by ADF&G from 1976 to 2008 to determine length and shell condition. Bycatch of sublegal males (observer data) from the summer fishery in 1987-90, 1992, and 1994 were also sampled by observers to determine length and shell condition. Total catch from all fisheries and effort (potlifts) from the summer fishery were obtained from the ADF&G office in Nome. Red king crabs were tagged and released during 1980-1991 (Powell et al. 1983; Brannian 1987); 222 tagged male crabs were recovered after spending at least one molting season at liberty. These tagging data were used to estimate a growth matrix and molting probabilities by premolt length.

E. Analytic Approach

1. **History of the modeling approach.**

A length-based synthesis model was developed by Zheng et al. (1998) for Norton Sound red king crab. The model was run by the ADF&G regional staff during 1998-2008. During the last two years, the model has been updated to provide information for the federal OFL setting.

2. Model Description

a. The model is an extension of the length-based synthesis model developed by Zheng et al. (1998). The model combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchabilities of the commercial pot gear, and parameters for selectivities and molting probabilities. A full model description is provided in Appendix A.

b-f. See appendix.

g. Critical assumptions of the model:

i. Natural mortality is constant over time and was estimated with a maximum age 25 and the 1% rule (Zheng 2005). Natural mortality for the last length group is 60% higher than for the other length groups (Zheng et al. 1998).

ii. Survey selectivities are a function of length and are constant over time and shell condition. Fisheries selectivities are constant over time except summer fishery selectivities that have two selectivity curves, one before 1993 and another after 1992 because of changes in fishing vessel composition and pot limits.

iii. Growth is a function of length and does not change over time.

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

v. A summer fishing season for the directed fishery is short.

vi. Handling mortality is assumed to be 20%.

vii. Annual retained catch is measured without error.

viii. Trawl survey catchability is set to 1.0 for legal males.

ix. Male crabs are mature at sizes ≥94 mm CL.

x. Length compositions have a multinomial error structure and abundance has a log-normal error structure.

h. Changes since last assessment: bycatch mortalities are now estimated. Length proportion data observed during 1986-1994 were used to estimate bycatch selectivities, which were used with annual harvest rates to estimate annual bycatch (appendix equation 4).

i. Code validation. Code from 2009 was error checked by A. Punt (University of Washington, pers. communication). Model code is available from the author.

3. Model Selection and Evaluation

a. Alternative model configurations. There were 7 alternative model formulations:

1) Last year's (2009) model
2) Same as above but with bycatch mortality
3) Same as above but with fishing effort weight = 20 (changed from 5)
4) Same as above but with selectivity changed for the last length group. The selectivity for the last length group was set to be 0.6 for alternatives 1-3, making a dome shape. This alternative will remove this third parameter, resulting in a high selectivity for the last length group and one parameter less than alternatives 1-3 (only two parameters for the logistic curve).
5) Same as above but with the maximum effective sample size for commercial catch and winter surveys = 100 (changed from 200).
6) Same as above but with *M* increased to 0.288 in the last length group
7) Same as above but M= 0.34

The main objectives to consider these alternatives are to reduce the bias of fit to the last length group and reduce the upward bias of the retrospective analysis. A weighting factor of 5 for the effort is equal to a CV of about 0.32, which has a very low weight. A weighting factor of 20 will result in a CV of about 0.16, giving the effort data a heavier weight. Removal of the third parameter for the selectivity of the last length group gets rid of this fixed parameter. There are data conflicts between the winter pot surveys and summer trawl surveys; change of the maximum effective sample size from 200 to 100 for commercial catch and winter surveys affects only a few years of data, reducing the influence of the winter survey data in some years. Increase in natural mortality in the last length group results in a less bias for fitting the last length group. This assumption is also consistent with all data that few crab were observed for this group.

b. Progression of results. The table below shows a progression in B_{MSY}, MMB, abundance, and likelihoods for the 7 alternatives. Note that comparisons between likelihoods are not advised where there are changes to weightings (alternatives 2 to 3 and 4 to 5).

Alternative	B_{MSY} (m.lbs)	MMB (m.lbs)	Legals (millions)	-Log Likelihood
1	3.074	6.374	1.973	13137.2
2	3.066	6.314	1.955	13135.7
3	3.115	5.812	1.795	13207.6
4.	2.748	5.445	1.702	13265.2
5	2.911	5.443	1.694	10359.3
6	3.117	5.441	1.694	10326.1
7	3.594	5.631	1.764	10282.5

c. Evidence of search for balance between realistic and simpler models. The 2009 model was somewhat simpler (did not include bycatch mortality). The addition of bycatch mortality was made to meet FMP requirements for estimation of total mortality. The addition of a separate *M* for the last length group was done to make a noticeable improvement in fit.

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. 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. Setting M = 0.34 (the best fit according to likelihood analysis) also helps reducing this bias.

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 for length compositions are shown in Figures 4 and 5.

i. Model evaluation is provided under Results, below.

4. Results

a. Effective sample sizes and weighting factors.

   i. Effective sample sizes for length compositions are given in Tables 8, 9, 10, and 11 for the various data sources.

   ii. Weighting factor for summer fishing effort, W_f = 20

iii. Weighting factor for recruitment, $W_R = 0.01$

b. Tables of estimates.

i. Parameter estimates are provided in Table 5.

ii. Abundance and biomass time series are provide in Table 6.

iii. Recruitment time series are in Table 6.

iv. Time series of catch/biomass are in Table 7.

c. Graphs of estimates.

i. Selectivities, molting probabilities, and proportions of legal crabs by length are provided in Table 4.

ii. Estimated male abundances (recruits, legal, and total) are plotted in Figure 6. Legal male abundance and mature male biomass are plotted in Figures 9 and 11.

iii. Estimated harvest rates are shown in Figure 7 (upper).

iv. Harvest rates are plotted against mature male biomass in Figure 7 (lower).

d. Graphic evaluation of the fit to the data.

i. Observed vs. estimated catches: not applicable. Catch is assumed to be measured without error.

ii. Model fits to survey numbers are shown in Figure 3 (upper).

iii. Model fits to catch and survey proportions by length: residual bubble plots are shown in Figures 4 and 5.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses are presented in this report: (1) historical results and (2) the 2010 model 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. Assuming the estimates in 2010 to be baseline values, we can also evaluate how well the model has done in the past. The 2010 model results are based on leaving one-year's data out at a time to evaluate how well the current model performs with less data.

Several biologists conducted the stock assessments of Norton Sound red king crab using this model during the last 10 years. Complete historical results were not available. The estimated legal male abundances in terminal years from 1999 to present were available and were graphed to compare the results made in 2010 (Figure 8). The 2005 result was omitted in this report because it was most likely affected by a data input error. The historical results in 2002, 2003, 2007, and 2009 were very close to those made in 2010 and quite different in 1999, 2004 and 2006 (Figure 8). Note that large differences happened in years when the last trawl survey occurred two to four years prior. These errors were due to terminal years as well as lack of trawl surveys in the previous one to three years.

Because no trawl survey was conducted prior to the abundance estimate before the summer fishery, the abundance estimate in a terminal year is like a one-year-ahead projection. Therefore, performance of the 2010 model includes leaving out data as well as one-year-ahead projection. The retrospective abundance and biomass estimates are generally biased higher during the recent years (Figure 9). Like the historical results, the years with a large difference were without a trawl survey one year earlier.

The large projection errors were mainly due to data conflicts between the trawl survey and the winter pot survey and the assumed low *M* value. Based on modal progressions of length frequencies from the winter pot survey, strong year classes were observed to go through the population during 1996-1999 and 2002-2006 (Figure 10), yet legal abundance estimates from trawl surveys in 2002, 2006 and 2008 were unexpectedly low. In years without trawl survey data, winter pot survey data played an important role in projecting population abundances. Trawl survey data were weighted more heavily than winter pot survey data, and in years when trawl survey data were available, they influenced abundance estimates greatly. Because a trawl survey was conducted every three or four years, measurement errors from a single trawl survey could affect the model results greatly. It is hard to determine whether the large projection errors were due to sampling errors in winter pot surveys or measurement errors in summer trawl surveys. The assumed low *M* value also overestimated mature and legal crab abundance and biomass because the trawl survey selectivity was forced to be 1.0 for all length groups. Next step of the study is to examine the impacts of winter pot surveys on terminal year's abundance estimates.

Legal abundance and mature male biomass estimates were slightly higher before 1991 for the 2010 model than the 2009 model and were lower during recent years (Figure 11). Legal abundance and mature male biomass estimates made in 2009 and 2010 were very close for the 2009 model (Figure 11).

f. Uncertainty and sensitivity analyses.

i. Impacts of Natural Mortality on Parameter and Abundance Estimates

Natural mortality affected the likelihood values, parameter estimates, and abundance estimates. The negative likelihood declined when *M* increased from 0.1 and reached the lowest value at about *M* = 0.34 (Figure 2). However, the likelihood values were basically flat with *M* = 0.29 to 0.37 for plus and minus 2 log likelihood units. Estimated mature male biomasses and legal male abundances generally decreased when *M* increased from 0.1 to 0.22, then increased from *M*=0.22 to 0.40, and decreased again from *M* = 0.40 to 0.50. These estimated values reflect trade-off between estimated survey selectivity and *M*; when *M* is low, estimated survey selectivity is equal to 1. *M* = 0.34 results in the maximum likelihood.

ii. Abundance and Parameter Estimates

The model fit well to observed sublegal and legal male trawl abundances except in 1979 when the trawl survey greatly underestimated the crab abundance (Figure 3a). This close fit between the observed effort for the summer commercial fishery and the model effort (Figure 3b), which is calculated from catch and abundance data, indicates that the CPUE of the summer commercial fishery is somewhat associated with the estimated legal abundance (Figure 3b).

The residuals of length compositions were generally large, except for the summer pot survey (Figures 4 and 5). The large residuals for the trawl survey are probably due to small sample sizes; all trawl surveys except in 1976 caught less than 200 legal crabs. The large residuals for the winter pot surveys and observer data also occurred in those years with a small sample size. The likelihood function placed less weight to those data with a small sample size. The sample sizes for the summer commercial fishery were large for most years; the large residuals may indicate a large sampling error. Residuals were generally uncorrelated among years and for length classes with two exceptions: (1) residuals of length classes for the winter pot surveys were generally negative for large length classes and positive for small length classes from 1981 to 1985 and opposite patterns from 1986 to 1993, and (2) residuals of length classes 2 and 6 for the summer trawl survey were mostly negative. These patterns could be modeled by increasing selectivity parameters. However, because the population abundance estimates are unaffected, we chose not to increase the number of model parameters to account for them.

Selectivities for summer trawl are equal to 1.0, which may be the artifact by a lower assumed *M* value. Selectivities for both summer trawl and pot surveys were higher than for the summer commercial pot fishery (Table 4). The winter pot surveys caught a small number of crabs in the last length class. A small proportion of crabs belonged to legal crabs in length class 3, and almost all crabs in the last three length classes were legal crabs (Table 4). Here the proportion of legal crabs was only used to separate retained catch in the observer data. For the purpose of this study, legal crab abundance was the sum of abundances in the last three length classes.

Population abundances were very high in the late 1970s and low in the early 1980s and mid 1990s (Figure 6). Due to lack of commercial fishing and likely favorable recruitments during the mid 1970s, the abundance in the late 1970s was close to a peak of the pristine condition. Recruitment fluctuated greatly during the past 3 decades. 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 was strong during the recent years (Figure 6). High harvest rates (>25%) from the summer fishery occurred from 1979 to 1981, and since then estimated harvest rates have been below 20% (Figure 7). Estimated harvest rates during the last 10 years were below 16% (Figure 7). Coefficients of variation for legal crab abundance and mature male biomass estimates were generally below 12% (Table 6).

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.

F. Calculation of the OFL

The Norton Sound red king crab stock is currently placed in Tier 4 (NPFMC 2007). For Tier 4 stocks, some abundance estimates are available, but complete population parameters are not available for computer simulation studies and spawning biomass per recruit analyses needed for Tier 3 stocks. The average of estimated biomasses for a given period is used to develop a B_{MSY}

proxy for Tier 4 stocks. We evaluated averages of mature male biomasses from three periods for the B_{MSY} proxy: 1976-2010, 1980-2010 and 1983-2010 (Figure 12).

The OFL is estimated by the F_{MSY} proxy, B_{MSY} proxy, and estimated legal male abundance and biomass:

$$F_{OFL} = \gamma M, \quad when\, B/B_{MSY} > 1, \qquad (a)$$
$$F_{OFL} = \gamma M\,(B/B_{MSY} - 0.1)/0.9, \quad when\, 0.25 < B/B_{MSY} \le 1, \quad (b)$$
$$F_{OFL} = bycatch\, mortality\, \&\, directed\ fishery\, F = 0, \quad when\, B/B_{MSY} \le 0.25, \quad (c),$$
$$OFL = \sum_l \left[(N_{s,l} + O_{s,l})\, legal_l\, w_l\, (1 - \exp(-F_{OFL}))\right],$$

where $N_{s,l}$ and $O_{s,t}$ 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. With the choice of M = 0.18 and γ = 1 by the CPT, F_{OFL} =0.18. Estimated legal male abundance and mature male biomass in 2010 are:

Legal males: 1.6940 million crabs with a standard deviation of 0.1892 million crabs.

Mature male biomass: 5.4410 million lbs with a standard deviation of 0.6284 million lbs.

Average of mature male biomasses during 1983-2010 was used as the B_{MSY} proxy. Estimated B_{MSY} proxy, F_{OFL} and retained catch limit in 2010 are:

B_{MSY} proxy = 3.1173 million lbs,

F_{OFL} = 0.18,

Retained catch limit: 0.2791 million crabs or 0.7335 million lbs.

Estimated mature male biomass in 2010 was 5.4410 million lbs, above all three B_{MSY} proxies. Because the population was at a near pristine condition in the late 1970s, we should not use the mature biomasses during that period for B_{MSY} proxy. Year classes after the 1976/77 regime shift (Overland et al. 1999) were expected to reach the mature population after 1982, and thus the average of mature biomasses during 1983-2010 is appropriate for B_{MSY} proxy.

With B_{MSY} proxy = 3.1173 million lbs, F_{OFL} = 0.18 (γ=1.0), B = 5.4410 million lbs in 2010, legal male abundance = 1.6940 million crabs or 4.4526 million lbs in 2010, the overfishing limits for retained catch in 2010 are 0.2791 million crabs or 0.7335 million lbs. The average weight for legal crabs is approximate and may need to be adjusted based on the actual mean weight of the catch.

Application of default proxy F_{OFL} = M and $F_{35\%}$ approaches to Norton Sound red king crab is questionable when the feasible estimate of M is high. When an artificially low M is used, the fishing mortalities or harvest rates based on these approaches may be plausible. This is the current choice of the CPT. However, a reasonable estimate of M may result in excessively high fishing mortalities or harvest rates for this stock. History of catch and estimated harvest rates (Figure 7) shows that the current harvest rates of 5-15% for the summer fishery may be reasonable, which allowed the stock to increase slowly. 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). The default M = 0.18 chosen by the CPT does not fit the data very well when applied to all length groups. The model with this M value consistently overestimates the crab abundance in the last length group. Historical tagging and returned data do not support the maximum age of 25 used to derive M=0.18 for this stock.

It is not easy to choose a period for average catch for tier 5. After no market for this fishery in 1991 when the summer fishery was closed, harvest rates have been set very conservatively. The mean catch before the current conservative harvest strategy (1977-1990) was 0.803 million lbs. The mean catch during 1977-2009 was 0.498 million lbs.

G. Rebuilding Analyses

Not applicable

H. Data Gaps and Research Priorities

(to be included at a later time)

I. Ecosystem Considerations

(to be included at a later time)

Acknowledgments

We thank Doug Woodby of ADF&G for reviewing the earlier draft of this report.

References

Alverson, D.L., and W.T. Pereyra. 1969. Demersal fish in the Northeastern Pacific Ocean - an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Board Can. 26:1985-2001.

Balsiger, J.W. 1974. A computer simulation model for the eastern Bering Sea king crab. Ph.D. thesis, Univ. Washington, Seattle, WA. 197 pp.

Brannian, L.K. 1987. Population assessment survey for red king crab (*Paralithodes camtschatica*) in Norton Sound, Alaska, 1985. Alaska Dept. Fish and Game, Tech. Data Rep. 214. 51 pp.

Clarke, M.W., C.J. Kelly, P.L. Connolly, and J.P. Molloy. 2003. A life history approach to the assessment and management of deepwater fisheries in the Northeast Atlantic. J. Northw. Atl. Fish. Sci. 31:401-411.

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

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. Amer. Fish. Soc. Sym. 6:66-82.

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

Otter Research Ltd. 1994. An introduction to AD Model Builder: for use in nonlinear modeling and statistics. Otter Research Ltd., Nanaimo, B.C., Canada. 44 pp.

Overland, J.E., J.M. Adams, and N.A. Bond. 1999. Decadal variability of the Aleutian Low and its relation to high-latitude circulation. Journal of Climate 12:1542-1548.

Powell, G.C., R. Peterson, and L. Schwarz. 1983. The red king crab, *Paralithodes camtschatica* (Tilesius), in Norton Sound, Alaska: History of biological research and resource utilization through 1982. Alaska Dept. Fish and Game, Inf. Leafl. 222. 103 pp.

Restrepo, V.R., G.G. Thompson, P.M. Mace, W.L. Gabriel, L.L. Low, A.D. MacCall, R.D. Methot, J.E. Powers, B.L. Taylor, P.R. Wade, and J.F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-31. 54 pp.

Shepherd, S.A., and P.A. Breen. 1992. Mortality in abalone: its estimation, variability, and causes. Pages 276-304 *In* S.A. Shepherd, M.J. Tegner, and S.A. Guzman del Proo (eds.). Abalone of the World: Biology, Fisheries, and Culture. Fishing News Books, Cambridge, UK.

Soong, J. 2007. Norton Sound winter red king crab studies, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 07-53, Anchorage.

Soong, J. 2008. Analysis of red king crab data from the 2008 Alaska Department of Fish and Game trawl survey of Norton Sound. Alaska Department of Fish and Game, Fishery Data Series No. 08-58, Anchorage.

Soong, J., A.O. Banducci, S. Kent, and J. Menard 2008. 2007 Annual Management Report Norton Sound, Port Clarence, and Kotzebue. Fishery Management Report No. 08-39.

Stevens, B.G., and R.A. MacIntosh. 1986. Analysis of crab data from the 1985 NMFS survey of the northeast Bering Sea and Norton Sound. Northwest and Alaska Fisheries Science Center, Processed Rep. 86-16. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 7600 Sand Point Way NE, Seattle, WA 98115, USA. 35 pp.

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

Zheng. J., and G.H. Kruse. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science 57: 438-451.

Zheng, J., and G.H. Kruse. 2006. Recruitment variation of eastern Bering Sea crabs: climate-forcing or top-down effects? Progress in Oceanography 68:184-204.

Zheng, J., G.H. Kruse, and L. Fair. 1998. Use of multiple data sets to assess red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska: A length-based stock synthesis approach. Pages 591-612 *In* Fishery Stock Assessment Models, edited by F. Funk, T.J. Quinn II, J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan, and C.-I. Zhang, Alaska Sea Grant College Program Report No. AK-SG-98-01, University of Alaska Fairbanks.

Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2009 (from Soong et al. 2008).

Year	Guideline Harvest Level (lbs) [b]	Commercial Harvest (lbs) [a, b] Open Access	Commercial Harvest (lbs) [a, b] CDQ	Total Number (incl. CDQ) Vessels	Total Number (incl. CDQ) Permits	Total Number (incl. CDQ) Landings	Total Pots Registered	Total Pots Pulls	Total Exvessel Price/lb	Total Fishery Value (millions $)	Season Length Days	Season Length Dates
1977	[c]	0.52		7	7	13		5,457	0.75	0.229	60	
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			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			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

[a] Deadloss included in total. [b] Millions of pounds.

Table 2. Summary of available data for Norton Sound male red king crab.

Data Set	Years	Data Types
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06, 08	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, 89-91,93,95-00,02-10	Proportion by length and shell condition
Summer preseason survey	95	Proportion by length and shell condition
Summer commercial fishery	76-90,92-10	Catch, effort, and prop. by length and shell condition
Observer data	87-90,92,94	Proportion by length and shell condition
Winter commercial fishery	76-10	Catch
Subsistence fishery	76-10	Catch
Tagging data	80-07	Mean and standard deviation of growth increment

Table 3. 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	74-83	84-93	94-103	104-113	114-123	124+
74-83	0	0.33	0.67	0	0	0
84-93	0	0	0.56	0.44	0	0
94-103	0	0	0	0.76	0.24	0
104-113	0	0	0	0.18	0.61	0.21
114-123	0	0	0	0	0.33	0.67
124+	0	0	0	0	0	1.00

Table 4. Estimated selectivities, molting probabilities, and proportions of legal crabs by length (mm CL) class for Norton Sound male red king crab.

			Selectivities					Molt. Prob.
Length Class	Length Range	Proportion of Legals	Summer Trawl	Summer Pot Surv	Winter Pot Surv	Summer Fishery 77-92	Summer Fishery 93-09	All Years
1	74 - 83	0.00	1.00	0.82	0.79	0.30	0.15	1.00
2	84 - 93	0.00	1.00	0.87	1.00	0.41	0.25	0.82
3	94 - 103	0.15	1.00	1.00	1.00	0.55	0.43	0.66
4	104 - 113	0.92	1.00	1.00	1.00	0.74	0.68	0.52
5	114 - 123	1.00	1.00	1.00	1.00	1.00	1.00	0.41
6	>123	1.00	1.00	1.00	0.38	1.00	1.00	0.31

Table 5. 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. deviation	Parameter	Value	Std. deviation
Log_N_{76}	8.7142	0.0190	Log_R_{01}	0.9729	0.2949
Log_mean	5.6232	0.2535	Log_R_{02}	1.1478	0.2778
Log_R_{77}	-3.7876	3.1285	Log_R_{03}	0.4527	0.3580
Log_R_{78}	-4.0737	2.9911	Log_R_{04}	-1.0868	0.9888
Log_R_{79}	-1.9847	0.6550	Log_R_{05}	0.6242	0.3300
Log_R_{80}	-0.6309	0.3319	Log_R_{06}	1.4615	0.2798
Log_R_{81}	1.2934	0.2692	Log_R_{07}	0.9768	0.3596
Log_R_{82}	0.6429	0.2870	Log_R_{08}	1.6572	0.2848
Log_R_{83}	0.8984	0.2989	Log_R_{09}	0.6053	0.5009
Log_R_{84}	1.0430	0.2788	log_q1	0.0000	6.9663
Log_R_{85}	0.6594	0.2808	log_q2	0.5760	0.0222
Log_R_{86}	-0.0572	0.3570	r1	-3.4794	0.3344
Log_R_{87}	0.2711	0.2895	log_α	4.1809	0.7364
Log_R_{88}	0.0465	0.2868	log_β	-1.3260	279.74
Log_R_{89}	0.3560	0.2874	log_Sst1	1.3482	1199.6
Log_R_{90}	0.0400	0.2981	log_Sst2	-3.2331	2.4647
Log_R_{91}	-0.4098	0.3154	log_Ssp1	3.7024	2.5522
Log_R_{92}	0.2046	0.3726	log_Ssp2	0.1098	0.3239
Log_R_{93}	-0.5140	0.6130	log_Sw1	4.3545	0.0045
Log_R_{94}	0.0482	0.3555	log_Sw2	0.3812	0.0449
Log_R_{95}	-0.1942	0.3382	Sw3	-3.5133	0.1481
Log_R_{96}	-0.1390	0.3026	log_ϕ_1	6.4578	199.13
Log_R_{97}	0.9475	0.2929	log_ω_1	-2.8046	0.3550
Log_R_{98}	0.9644	0.2769	log_ϕ_2	4.8179	0.1921
Log_R_{99}	-2.0307	0.6059	log_ω_2	0.9729	0.2949
Log_R_{00}	-0.4051	0.4140			

Data Component	Neg.Likelihood Value
Trawl immat. indices	9.975
Trawl mat. indices	20.532
Pot immat. indices	1.664
Pot mat. indices	3.494
Total effort	5.423
Trawl length compos.	2340.990
Pot length compos.	1284.800
Winter length compos.	2619.940
Summer length compos	3417.240
Observed length comp.	531.916
Recruitment deviation	0.568
Total	10326.100

Table 6. Annual abundance estimates (million crabs) and mature male biomass (MMB, million lbs) for Norton Sound red king crab estimated by length-based analysis from 1976-2010.

				Legals (> 103 mm)				MMB	
Year	Recruits	Total (> 73 mm)	Matures (> 93 mm)	Abund.	St. Dev.	Biomass	St. Dev.	Biomass	St. Dev.
1976	NA	6.0887	5.2205	3.9151	0.0745	9.7098	0.1849	11.9650	0.2278
1977	0.0047	5.0462	4.8913	4.1180	0.0706	11.0120	0.1860	12.3700	0.2140
1978	0.0380	3.9518	3.9241	3.6034	0.0646	10.2780	0.1812	10.8600	0.1937
1979	0.1473	2.6913	2.6516	2.5324	0.0559	7.5957	0.1625	7.8186	0.1698
1980	1.0089	1.5017	1.3568	1.3031	0.0468	4.0350	0.1415	4.1342	0.1445
1981	0.5265	1.8664	0.8994	0.8218	0.0380	2.5906	0.1188	2.7244	0.1230
1982	0.6797	1.6753	0.9813	0.5651	0.0367	1.5691	0.1088	2.2651	0.1424
1983	0.7854	1.9389	1.1707	0.7652	0.0455	1.9936	0.1217	2.6805	0.1653
1984	0.5352	2.1958	1.3088	0.8723	0.0494	2.2487	0.1318	2.9893	0.1674
1985	0.2614	2.1729	1.4934	0.9969	0.0533	2.5653	0.1407	3.4075	0.1789
1986	0.3630	1.8940	1.5157	1.0871	0.0595	2.8361	0.1570	3.5677	0.1955
1987	0.2900	1.7447	1.3348	1.0490	0.0608	2.8181	0.1656	3.3109	0.1898
1988	0.3951	1.6085	1.2545	0.9933	0.0587	2.7433	0.1636	3.1918	0.1852
1989	0.2881	1.6113	1.1728	0.9444	0.0568	2.6577	0.1606	3.0500	0.1811
1990	0.1837	1.5020	1.1433	0.8913	0.0554	2.5235	0.1573	2.9533	0.1809
1991	0.3396	1.3357	1.0928	0.8668	0.0552	2.4615	0.1565	2.8481	0.1780
1992	0.1655	1.3858	1.0222	0.8507	0.0538	2.4562	0.1535	2.7517	0.1711
1993	0.2905	1.2589	1.0283	0.8202	0.0503	2.3788	0.1447	2.7337	0.1692
1994	0.2279	1.1858	0.8711	0.7129	0.0478	2.0598	0.1380	2.3315	0.1507
1995	0.2409	1.0746	0.7971	0.6180	0.0440	1.7700	0.1274	2.0749	0.1456
1996	0.7139	1.0075	0.7277	0.5585	0.0438	1.5729	0.1252	1.8616	0.1437
1997	0.7260	1.4217	0.7018	0.5330	0.0445	1.4867	0.1261	1.7746	0.1474
1998	0.0363	1.8074	0.9788	0.6264	0.0469	1.6799	0.1301	2.2736	0.1699
1999	0.1846	1.5081	1.3021	0.8497	0.0559	2.2181	0.1494	2.9835	0.1882
2000	0.7323	1.3965	1.1922	0.9683	0.0605	2.6114	0.1644	3.0009	0.1870
2001	0.8722	1.7265	1.0045	0.8458	0.0574	2.3725	0.1621	2.6485	0.1814
2002	0.4352	2.1370	1.1715	0.8187	0.0568	2.2673	0.1602	2.8631	0.1977
2003	0.0934	2.0783	1.4727	0.9648	0.0670	2.5636	0.1805	3.4215	0.2322
2004	0.5167	1.7151	1.5095	1.1037	0.0743	2.9299	0.2014	3.6230	0.2400
2005	1.1936	1.7785	1.2625	1.0516	0.0730	2.8874	0.2035	3.2552	0.2253
2006	0.7351	2.4467	1.2281	0.9432	0.0696	2.6311	0.1972	3.1168	0.2308
2007	1.4517	2.5530	1.6104	1.0181	0.0800	2.7105	0.2168	3.7079	0.2898
2008	0.5070	3.3427	1.8068	1.2400	0.1030	3.2409	0.2698	4.2039	0.3631
2009	0.8808	3.0985	2.3027	1.4868	0.1436	3.8381	0.3653	5.2179	0.5081
2010		3.2395	2.2703	1.6940	0.1892	4.4526	0.4872	5.4410	0.6284

Table 7. 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	0.0084	0.5775	0.05
1978	2.0900	NA	0.0004	0.0137	2.1041	0.19
1979	2.9300	NA	0.0004	0.0121	2.9425	0.38
1980	1.1900	0.0000	0.0007	0.0059	1.1966	0.29
1981	1.3800	NA	0.0026	0.0393	1.4219	0.52
1982	0.2300	0.0014	0.0209	0.0151	0.2674	0.12
1983	0.3700	0.0021	0.0224	0.0237	0.4182	0.16
1984	0.3900	0.0029	0.0168	0.0245	0.4342	0.15
1985	0.4270	0.0054	0.0141	0.0221	0.4686	0.14
1986	0.4795	0.0026	0.0115	0.0172	0.5108	0.14
1987	0.3271	0.0011	0.0054	0.0088	0.3424	0.10
1988	0.2367	0.0010	0.0123	0.0061	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	0.0013	0.0820	0.03
1993	0.3358	0.0144	0.0082	0.0061	0.3645	0.13
1994	0.3289	0.0188	0.0109	0.0059	0.3645	0.16
1995	0.3227	0.0044	0.0034	0.0069	0.3374	0.16
1996	0.2235	NA	0.0015	0.0052	0.2302	0.12
1997	0.0930	0.0025	0.0172	0.0034	0.1161	0.07
1998	0.0297	0.0068	0.0151	0.0015	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	0.0101	0.2951	0.10
2003	0.2672	0.0013	0.0024	0.0102	0.2811	0.08
2004	0.3407	0.0053	0.0079	0.0081	0.3620	0.10
2005	0.4011	NA	0.0025	0.0075	0.4111	0.13
2006	0.4517	0.0083	0.0214	0.0152	0.4966	0.16
2007	0.3129	0.0145	0.0190	0.0143	0.3607	0.10
2008	0.3951	0.0124	0.0095	0.0176	0.4346	0.10
2009	0.3976	0.0097	0.0100	0.0156	0.4329	0.08

Table 8. Sample sizes for length compositions in the summer commercial fishery.

Year	Observed	Model	Effective N
1977	1549	100	27
1978	389	39	131
1979	1660	100	48
1980	1068	100	30
1981	1784	100	10
1982	1093	100	20
1983	802	80	28
1984	963	96	28
1985	2691	100	58
1986	1138	100	71
1987	1985	100	12
1988	1522	100	272
1989	2593	100	92
1990	1289	100	51
1991			
1992	2562	100	72
1993	17802	100	37
1994	404	40	99
1995	1174	100	41
1996	787	79	31
1997	1198	100	13
1998	1055	100	56
1999	378	38	12
2000	17213	100	45
2001	20030	100	747
2002	5220	100	211
2003	5226	100	89
2004	9605	100	43
2005	5360	100	30
2006	6707	100	52
2007	6125	100	46
2008	5766	100	21
2009	6026	100	59

Table 9. Sample sizes for length compositions in the summer pot survey.

Year	Observed	Model	Effective N
1980	3619	200	29
1981	4588	200	50
1982	6354	200	383
1985	9900	200	76

Table 10. Sample sizes for length compositions in the winter pot survey.

Year	Observed	Model	Effective N
1981	243	24	129
1982	2520	100	111
1983	1655	100	375
1984	773	77	35
1985	568	57	55
1986	144	14	63
1987	492	49	257
1988	2072	100	77
1989	1281	100	71
1990	181	18	13
1992	850	85	21
1994	776	78	515
1995	1582	100	157
1996	399	40	24
1997	882	88	61
1998	1308	100	178
2001	832	83	25
2002	826	83	145
2003	286	29	66
2004	406	41	103
2004	512	51	53
2006	160	16	50
2007	3482	100	123
2008	526	53	114
2009	581	58	61

Table 11. Sample sizes for length compositions in the summer trawl survey.

Year	Observed	Model	Effective N
1976	1311	200	
1979	133	66.5	33
1982	256	128	24
1985	311	155.5	116
1988	306	153	35
1991	250	125	53
1996	196	98	20
1999	274	137	126
2002	230	115	31
2006	208	104	90
2008	242	121	85

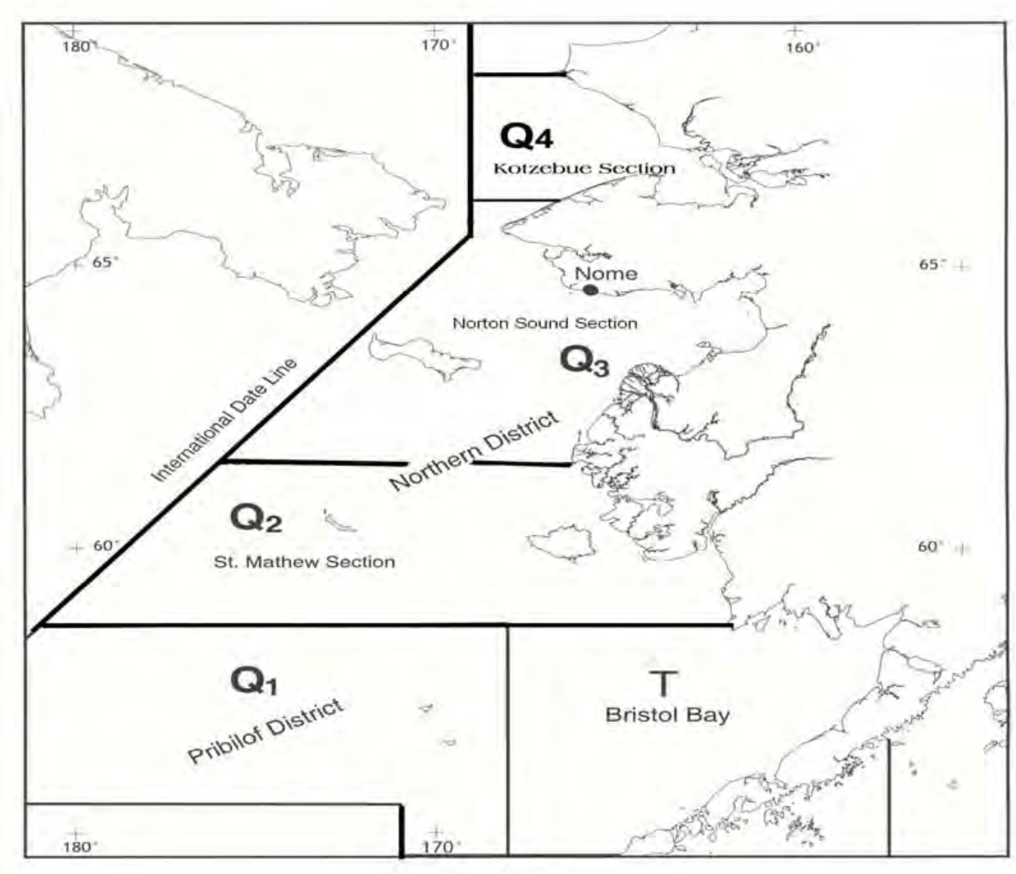


Figure 1. King crab fishing districts and sections of Statistical Area Q.

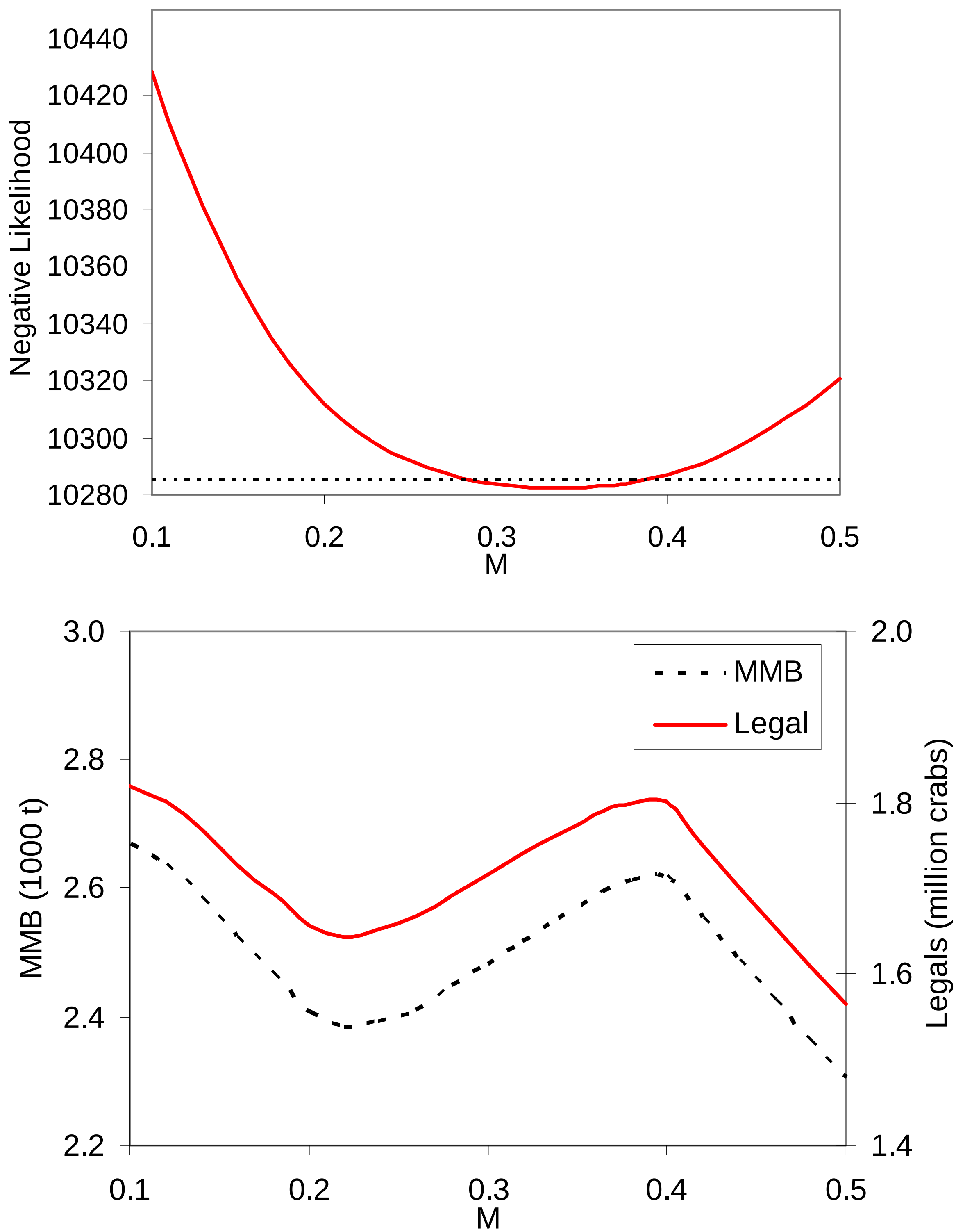


Figure 2. Likelihood profile for natural mortality, estimated legal abundance and mature male biomass in 2010 under different natural mortality values. The dotted line in the upper plot is the minimum negative likelihood plus 2.0.

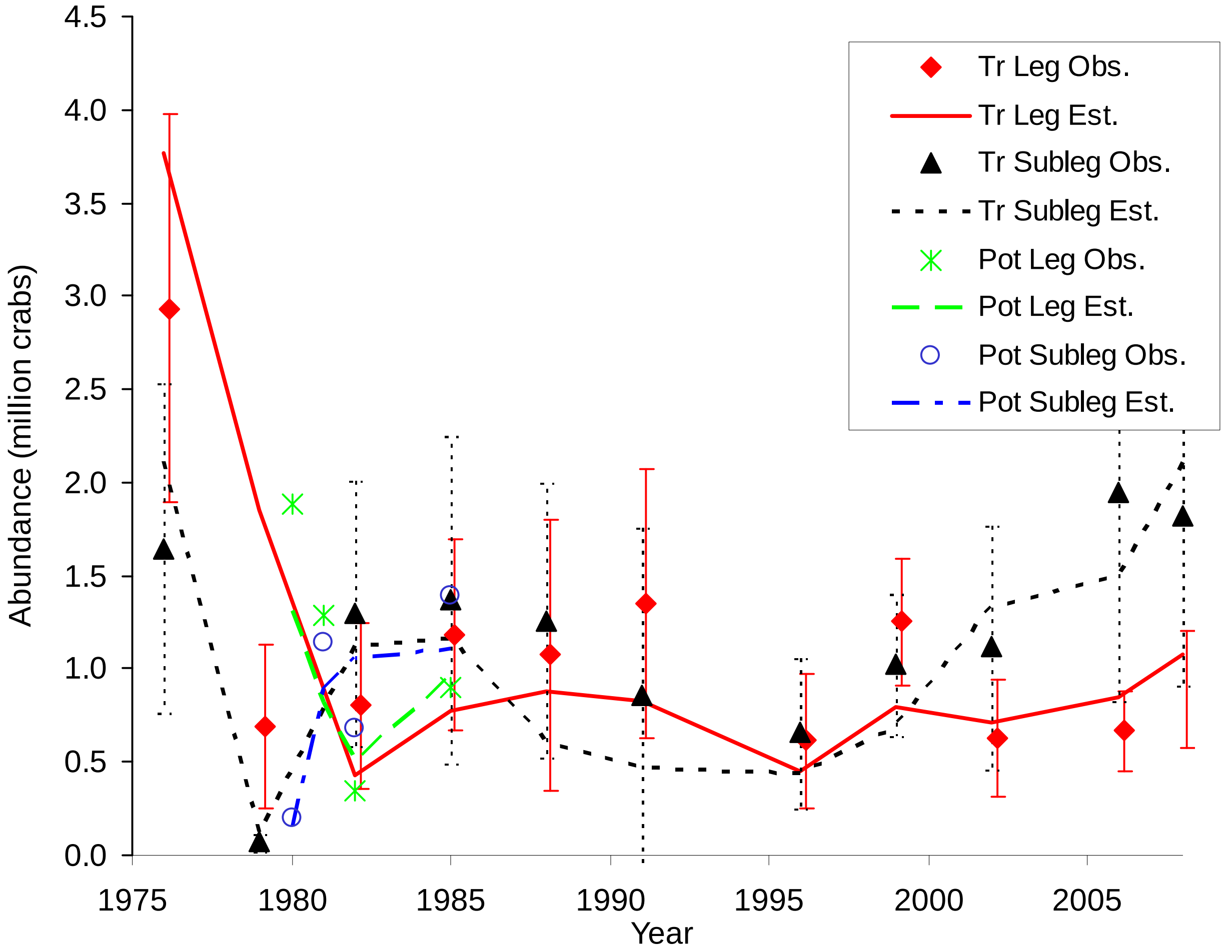
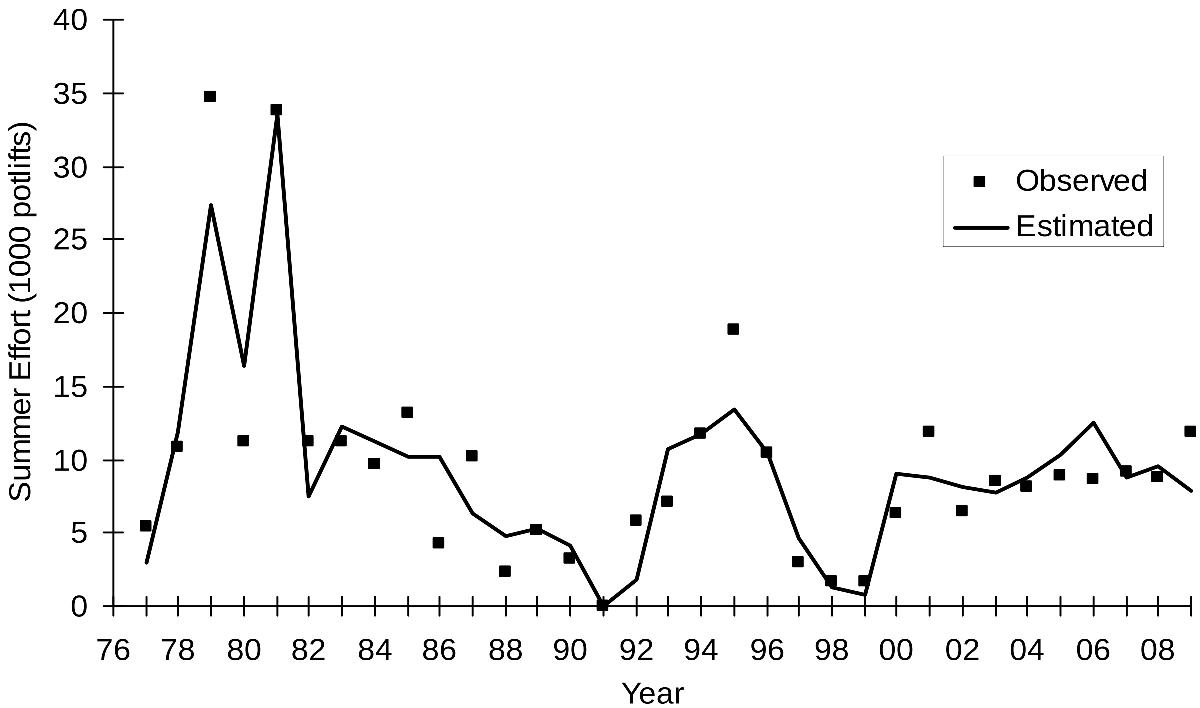


Figure 3a. Comparison of observed and estimated Norton Sound red king crab abundances (legal and sublegal males) by summer trawl and pot surveys (upper plot). "Tr" is trawl, "Leg" is legal, "Obs." is observed or survey abundance, and "Est." is estimated catchable abundance. The 95% C.I. were plotted separately for sublegal and legal crabs from the summer trawl surveys.



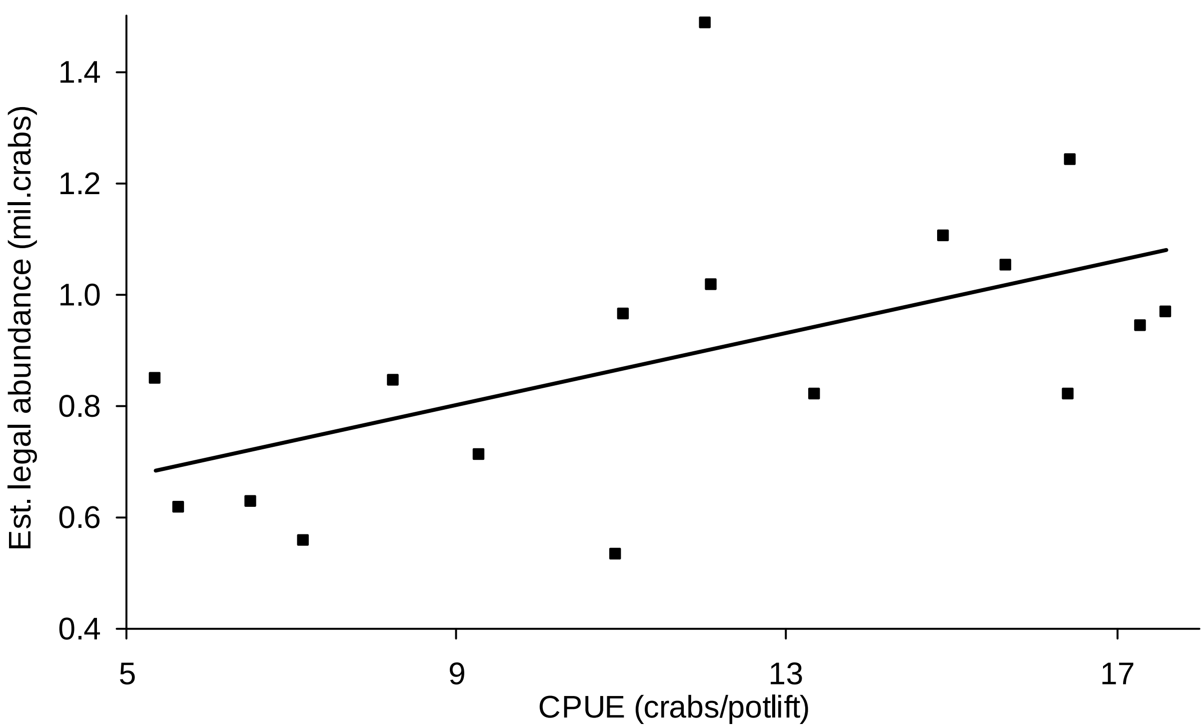


Figure 3b. Comparison of observed and estimated summer fishing efforts (upper plot) during 1977-2009 and the relationship between estimated legal male abundance and summer commercial catch per potlift during 1993-2009 (lower plot).

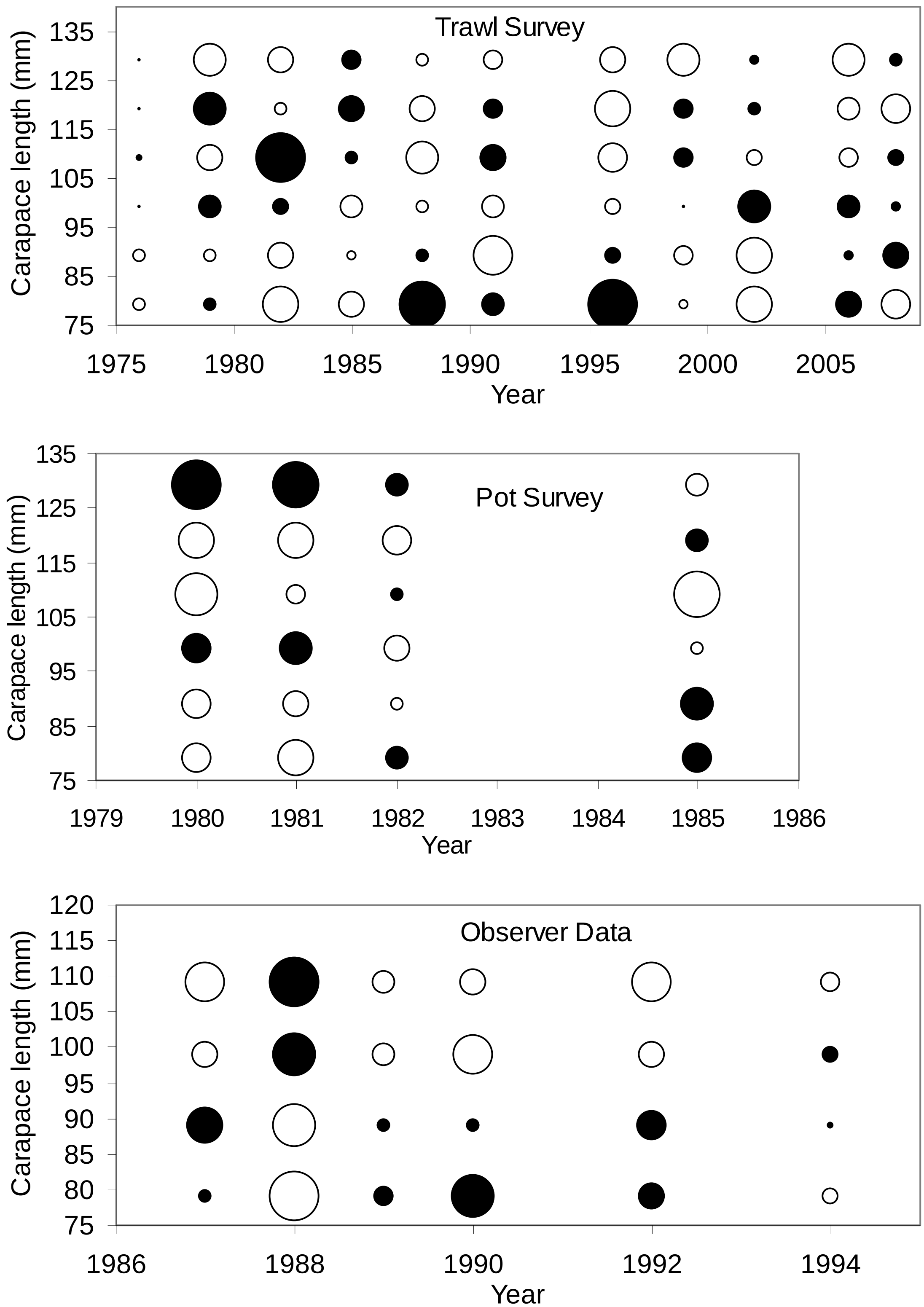


Figure 4. Residuals of length compositions by year for summer trawl and pot surveys and observer data for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.

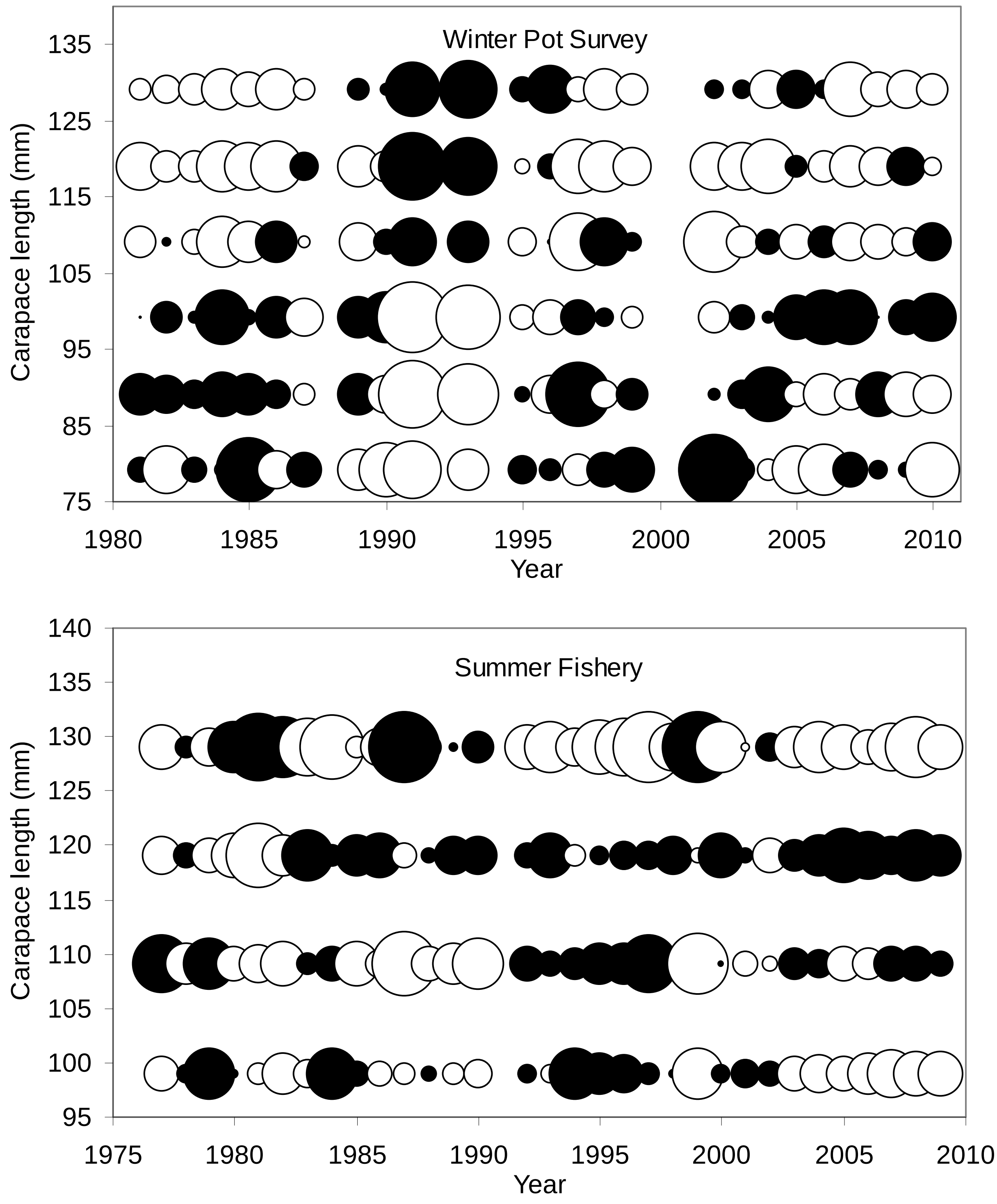


Figure 5. Residuals of length compositions by year for winter pot surveys and summer fishery for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.

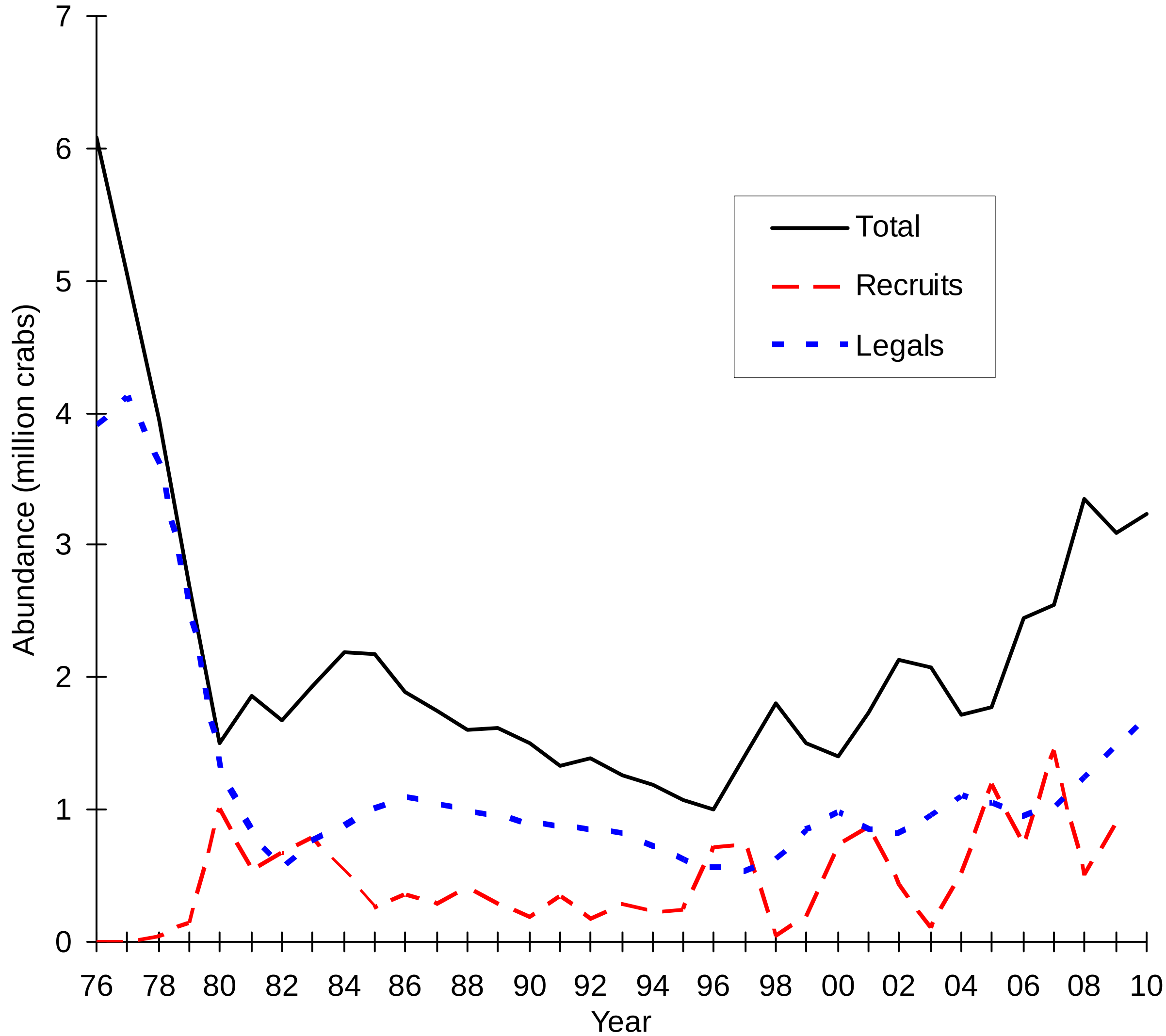


Figure 6. Estimated total (crabs>73 mm CL) and legal male abundances and recruits from 1976 to 2010.

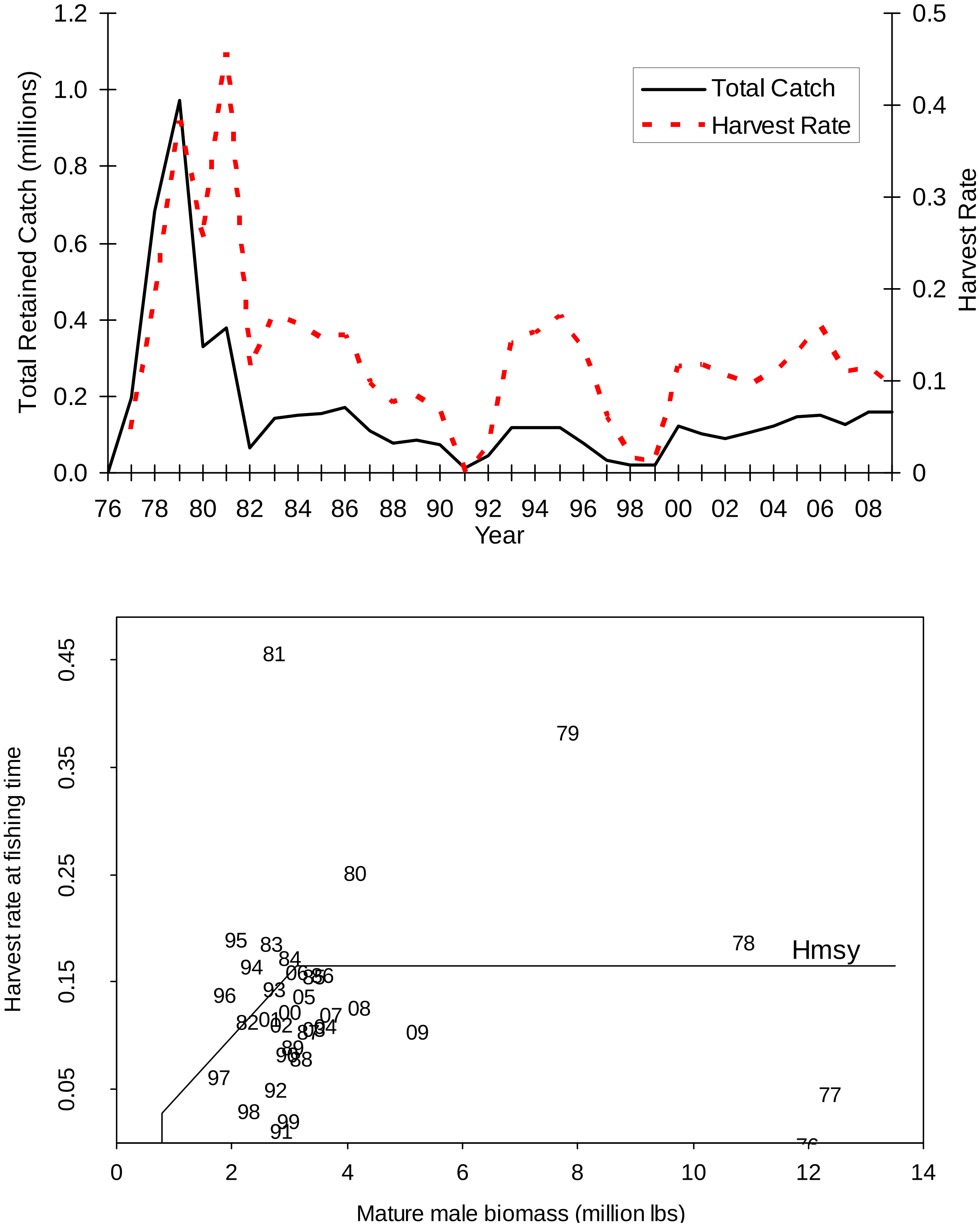


Figure 7. Total retained catches and harvest rates (upper plot) and relationship between harvest rates and mature male biomass (lower plot) of Norton Sound red king crab from June 1, 1976 to May 31, 2010. *Hmsy* is a proxy MSY harvest rate corresponding to *Fmsy* with γ=1.0 and *M*=0.18.

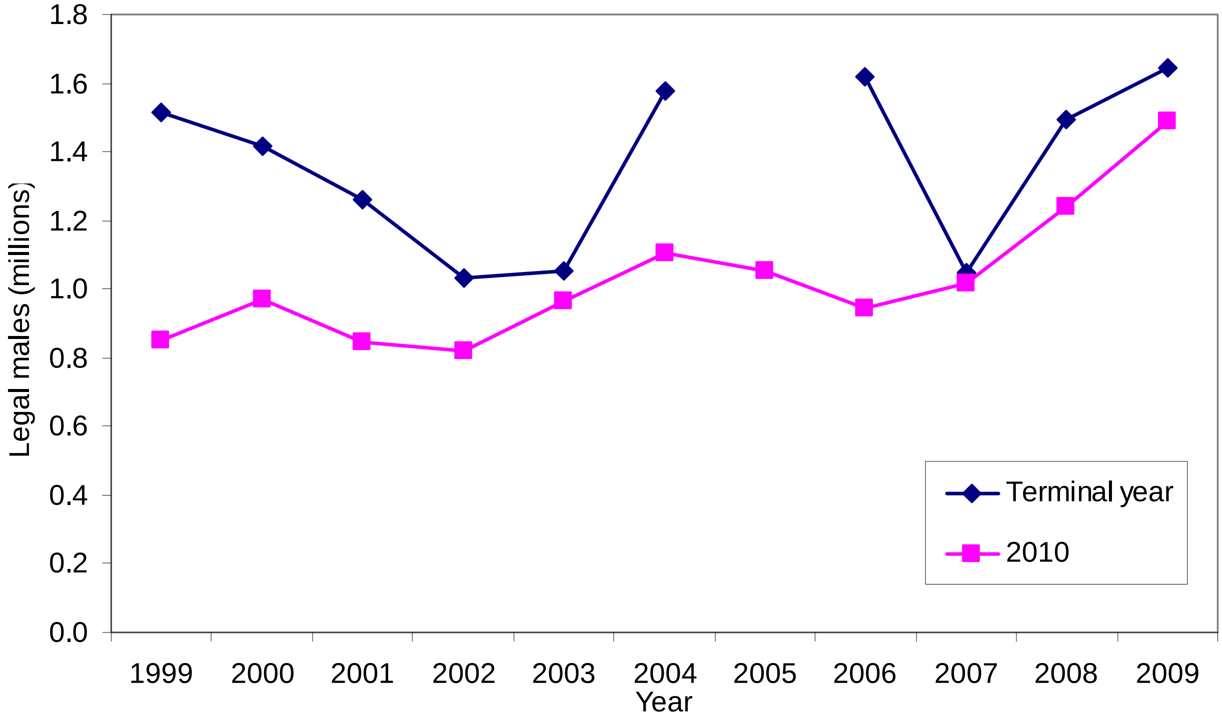


Figure 8. Comparison of estimates of legal male abundance of Norton Sound red king crab with terminal years 1999-2010. These are results of historical assessments. Legend shows the year in which the assessment was conducted.

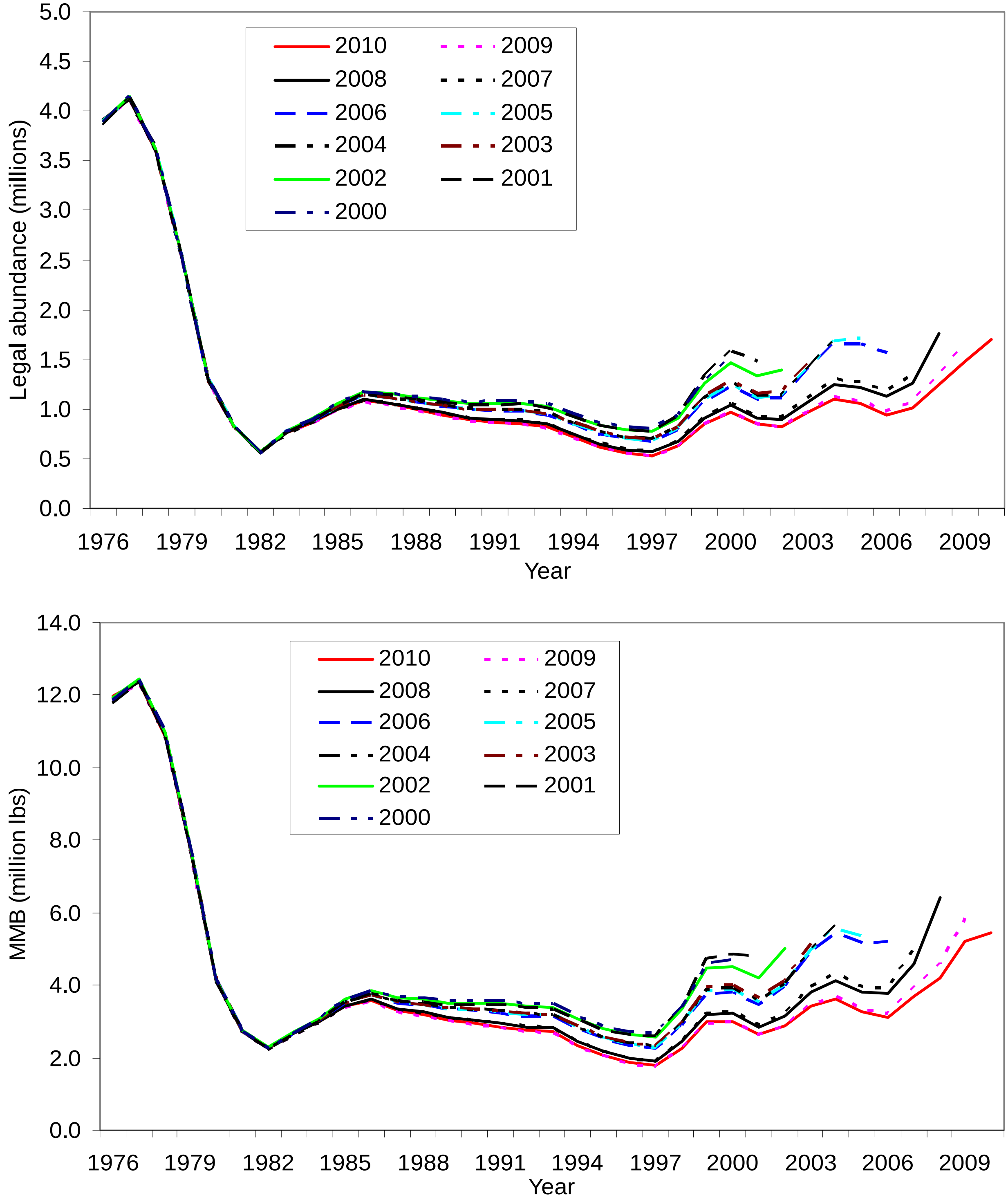


Figure 9. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of Norton Sound red king crab from 1976 to 2010 made with terminal years 2000-2010. These are results of the 2010 model. Legend shows the year in which the assessment was conducted.

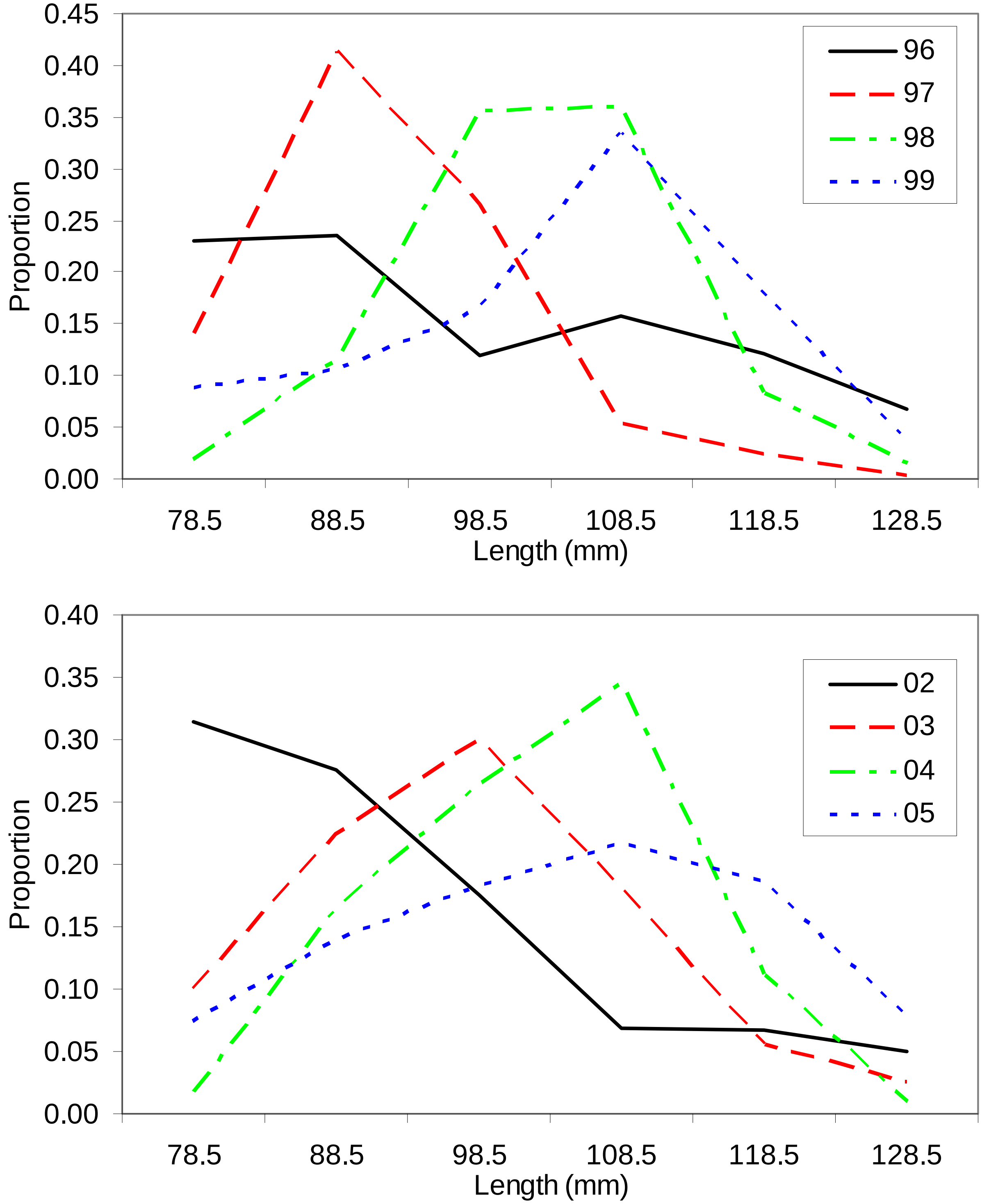
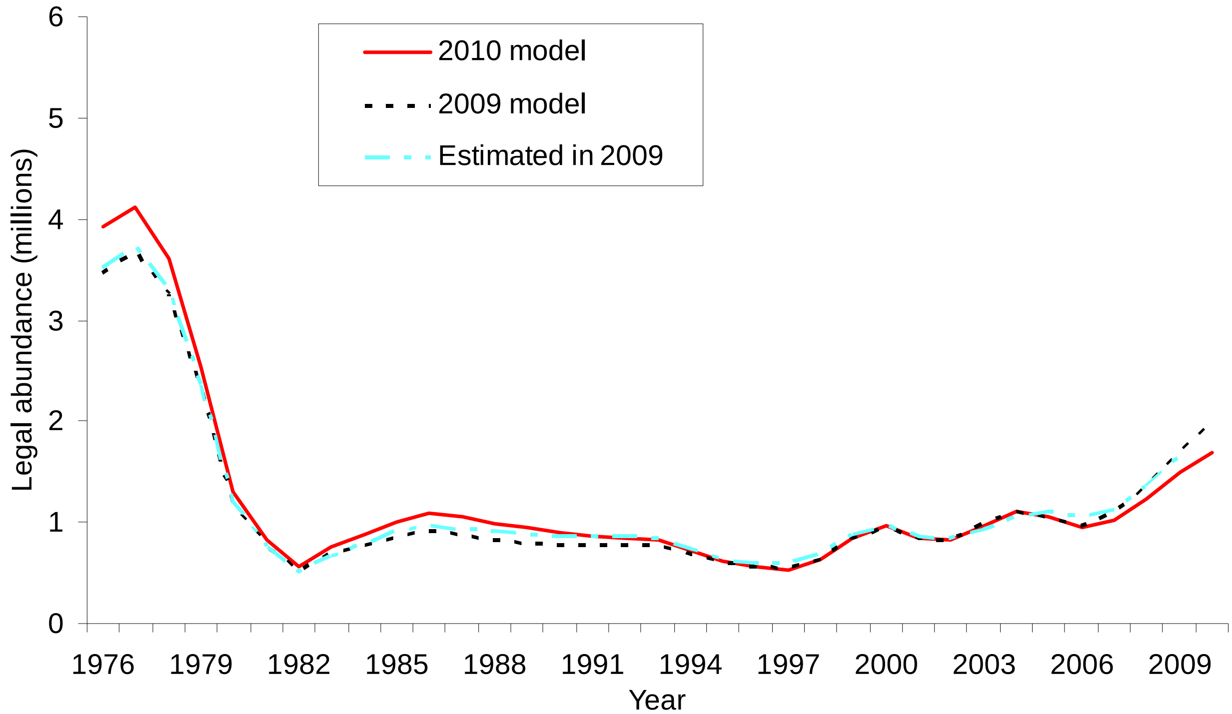


Figure 10. Length frequency of newshell crabs from the winter survey during two periods: 1996-1999 and 2002-2005.



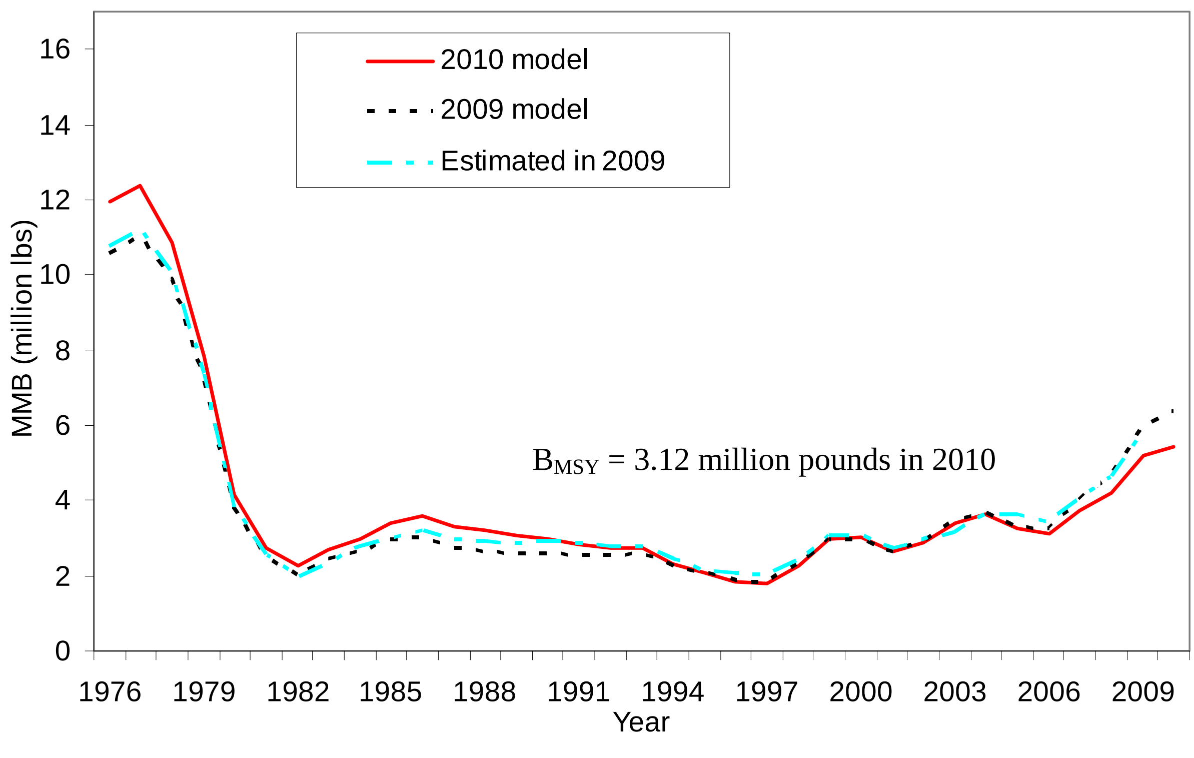


Figure 11. Comparison of legal abundance and mature male biomass estimates made in 2009 (dashed-dotted line), in 2010 by the 2009 model (dotted line), and in 2010 by the 2010 model (solid line). BMSY in the lower plot is 3.12 million pounds in 2010.

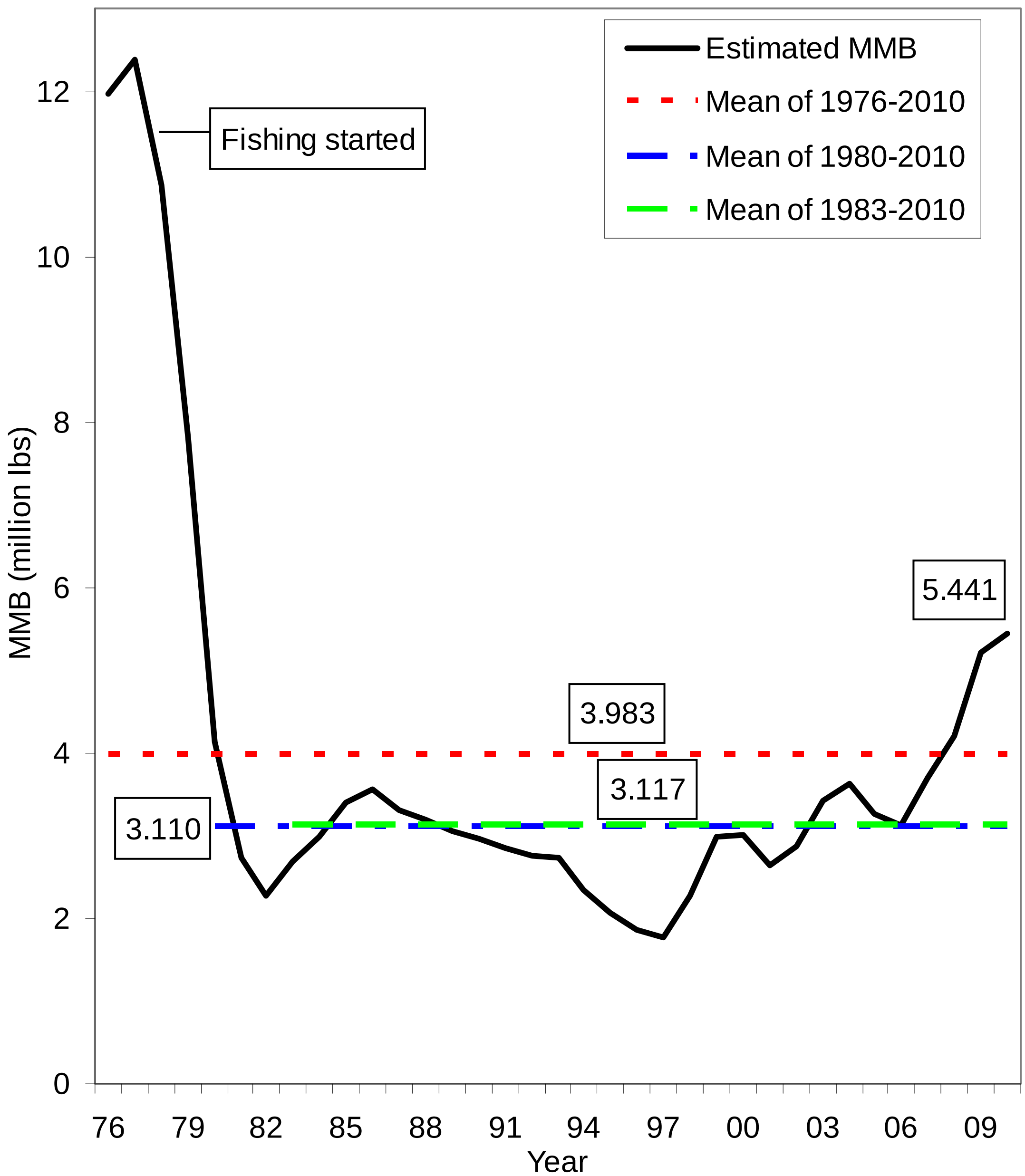


Figure 12. Comparison of estimated mean mature male biomasses during different periods of Norton Sound red king crab.

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 abundances are the survivors of crabs from the previous winter:

$$\begin{aligned} N_{s,l,t+1} &= (N_{w,l,t} - C_{w,t}P_{w,n,l,t} - C_{p,t}P_{p,n,l,t})e^{-0.417M_l}, \\ O_{s,l,t+1} &= (O_{w,l,t} - C_{w,t}P_{w,o,l,t} - C_{p,t}P_{p,o,l,t})e^{-0.417M_l}, \end{aligned} \quad (1)$$

where $N_{s,l,t}$ and $O_{s,l,t}$ are summer abundances of newshell and oldshell crabs in length class l in year t, $N_{w,l,t}$ and $O_{w,l,t}$ are winter abundances of newshell and oldshell crabs in length class l in year t, $C_{w,t}$ and $C_{p,t}$ are total winter and subsistence catches in year t, $P_{w,n,l,t}$ and $P_{p,n,l,t}$ are length compositions of winter and subsistence catches for newshell crabs in length class l in year t, $P_{w,o,l,t}$ and $P_{p,o,l,t}$ are length compositions of winter and subsistence catches for oldshell crabs in length class l in year t, and M_l is instantaneous natural mortality in length class l. For simplicity, we assumed constant (M) for all sizes and shell conditions except for the last length class, in which M is 60% higher than the other classes. The time from Feb. 1 to July 1 is 5 months, or 0.417 year.

Winter abundance of newshell crabs is the combined result of growth, molting probability, mortality, and recruitment from the summer population:

where $G_{l',l}$ is a growth matrix representing the expected proportion of crabs molting from length

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} [G_{l',l}((N_{s,l',t} + O_{s,l',t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l',t} + P_{s,o,l',t}) - D_{l',t})m_{l'}e^{-(0.583-y_t)M_l}] + R_{l,t}, \quad (2)$$

class l' to length class l, $C_{s,t}$ are total summer catch in year t, $P_{s,n,l,t}$ and $P_{s,o,l,t}$ are length compositions of summer catch for newshell and oldshell crabs in length class l in year t, $D_{l,t}$ are bycatches in length class l in year t, m_l is molting probability in length class l, y_t is the time in year from July 1 to the mid-point of the summer fishery, and $R_{l,t}$ is recruitment into length class l in year t. The time from July 1 to Feb. 1 is 7 months, or 0.583 year. Winter abundance of oldshell crabs is the non-molting portion of survivors of crabs from summer:

$$O_{w,l,t} = [(N_{s,l,t} + O_{s,l,t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l,t} + P_{s,o,l,t}) - D_{l,t}](1 - m_l)e^{-(0.583-y_t)M_l}. \quad (3)$$

Males >123 mm CL were grouped together to form the last length class. Sublegal males (<104 mm CL) are not legally retained in the commercial catch but are sorted, discarded, and subject to handling mortality. Due to complexity and lack of data, we did not model handling mortality.

Bycatches in the pot fishery are estimated as:

$$D_{l,t} = (N_{s,l,t} P_{s,n,l,t} + O_{s,l,t} P_{s,o,l,t})\,(1 - legal_l)\,hm\,[C_{s,t} / \sum_l (N_{s,l,t} + O_{s,l,t})\,legal_l\,], \tag{4}$$

where *hm* is handling mortality rate assumed to be 0.2, and $legal_l$ is the proportion of legal males in length class *l*.

Following Balsiger's (1974) findings, we used a reverse logistic function to fit molting probabilities as a function of length and time:

$$m_l = 1 - \frac{1}{1 + e^{-\alpha(\iota - \beta)}}, \tag{5}$$

where α and β are parameters, and *i* is the mean length of length class *l*. The sample size for the mark-recapture data is too small to estimate annual molting probabilities.

We modeled recruitment, R_t, as a stochastic process about the mean, R_0:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2). \tag{6}$$

R_t was assumed only to enter length classes 1 and 2; thus, $R_{l,t} = 0$ when $l \geq 3$. The recruits belonging to the first two length classes are:

$$R_{1,t} = r\,R_t, R_{2,t} = (1 - r)\,R_t, \tag{7}$$

where *r* is a parameter with a value less than or equal to 1.

Estimated length/shell compositions of winter commercial catch were derived from the winter population, winter selectivity for pots, and proportion of legal crabs for each length class:

$$\begin{aligned} P_{w,n,l,t} &= N_{w,l,t} S_{w,l} L_l / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l\,], \\ P_{w,o,l,t} &= O_{w,l,t} S_{w,l} L_l / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l\,], \end{aligned} \tag{8}$$

Where L_l is proportion of legal crabs for length class *l*, estimated from the observer data, and $S_{w,l}$ is winter selectivity for pots for length class *l*. Based on winter pot survey data, winter selectivities for length classes 3-5 were assumed to be one, and $S_{w,1}$, $S_{w,2}$ and $S_{w,6}$ were estimated as parameters.

The subsistence fishery does not have a size limit, but crabs with size smaller than length class 3 are generally not retained. So, we estimated length compositions of subsistence catch as follow when *l* > 2:

$$\begin{aligned} P_{p,n,l,t} &= N_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}\,], \\ P_{p,o,l,t} &= O_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}\,]. \end{aligned} \tag{9}$$

Estimated length compositions of winter pot survey for newshell and oldshell crabs, $P_{sw,n,l,t}$ and

$P_{sw,o,l,t}$, were also based on equation (7) except that $l \geq 1$.

Estimated length/shell condition compositions of the summer commercial catch were based on summer population, selectivity, and legal abundance:

$$P_{s,n,l,t} = N_{s,l,t} S_{s,l} L_l / A_t,$$
$$P_{s,o,l,t} = O_{s,l,t} S_{s,l} L_l / A_t, \qquad (10)$$

where $S_{s,l}$ is pot selectivity for the summer commercial fishery, and A_t is exploitable legal abundance in year t. $S_{s,l}$ was described by a logistic function with parameters ϕ and ω:

$$S_{s,l} = \frac{1}{1+e^{-\phi(l-\omega)}}. \qquad (11)$$

$S_{s,l}$ was 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. Exploitable abundance was estimated as:

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} L_l]. \qquad (12)$$

Summer fishing effort (f_t) measured as the number of pot-lifts was estimated as total summer catch, C_t, divided by the product of catchability q and mean exploitable abundance:

$$f_t = C_t / [q(A_t - 0.5C_t)]. \qquad (13)$$

Because of the change in the fishing fleet and pot limit in 1993, q was replaced by q_1 for fishing efforts before 1993 and by q_2 after 1992. Estimated length/shell compositions of bycatch were:

$$P_{b,n,l,t} = N_{s,l,t} S_{s,l}(1-L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}(1-L_l)],$$
$$P_{b,o,l,t} = O_{s,l,t} S_{s,l}(1-L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}(1-L_l)]. \qquad (14)$$

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:

$$P_{sf,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}],$$
$$P_{sf,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]. \qquad (15)$$

Estimated length/shell condition compositions of summer pot survey abundance were:

$$P_{sp,n,l,t} = N_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}],$$
$$P_{sp,o,l,t} = O_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}] \qquad (16)$$

where $S_{sp,l} = 1$ when $l \geq 3$, and $S_{sp,1}$ and $S_{sp,2}$ were estimated as two parameters. Similarly, length/shell condition compositions of summer trawl survey abundance were estimated with selectivity $S_{st,l} = 1$ when $l \geq 3$, and $S_{st,1}$ and $S_{st,2}$ were two parameters. Because some trawl surveys occurred during the molting period, we combined the length compositions of newshell and oldshell crabs as one single shell condition, $P_{st,l,t}$.

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:

$$\sum_{i=1}^{i=5}\sum_{t=1}^{t=n_i}\{K_{i,t}\sum_{l=1}^{l=6}[\hat{P}_{i,l,t}\,ln(P_{i,l,t}+\kappa)]\}-\sum_{i=1}^{i=2}\sum_{k=1}^{k=2}\sum_{t=1}^{t=n_i}[ln(\hat{B}_{i,k,t}+\kappa)-ln(B_{i,k,t}+\kappa)]^2/(2*ln(CV_{i,k,t}^2+1))$$

$$-W_f\sum_{t=1}^{t=32}[ln(\hat{f}_t+\kappa)-ln(f_t+\kappa)]^2-W_R\sum_{t=1}^{t=32}\tau_t^2, \qquad (17)$$

where i stands for a data set: 1 for summer trawl survey, 2 for summer pot survey, 3 for winter pot survey, 4 for summer fishery, and 5 for observer data during the summer fishery; n_i is the number of years in which data set i is available; $k = 1$ stands for legal crabs and $k = 2$ for non-legal crabs; $K_{i,t}$ is the effective sample size of length compositions for data set i in year t; $\hat{P}_{i,l,t}$ and $P_{i,l,t}$ are observed and estimated length compositions for data set i, length class l, and year t; κ is a constant equal to 0.001; CV is coefficient of variation for the survey abundance; and $B_{i,k,t}$ are observed and estimated annual total abundances for data set i and year t; W_f is the weighting factor of the summer fishing effort;and f_t are observed and estimated summer fishing efforts; and W_R is 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):

$$M = -\ln(p)/t_{\max}, \tag{18}$$

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). A 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. We varied M from 0.1 to 0.5 to investigate its impacts on stock assessments.

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 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).

DRAFT

Aleutian Islands golden king crab (*Lithodes aequispinus*) stock assessment

M.S.M. Siddeek[1], David R. Barnard[2], and Robert K. Gish[2]

Alaska Department of Fish and Game

1. Division of Commercial Fisheries
P.O. Box 115526
Juneau, Alaska 99811

2. Division of Commercial Fisheries
211 Mission Road
Kodiak, Alaska 99615

Executive Summary

1. Stock: Golden king crab, *Lithodes aequispinus* / east of 174°W longitude (ES) and west of 174°W longitude (WS)

2. Catches:

Aleutian Islands golden king crab commercial fishery developed in the early 1980s, the harvest peaked in 1986/87 (5.9 and 8.8 million pounds for east and west of 174°W longitude, respectively), and became steady since 1996/97 because of implementation of fixed guideline harvest levels (total allowable catch, TAC) of 3 and 2.7 million pounds for east and west of 174°W longitude, respectively. The TACs were increased to 3.15 and 2.835 million pounds for the two respective regions for the 2008/09 fishery following the Alaska Board of Fisheries decision, which were below the limit TACs determined under Tier 5 criteria (considering 1991-1995 mean catch as the limit catch) under the new crab management plan.

3. Stock biomass:

Estimates of legal male and mature male biomasses under Tier 4 assessment model are provided for ES in Table 4 and Figure 13, and for WS in Table 8 and Figure 24. Mature male and legal male biomasses showed increasing trend since 2005 for ES, but declining trend during 1989 to 2001 and steady since 2002 for WS. The 2009 legal male and mature male biomasses were slightly low compared to that of 2008 for the ES. The 2009 legal male biomass was slightly low compared to that of 2008 and 2009 mature male biomass was slightly high compared to that in 2008 for the WS.

4. Recruitment:

Estimates of recruit abundance are provided for ES in Table 4 and Figure 12, and for WS in Table 8 and Figure 23. The number of recruits to the model size group (>= 101 mm CL) peaked in 1997 and 2004 for ES, but fluctuated with a peak in 2004 and 2008 for the WS. The 2009 recruit abundance was similar to that of 2008 for ES, but the 2009 recruit abundance was low compared to that of 2008 for WS.

5. Management performance:

See Pengilly's Executive summary under Tier 5 analysis.

6. Basis for the OFL:

A length-based model for Tier 4 analysis was developed for the ES and WS. This model combined commercial retained and discard catch, observer retained and discard catch-per-unit-effort (CPUE), fishery retained and discard size composition, triennial pot survey CPUE, and pot survey size composition to estimate stock assessment parameters. The model structure was the same for ES and WS, but there was no pot survey component in the WS model. The data series used in the current assessment for the ES ranges from 1990 to 2008 (note: 1990 refers to 1990/91 fishery) for catch, CPUE, and catch length composition, 1997-2006 for triennial pot survey standardized CPUE. Data series considered for the WS ranges from 1989 to 2008 for catch, CPUE, and catch length composition. A maximum likelihood method was used to estimate stock assessment parameters and the time series of abundance of male recruits (≥101 mm carapace length, CL) as well as biomasses of legal males (≥136 mm CL), and mature males ((≥121 mm CL).

The model was used to determine the overfishing harvest level (OFL) separately for ES and WS, under different options of the multiplier λ on estimated *M* (0.26 for both regions), which was considered as the F_{OFL} under Tier 4. The options for limit harvest levels are provided below. The mean mature biomass was calculated considering all years of mature biomass estimates for the respective region (February 15, 1991- February 15, 2009 for ES and February 15, 1990 - February 15, 09 for WS):

ES stock:

Option	λ	Mean Mature Biomass (t) (Feb 1991-Feb 2009)	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)
1	1	47,991	11,875	645	12,520	27.60
2	0.5		6,223	358	6581	14.51
3	0.25		3,187	189	3,376	7.44

Considering the mean estimate of realized F, 0.05, Option 3 is recommended for setting the OFL for ES.

WS stock:

Option	λ	Mean Mature Biomass (t) (Feb 1990-Feb 2009)	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)
1	1	71,752	7,377	648	8,025	17.69
2	0.5		3,999	359	4,358	9.61
3	0.25		2,090	190	2,280	5.03

Considering the mean estimate of realized F, 0.03, Option 3 is recommended for setting the OFL for WS.

Under Option 3, the total OFL for the whole region (ES and WS combined) is 5,277 t (11.63 million pounds).

Because the 2009/10 fishery is still in progress, the selected limit harvest level from one of the above options (Option 3 preferred) can be considered for the 2010/11 fishing season.

We did not consider the groundfish bycatch data in the model. Total groundfish bycatch of golden king crab for 1996/97 to 2008/09 are provided in Pengilly's Table 4 (Pengilly, this SAFE report). The 2007/08 and 2008/09 from the region were 58.98 t (0.13 million pounds) and 32.89 t (0.07 million pounds), respectively.

A. Summary of major changes

The model has been greatly improved (see Appendix A).

B. Responses to CPT comments

The May 2009 CPT meeting comments are listed below with authors' response:

1. The model assumes mixing between stocks and the team recommends evaluation of CPUE disaggregated by the hot spots to see if there are similar trends in each area.
   - Not considered in the current model.

2. The CPT, noting that the penalty on fishing mortality was not well documented, discussed the use of CPUE with respect to the relevant SSC comment (i.e. the SSC did not intend for CPUE to be removed entirely from assessment, but their intent was instead that consideration be given to scenarios with and without these data).
   - Considered with and without CPUE information, but without CPUE information the model did not fit the data properly. So, all model scenarios considered CPUE.

Other comments on the model:

- Fits to the discard size-composition data suggest that the model is mis-specified.
  - The model has been extensively revised. This problem is sorted out.

- Retained selectivity: Three selectivity patterns were included in the assessment; the CPT was unclear what fully-selected F means when selectivity does not reach 1.0 at any size.

- The selectivity model is refined in this version, and the retained selectivity, on its own, reaches 1 for at least one size group. The selectivity figures given in this document are for the combined total and retained selectivity.

- Discard of large crab: the model suggests that some large crab are not being retained. It was also noted that some large crabs known as "leather backs" may be discarded.
  - The improved model fits the retained and discard catch composition properly.

- Equation 25 may be redundant since catch is already in Equation 21, although it should be clarified what is observed and what is predicted, and model sensitivity to removal should be examined.
  - Model equations have been revised.

- Note that the penalties are in different units such that equivalent penalty terms can have substantially different effects on model performance.
  - In Appendix A, penalties with corresponding CVs are given for clarification.

- Equations 10 and 11 - clarify typos on variables for C and D
  - This has been corrected.

- Recommendation to include scenarios with and without commercial CPUE data.
  - Please see response to item 2.

SSC agreed with the CPT comments and the model was not accepted for use to determine OFL for 2009/10.

Introduction

The golden king crab (*Lithodes aequispinus*) stocks in the Aleutian Islands have produced steady catches and steadily increasing catch-per-unit-effort (CPUE, defined as number of crabs per pot lift) in recent years (Figures 1 and 2). They are not surveyed by trawl gear because of the deep water and rocky habitats they live in. Therefore, annual stock-abundance estimates are not provided for this species from National Marine Fisheries Service (NMFS) surveys.

Data limitations combined with life history characteristics of golden king crab pose problems to development of appropriate stock assessment models. Golden king crab larvae are lecithotrophic and not known to rise to the upper water layer to feed, suggesting that the spring bloom is an unlikely cue for spawning and the spawning period is protracted (Shirley and Zhou 1997, Otto and Cummiskey 1985). Limited stock information and lack of annual survey data prevent developing the standard length-based assessment model as used in snow crab (*Chionoecetes opilio*) and red king crab

(*Paralithodes camtschaticus*) stock assessments (Turnock and Rugolo 2007, Zheng 2007). To overcome these problems, we developed an integrated analysis method, which combines commercial catch, catch size frequency composition, and triennial pot survey CPUE (restricted to ES stock) standardized to soak-time. The 1990-2008 data series from the WS and the 1989-2008 data series from the WS regions were used in the analysis. The model estimates of historical male recruit, legal male, and mature male abundances; full selection fishing mortality; and a number of stock assessment parameters are provided in this report.

Fishery

The Aleutian Islands golden king crab fishery developed in early 1980s and became a lucrative fishery after the collapse of a number of commercial crab stocks in the Bering Sea and Aleutian Islands (BSAI). Because of deep water habitat, the fishery is conducted using sets of pots in a long-line fashion. Since 1996, the Alaska Department of Fish and Game (ADF&G) has divided the Aleutian Islands golden king crab fishery into eastern and western districts at 174°W longitude (ADF&G 2002). Hereafter the east of 174°W longitude stock segment is referred to as ES and the west of 174°W longitude stock segment is referred to as WS. The stocks in the two areas are managed with a constant annual guideline harvest level or total allowable catch (3.0 million pounds for the ES and 2.7 million pounds for the WS). In 2008, however, the total allowable catch was increased to 3.15 and 2.835 million pounds for ES and WS, respectively, following the Alaska Board of Fisheries decision (approximately 5% increase in TAC). Because of a lack of information on total removal of crabs, the total allowable catch was determined to be the retained catch. Additional management measures include a male-only fishery and a minimum legal size limit (152.4-mm carapace width or approximately 136 mm CL), which is at least one annual molt increment larger than the 50% maturity length of 120.8 mm CL for males (Otto and Cummiskey 1985). Daily catch and CPUE are determined for in-season monitoring of fishery performance. Beginning in 2000, and with the introduction of crab rationalization in 2005, the CPUE increased. This is likely due to gear modification (crab fishers, personal communication, July 1, 2008), increased soak time, and decreased competition from the reduction in the number of vessels fishing. Decreased competition allows crab vessels to target only the most productive areas.

Data

A time series of commercial retained and discarded catch by length, observer CPUE data by length, triennial pot survey CPUE data by length (restricted to the ES), and the mean annual growth increment per molt (Watson et al. 2002) are the primary data and parameter values considered for model fitting and evaluation. The annual CPUE, retained, and discard catch are listed in Table 1 for the ES and in Table 5 for the WS.

The Aleutian Islands golden king crab fishery observer coverage declined from 100% of vessels and 100% of their catch prior to the 2004/05 season to 100% of vessels and 65-70% of their catch during the 2005/06 to 2007/08 seasons. Observers randomly selected a pre-determined number of pots daily and examined the entire pot contents for catch composition, including measuring carapace lengths and scoring shell conditions. The number of pots sampled accounts for 4-8% of the total pot lifts (Moore et al. 2000, Barnard et al. 2001, Neufeld and Barnard 2003, Barnard and Burt 2004). Observer data have been collected since 1988, but initial years' data from the collection are not comprehensive, so shorter time series of data for the period 1990-2008 for the ES and for the period 1989-2008 for the WS were selected for analysis along with other data sets.

Length-specific CPUE data collected by at-sea observers provide information on a wider size range of the stock than does the commercial catch length frequency data obtained from dockside samples. Monthly mean length frequency data were constructed from observer samples. The mean CPUE for retained and discarded male crabs were estimated for each month. The size range was restricted to 101 mm CL to 185 mm CL to allow use of an externally estimated mean growth increment as input when fitting the population dynamics model. The total male CPUE for each month was estimated by adding each male CPUE category (retained legal, discarded legal, and sublegal). The observer sample monthly length frequency was used to split the total monthly CPUE into monthly length-specific CPUE. If the fishing season exceeded one month, a weighted average (weighted by the effort) of the monthly length-specific CPUE was determined for the fishing season. The length-specific CPUEs were summed by length to obtain the total CPUE for the season. The length specific discard CPUE for the season was estimated similarly, but using only the sum of discarded legal and sublegal CPUE categories.

The monthly commercial catch and length frequency data were estimated from ADF&G landing records (fish tickets) and dockside length measurements. The monthly length frequency data were used to distribute the monthly total catch into different size intervals and summed by month to obtain the annual retained catch by size. The annual discard (dead) catch by size was estimated using the annual observer discard CPUE by size data multiplied by the annual effort (pot lifts) and a 20% handling mortality. Note that the observer CPUE by length data were used only for estimating discard catch by size to input into the population dynamic model, but not included in the parameter estimation.

The pot survey CPUE by length was estimated with the same method used for the observer data, except that the entire set of pot catches were measured and CPUE was estimated as the catch divided by the effort (pot lifts) (Watson 2007). The CPUE were standardized to soak-time by considering only those pot hauls with soak-time in the range of 30-140 hours. Box plot provided a 95th percentile value of 140-hour soak-time. Very few fell above 140-hour soak-time. The pot survey catches also cover a wider size range than the commercial size frequency. Furthermore, the four sets (1997, 2000, 2003, and 2006) of CPUE data came from a standard survey grid in a restricted area (between 52°15' and 53°00' N latitude and 170°00' and 171°30' W longitude), using a standard pot configuration, which may reflect the actual in situ population abundance. The majority of the ES commercial fishery takes place in this area; however, the soak time between the commercial and research pots may vary.

The model input parameters also include elapsed time from a biological start year to the mid-fishing period. The biological start of the year was arbitrarily set to July 1 (mid-survey time). The elapsed time from July 1 to the mid-date of fishing season y_t (as a fraction of a year) was estimated for each year (Table 2 for the ES and Table 6 for the WS fisheries).

Analytical Approach

Model Structure

The underlying population dynamics models are length-based. Overall negative likelihood is the sum of the negative log likelihoods of robust normal distribution of length composition (Fournier et al., 1990), lognormal pot survey standardized CPUE, lognormal catch biomass, log normal fishing mortality deviation, log normal recruit deviation, natural mortality penalty, and initial abundance size composition penalty (see Appendix A for detailed model structure). AD Model Builder, ver. 8.0.2 (Otter Research Ltd., 2007), was used to estimate the model parameters and to derive statistics, such as biomass and limit yield.

Parameters estimated independently

The analysis of tagging data indicated that the linear relationship between annual growth increment and pre-molt length was not significant ($p > 0.05$). Thus, a mean annual growth increment 14.4 mm CL was computed from the original tagging data to be applicable to the entire length range considered in the analysis (Watson et al. 2002, Siddeek et al. 2005).

Scant information is available on the level of handling mortality as a result of capture and release of unmarketable crabs although a large number of sublegal males and females are captured and released in the fishery (Neufeld and Barnard 2003, Blau et al. 1996). Lacking such information for golden king crab, we used an arbitrary 20% handling mortality rate on discarded males, which was obtained from the red king crab literature (Siddeek 2002, Kruse et al. 2000).

A length-weight model ($W = a1 * CL^{b1}$) for males was determined using 276 measurements taken during April – July 1997. The estimated parameters were: a1 = $2.988*10^{-4}$ and b1 = 3.135 (R^2_{adj} = 0.93).

Parameters estimated conditionally

The following stock parameters were estimated by minimizing the overall negative log likelihood function:

a and b: for the molt probability model;

c and d: for the total and pot survey selectivity model;

c_1 and d_1: for the total selectivity model for the period 1989-1997;

c_2 and d_2: for the total selectivity model for the period 1998-2004;

c_3 and d_3: for the total selectivity model for the period 2005 onward;

aa_1 and bb_1: for the retention selectivity model for the period 1989-1997;

aa_2 and bb_2: for the retention selectivity model for the period 1998-2004;

aa_3 and bb_3: for the retention selectivity model for the period 2005 onward;

selP1, selP2: multiplier for total and survey selectivity;

R_{90} to R_{09},: total number of male recruits for each year, except the first year;

q: pot survey catchability;

q_1: pot fishery catchability for the period 1989-1997;

q_2: pot fishery catchability for the period 1998-2004;

q_3: pot fishery catchability for the period 2005 onward;

F_{89} to F_{08}: full selection fishing mortality for 1989 to 2008;

β: shape parameter of the gamma growth function;

M: natural mortality;

N_{89}, N_{90}: available initial total number of new-shell crabs; and

O_{89}, O_{90}: available initial total number of old-shell crabs.

Different fishery retention selectivities and catchabilities were considered for the time period before 1997, between 1998 and 2004, and 2005 onwards. In 1985, the size limit was lowered from 6.5 to 6.0 inches and long-lined pots began to be used at this time as well (Forrest Bowers, personal communication). In 1999-2000, the industry changed the pot webbing to large mesh size (9.5”) (Jeff Davis, Crab fisher, personal communication, July 1, 2008). Since 2005, crab rationalization was in place, which has led to long soak time and hence more self-sorting on the bottom.

Model evaluation

Predicted vs. observed value plots, profile likelihood, and marginal size composition were the major criteria for model evaluation.

The weights attached to negative log likelihood components with the corresponding coefficient of variation are listed in Appendix A. The weights were chosen arbitrarily to obtain better fits to observed data.

Time varying effective sample sizes (K_t) were used for robust normal length composition log likelihoods (Fournier and Archibold 1980, Pribac and Punt 2005). They were estimated using the formula $K_t = \dfrac{400 \times n_t}{\max n_t}$ where n_t is the number of length measurements in year t and 400 is the maximum cap placed on effective sample size (Fournier and Archibold 1980). They were calculated separately for retained and discarded catch (Table 9).

Results

Model evaluation

ES:

The time series of predicted versus observed fishery retained (a), discard (b), and pot survey CPUEs (c) are shown in Figure 3a-c. All fits are reasonable. The time series of predicted vs. observed retained catch relative length frequency (Figure 4) and discard catch relative length frequency (Figure 5) depicted good fits for the ES. The marginal retained and discard length composition (estimated using equation 6 given in Punt and Kinzey, 2009) also showed good agreement (Figure 6). The pot survey CPUE size composition for 1997, 2000, 2003, and 2006 also depicted reasonably good fit (Figure 7). The profile likelihood of model estimated M indicated a peak near the 0.26 value (Figure 9).

Negative log likelihood components

Retained length composition	-908.86
Discard length composition	-828.31
Pot survey CPUE	-191.73
Retained CPUE	318.15
Discard CPUE	164.07

Retained catch biomass	9.36
Discard catch biomass	23.70
Recruitment deviation	19.36
Fishing mortality deviation	6.13
M penalty	0.03
Initial abundance composition penalty	0.05

WS:

The time series of predicted versus observed fishery retained (a) and discard (b) CPUEs are shown in Figure 14a-b. All fits are reasonable. The time series of predicted vs. observed retained catch relative length frequency (Figure 15) and discard catch relative length frequency (Figure 16) depicted good fits for the WS. The marginal retained and discard length composition also showed good agreement (Figure 17). The profile likelihood of model estimated *M* indicated a peak near the 0.26 value (Figure 19).

Negative log likelihood components

Retained length composition	-942.64
Discard length composition	-905.66
Retained CPUE	82.84
Discard CPUE	73.03
Retained catch biomass	2.22
Discard catch biomass	8.34
Recruitment deviation	29.31
Fishing mortality deviation	4.46
M penalty	0.01
Initial abundance composition penalty	1.72

Parameters estimated conditionally

ES:

Table 3 lists the parameter values estimated from the base model fit.

The molting probability systematically decreased as the crab size increased with the 50% probability near 135.63 mm CL (Figure 10). The effective retained selectivity (Total*retained) for the three periods (1990-97, 1998-04, and 2005 –onwards) peaked at the mid length168 mm CL and dropped thereafter (Figure 8). The 168 mm CL is the 14th size group and the drop thereafter was due to scaling down the selectivity beyond 168 mm CL by a constant parameter. This procedure fitted the size composition data well (see Appendix A for further explanation). The catchability in the survey pot gear and the fishery pot gear for the three periods ranged from $1.09*10^{-7}$ to $1.01*10^{-6}$ (Table 3). Fishery catchability has dramatically increased during the last period, perhaps due to increase in fishing efficiency.

Estimated time series of number of recruits to the size group considered in the model (101-185 mm CL), legal male biomass (≥ 136 mm CL) and mature male biomass (≥ 121 mm CL) are provided in Table 4. The estimated male recruit abundance to the model systematically increased to from 1991 to 1997, dropped thereafter, peaked in 2004, declined in 2005 and 2006, and increased to a steady level during 2007-2009 (Figure 11). The legal and mature biomasses systematically increased until 1997, declined until 2004, peaked in 2005, and remained steady during 2006-2009 (Figure 12a-b). The estimated full selection instantaneous fishing mortality systematically reduced since 1998 and was low in 2008 (Figure 13).

WS:

Table 7 lists the parameter values estimated from the base model fit.

The molting probability systematically decreased as the crab size increased with the 50% probability near 97.64 mm CL (Figure 20). However, the 50% molt probability was smaller compared to that for ES. The effective retained selectivity (Total*retained) for the three periods peaked at the mid length168 mm CL and dropped thereafter (Figure 18). The reason for this behavior is given under ES and Appendix A. The catchability ranged from $2.16*10^{-7}$ to $1.01*10^{-6}$ for the fishery pot gear for different periods. Different fishery catchabilities were considered for the time period before 1997, between 1998 and 2004, and 2005 onwards (Table 7). Fishery catchability has increased during the last period, perhaps due to increase in fishing efficiency.

Estimated time series of number of recruits to the size group considered in the model (101-185 mm CL), legal male biomass (≥ 136 mm CL) and mature male biomass (≥ 121 mm CL) are provided in Table 8. The estimated male recruit abundance to the model fluctuated throughout the time period under concern and peaked in 2004 and 2008 (Figure 21). The legal and mature biomasses systematically decreased until 2001, then increased to a peak in 2004 and then remained steady (Figure 22 a-b). The estimated full selection instantaneous fishing mortality fluctuated, peaked in 2000, and systematically reduced thereafter (Figure 23).

Harvest alternatives

The limit harvest levels for the ES under Tier 4, assuming the model estimated *M* value of 0.26 for the two regions, were estimated by an iterative procedure because the mature biomass, which was used in determining the *F* level, had to be estimated after the fishery was completed. Three options for limit harvest level are provided below:

ES stock:

Option	λ	Mean Mature Biomass (t) (Feb 1991-Feb 2009)	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)
1	1	47,991	11,875	645	12,520	27.60
2	0.5		6,223	358	6581	14.51
3	0.25		3,187	189	3,376	7.44

Considering the mean estimate of realized F, 0.05, Option 3 is recommended for setting the OFL for ES.

WS stock:

Option	λ	Mean Mature Biomass (t) (Feb 1990-Feb 2009)	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)

1	1	71,752	7,377	648	8,025	17.69
2	0.5		3,999	359	4,358	9.61
3	0.25		2,090	190	2,280	5.03

Considering the mean estimate of realized F, 0.03, Option 3 is recommended for setting the OFL for WS.

Under Option 3, the total OFL for the whole region (ES and WS combined) is 5,277 t (11.63 million pounds).

Because the 2009/10 fishery is still in progress, the selected limit harvest level from one of the above options (Option 3 preferred) can be considered for the 2010/11 fishing season.

Data gaps and research priorities

The recruit abundances were estimated from commercial catch sampling data. The implicit assumption in the analysis was that the estimated recruits came from the same exploited stock through growth and mortality. However, there is a possibility that additional recruitment can occur as a result of immigration from neighboring areas and possibly separate sub-stocks; however, the current analysis did not consider this possibility. Extensive tagging experiments are needed to investigate stock distributions.

Standardization of commercial CPUE data with respect to soak-time and depth were not pursued in this assessment; instead the pot survey data were standardized to soak-time. Pot survey soak-time ranged from approximately 30 to over 300 hours, but Box plot of the four pot survey data indicated that the 95th percentile soak-time was 140 hours. Nominal CPUE (catch / pot haul) of selected pots with 30-140 hours soak-time were considered as standard CPUE to input into to the likelihood function.

The natural mortality was estimated by the model fit. An independent estimate of *M* is needed for this stock. Tagging is one possibility. An extensive tagging study will also provide independent estimates of molting probability and growth increment.

An arbitrary 20% handling mortality rate on discarded males was used, which was obtained from the red king crab literature (Siddeek 2002, Kruse et al. 2000). An experiment based independent estimate of handling mortality is needed for golden king crab.

Summary

Aleutian Islands golden king crab stocks were assessed in an attempt to upgrade them from Tier 5 to Tier 4 level as defined in the proposed new crab fishery management plan (NPFMC 2007). The following table provides the essential parameters and derived statistics obtained from the ES and WS stocks analysis for Tier 4 upgrade:

Parameters/Tier	**Parameter values/Tier level**	
	ES	WS
M	0.26	0.26
Mature male biomass on 15 Feb 2009	63,052 t	64,055 t
MSY mature male biomass (1991-09 mean for ES,1990-09 mean for WS)	47,991 t	71,752 t
Tier allocation	4(a)	4(b)
F_{OFL} (1991-09 / 1990-09 option)	0.26	0.11
Suggested limit total catch (λ = 0.25)	7.44 mill. pounds	5.03 mill. pounds

Total groundfish bycatch of golden king crab for 1996/97 to 2008/09 are provided in Pengilly’s Table 4 (Pengilly, this SAFE report). The 2007/08 and 2008/09 from the region were 58.98 t (0.13 million pounds) and 32.89 t (0.07 million pounds), respectively. We did not consider groundfish bycatch removal assuming that it was minor for the size range considered in the model.

Acknowledgments

We thank Andre Punt for technical advice on improving the model, Doug Woodby, Jie Zheng, and Doug Pengilly for initial review of various versions of the model development.

References

ADF&G (Alaska Department of Fish and Game). 2002. Annual management report for the shellfish fisheries of the westward region, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K02–54, Kodiak, Alaska.

ADF&G (Alaska Department of Fish and Game). 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward region's shellfish observer program, 2006/07. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 08-02, Anchorage, Alaska.

Barnard, D.R., R. Burt, and H. Moore. 2001. Summary of the 2000 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K01–39, Kodiak, Alaska.

Barnard, D.R. and R. Burt. 2004. Summary of the 2002 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K04–27, Kodiak, Alaska.

Blau, S.F., D. Pengilly, and D.A. Tracy. 1996. Distribution of golden king crabs by sex, size, and depth zones in the eastern Aleutian Islands, Alaska. Pages 167-185 *In*: High latitude crabs biology, management, and economics. Alaska Sea Grant College Program, AK-SG-96-02, Fairbanks, Alaska.

Braumann, C.A. 2001. Constant effort and constant quota fishing policies with cut-offs in a random environment. Natural Resource Modeling, 14(2): 199-232.

Fournier, D. and C. P. Archibald. 1980. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39: 1195-1207.

Fournier, D., J. R. Sibert, J. Majkowski, and J. Hampton. 1990. MULTIFAN a likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). 1990. Can. J. Fish. Aquat. Sci. 47: 301-317.

Kruse, G.H., L.C. Byrne, F.C. Funk, S.C. Matulich, and J. Zheng. 2000. Analysis of minimum size limit for the red king crab fishery in Bristol Bay, Alaska. N. Am. J. Fish. Manage. 20:307-319.

Moore, H., L.C. Byrne, and M.C. Schwenzfeier. 2000. Summary of the 1999 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K00–50, Kodiak, Alaska.

Neufeld, G., and D.R. Barnard. 2003. Summary of the 2001 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K03–2, Kodiak, Alaska.

NPFMC (North Pacific Fishery Management Council) 1999. Amendment 7 to the Fishery Management Plan for the Commercial King and Tanner Crab Fisheries in the Bering Sea/Aleutian Islands to: 1. Revise Definitions of overfishing, MSY, and OY. 2. Update the BSAI Crab FMP. North Pacific Fishery Management Council, Anchorage, Alaska.

NPFMC (North Pacific Fishery Management Council) 2007. Amendment 24 to the fishery management plan for Bering Sea and Aleutian Islands king and Tanner crabs to revise overfishing definitions. North Pacific Fishery Management Council, Anchorage, Alaska.

Otter Research Ltd. 2007. An introduction to AD Model Builder (ver. 8.0.2) for use in nonlinear modeling and statistics. Otter Research Ltd., Box 2040, Sidney B.C., V8L 3S3, Canada.

Otto, R.S., and P.A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (*Lithodes aequispina*) in the Bering Sea and Aleutian Islands. Pages 123-135 In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Pribac, F. and A. E. Punt. 2005. Using length, age and tagging data in a stock assessment of a length selective fishery for gummy shark (*Mustelus antarcticus*). E-Journal of Northwest Atlantic Fishery Science, 35: art. 39.

Shirley, T.C., and S. Zhou. 1997. Lecithotrophic development of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). J. Crust. Biol., 17(2):207-216.

Siddeek, M.S.M. 2002. Review of biological reference points used in Bering Sea and Aleutian Islands (king and Tanner) crab management. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J02-06, Juneau, Alaska.

Siddeek, M.S.M., D.R. Barnard, L.J. Watson, and R.K. Gish. 2005. A modified catch-length analysis model for golden king crab (*Lithodes aequispinus*) stock assessment in the eastern Aleutian Islands. Pages 783-805 *In*: Fisheries assessment and management in data limited situations, Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, Alaska.

Turnock, B.J. and L.J. Rugolo. 2007 Stock Assessment of Eastern Bering Sea Snow Crab. Appendix A. In: Stock Assessment and Fishery Evaluation Report for the Bering Sea Aleutian Island King and Tanner Crab Fisheries. Compiled by the BSAI Crab Plan Team. North Pacific Fishery Management Council, Anchorage, Alaska.

Watson, L.J., D. Pengilly, and S.F. Blau. 2002. Growth and molting of golden king crabs (*Lithodes aequispinus*) in the eastern Aleutian Islands, Alaska. Pages 169-187 *In*: Crabs in cold water regions: biology, management, and economics, Alaska Sea Grant College Program, AK-SG-02-01, Fairbanks, Alaska.

Watson, L.J. 2007. The 2006 triennial Aleutian Islands golden king crab survey. Fishery Management Report No. 07-07, Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska. 71pp.

Zheng, J. 2007. Bristol Bay red king crab stock assessment in 2007. Appendix B. In: Stock Assessment and Fishery Evaluation Report for the Bering Sea Aleutian Island King and Tanner Crab Fisheries. Compiled by the BSAI Crab Plan Team. North Pacific Fishery Management Council, Anchorage, Alaska.

Table 1. Time series of annual retained catch (number of crabs), discarded and dead catch (assuming a handling mortality of 20%), observer retained catch-per-unit-effort (CPUE, number of crabs per pot lift), observer discard CPUE, and pot survey CPUE for the ES golden king crab stock. The data are for the size range 101-185 mm CL. NO=no sampling information, and + = low value not considered in the fit.

Year	Retained Catch	Discarded and Dead Catch	Observer Retained CPUE	Observer Discard CPUE	Pot Survey CPUE
1990	950,008	458,060	6.5071	21.3435	
1991	1,093,983	289,390	5.3043	10.8444	
1992	1,118,955	572,451	11.3052	21.4618	
1993	832,194	149,178	NO	NO	
1994	1,128,013	536,467	NO	NO	
1995	1,046,780	248,104	5.2710	6.9781	
1996	731,909	167,578	5.6212	7.3849	
1997	780,610	201,238	7.1164	9.4564	24.3435
1998	740,011	250,371	8.7964	15.0142	
1999	709,332	170,431	9.0003	10.7692	
2000	704,702	205,392	9.8166	14.3528	19.0676
2001	730,030	625	10.9693	0.0499+	
2002	643,886	107,952	11.8289	10.3717	
2003	643,074	97,249	10.9252	8.2578	7.9807
2004	637,536	74,610	18.7475	10.7051	
2005	623,971	42,997	26.7399	8.7502	
2006	650,587	45,746	24.0939	8.7319	8.4636
2007	633,253	43,963	29.7912	9.7037	
2008	666,946	45,504	28.4796	9.2995	

Table 2. Elapsed time (in years) between July 1 (an arbitrarily set mid-survey time) and mid-date of the golden king crab fishery, y_t, in the ES, 1990-2007. Data are from ADF&G (2008).

Fishing Season	y_t
1990/01	0.2630
1991/02	0.2712
1992/03	0.2740
1993/04	0.4603
1994/05	0.2479
1995/06	0.2219
1996/07	0.3274
1997/08	0.2849
1998/09	0.2630
1999/00	0.2452
2000/01	0.1781
2001/02	0.1589
2002/03	0.1548
2003/04	0.1562
2004/05	0.1425
2005/06	0.3932
2006/07	0.3548
2007/08	0.3932
2008/09	0.2904

Table 3. Estimates of parameters by the base model for the golden king crab data from the ES, 1990-2008.

Parameter	Estimate
molt: a, b	0.09, 135.63
Pot survey sel: c, d	0.50, 96.50
Total sel. 90-97: c_1, d_1	0.11,124.68
Total sel. 98-04: c_2, d_2	0.0.08, 150.0
Total sel. 05-: c_3, d_3	0.5, 132.55
Ret. sel. 90-97: aa_1, bb_1	0.5, 135.28
Ret. sel. 98-04: aa_2, bb_2	0.13, 142.78
Ret. sel. 05-: aa_3, bb_3	0.02, 160.0
α_r, β_r	200., 1.80
selP1, *selP2*	0.25, 0.25
Catchability 90-97: q_1	$2.73*10^{-7}$
Catchability 98-04: q_2	$9.17*10^{-7}$
Catchability 05-: q_3	$1.01*10^{-6}$
Pot survey Catchability: q	$1.09*10^{-7}$
F_{90} to F_{08}	0.06, 0.06, 0.07, 0.04, 0.10, 0.05, 0.03, 0.03, 0.08, 0.07, 0.06, 0.05, 0.05, 0.05, 0.04, 0.02, 0.03, 0.03, 0.03
β	0.53
M	0.26
N_{90} (million crabs)	95.75
O_{90} (million crabs)	1.02

Table 4. Annual abundance estimates of recruits to the model (millions of crabs), available legal male biomass (t), and available mature biomass (t) for golden king crab in the ES. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available.

Year	Recruits to the model (≥ 101 mm CL)	Mature male Biomass (≥ 121 mm CL)	Legal male Biomass (≥ 136 mm CL)
1990	NA	43,412	32,288
1991	17.83	47,951	37,570
1992	24.62	49,423	41,350
1993	29.59	49,847	43,726
1994	39.46	48,900	44,866
1995	35.75	51,277	43,519
1996	41.92	56,778	44,995
1997	49.54	62,296	49,090
1998	43.73	29,163	27,677
1999	30.17	32,347	30,340
2000	32.08	35,460	33,691
2001	10.50	37,724	37,211
2002	11.29	39,178	39,849
2003	12.52	38,692	41,186
2004	68.60	36,958	40,675
2005	8.52	65,691	74,358
2006	10.19	59,546	65,878
2007	24.30	64,141	66,466
2008	24.25	63,052	68,334
2009	24.25	NA	64,677

Table 5. Time series of annual retained catch (number of crabs), discarded and dead catch (assuming a handling mortality of 20%), observer retained catch-per-unit-effort (CPUE, number of crabs per pot lift), observer discard CPUE, and pot survey CPUE for the WS golden king crab stock. The data are for the size range 101-185 mm CL.

Year	Retained Catch	Discarded and Dead Catch	Observer Retained CPUE	Observer Discard CPUE
1989	1,585,080	465,045	8.8093	11.4803
1990	757,610	212,733	4.9755	9.8241
1991	753,415	190,614	7.6125	9.3964
1992	409,373	137,176	5.6989	9.8769
1993	565,336	255,809	6.7760	10.0110
1994	796,258	399,059	6.3274	10.2250
1995	535,553	200,387	4.7003	8.6937
1996	605,137	160,413	5.7014	8.0557
1997	569,550	127,647	6.5811	7.3520
1998	409,531	107,749	10.9770	14.9985
1999	676,558	165,544	6.0588	7.7328
2000	705,613	190,119	6.6000	9.3896
2001	686,738	172,061	6.3609	8.1536
2002	665,045	176,065	7.7090	9.2056
2003	676,633	112,150	9.2891	8.4659
2004	685,465	127,386	10.8300	11.2045
2005	639,368	73,526	21.0381	12.2071
2006	523,701	52,351	21.1843	9.8073
2007	600,604	68,473	20.3124	11.4312
2008	587,661	71,143	24.1690	13.5770

Table 6. Elapsed time (in years) between July 1 (an arbitrarily set mid-survey time) and mid-date of the golden king crab fishery, y_t, in the WS, 1989-2008. Data are from ADF&G (2008).

Fishing Season	y_t
1989/90	0.7315
1990/91	0.7315
1991/92	0.7329
1992/93	0.7315
1993/94	0.7315
1994/95	0.7315
1995/96	0.7329
1996/97	0.6699
1997/98	0.6699
1998/99	0.6699
1999/00	0.6466
2000/01	0.5151
2001/02	0.4342
2002/03	0.4041
2003/04	0.3630
2004/05	0.3164
2005/06	0.4137
2006/07	0.4753
2007/08	0.4753
2008/09	0.4753

Table 7. Estimates of parameters by the base model for the golden king crab data from the WS, 1989-2008.

Parameter	Estimate
molt: a, b	0.50, 97.64
Total sel. 90-97: c_1, d_1	0.23,122.53
Total sel. 98-04: c_2, d_2	0.14, 132.24
Total sel. 05-: c_3, d_3	0.17, 138.50
Ret. sel. 90-97: aa_1, bb_1	0.5, 135.79
Ret. sel. 98-04: aa_2, bb_2	0.12, 141.80
Ret. sel. 05-: aa_3, bb_3	0.07, 136.77
α_r, β_r	37.39, 2.97
selP1	0.20
Catchability 90-97: q_1	$2.16*10^{-7}$
Catchability 98-04: q_2	$4.68*10^{-7}$
Catchability 05-: q_3	$1.01*10^{-6}$
F_{89} to F_{08}	0.04, 0.02, 0.02, 0.01, 0.02, 0.03, 0.03, 0.02, 0.02, 0.02, 0.05, 0.05, 0.05, 0.04, 0.03, 0.03, 0.03, 0.03, 0.03, 0.03
β	2.50
M	0.26
N_{89} (million crabs)	1808.04
O_{89} (million crabs)	1.02

Table 8. Annual abundance estimates of recruits to the model (millions of crabs), available legal male biomass (t), and available mature biomass (t) for golden king crab in the WS. Legal male biomass was estimated at the survey time and mature male biomass for year y was estimated on February 15, year y+1 after the year y fishery total catch removal. NA = not available.

Year	Recruits to the model (≥ 101 mm CL)	Mature male Biomass (≥ 121 mm CL)	Legal male Biomass (≥ 136 mm CL)
1989	NA	107,004	88,622
1990	5.12	99,010	72,704
1991	15.55	103,325	73,905
1992	6.73	93,563	64,310
1993	13.65	92,952	65,359
1994	9.70	85,596	61,093
1995	3.80	72,135	50,343
1996	18.14	79,667	59,403
1997	19.69	87,102	68,106
1998	14.64	63,477	58,677
1999	1.36	49,438	46,072
2000	10.11	47,309	44,663
2001	8.57	44,151	42,001
2002	19.28	52,506	50,737
2003	19.99	59,705	58,211
2004	25.61	70,863	69,654
2005	14.71	55,347	59,519
2006	14.17	53,632	57,598
2007	16.66	54,198	58,452
2008	28.05	64,055	69,037
2009	11.57	NA	62,635

Table 9. Effective sample sizes, K_t , for fitting relative retained and discarded catch compositions in ES and WS and pot survey CPUE composition for golden king crab. NC = not considered.

Year	East of 174°W longitude		West of 174°W longitude		Pot Survey
	Retained Catch	Discard Catch	Retained Catch	Discard Catch	
1989	NC	NC	400	65	
1990	300	17	109	16	
1991	400	18	133	30	
1992	328	24	72	21	
1993	28	129*	30	11	
1994	49	129*	47	54	
1995	105	136	6	400	
1996	87	380	78	160	
1997	119	341	83	98	400
1998	128	400	57	69	
1999	98	305	68	120	
2000	71	128	48	145	259
2001	73	138	55	122	
2002	70	87	49	78	
2003	33	74	37	62	125
2004	51	53	36	60	
2005	33	23	34	30	
2006	26	19	35	29	143
2007	46	23	27	32	
2008	47	29	29	31	

* = Mean for the entire time series of discarded catch K_t values was substituted for missing observer samples for discarded crab.

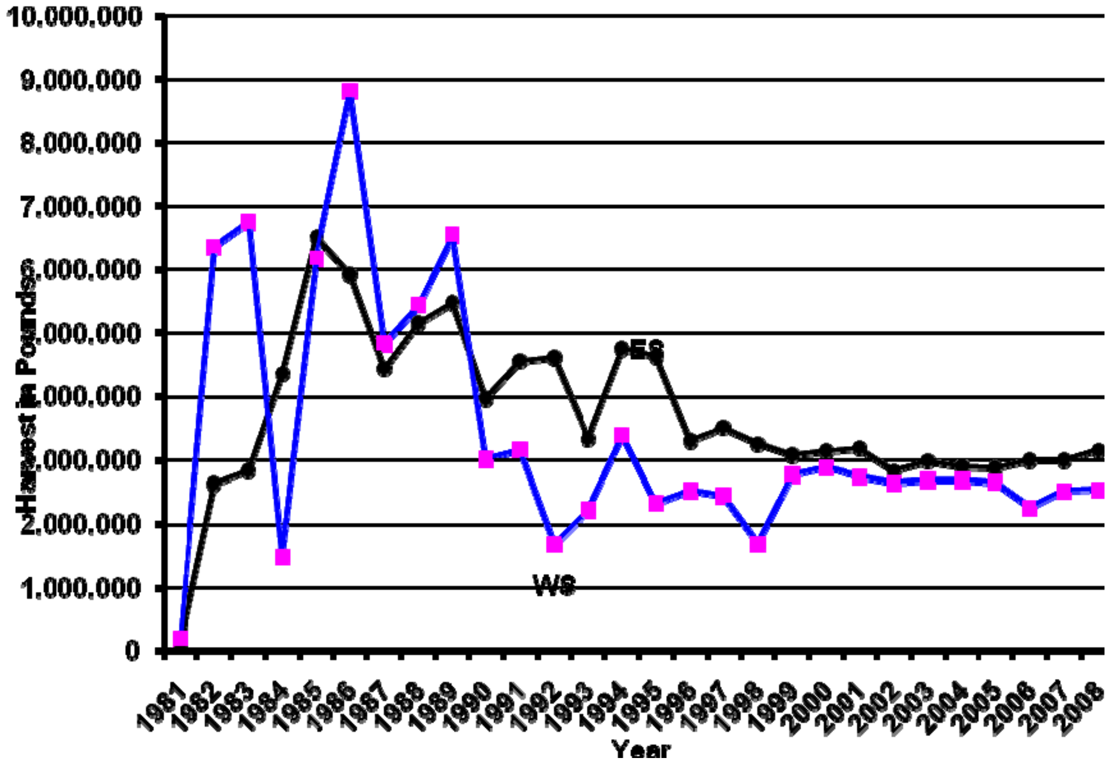


Figure 1. Historical commercial harvest (in pounds) of golden king crab east of 174°W longitude (ES, Eastern Segment) and west of 174°W longitude (WS, Western Segment), 1981-2008 (note: 1981 = 1981/82 fishery).

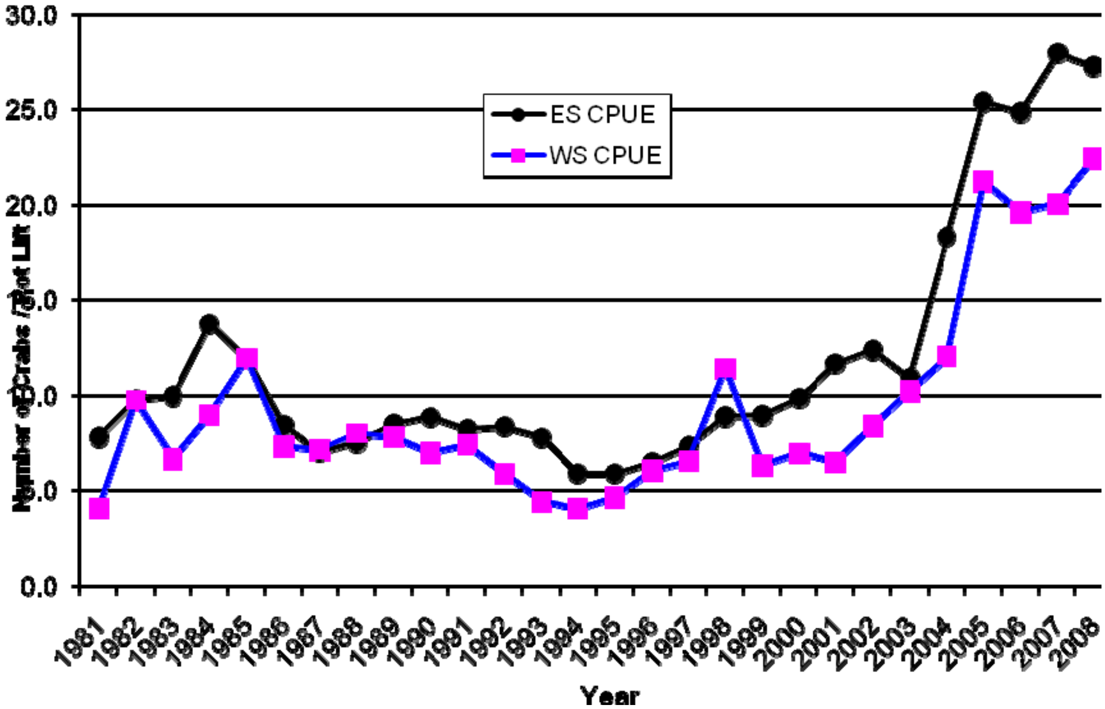


Figure 2. Historical catch-per-unit-effort CPUE (number of crabs per pot lift) in the commercial fishery for golden king crab in the ES and the WS, 1981-2008 (note: 1981 = 1981/82 fishery).

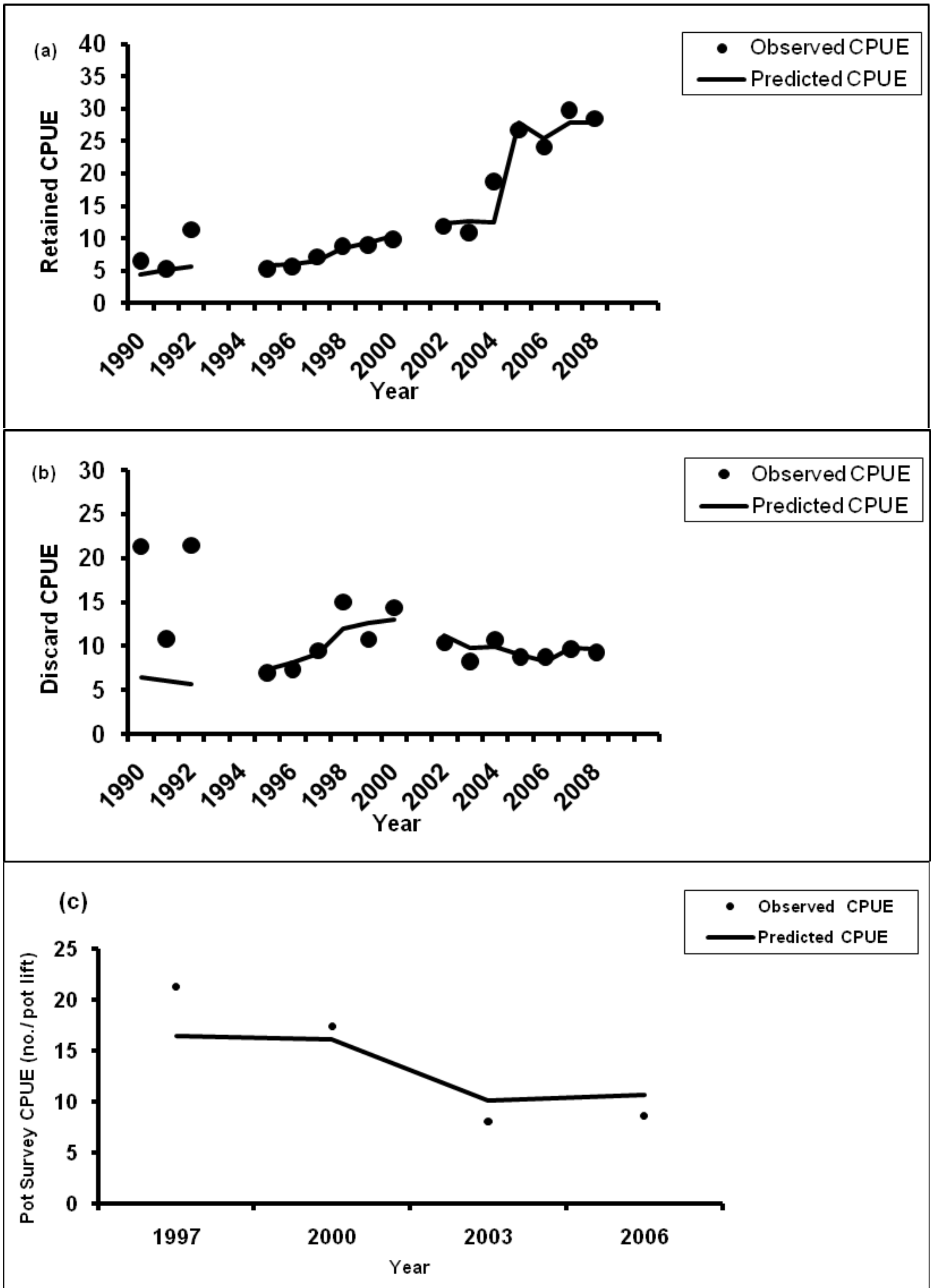


Figure 3. Predicted (line) versus observed (filled circle) (a) retained catch-per-unit-effort (CPUE), (b) discard CPUE, and (c) pot survey CPUE for golden king crab in the ES. Fishery CPUE values are for 1990-2008 (note: 1990 = 1990/91 fishery) and pot survey CPUE values are for 1997, 2000, 2003, and 2006.

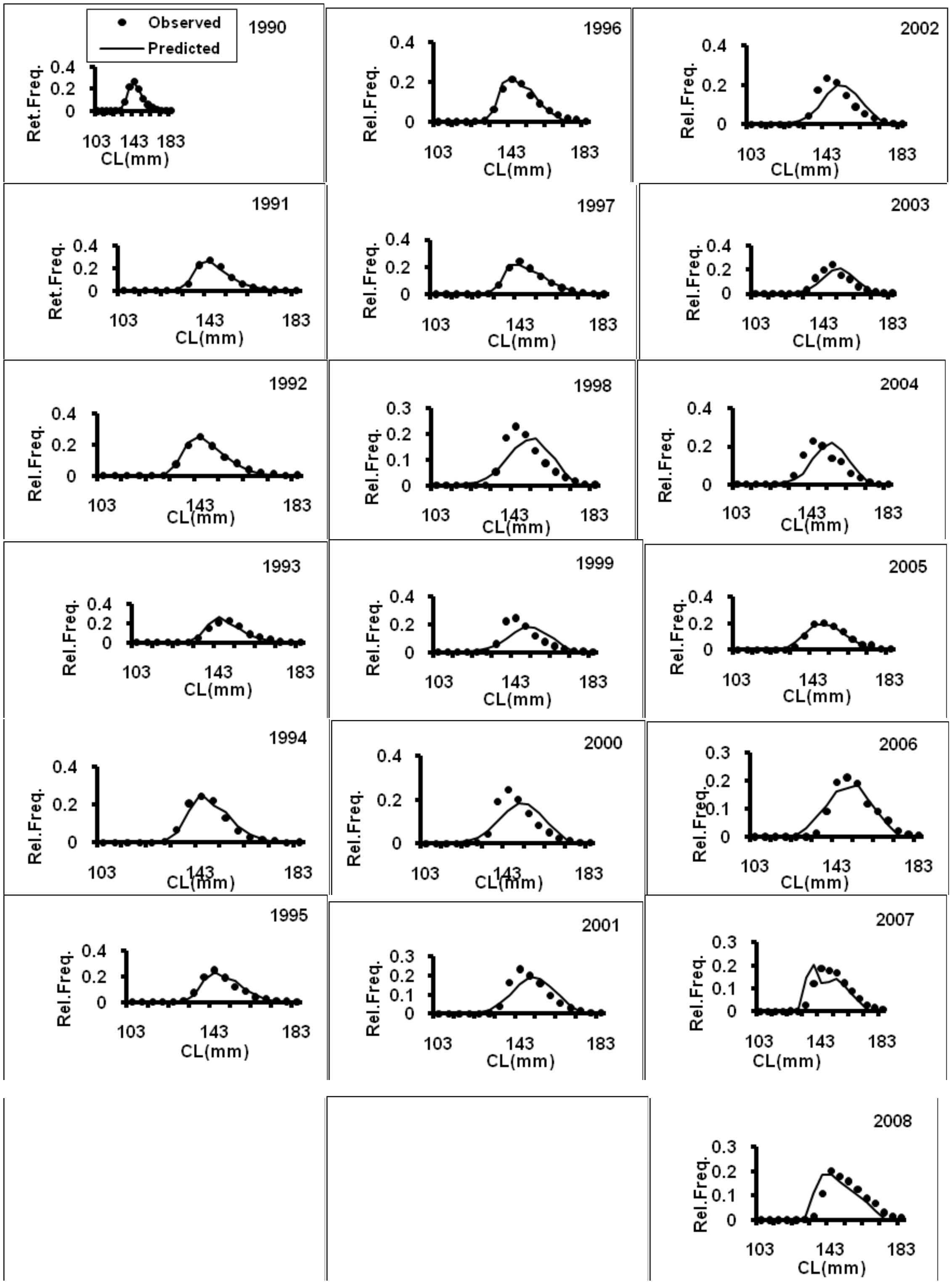


Figure 4. Predicted (line) vs. observed (filled circle) retained catch relative length frequency distributions of golden king crab in the ES, 1990 to 2008 (note: 1990 = 1990/91 fishery).

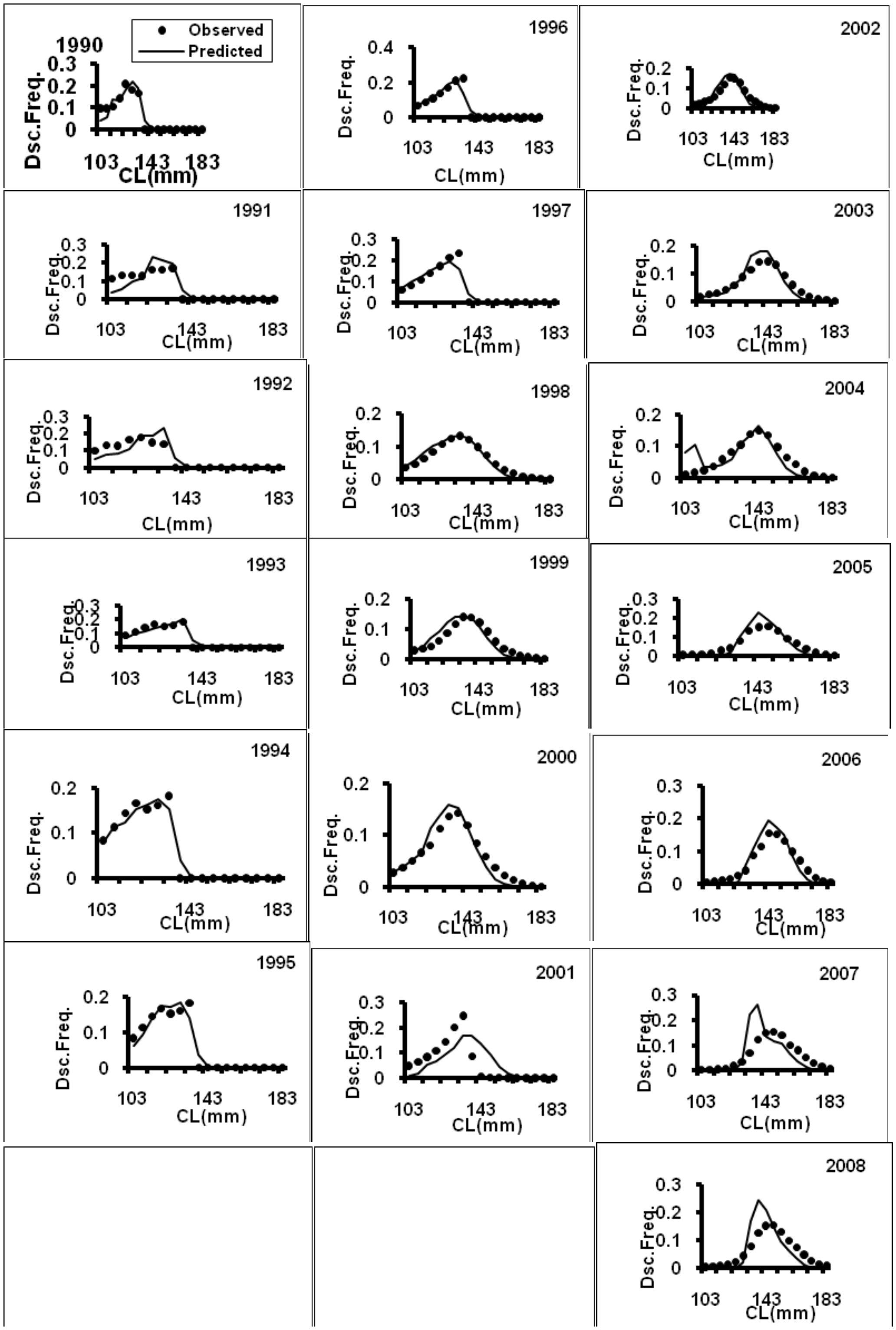


Figure 5. Predicted (line) vs. observed (filled circle) discarded catch relative length frequency distributions of golden king crab in the ES, 1990 to 2008 (note: 1990 = 1990/91 fishery).

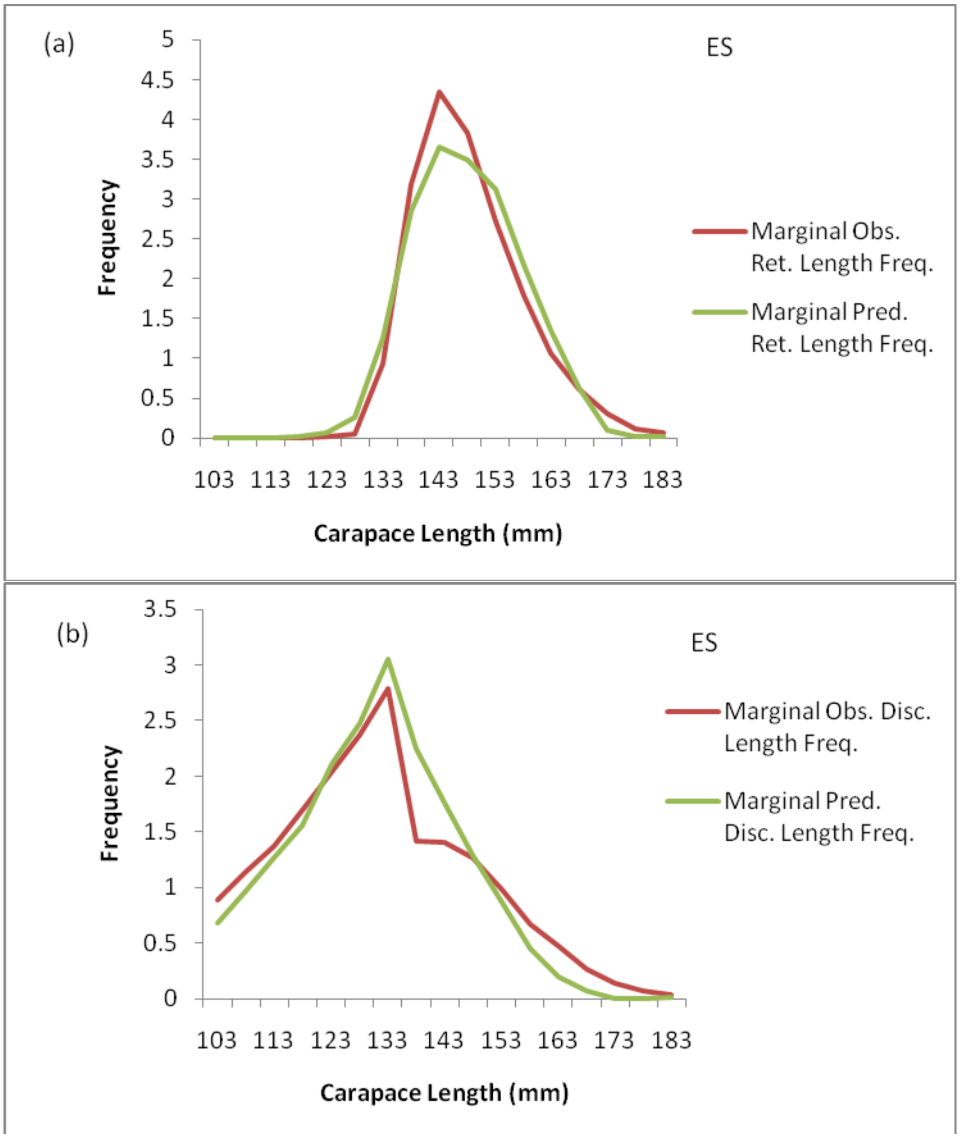


Figure 6. Observed (red line) and predicted (green line) marginal length frequency distributions of (a) retained and (b) discard catches vs. carapace length of golden king crab in the ES, 1990 to 2008 (note: 1990 = 1990/91 fishery).

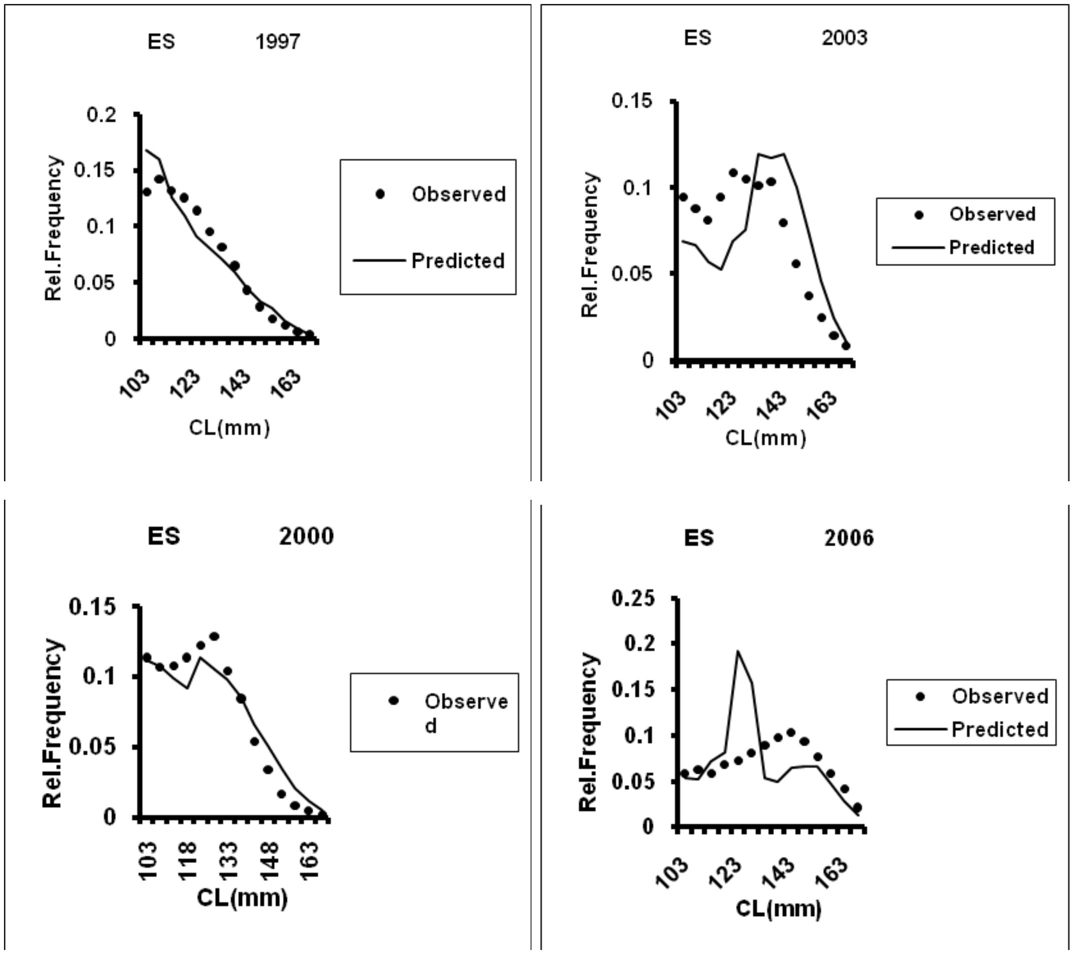


Figure 7. Predicted (line) vs. observed (filled circle) CPUE relative length frequency distributions of golden king crab in the triennial pot surveys in a restricted area in the ES, 1997 to 2006.

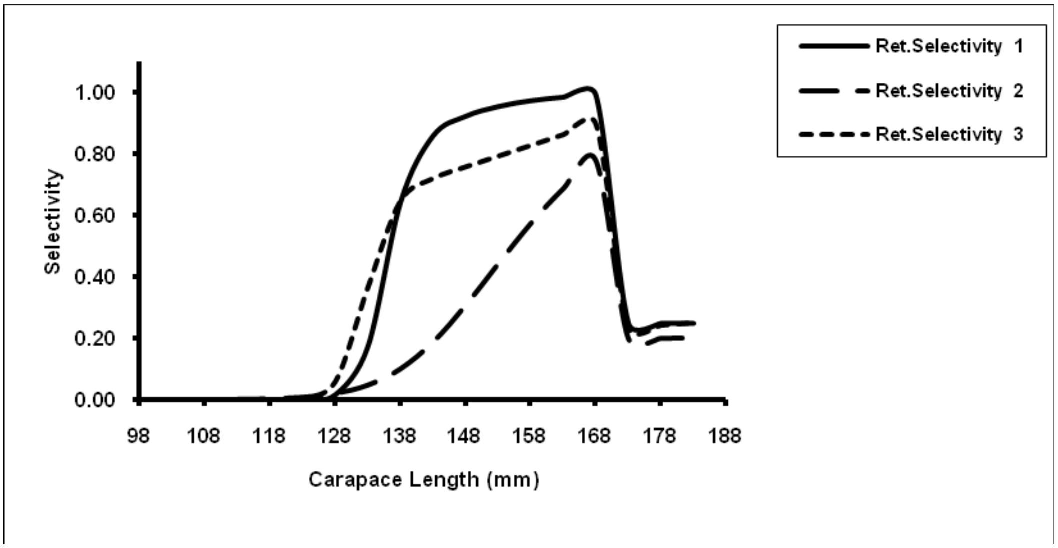


Figure 8. Estimated effective retained catch selectivity (total selectivity*retained selectivity) for the period 1990-97 (Ret. Selectivity 1), 1998-04 (Ret. Selectivity 2), and 2005- onwards (Ret. Selectivity 3) in ES golden king crab fishery.

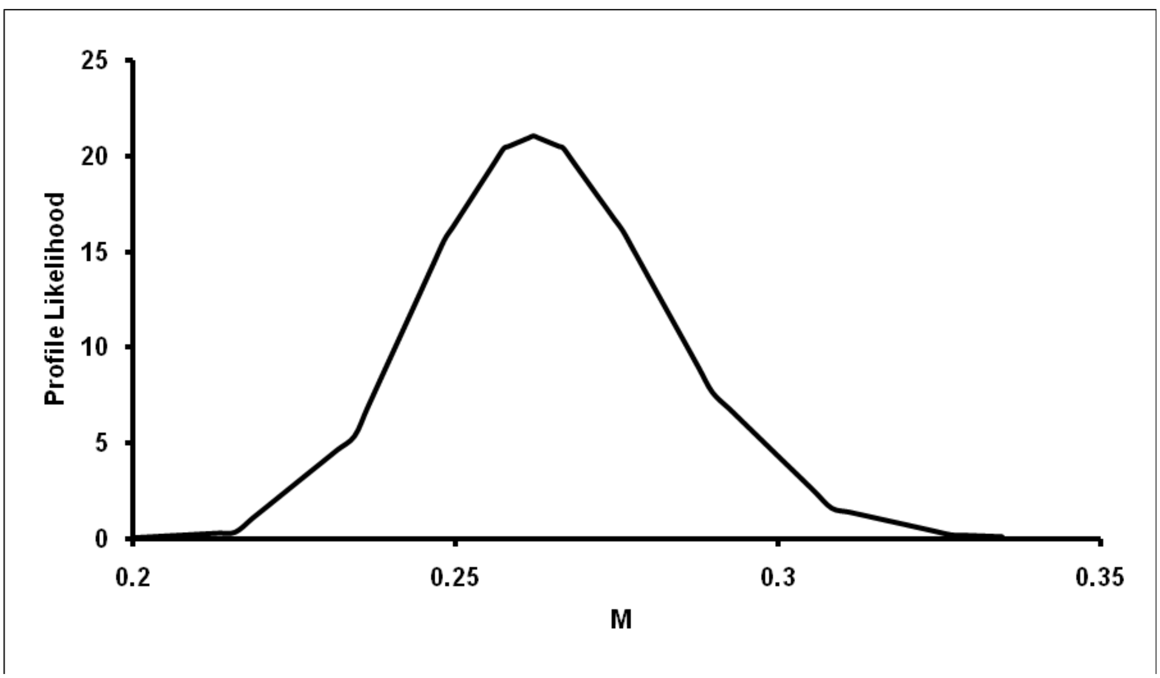


Figure 9. Profile likelihood of estimated natural mortality (*M*) based on 1990-2008 data for ES golden king crab.

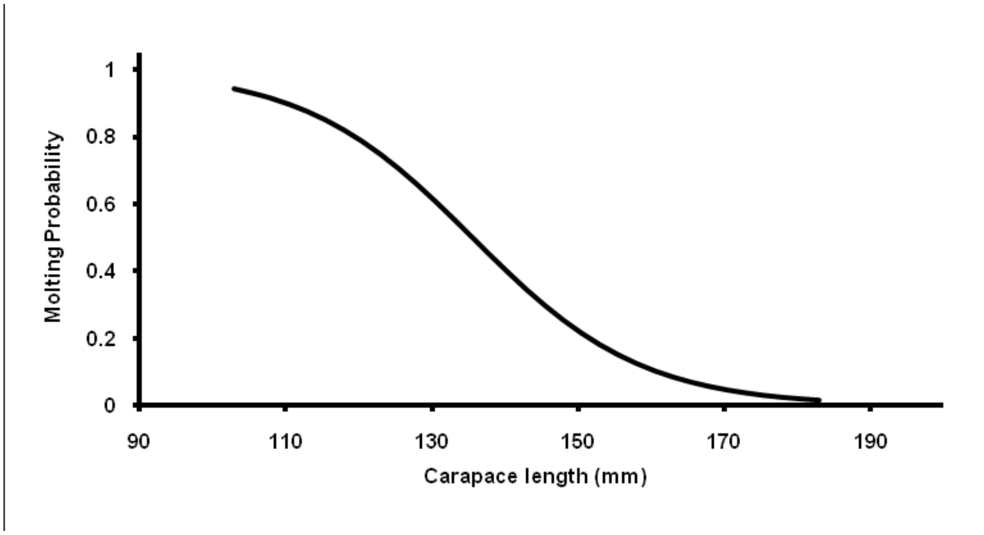


Figure 10. Estimated molt probability of ES golden king crab.

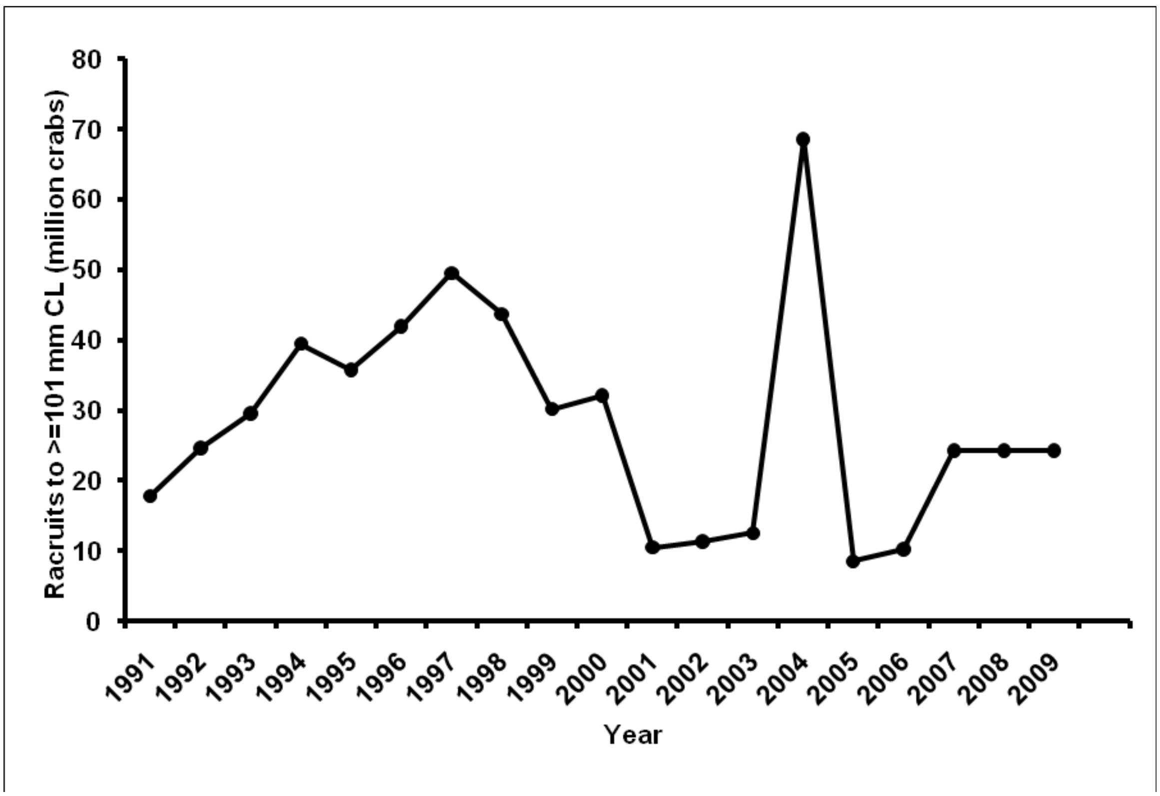


Figure 11. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab fishery in ES, 1991-2009.

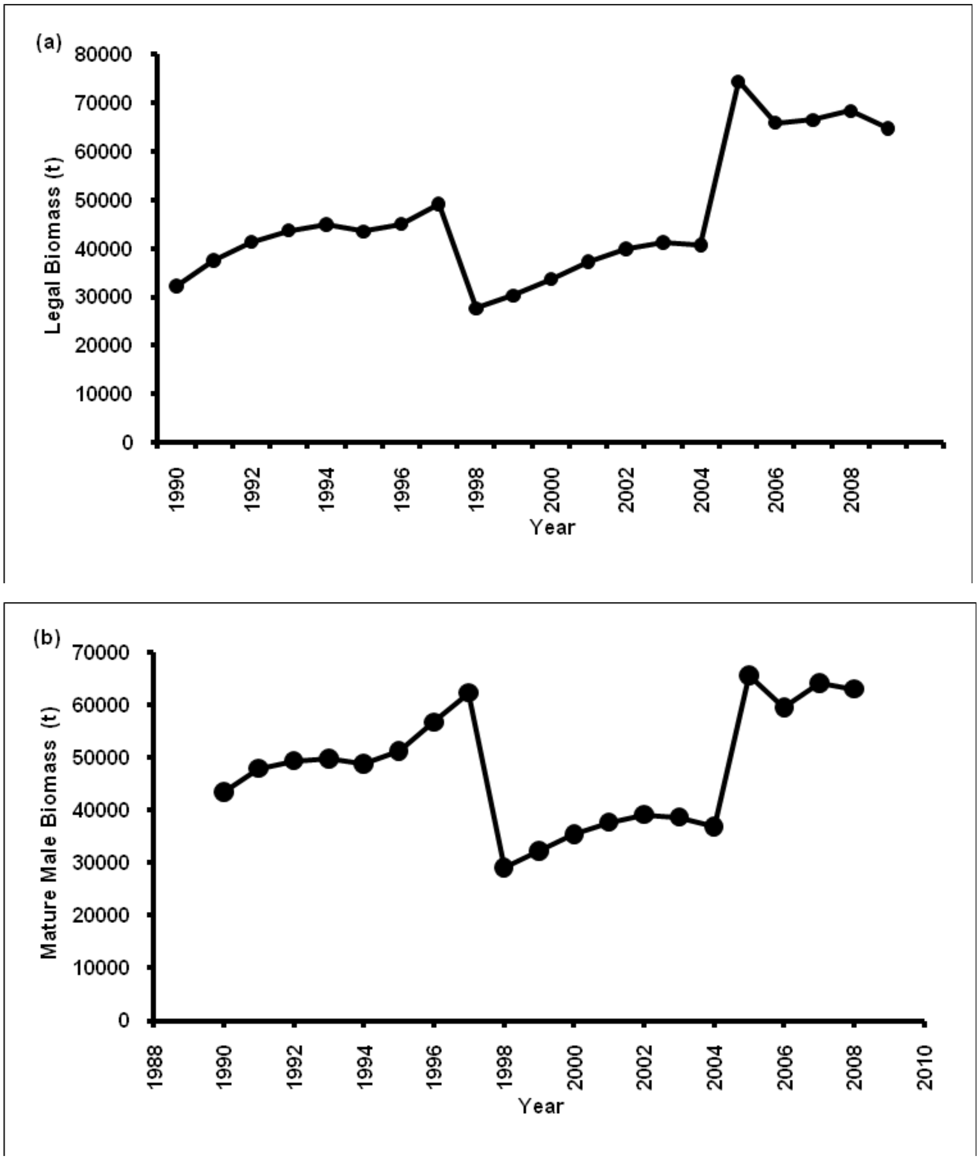


Figure 12. (a) Trends in available golden king crab (a) legal male biomass (t) and (b) mature male biomass in the ES, 1990-2009. Legal male crabs are ≥ 136 mm CL and mature male crabs are ≥ 121 mm CL.

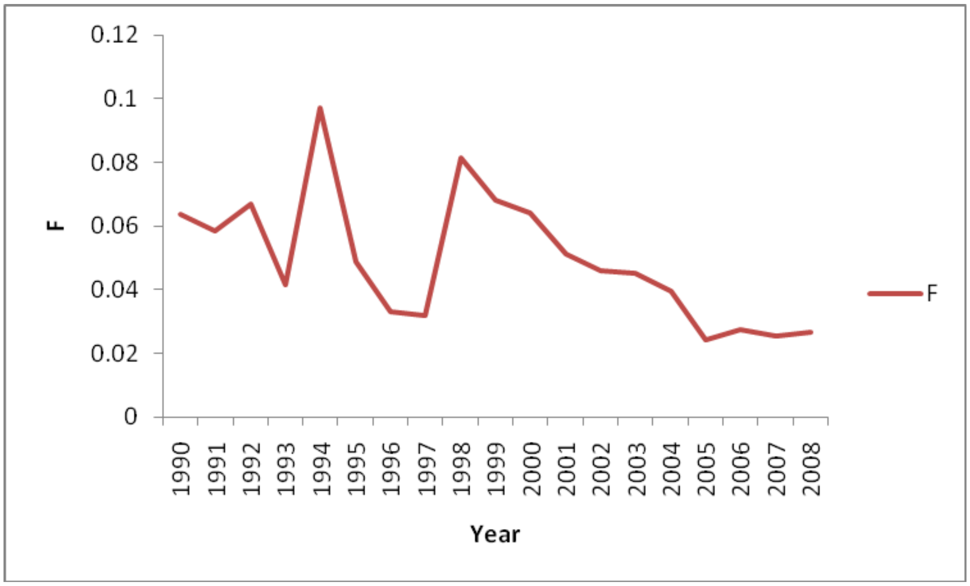


Figure 13. Trend in full selection fishing mortality of golden king crab in the ES, 1990-2008

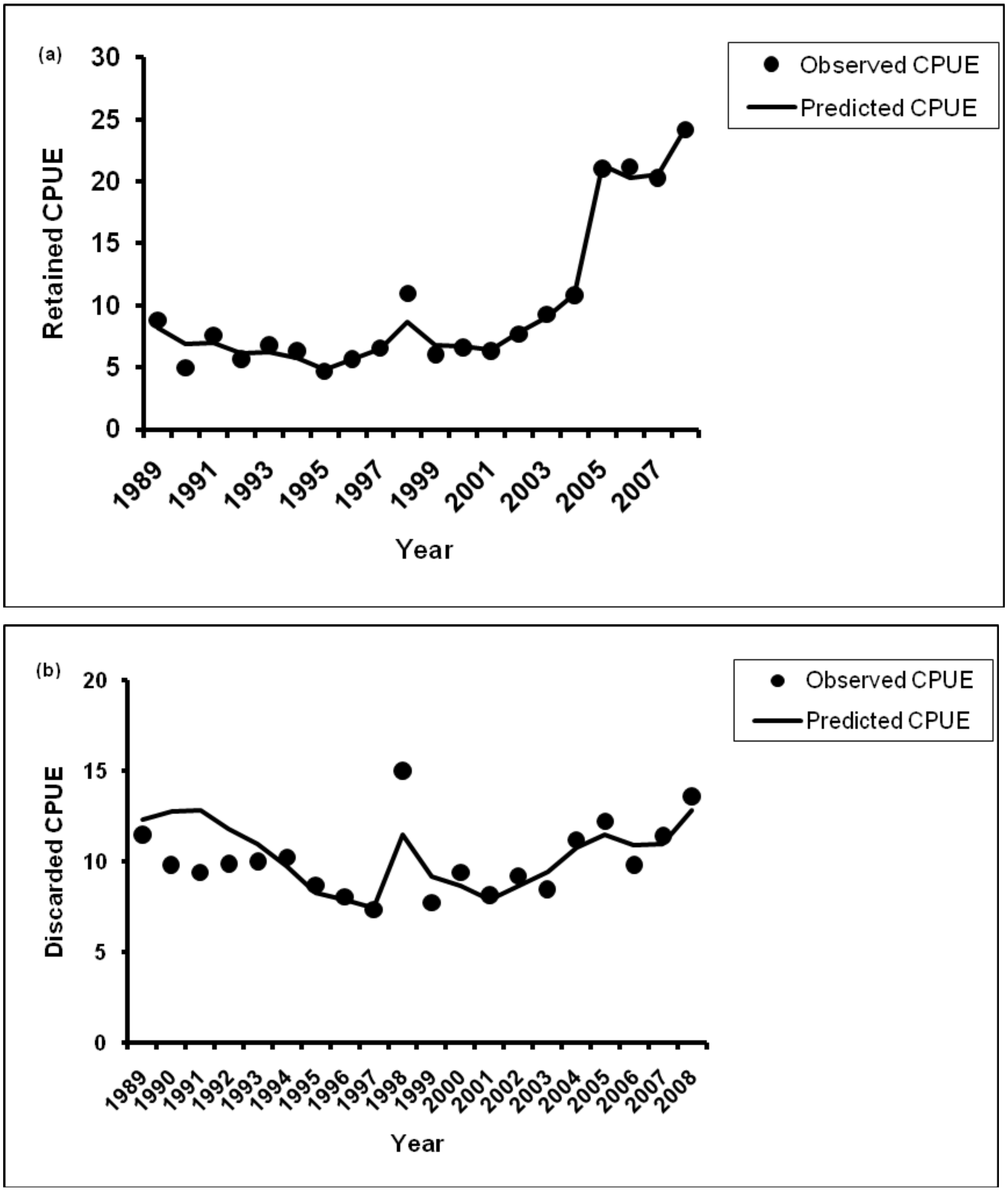


Figure 14. Predicted (line) versus observed (filled circle) (a) retained catch-per-unit-effort (CPUE), (b) discard CPUE for golden king crab in the WS, 1989 to 2008 (note: 1989 = 1989/90 fishery).

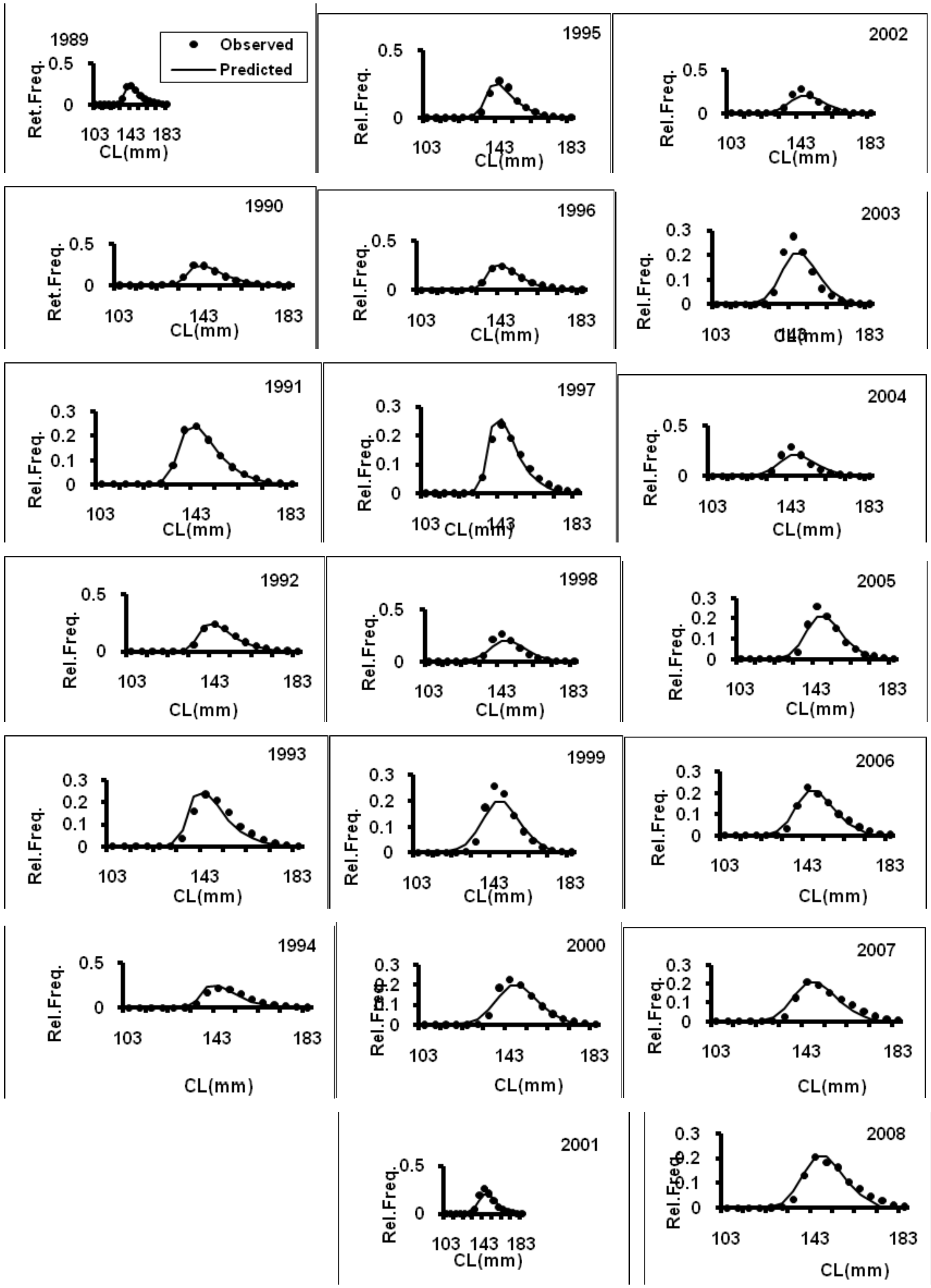


Figure 15. Predicted (line) vs. observed (filled circle) retained catch relative length frequency distributions of golden king crab in the WS, 1989 to 2008 (note: 1989 = 1989/90 fishery).

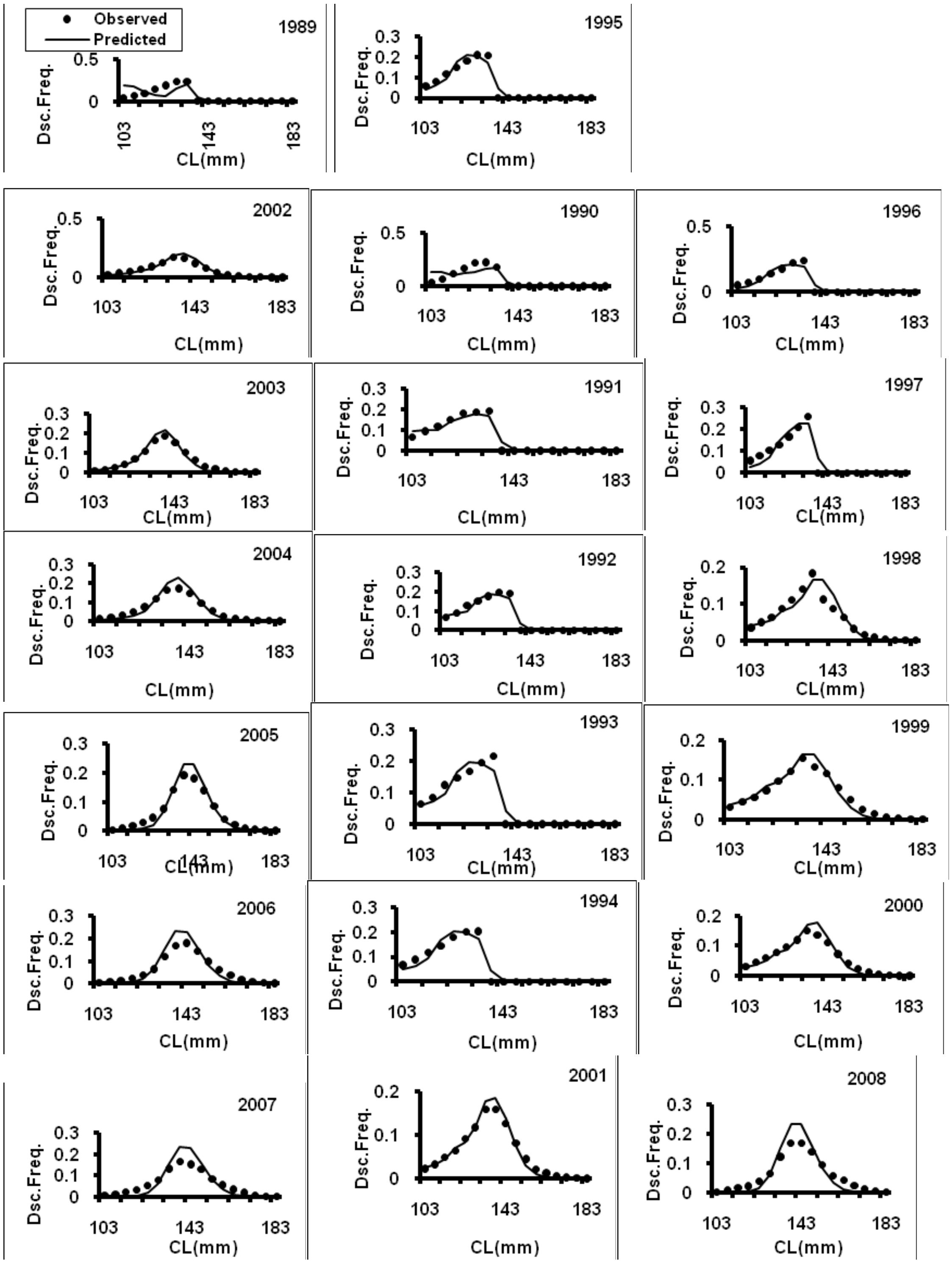


Figure 16. Predicted (line) vs. observed (filled circle) discarded catch relative length frequency distributions of golden king crab in the WS, 1989 to 2008.

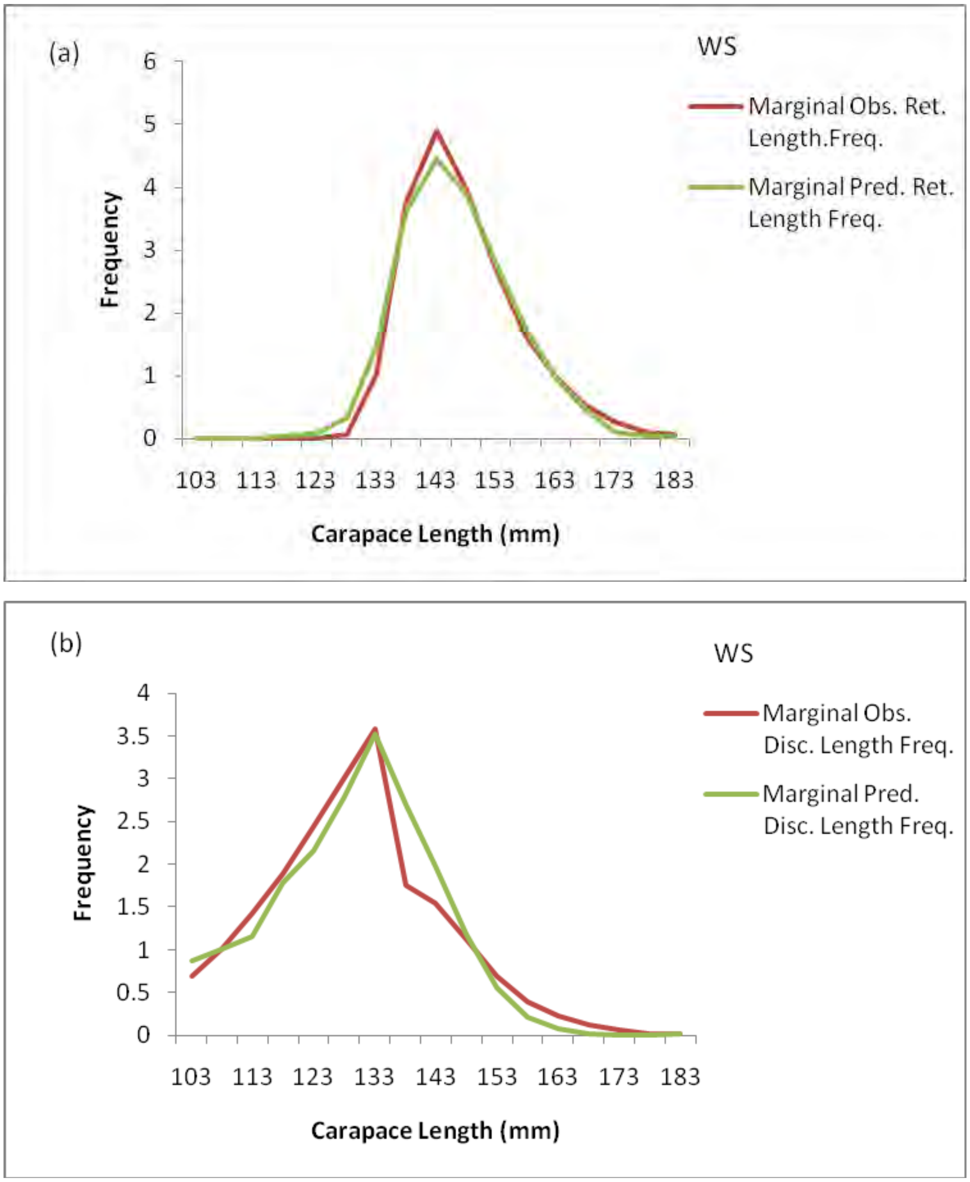


Figure 17. Observed (red line) and predicted (green line) marginal length frequency distributions of (a) retained and (b) discard catches vs. carapace length of golden king crab in the WS, 1989 to 2008 (note: 1989 = 1989/90 fishery).

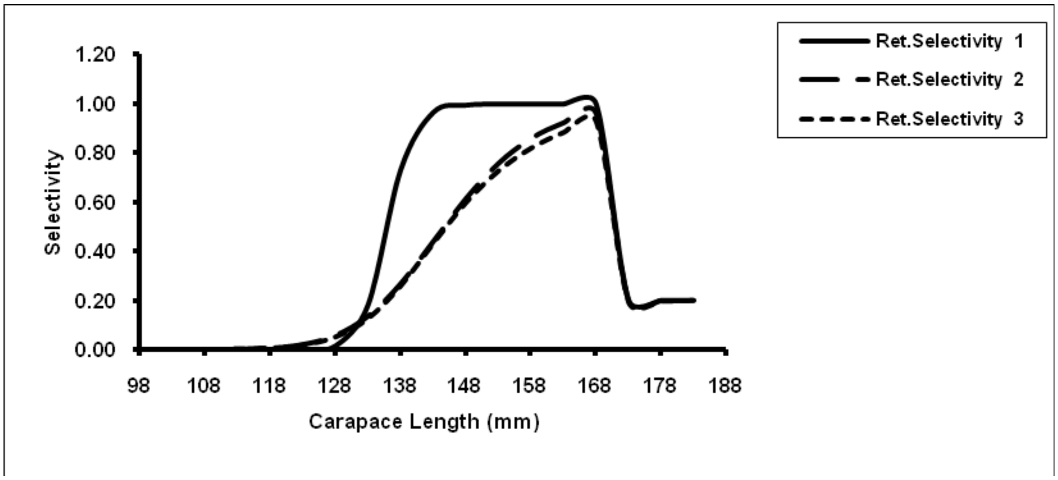


Figure 18. Estimated effective retained catch selectivity (total selectivity*retained selectivity) for the period 1989-97 (Ret. Selectivity 1), 1998-04 (Ret. Selectivity 2), and 2005- onwards (Ret. Selectivity 3) in WS golden king crab fishery.

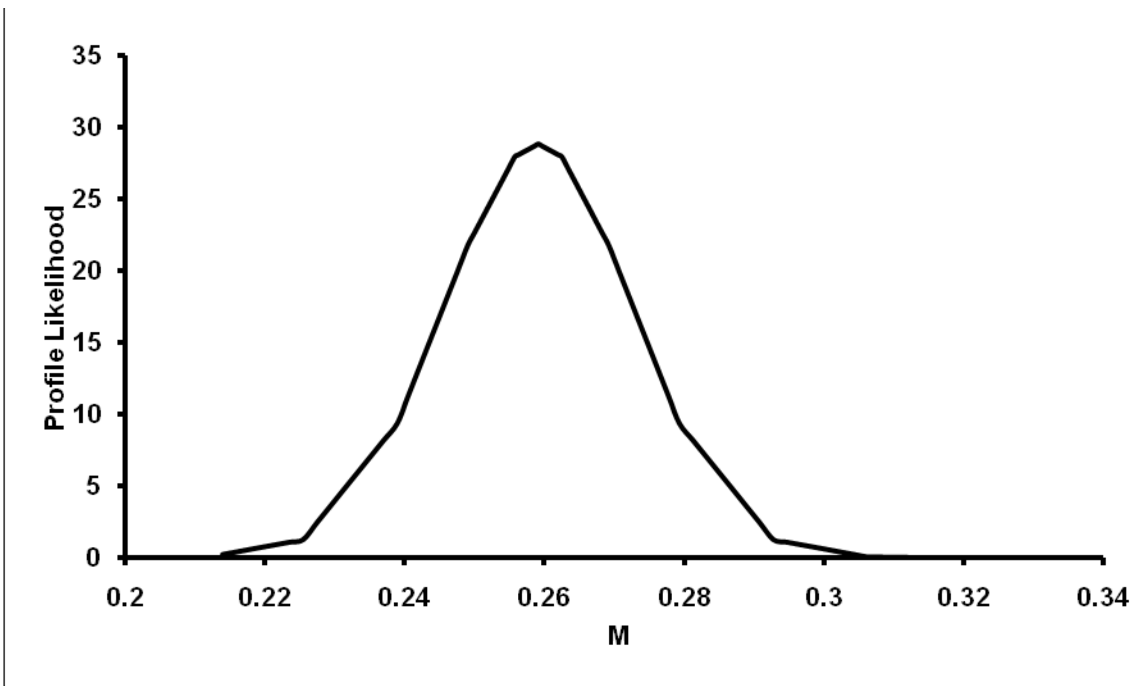


Figure 19. Profile likelihood of estimated natural mortality (M) based on 1989-2008 data for WS golden king crab.

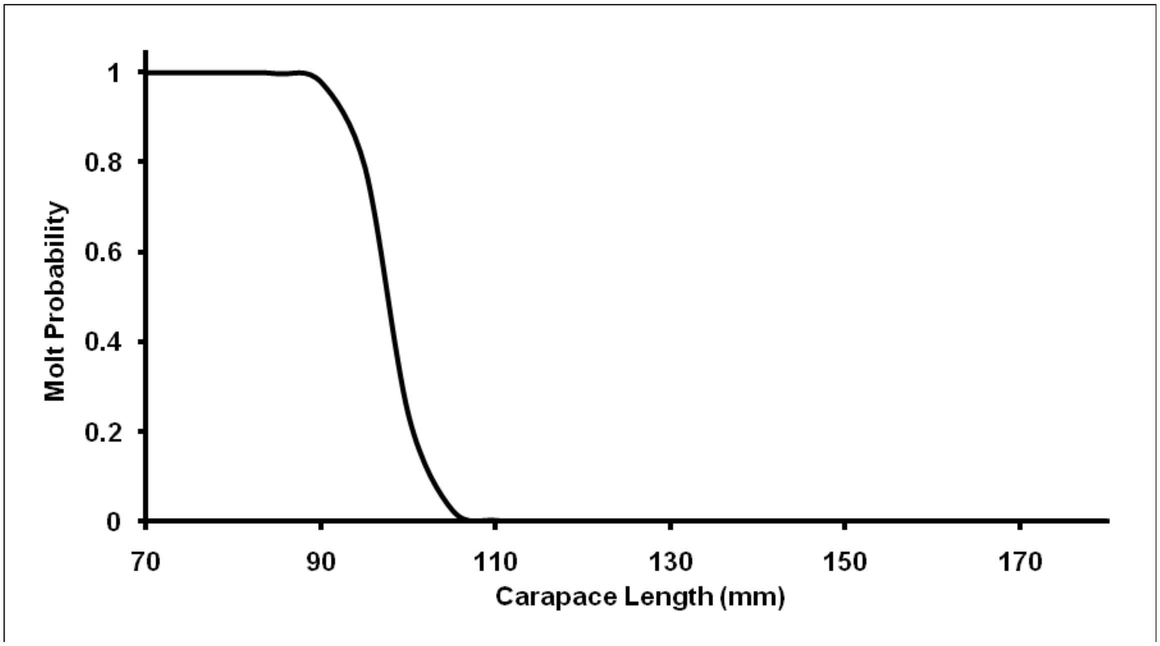


Figure 20. Estimated molt probability of WS golden king crab.

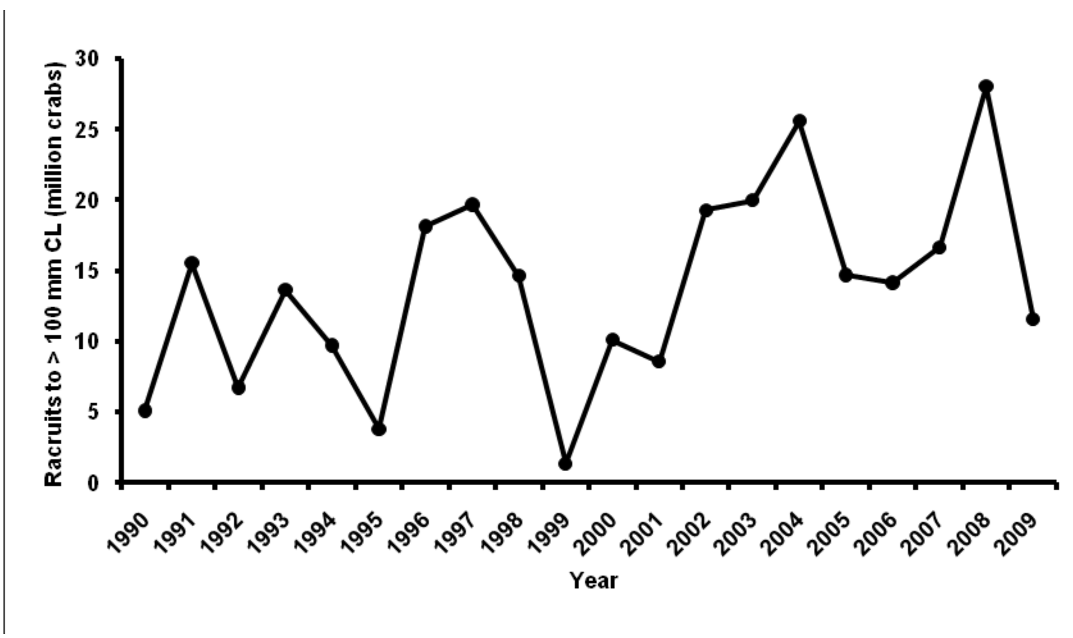


Figure 21. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab fishery WS, 1990-2009.

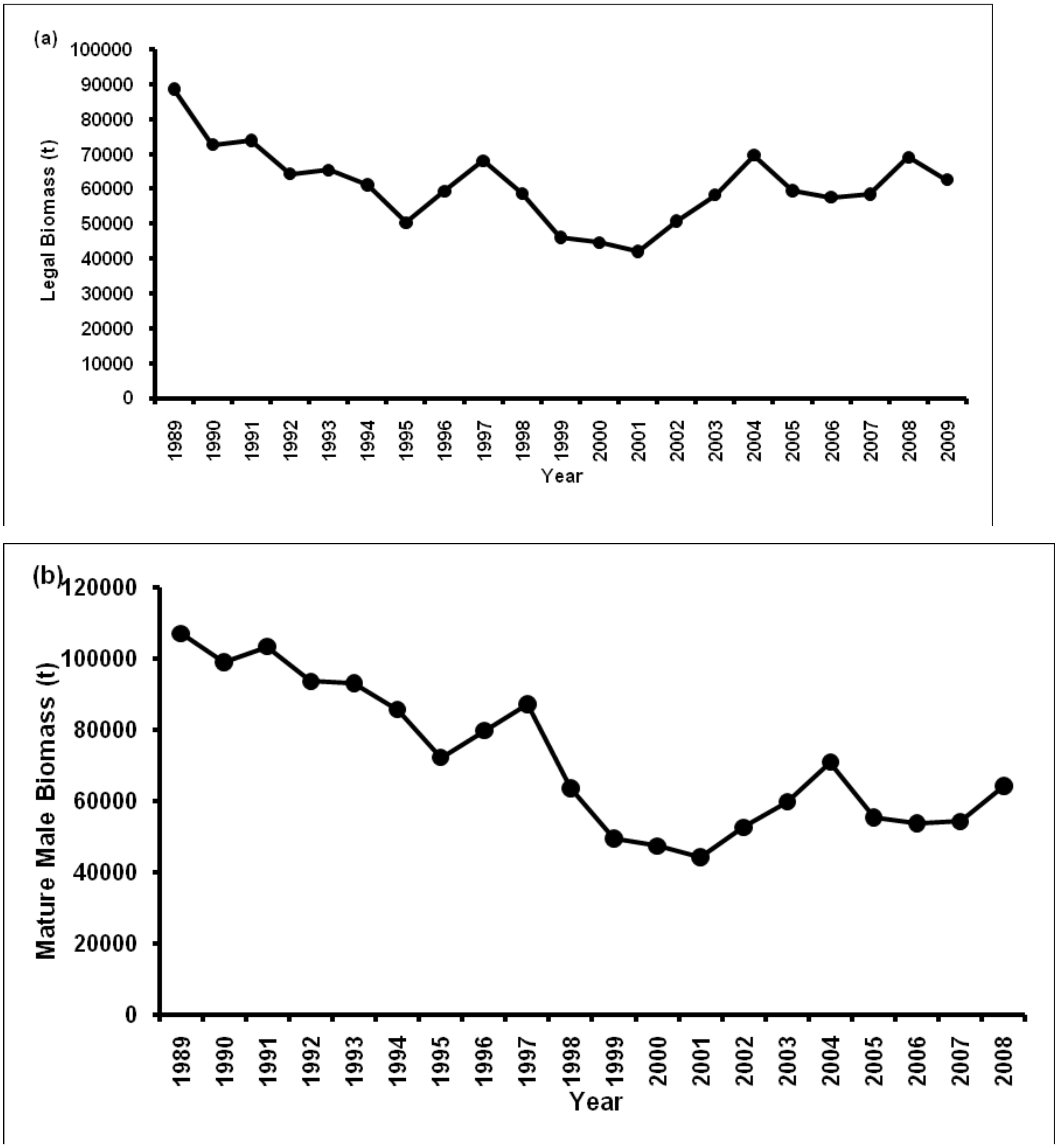


Figure 22. Trends in available golden king crab (a) legal male biomass (t) and (b) mature male biomass in the WS, 1989-2009. Legal male crabs are ≥ 136 mm CL and mature male crabs are ≥ 121 mm CL.

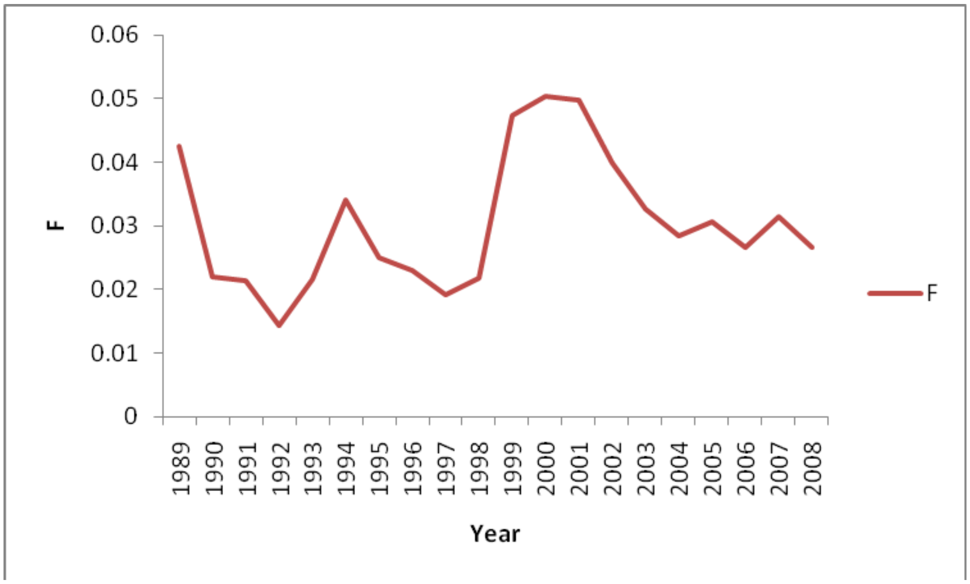


Figure 23. Trend in full selection fishing mortality of golden king crab in the WS, 1989-2008.

Appendix A: Integrated model

Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Stock Assessment Model Development- East of 174W (ES) and west of 174W (WS) Aleutian Island stocks

Parameters estimated conditionally

a and *b*: for the molt probability model;
S_i^T : total selectivity;
S_i^{surv} : survey selectivity for the ES only;
S_i^r : retained selectivity;

Note: The total and survey selectivity logistic models are set to a constant multiple of the 14th bin selectivity for adequate fits of the length compositions. The constants are estimated as parameters in the model fits.

R_t: total number of male recruits for each year, except the first year, $R_{91}$to R_{09} for the ES and R_{90} to R_{09} for the WS;
q: pot survey catchability;
q_1: pot fishery catchability for the period 1990-1997;
q_2: pot fishery catchability for the period 1998-2004;
q_3: pot fishery catchability for the period 2005 onward;
selP1: constant multiplier for the total selectivity curve;
selP2: constant multiplier for the survey selectivity curve;
F_t : Instantaneous full selection fishing mortality for each year, F_{90} to F_{08} for the ES and F_{89} to F_{08} for the WS;
β: shape parameter of the gamma growth function;
α_r, β_r : recruitment parameters for the Gamma function;
M: instantaneous natural mortality;
N_{ini}: initial total number of new-shell crabs, N_{90} for the ES and N_{89} for the WS;
O_{ini}: initial total number of old-shell crabs, O_{90} for the ES and O_{89} for the WS; and
pn_i & po_i : relative length frequency proportions for new- and old-shell, respectively (17 parameters each for 17 bins) for start year, 1990 for the ES and 1989 for the WS, abundance distribution.

Parameters fixed

Mean growth increment, 14.4 mm CL (to estimate the α parameter of the gamma growth function) based on tagging studies.

Likelihood and penalty weights

Following table provides the weights (λ) (and the corresponding CV) attached to log likelihood and penalty components for the ES and WS stocks:

Likelihood Component	ES		WS	
	Weight, λ	CV	Weight, λ	CV
Retained catch CPUE*	-	0.02-0.12	-	0.01-0.07
Discard catch CPUE*	-	0.02-0.19	-	0.02-0.13
Survey CPUE*	-	0.05-0.07	-	-
Retained catch biomass	100	0.07	100	0.07
Discard catch biomass	30	0.13	30	0.13
Recruitment deviation	3	0.43	3	0.43
Fishing mortality deviation	2	0.53	2	0.53
Natural mortality penalty	5	0.32	2	0.53
Initial abundance length frequency penalty	3	0.43	3	0.43

*Annually varying CV is used in the likelihood

Time varying effective sample sizes (K_t) are used for robust normal length composition log likelihoods. They are estimated using the formula $K_t = \frac{400 \times n_t}{\max n_t}$ where n_t is the number of length measurements in year t and 400 is the maximum cap placed on effective sample size. They are calculated separately for retained and discard catch.

Model

Molting probability

The molting probability (m_i) for a length class i is

$$m_i = \frac{1}{1 + e^{a(i-b)}} \tag{1}$$

where a and b are parameters.

Growth increment probability

A gamma distribution was selected to describe the variation in growth increment per molt:

$$gamma(\,x / \alpha_i, \beta\,) = \frac{x^{\alpha_i - 1} e^{-\frac{x}{\beta}}}{\beta^{\alpha_i} \Gamma(\alpha_i)} \tag{2}$$

where x is the growth increment, α_i and β are parameters, and α_i = mean growth increment /β. The expected proportion of molting crabs ($P_{i,j}$) growing from length class i to length class j during a year was estimated by

$$P_{i,j} = \frac{\int_{j_1 - \tau_i}^{j_2 - \tau_i} gamma(\,x / \alpha_i, \beta\,)dx}{\sum_{j=1}^{n} \int_{j_1 - \tau_i}^{j_2 - \tau_i} gamma(\,x / \alpha_i, \beta\,)dx} \tag{3}$$

where j_1 and j_2 are lower and upper limits of the receiving length interval j, τ_i is the mid-point of the contributing length interval i, and n is the total number of receiving length intervals. The summation in the denominator is a normalizing factor for the discrete gamma function.

Recruit distribution

Similar Gamma function as above with α_r, and β_r parameters.

Selectivity

Fishery selectivity and survey selectivity(only for the ES*)*

The total fishery (S_i^T) selectivity, pot survey selectivity (S_i^{surv}), and retained selectivity (S_i^r) are modeled as logistic functions.

$$S_i = \frac{1}{1+e^{-a_k(i-b_k)}} \tag{4}$$

However, the total selectivity and survey selectivity values above 14th bin are scaled down as a constant proportion of the estimated selectivity at 14th bin (this bin is selected based on trial runs). The constant proportions, selP1 for total and selP2 for survey, are estimated in the model. Because of size dependent availability and selectivity of deep water golden king crab, there is a likelihood of very low selectivity for large size group.

Three sets of selectivity (a_k, b_k) and catchability (q_k) parameters for the periods 1990-1997, 1998-2004, and 2005 – onward are considered for fishery (total and retained) selectivity. One set of selectivity (a, b) and catchability parameter, q, are considered for pot survey.

Population dynamics

Initial year (1990 for the ES and 1989 for the WS) stock abundance is modeled as

$$N_{i,1} = N_1 pn_i \tag{5}$$

$$O_{i,1} = O_1 po_i \tag{6}$$

where N_1 and O_1 are respective total new-shell and old-shell initial abundance parameters and pn_i & po_i are relative size frequency parameters in size class i. These proportions are treated as separate parameters (for 17 bins) to be estimated from model fit. Sum of these proportions are set to one in the following formulation:

Let α_i are any real numbers (we used a bound -5 to 5 for convergence purpose) and set $\alpha_5 = 0$. So, there are 16 remaining α_i s to be estimated. pn_i or po_i are determined using the following formulas such that all pn_i and po_i add up to 1:

$$pn_i = \frac{e^{\alpha_i}}{\sum_j e^{\alpha_j}} \quad \text{and} \quad po_i = \frac{e^{\alpha'_i}}{\sum_j e^{\alpha'_j}} \tag{7}$$

The annual abundances by size and shell condition for other years are modeled considering growth, mortality, and recruitment:

$$N_{t+1,j} = \sum_{i}^{j} [(N_{t,i} + O_{t,i})e^{-M} - (\hat{C}_{t,i} + \hat{D}_{t,i})e^{(y_t - 1)M}]m_i P_{i,j} + R_{t+1,j} \tag{8}$$

$$O_{t+1,j} = [(N_{t,j} + O_{t,j})e^{-M} - (\hat{C}_{t,j} + \hat{D}_{t,j})e^{(y_t - 1)M}](1 - m_j) \tag{9}$$

where $N_{t,j}$ and $O_{t,j}$ are respective abundances of new-shell and old-shell crabs in length class *j* on 1 July (start of biological year coincided with mid survey time) in year *t*; $\hat{C}_{t,j}$ and $\hat{D}_{t,j}$ are predicted fishery retained and discard dead total catches determined by equations (16) & (17) in length class *j* and year *t*; y_t is elapsed time period from 1 July to the mid –point of fishing period in year *t*; and *M* is instantaneous natural mortality.

Predicted fishery CPUE

Total catch-per-unit-effort by length and year is estimated as

$$C\hat{P}UE^{T}_{t,j} = q_k [s^T_j \; (N_{t,j} + O_{t,j})e^{-y_t M} - 0.5(\hat{C}_{t,j} + \hat{D}_{t,j})] \tag{10}$$

Retained catch-per-unit-effort by length and year is estimated as

$$C\hat{P}UE^{r}_{t,j} = q_k [s^T_j s^r_j \; (N_{t,j} + O_{t,j})e^{-y_t M} - 0.5\hat{C}_{t,j}] \tag{11}$$

Discarded catch-per-unit-effort by length and year is estimated as

$$C\hat{P}UE^{d}_{t,j} = C\hat{P}UE^{T}_{t,j} - C\hat{P}UE^{r}_{t,j} \tag{12}$$

where ^ sign refers to predicted value.

Assuming that CPUE have log normally distributed measurement errors, the negative log likelihoods for the retained and discard catch-per-unit-effort data are

$$LL^{CPUE}_{r} = \lambda_{rCPUE} \frac{\sum_t \sum_j \{\log(C\hat{P}UE^{r}_{t,j} + c) - \log(CPUE^{r}_{t,j} + c)\}^2}{\sigma^2_{r,t}} \tag{13}$$

$$LL^{CPUE}_{D} = \lambda_{TCPUE} \frac{\sum_t \sum_j \{\log(C\hat{P}UE^{D}_{t,j} + c) - \log(CPUE^{D}_{t,j} + c)\}^2}{\sigma^2_{D,t}} \tag{14}$$

where c is a small constant (0.001), λs are weights, and $\sigma^2_{r,t}$ and $\sigma^2_{D,t}$ are the annual variances of log(CPUE), estimated from observed variances.

Predicted retained and discarded dead catches

The predicted total, retained and discarded dead catches are estimated as

$$\hat{C}^{T}{}_{t,j} = (N_{t,j} + O_{t,j})e^{-y_t M}(1 - e^{-F_t s_j^T}) \tag{15}$$

$$\hat{C}_{t,j} = (N_{t,j} + O_{t,j})e^{-y_t M}(1 - e^{-F_t s_j^T s_j^r}) \tag{16}$$

$$\hat{D}_{t,j} = 0.2 * (\hat{C}^{T}{}_{t,j} - \hat{C}_{t,j}) \tag{17}$$

(a 20% discard death rate is used)

Assuming catch biomasses have log normally distributed measurement errors, the negative log likelihoods for the retained and discard catch biomass data are

$$LL_r^{catch} = \lambda_r \sum_t \{log(\sum_j \hat{C}_{t,j} w_j + c) - log(\sum_j C_{t,j} w_j + c)\}^2 \tag{18}$$

$$LL_D^{catch} = \lambda_D \sum_t \{log(\sum_j \hat{C}^{D}{}_{t,j} w_j + c) - log(\sum_j C^{D}{}_{t,j} w_j + c)\}^2 \tag{19}$$

where λ_r and λ_D are retained and discard catch weights for the likelihoods.

Predicted pot survey CPUE(only for the ES)

Pot survey $CPUE_t^s$ by length and year was estimated as

$$C\hat{P}UE_{t,j}^s = q_k s_j^{surv} (N_{t,j} + O_{t,j}) \tag{20}$$

Assuming that CPUE have log normally distributed measurement errors, the negative log likelihood for the pot survey catch-per-unit-effort data is

$$LL_s^{CPUE} = \lambda_{sCPUE} \frac{\sum_t \sum_j \{\log(C\hat{P}UE_{t,j}^s + c) - \log(CPUE_{t,j}^s + c)\}^2}{\sigma^2_{s,t}} \tag{21}$$

where c is a small constant (0.001), λ_{sCPUE} is the weight, and $\sigma^2_{s,t}$ is the annual variance of log(CPUE)), estimated from observed variances.

Length composition

Retained length composition $L^r_{t,j}$ in year t is computed as

$$L^r_{t,j} = \frac{\hat{C}_{t,j}}{\sum_j^n \hat{C}_{t,j}} \tag{22}$$

Retained length composition is assumed to follow a robust normal distribution and the negative log likelihood is

$$LL^{LF}_r = 0.5\sum_t\sum_j log(2\pi\sigma^2_{t,j}) - \sum_t\sum_j log\left[e^{-\frac{(L^r_{j,t}-\hat{L}^r_{t,j})^2}{2\sigma^2_{t,j}}} + 0.01\right] \tag{23}$$

Where

$$\sigma^2_{t,j} = \left[(1-\hat{L}^r_{t,j})\hat{L}^r_{t,j} + \frac{0.1}{n}\right] / S_t$$

n= number of size classes, and S_t = effective sample size for year t.

Predicted discard catch length composition $\hat{L}^D_{t,j}$ in year t is computed as

$$L^D_{t,j} = \frac{\hat{C}^D_{t,j}}{\sum_j^n \hat{C}^D_{t,j}} \tag{24}$$

Negative log likelihood, LL^{LF}_D , for discard length composition is similar to equation (23) with discard catch effective sample size and length composition replacing the corresponding retained values.

Pot survey (only for the East) length composition $L^s_{t,j}$ in year t is computed as

$$L^S_{t,j} = \frac{\hat{C}^S_{t,j}}{\sum_j^n \hat{C}^S_{t,j}} \tag{25}$$

Negative log likelihood, LL^{LF}_s , for pot survey length composition is similar to equation (23) with pot survey sample size and length composition replacing the corresponding retained values.

Fishing mortality penalty
Assuming lognormal distribution of annual F, the weighted negative log likelihood is

$$LL_F = \lambda_F \sum_t \{\log(F_t) - \log(\overline{F})\}^2 \qquad (26)$$

where $\overline{F}$ is the mean fishing mortality parameter and λ_F is the fishing mortality weight.

Recruitment penalty

Assuming lognormal distribution of annual recruitment, the weighted negative log likelihood is

$$LL_R = \lambda_R \sum_t \{\log(R_t) - \log(\overline{R})\}^2 \qquad (27)$$

where $\overline{R}$ is the mean recruitment parameter and λ_R is the recruitment weight.

The initial relative length frequency penalty function is

$$LL_{LFQ} = \lambda_{LFQ}\left[\sum_i (pn_i - pn_i^{obs})^2 + (\sum_i po_i - po_i^{obs})^2\right] \qquad (28)$$

where pn_i and po_i are model predicted parameter values, and pn_i^{obs} and po_i^{obs} are observed relative frequency proportions.

The natural mortality penalty function is

$$LL_M = \lambda_M (M - 0.18)^2 \qquad (29)$$

Thus, the objective function for minimization is

$$f = LL_r^{CPUE} + LL_D^{CPUE} + LL_s^{CPUE} + LL_r^{LF} + LL_D^{LF} + LL_s^{LF} + LL_r^{catch} + LL_D^{catch} + LL_F + LL_M + LL_R + LL_{LFQ}$$

. (30)

Following quantities are computed from the estimated parameters:

Harvest rate

Total harvest rate:

$$E_t = \frac{\hat{C}_t + \hat{D}_t}{\sum_j^n \{s_j^T \ (N_{j,t} + O_{j,t})e^{-y_t M} - 0.5(\hat{C}_{j,t} + \hat{D}_{j,t})\}} \qquad (31)$$

where $\hat{C}$ and $\hat{D}$ are predicted retained and discarded catches.

Vulnerable legal male biomass at the survey time in year *t*:

$$LM_t = \sum_{j=legal\ size}^{n} s_j^T (N_{j,t} + O_{j,t}) w_j \tag{32}$$

Mature male biomass on 15 February spawning time (NPFMC 2007) in the following year:

$$MMB_t = \sum_{j=mature\ size}^{n} s_j^T \{(N_{j,t} + O_{j,t}) e^{-y'M} - (C_{j,t} + D_{j,t}) e^{-(y_t - y')M}\} w_j \tag{33}$$

where y' is the elapsed time from 1 July to 15 February in the following year.

For estimating next year limit harvest level from current year stock abundance, a limit F' value is needed. Current crab management plan specifies five different Tier formulas for different stocks depending on the strength of information available for a stock, for computing F' (NPFMC 2007). For the golden king crab, the following Tier 4 formula is applied to compute F':

(a) If $MMB_t \geq M\overline{M}B$, $F' = \gamma M$,

(b) If $MMB_t < M\overline{M}B$ and $MMB_t > 0.25M\overline{M}B$,

$$F' = \gamma M \frac{\left(\frac{MMB_t}{M\overline{M}B} - \alpha\right)}{(1-\alpha)} \tag{34}$$

(c) If $MMB_t \leq 0.25M\overline{M}B$, $F' = 0$

where γ is a constant multiplier of M, α is a parameter, and $M\overline{M}B$ is the mean mature biomass for a selected time period, which is a proxy for maximum sustainable yield (*MSY*) producing mature biomass under Tier 4.

Because projected MMB_t is depended on the intervening retained and discard catch (i.e., MMB_t is estimated after the fishery), an iterative procedure is used using equations (33) and (34) with retained and discard catch predicted from equations (16) and (17). The next year limit harvest catch is estimated using equations (16) and (17) with the estimated F' value.

Pribilof Islands Golden King Crab

May 2010 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 crabs in the Pribilof District has been concentrated in the Pribilof Canyon. The fishing season for this stock has defined as a calendar year since 1984. The domestic fishery developed in 1981/82. Peak harvest occurred in the 1983/84 season with a retained catch of 856-thousand pounds 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 342-thousand pounds in 1995, when seven vessels made landings. The fishery is not rationalized and has been managed towards a GHL of 150-thousand pounds since 2000. Non-retained bycatch can occur in the directed fishery, as well as in the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and Bering Sea groundfish fisheries. Estimated weight of non-retained bycatch during crab fisheries ranges from 0 pounds to 49-thousand pounds annually during calendar years 2001–2008; estimates of total fishery mortality (in terms of catch) during 2002–2009 crab fisheries range from 0 pounds to 169-thousand pounds (average = 68-thousand pounds). Estimates of discarded bycatch during Bering Sea groundfish fisheries ranges from 0.3-thousand to 27-thousand pounds annually during the 1991/92–2008/09 crab fishery years; estimates of fishery mortality during 1991/92–2008/09 groundfish fisheries range from 0.2-thousand pounds to 19-thousand pounds (average = 6-thousand pounds). There was no participation in the fishery and no landings for the fishery in 2006–2009. One vessel has landed catch in the ongoing 2010 season.

3. Stock biomass:

Stock biomass (all sizes, both sexes) of golden king crabs 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 919 metric tons (2.03-million pounds).

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 682 metric tons (1.50-million pounds) in 2002 to 919 metric tons (2.03-million pounds) in 2008.

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 2008 (the Pribilof Island golden king crab season is based on a calendar year); there was no participation in the fishery and no landings for the fishery in 2009. See table, below.

Year[a]	**MSST**	**Biomass (MMB)**	**GHL**[b]	**Retained Catch**[c]	**Total Catch**[c,d]	**OFL**[c,e]
2007	N/A	N/A	0.150	0	0.000	N/A
2008	N/A	N/A	0.150	0	0.000	N/A
2009	N/A	N/A	0.150	0	0.001	0.17
2010	N/A	N/A	0.150	TBD	TBD	0.17
2011	N/A	N/A	0.150			0.17

a. The Pribilof Island golden king crab season is based on a calendar year.
b. Guideline harvest level, 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 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 bycatch mortality during 2004/05–2008/09 groundfish fisheries are ≤0.001-million pounds.
e. Retained-catch OFL.

6. **Basis for the OFL:** See table, below.

Year[a]	**Tier**	**Years to define Average catch (OFL)**	**Natural Mortality**
2010	5	1993–1998[b]	0.18[c]
2011	5	1993–1998[b]	0.18[c]

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. Assumed value for FMP king crabs in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.

7. **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 150-thousand pounds. One vessel has participated so far during the ongoing 2010 fishery.

2. **Changes to the input data:**

- Retained catch data has been updated with the results for 2009, during which there was no fishery participation and 0 pounds of retained catch.

3. **Changes to the assessment methodology:** None.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:**
   - The OFL for 2010 was 0.17-million pounds of retained catch and was estimated by the average annual retained catch (not including deadloss) for the period 1993–1998. The recommended retained-catch OFL for 2011 is the same: 0.17-million pounds and estimated as the average retained catch (including deadloss) for the period 1993–1998.

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 2009: *"The timing for final assessments for Tier 5 stocks should be done annually in May and only brought back to the CPT as an agenda item in September should there be new information over the summer and/or modification to CPT recommendations from the SSC."*
     - Response: That is being done.
   - SSC, June 2009: *"The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number a number of years that are common across groups of species or areas."*
     - Response: The stock assessment author has not addressed this question yet and does not recall a larger discussion on this by the CPT as whole.
   - CPT, September 2009: None that I could find.
   - SSC, October 2009: *"The SSC offers these general comments to all stock assessment authors: (1) at the beginning of each SAFE chapter, summarize the SSC and Plan team requests to the author (and response to each) to assure that these requests are not overlooked, … and (2) each assessment should clearly state what is new and not new from the previous assessment. (3) All assessment authors should structure their assessment documents following the guidelines established by the crab plan team."*
     - Response: It is done.

2. **Responses to the most recent two sets of SSC and CPT comments specific to the assessment:**
   - CPT, May 2009: None pertaining to this assessment. Relative to the September 2009 assessment: *"The team supported the author's recommendation to use the same years for calculating the retained OFL for this stock. Bycatch data will be compiled and included in the September assessment."*
     - Response: Those comments were addressed in the September 2009 SAFE.
   - SSC, June 2009: Not applicable. A Pribilof Islands golden king crab stock assessment report was not reviewed by SSC at the June 2009 meeting.
   - CPT, September 2009: *"The team recommends the assessment author further evaluate all sources of mortality in order to present alternative total catch OFL options for the 2010 assessment. The team encourages further inclusion of the slope survey data to consider whether or not information may be sufficient to move this assessment up to Tier 4 in future years."*
     - Response: All known sources of data on fishery bycatch were evaluated in the September 2009 assessment. No new data are available for the last completed fishery

year, 2009. Average bycatch in non-directed fisheries are shown here with data pooled to protect confidentiality of data. An average bycatch rate for the directed fishery is shown here with data pooled to protect confidentiality of data. Those values can be coupled with the average bycatch mortality in the groundfish fisheries to provide an expected additional mortality due to bycatch at a given retained-catch OFL. That could be used to compute the desired total catch OFL. That "expected additional mortality due to bycatch" may be a poor estimate when applied to the data for which the retained-catch OFL is computed. No further inclusion of slope data, beyond that which was in the last assessment, was added to this assessment.

- SSC, October 2009: *"The SSC also agrees with the Tier 5 designation and the use of the time period of 1993–1998 for calculation of OFL for Pribilof Islands golden king crab."*
    - Response: The author does as well.

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 (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 Pribilof Islands king crab stock boundary is defined by the boundaries of the Pribilof District of Registration Area Q (Figure 1). Bowers et al. (2008, page 84) 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 (kg/ha and number/ha) 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. 2008, 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:** We are 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 (2001c) 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 crabs 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. <u>Brief summary of management history</u>:

A complete summary of the management history is provided in Bowers et al. (2008, pages 88–90). The first domestic harvest of golden king crabs in the Pribilof District was in 1982 when two vessels fished (Bowers et al. 2008). Peak harvest and participation occurred in the 1983/84 season with a retained catch of 856-thousand pounds (Table 1, Figure 3) from landings 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 342-thousnad 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 ongoing 2010 season. The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was 200-thousand pounds, whereas for the 2000-2010 the GHL has been 150-thousand 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 crabs 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>:

- Retained catch (0 pounds) during 2009 has been added to the retained catch time series.

2. <u>Data presented as time series</u>:

a. Total catch and b. Information on bycatch and discards:

- The 1981/82–1983/84, 1984–2007 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 table does not include the 0 values for the last two completed seasons, 2008 and 2009, during which there was no directed fishing effort.
- The 1981/82–1983/84, 1984–2009 time series of retained catch (pounds of landed crabs) is presented graphically in Figure 3.
- The 2001–2009 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 crabs. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of golden king 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 or observer data from at least one of the fisheries is confidential for 2001 and for 2003–2005. Estimates of the weight of fishery mortality can be made for 2002–2009 without revealing confidential data by pooling of data; the estimate of total fishery mortality during crab fisheries for 2001 cannot be presented without revealing confidential data. Following Siddeek et al. (2009), the handling mortality rate of king crabs captured and discarded during Aleutian Islands

king crab fisheries was assumed to be 0.2. Following Foy and Rugolo (2009), handling mortality rate during the snow crab fishery was assumed to be 0.5. The handling mortality rate during the grooved Tanner crab fishery was also assumed to be 0.5. Average annual total fishery mortality in crab fisheries during 2002–2009 is estimated at 68-thousand pounds. Average estimated annual bycatch mortality due to the Bering Sea grooved Tanner crab and snow crab fisheries during years that are not revealed so as to protect confidentiality is 0.4-thousand pounds. Average annual rate of pounds of bycatch mortality per pound of retained catch during years that are not revealed so as to protect confidentiality is 0.05 (CV=0.08).

- The 1991/92–2008/09 time series of estimated 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 (fixed or trawl) is provided in Table 3. Following Foy and Rugolo (2009), the handling 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. Due to the mismatch in definition of years for the crab fishery and groundfish fishery data, the estimates of total fishery mortality during groundfish fisheries cannot be directed to the estimates of total fishery mortality during crab fisheries. Average annual total fishery mortality in groundfish fisheries during 1991/92–2008/09 is estimated at 5.8-thousand pounds

c. Catch-at-length:

The size (carapace length, CL, mm) distribution of retained legal male golden king crabs from the Pribilof Islands golden king crab fishery sampled prior to processing at-sea and dockside by observers and ADF&G catch samplers during 2002 is provided in Figure 4. 2002 is the only year for which these data are not confidential and which can be separated from catch samples from the St. Matthew golden king crab fishery.

d. Survey biomass estimates:

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 variances and CVs are presented in Table 5.

e. Survey catch at length:

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 in presented in Figure 5.

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):

We are 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.

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 golden 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; 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 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 crabs 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).

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:** *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 represents the average retained catch from a time period determined to be representative of the production potential of the stock" (Amendment 24). Additionally, Amendment 24 states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, would be based on the best scientific information available and provide the appropriate risk aversion for stock conservation and utilization goals."

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 (Amendment 24; Federal Register/Vol. 73, No. 116, 33926). Hence, alternative configurations for the Tier 5 model are limited to: 1) a retained-catch versus total-catch OFL, and 2) alternative time periods for computing the average catch (whether retained or total). The important questions to resolve when choosing from among alternative time periods for computing average catch (whether retained or total) as an estimate of OFL are:

1. Over what time period in the history of the fishery was the retained catch "representative of the production potential of the stock?"
2. In choosing the time period, what available information should be used when considering "the required risk aversion for stock conservation?"
3. In choosing the time period, what available information should be used when considering "utilization goals?"

NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof Islands golden king crabs. 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, whereas in 2009 the CPT and SSC recommended that the retained-catch OFL for 2010 be set as the average retained catch during 1993–1998 so as to exclude 1999, the first year that a GHL was established for the fishery.

Although not endorsed by the assessment author, an approach to calculating a total-catch OFL is presented here in addition to alternatives for a retained-catch OFL.

3. <u>Model Selection and Evaluation</u>:

a. <u>Description of alternative model configurations</u>

The recommended OFL is set as a retained-catch OFL due to lack of data on bycatch of golden king crabs during the Pribilof District golden king crab fishery prior to the establishment of GHLs (GHLs were first established in 1999 and observers were not deployed to the fishery until 2001.

Three alternative configurations for computing average retained catch to estimate a retained-catch OFL for 2010 were considered and described below (the "Base" and Alternatives 1 and 2). In 10 of the 12 seasons prior to the 1993 season, there was either no fishery effort (five seasons) or the fishery data are confidential (five seasons). Hence the author recommends that years prior to the 1993 fishery season not be included in any computation of average retained-catch weight as a measure of OFL. Likewise, in the six completed seasons after 2002 (i.e., 2003–2008), fishery data for 2003–2005 are confidential and there was no fishery effort in 2006–2008. Hence the author recommends that years after the 2002 fishery season not be included in any computation of average retained catch weight as an estimate of OFL.

For choice of a time period within 1993–2002, the following should be considered. No GHL was established for the fishery prior to the 1999 season. The 1999 season was managed with a GHL of 200-thousand pounds, which was established inseason in response to higher-than-expected catch rates, and the fishery was closed by emergency order to avoid exceeding the GHL (Morrison et al. 2000). The actual fishery harvest for 1999 was 177-thousand pounds, which was nearly equal to that for 1997 (185-thousand pounds) and to the average for 1993–1998 (176-thousand pounds), but far above that for 1998 (36-thousand pounds; Table 1, Figure 3). The 2000–2002 seasons were each constrained by a GHL of 150-thousand pounds that was established pre-season and which was below the average catch for 1993–1999 (176-thousand pounds). Whereas the fishery remained open through the entirety of 2000 without achieving the GHL, the fishery was closed by emergency order in both 2001 and 2002 to avoid exceeding the GHL. The average retained catch during the 2000–2002 seasons was 148-thousand pounds.

Model	**Retained-vs. Total-catch**	**Time Period (n of years)**	**Description/Comments**
Base	Retained	1993–1998 (6)	• Used to determine the 2010 OFL • Shortest, least recent time period considered • Catch was not constrained by GHL in any year
Alt. 1	Retained	1993–1999 (7)	• Used to determined the 2009 OFL • Catch was not constrained by GHL during 1993–1998 • Catch for 1999 was constrained by GHL
Alt. 2	Retained	1993–2002 (10)	• Longer time period than the Base • Includes more recent years of data than the Base • The catch in the additional, more-recent years were constrained by the GHL in 2001–2002

A possible approach to “converting” any of the alternative retained-catch OFLs into a total-catch OFL would be to assume that pounds of bycatch mortality in the non-directed crab fisheries and groundfish fisheries occurs at a background level that is independent of the Pribilof Island golden king crab stock size and the Pribilof Island golden king crab retained catch, whereas as the pounds of bycatch mortality due to the directed fishery is directly proportional to the retained catch.

Estimates of the annual bycatch mortality in the non-directed crab fisheries and the groundfish fisheries were provided in the third bullet of section D.2.a:

- Average bycatch mortality in non-directed crab fisheries = 0.4-thousand pounds.
- Average bycatch mortality in groundfish fisheries = 5.8-thousand pounds.

Hence 6.2-thousand pounds provides an estimate of the average total "background" bycatch mortality due to the non-directed crab and groundfish fisheries.

An estimate of the average annual ratio of pounds of bycatch mortality during the directed fishery per pound of retained catch was provided in third bullet of section D.2.a as 0.05 pounds of bycatch mortality per pound of retained catch.

Given those values, the approach given here for consideration is to calculate a total-catch OFL (OFL_{TOT}) from any of the alternative retained-catch OFLs (OFL_{RET}) that is chosen as,

$$OFL_{TOT} = 1.05 \cdot OFL_{RET} + 0.006\text{-million.}$$

Applying this approach to any of the alternatives for retained-catch OFL considered here would result in a total-catch OFL that is 0.01-million pounds higher than the original retained catch OFL. The assessment author feels very uncomfortable about this approach as it relies on estimates using data that cannot be revealed and applies those estimates to a time period outside of the time period that the unrevealed data were collected.

b. ***<u>Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed</u>:*** See the table, below.

Model	**Retained- vs. Total-catch**	**Time Period (n of years)**	**Resulting OFL (millions of pounds)**
Base	Retained	1993–1998 (6)	0.17
Alt. 1	Retained	1993–1999 (7)	0.17
Alt. 2	Retained	1993–2002 (10)	0.16

c. ***<u>Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models</u>:***

All alternatives assume that catch is indicative of stock productivity without any regard to harvest restraints (GHLs, TACs, fishery closures, etc) that were imposed by management during the history of the fishery. The reality of that assumption was discussed for the time periods considered in section E.3.a. Alternative 2 is the most realistic in this regard.

d. ***<u>Convergence status and convergence criteria for the base-case model (or proposed base-case model)</u>:*** 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?:***

- Estimates of total retained catch (pounds) during a season are from fish tickets landings recorded at landings and are assumed here to be correct.

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):*** Not applicable.

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. Alternative retained-catch OFLs are graphed relative to actual retained catch during history of fishery in Figure 6.

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.):*** Not applicable for Tier 5 stock.

F. Calculation of the OFL

1. Specification of the Tier level and stock status level for computing the OFL:

- Recommended as Tier 5: Retained-catch OFL estimated by average retained catch over a specified period (as recommended by CPT in May 2009; see section B.2).
- Recommended time period for computing retained-catch OFL: 1993–1998.
  - The is the time period and the OFL established for the 2010 season. The time period 1993–1998 provides the longest continuous time period through 2008 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. There is no difference between the retained-catch OFL computed from 1993–1999 data (the time period for the 2009 OFL) and that computed from 1993–1998 data at the level of precision that the OFL is specified in this assessment.

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). According to Amendment 24 of the FMP, itself:

> For Tier 5 stocks, the historical performance of the fishery is used to set OFLs in terms of retained catch. The OFL represents the average retained catch from a time period determined to be representative of the production potential of the stock. The time period selected for computing the average catch, hence the OFL, would be based on the best scientific information available and provide the appropriate risk aversion for stock conservation and utilization goals. In Tier 5, the OFL is specified in terms of an average catch value over 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.
>
> For most Tier 5 stocks, only retained catch information is available so the OFL will be estimated for the retained catch portion only, with the corresponding overfishing comparison on the retained catch only. In the future, as information improves, the OFL calculation could include discard losses, at which point the OFL would be applied to the retained catch plus the discard losses from directed and non-directed fisheries.

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]
2007	N/A	N/A	0.150	0	0.000	N/A
2008	N/A	N/A	0.150	0	0.000	N/A
2009	N/A	N/A	0.150	0	0.001	0.17
2010	N/A	N/A	0.150	TBD	TBD	0.17
2011	N/A	N/A	0.150			0.17

a. The Pribilof Island golden king crab season is based on a calendar year.
b. Guideline harvest level, 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 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; the average of the annual estimates of bycatch mortality during 1991/92–2008/09 groundfish fisheries is 0.006-million pounds.
e. Retained-catch OFL.

4. <u>Recommendation for F_{OFL}, OFL total catch (or OFL retained catch) for the coming year</u>:

Recommended OLF = 0.17-million pounds, retained-catch.

G. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

H. 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.

I. Ecosystem Considerations

1. Ecosystem Effects on Stock:

a. ***<u>Prey availability/abundance trends (historically and in the present and foreseeable future)</u>:*** Existence and availability of such information is not known to the author.

b. ***<u>Predator population trends (historically and in the present and foreseeable future)</u>:*** Existence and availability of such information is not known to the author.

c. ***Changes in habitat quality (historically and in the present and foreseeable future):*** Existence and availability of such information is not known to the author.

2. Fishery Effects on the Ecosystem

a. ***Fishery-specific bycatch of HAPC biota marine mammals and birds, and other sensitive non-target species:***

A summary of bycatch during the 2001 and 2002 Pribilof District golden king crab fisheries, the two most recent years for which data is not confidential, are provided in Tables 6 and 7. Note that, due to no participation in the fishery, there was no bycatch due to the fishery during 2006–2009.

b. ***Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components:***

Existence and availability of such information is not known to the author. Note that, the fishery is concentrated in the Pribilof Canyon, typically at depths of 100–300 fathoms (183–549 m; see section C.2). Note that, due to no participation in the fishery, there has been no effect during 2006–2009.

c. ***Fishery-specific effects on amount of large size target crabs:***

The fishery can only retain males ≥ 5.5-inches carapace width. Bycatch of sublegal males has been low relative to catch of legal males in seasons for which observer data is available and not confidential; estimated catch of sublegal males was roughly 1/3 that of legal males in 2001 (Neufeld and Barnard 2003) and approximately half that of legal males in 2002 (Barnard and Burt 2004). Hence the fishery, when prosecuted, would be expected to decrease the amount of large size males. However, without background information on the available biomass of large size males, the magnitude of the effect cannot be estimated. Due to lack of fishery effort there has been no effect during 2006–2009.

d. ***Fishery-specific contribution to discards:***

Estimated contribution of discards of Pribilof Islands golden king crabs in the Pribilof District golden king crab fishery relative to the retained catch and to the bycatch in other Bering Sea crab fisheries during 2001–2002 is provided in Table 2. See Table 3 for comparison with the estimated bycatch of Pribilof Islands golden king crabs in federal groundfish fisheries during 1991/92–2008/09. Note that, due to lack of participation in the fishery, there has been no contribution from the directed fishery during 2006–2009.

e. **Fishery-specific effects on age-at-maturity and fecundity of the target species:**

Existence and availability of such information is not known to the author. Note that, due to no participation in the fishery, there has been no effect during 2006–2009.

f. ***Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance):***

Number of pot lifts performed in the Pribilof District golden king crab fishery, 1981/82–1983/84 and 1984–2009 is plotted in Figure 7 (see also Table 1). Note that most of the fishery effort has been concentrated in the Pribilof Canyon (see section C.2).

J. Literature Cited

Barnard, D. R. and R. Burt. 2004. Alaska Department of Fish and Game summary of the 2002 mandatory shellfish observer program database for the general and CDQ crab fisheries. Alaska Department of Fish and Game, Regional Information Report No. 4K04-27, Kodiak.

Barnard, D. R. and R. Burt. 2006. Alaska Department of Fish and Game summary of the 2005 mandatory shellfish observer program database for the non-rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 06-36, Anchorage.

Blau, S. F., and D. Pengilly. 1994. Findings from the 1991 Aleutian Islands golden king crab survey in the Dutch Harbor and Adak management areas including analysis of recovered tagged crabs. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K94-35, Kodiak.

Blau, S. F., L. J. Watson, and I. Vining. 1998. The 1997 Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K98-30, Kodiak.

Bowers, F. R., K. Herring, E. Russ, J. Shaisnikoff, and H. Barnart. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Bering Sea, 2007/08. Pages 76–184 *in* Bowers, F. R., M. Schwenzfeier, K. Milani, B. Failor-Rounds, K. Milani, M. Salmon, K. Herring, J. Shaishnikoff, E. Russ, R. Burt, and H. Barnhart. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2007/08. Alaska Department of Fish and Game, Fishery Management Report No. 08-73, Anchorage.

Burt, R. and D. R. Barnard. 2005. Alaska Department of Fish and Game summary of the 2003 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 05-05, Anchorage. Alaska Department of Fish and Game, Division of Comercial Fisheries, Fishery Research Bulletin No. 92-02. Juneau.

Burt, R., and D. R. Barnard. 2006. Alaska Department of Fish and Game summary of the 2004 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 06-03, Anchorage.

Foy, R. J., and L. Rugolo. 2009. Draft 2009 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions. May 2009. http://www.fakr.noaa.gov/npfmc/membership /plan_teams/CPT/509chapters/PIBKC509.pdf

Haaga, J. A., S. Van Sant, and G. R. Hoff. 2009. Crab abundance and depth distribution along the continental slope of the eastern Bering Sea. Poster presented at the 25th Lowell Wakefield Fisheries Symposium (Biology...Crab Populations under Climate Change...), Anchorage, AK, March 2009. Available online at: ftp://ftp.afsc.noaa.gov/posters/pJHaaga01_ebs-crab.pdf

Hiramoto, K. 1985. Overview of the golden king crab, *Lithodes aequispina*, fishery and its fishery biology in the Pacific waters of Central Japan. In: Proc. Intl. King Crab Symp., Univ. of Alaska Sea Grant Rpt. 85-12, Fairbanks, pp. 297-317.

Hiramoto, K., and S. Sato. 1970. Biological and fisheries survey on an anomuran crab, *Lithodes aequispina* Benedict, off Boso Peninsula and Sagami Bay, central Japan. Jpn. J. Ecol. 20:165-170. In Japanese with English summary.

Hoff, G.R., and L. Britt. 2005. Results of the 2004 easrern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-156. 277 p.

Jewett, S. C., Sloan, N. A., and Somerton, D. A. 1985. "Size at sexual maturity and fecundity of the fjord-dwelling golden king crab *Lithodes aequispina* Benedict from northern British Columbia." *J. Crust. Biol.*, 5, pp. 377-385.

McBride, J., D. Fraser, and J. Reeves. 1982. Information on the distribution and biology of the golden (brown) king crab in the Bering Sea and Aleutian Islands area. NOAA, NWAFC Proc. Rpt. 92-02.

Morrison, R., F. B. Bowers, R. Gish, E. Wilson, W. Jones, B. Palach.. 2000. Annual management report for the shellfish fisheries of the Bering Sea. Pages 147–261 *in* Alaska Department of Fish and Game. 2000. Annual management report for the shellfish fisheries of the Westward Region, 1999. Alaska Department of Fish and Game, Regional Information Report No. 4K00-55, Kodiak.

National Marine Fisheries Service (NMFS). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668, August 2004.

Neufeld, G. and D. R. Barnard. 2003. Alaska Department of Fish and Game summary of the 2001 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K03-2, Kodiak.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Nyblade, C.F. 1987. Phylum or subphylum Crustacea, class Malacostraca, order Decopoda, Anomura. In: M.F. Strathman (ed), Reproduction and development of marine invertebrates on the northern Pacific Coast. Univ. Wash. Press, Seattle, pp.441-450.

Otto, R. S., and P. A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (*Lithodes aequispina*) in the Bering Sea and Aleutian Islands. Pages 123–136 *in* Proceedings of the International King Crab Symposium. University of Alaska Sea Grant Report No. 85-12, Fairbanks.

Paul, A. J., and J. M. Paul. 2000. Changes in chela heights and carapace lengths in male and female golden king crabs *Lithodes aequispinus* after molting in the laboratory. Alaska Fishery Research Bulletin 6(2): 70–77.

Paul, A. J., and J. M. Paul. 2001a. Growth of juvenile golden king crabs *Lithodes aequispinus* in the laboratory. Alaska Fishery Research Bulletin 8(2): 135–138.

Paul, A. J., and J. M. Paul. 2001b. Size of maturity in male golden king crab, *Lithodes aequispinus* (Anomura: Lithodidae). J. Crust. Biol. 21:384.

Paul, A. J., and J. M. Paul. 2001c. The reproductive cycle of golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). J. Shellfish Res. 20:369–371.

Shirley, T. C., and S. Zhou. 1997. Lecithotrophic development of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). Journal of Crustacean Biology 17:207–216.

Siddeek, M.S.M., L. J. Watson, D. R. Barnard, and R. K. Gish. 2009. Draft Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Stock Assessment Model Development. May 2009. http://www.fakr.noaa.gov/npfmc/membership/plan_teams/CPT/509chapters/GKCModel509.pdf.

Sloan, N.A. 1985. Life history characteristics of fjord-dwelling golden king crabs *Lithodes aequispina*. Mar. Ecol. Prog. Ser. 22:219-228.

Somerton, D.A., and R.S. Otto. 1986. Distribution and reproductive biology of the golden king crab, *Lithodes aequispina*, in the eastern Bering Sea. Fish. Bull. 84:571-584.

Watson, L. J., D. Pengilly, and S. F. Blau. 2002. Growth and molting probability of golden king crabs (*Lithodes aequispinus*) in the eastern Aleutian Islands, Alaska. Pages 169–187 *in* 2002. A. J. Paul, E. G. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley, and D. Woodby (eds). Crabs in coldwater regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks. 876 pp.

Table 1. Harvest history for the Pribilof Islands golden king crab fishery from the 1981/82 season through the 2007 (from Bowers et al. 2008); though not included in this table, there was no effort or landings in 2008 or in 2009.

	Number of					Average			
Season	Vessels	Landings	Crabs[a]	Pots lifted	Harvest[a,b]	Weight[b]	CPUE[c]	Length[d]	Deadloss[b]
1981/82	2				CONFIDENTIAL				
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				NO LANDINGS				
1985	1				CONFIDENTIAL				
1986	0				NO LANDINGS				
1987	1				CONFIDENTIAL				
1988	2				CONFIDENTIAL				
1989	2				CONFIDENTIAL				
1990	0				NO LANDINGS				
1991	0				NO LANDINGS				
1992	0				NO LANDINGS				
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	177,108	4.0	15	NA	319
2000	7	19	29,145	5,450	127,217	4.4	5	NA	4,599
2001	6	14	33,723	4,262	145,876	4.3	8	143	8,227
2002	8	20	34,860	5,279	150,434	4.3	6	144	8,984
2003	3				CONFIDENTIAL				
2004	5				CONFIDENTIAL				
2005	4				CONFIDENTIAL				
2006-2007	0				NO LANDINGS				

Notes: "Confidential" = Less than three vessels or processors participated in the fishery, and "NA" = Not available.

[a] Deadloss included.

[b] In pounds.

[c] Number of legal crabs per pot lift.

[d] 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, 2001–2009 (from Pengilly 2009, with update for 2009 and corrections for 2008 made).

		Bycatch by fishery			
Year	Retained Catch	Pribilof Islands golden king crab	Bering Sea snow crab	Bering Sea grooved Tanner crab	Total Fishery Mortality
2001	154,103	39,278	0	confidential	confidential
2002	159,418	41,894	2,335	no fishing	168,964
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]

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 fishery 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, 1991/92–2008/09 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office through R. Foy AFSC, Kodiak Laboratory, 7 August 2009).

Season	Fixed	Trawl	Total Bycatch	Total Bycatch Mortality
1991/92	110	13,464	13,574	10,827
1992/93	7,690	19,544	27,234	19,480
1993/94	1,116	21,248	22,364	17,555
1994/95	558	7,103	7,661	5,961
1995/96	895	4,187	5,082	3,796
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	7,780
1999/00	10,556	1,426	11,982	6,420
2000/01	3,589	4,134	7,723	5,101
2001/02	3,300	783	4,083	2,277
2002/03	1,219	472	1,691	988
2003/04	503	401	904	573
2004/05	342	860	1,202	860
2005/06	198	126	324	201
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
Mean	4,356	4,508	8,865	5,785
CV of Mean	30%	35%	21%	23%

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. Summary of contents of 1,351 pot lifts sampled by observers during the 2001 Pribilof District golden king crab fishery (total fishery pot lifts was 4,262).

Species or species group	Non-crabs	Crabs, female	Crabs, sub-legal	Crabs, legal	Crabs, marketed
arrowtooth flounder	11	0	0	0	0
basket star	49	0	0	0	0
bigmouth sculpin	2	0	0	0	0
brittle star unident.	1	0	0	0	0
dusky rockfish	2	0	0	0	0
flatfish unident.	4	0	0	0	0
giant octopus	4	0	0	0	0
golden king crab	0	3506	3374	10771	10717
graceful decorator crab	1	0	0	0	0
Greenland halibut (or Greenland turbot)	3	0	0	0	0
grenadier (rattail) unident.	1	0	0	0	0
grooved Tanner crab	0	0	24	0	0
hair crab	0	0	0	19	0
hairy triton (or Oregon triton)	8	0	0	0	0
hermit crab unident.	16	0	0	0	0
hybrid C. bairdi	0	1	0	0	0
hybrid Tanner crab	0	0	2	0	0
Pacific cod	62	0	0	0	0
Pacific halibut	496	0	0	0	0
Pacific lyre crab	2	0	0	0	0
Pacific ocean perch	4	0	0	0	0
Pribilof neptune (or Pribilof whelk)	6	0	0	0	0
prowfish	4	0	0	0	0
redbanded rockfish	1	0	0	0	0
red king crab	0	0	3	0	0
rockfish unident.	4	0	0	0	0
sablefish (or black cod)	2	0	0	0	0
scarlet king crab	0	0	0	1	0
sculpin unident.	225	0	0	0	0
sea anemone unident.	1	0	0	0	0
sea cucumber unident.	2	0	0	0	0
sea urchin unident.	2	0	0	0	0
skate unident.	17	0	0	0	0
snailfish unident.	58	0	0	0	0
snail unident.	255	0	0	0	0
snow crab	0	0	0	13	0
spinyhead sculpin	40	0	0	0	0
starfish unident.	30	0	0	0	0
Tanner crab	0	7	99	1	0
yelloweye rockfish	1	0	0	0	0
yellow Irish lord	112	0	0	0	0

Table 7. Summary of contents of 1,504 pot lifts sampled by observers during the 2002 Pribilof District golden king crab fishery (total fishery pot lifts was 5,279).

Species or species group	Non-crabs	Crabs, female	Crabs, sub-legal	Crabs, legal	Crabs, marketed
arrowtooth flounder	197	0	0	0	0
basket star	53	0	0	0	0
brittle star unident.	39	0	0	0	0
Coral unident.	5	0	0	0	0
eelpout unident.	2	0	0	0	0
flatfish unident.	13	0	0	0	0
giant octopus	3	0	0	0	0
golden king crab	0	2842	4913	11562	11485
graceful decorator crab	1	0	0	0	0
Greenland halibut (or Greenland turbot)	21	0	0	0	0
grenadier (rattail) unident.	1	0	0	0	0
grooved Tanner crab	0	27	276	259	0
hair crab	0	0	2	14	0
hermit crab unident.	16	0	0	0	0
hybrid C. bairdi	0	0	2	0	0
jellyfish unident.	3	0	0	0	0
Kamchatka flounder	1	0	0	0	0
lampshell unident.	3	0	0	0	0
limpet unident.	1	0	0	0	0
Pacific cod	49	0	0	0	0
Pacific halibut	615	0	0	0	0
Pacific lyre crab	2	0	0	0	0
Pacific ocean perch	2	0	0	0	0
Pribilof neptune (or Pribilof whelk)	22	0	0	0	0
prowfish	1	0	0	0	0
red-tree coral	1	0	0	0	0
rockfish unident.	6	0	0	0	0
rougheye rockfish	1	0	0	0	0
sablefish (or black cod)	16	0	0	0	0
scarlet king crab	0	0	1	1	0
sculpin unident.	111	0	0	0	0
sea anemone unident.	3	0	0	0	0
sea cucumber unident.	5	0	0	0	0
sea pen or sea whip unident.	1	0	0	0	0
sea urchin unident.	5	0	0	0	0
shortspine thornyhead	2	0	0	0	0
shrimp unident.	1	0	0	0	0
skate unident.	6	0	0	0	0
snailfish unident.	8	0	0	0	0
snail unident.	169	0	0	0	0
snow crab	0	2	0	6	0
sponge unident.	50	0	0	0	0
starfish unident.	24	0	0	0	0
Tanner crab	0	11	52	1	0
triangle Tanner crab	0	0	5	0	0
walleye pollock	1	0	0	0	0
yellowfin sole	1	0	0	0	0
yellow Irish lord	17	0	0	0	0

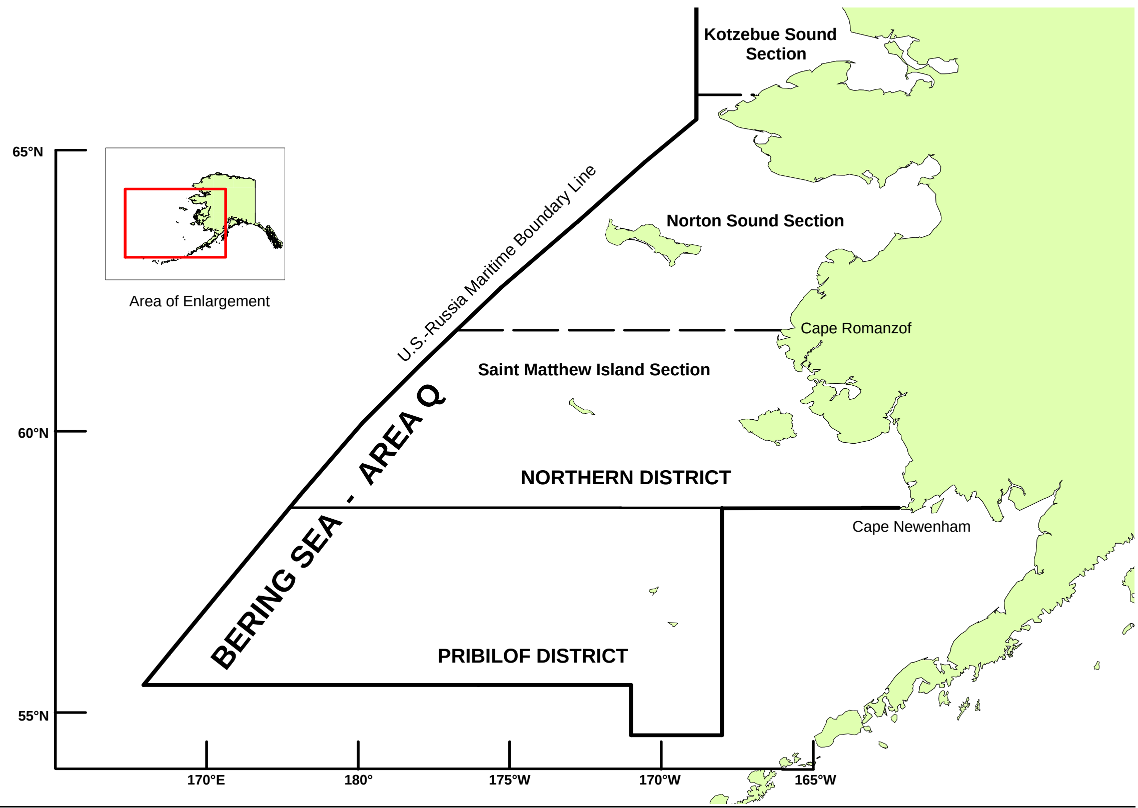
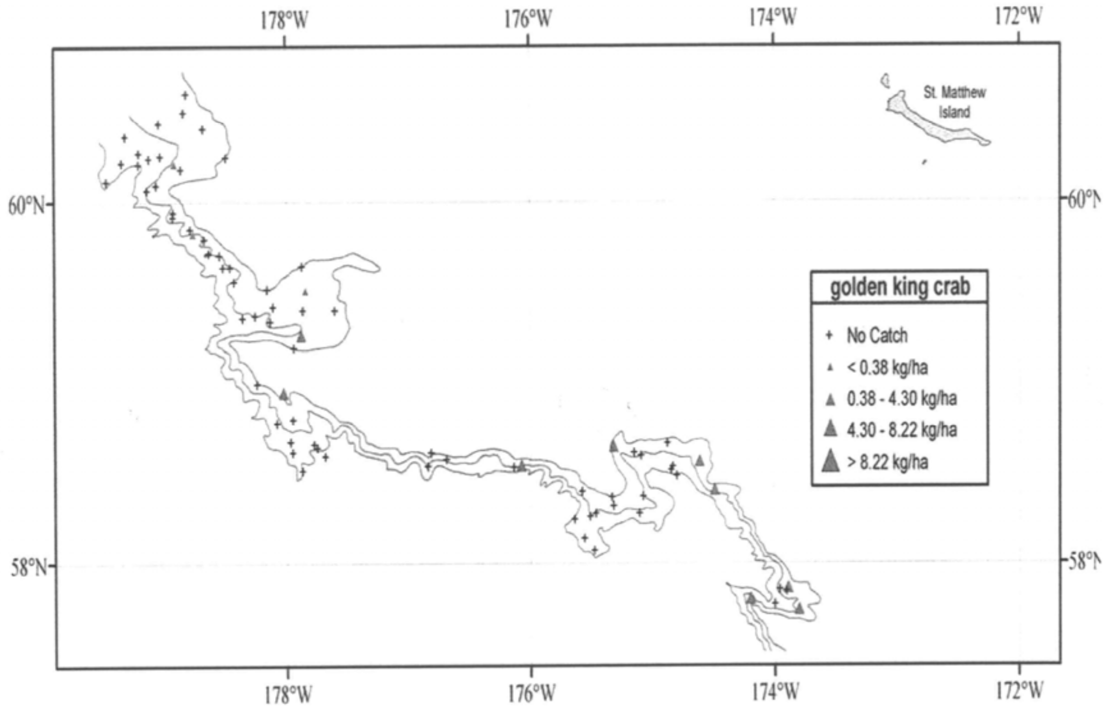


Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Bowers et al. 2008).



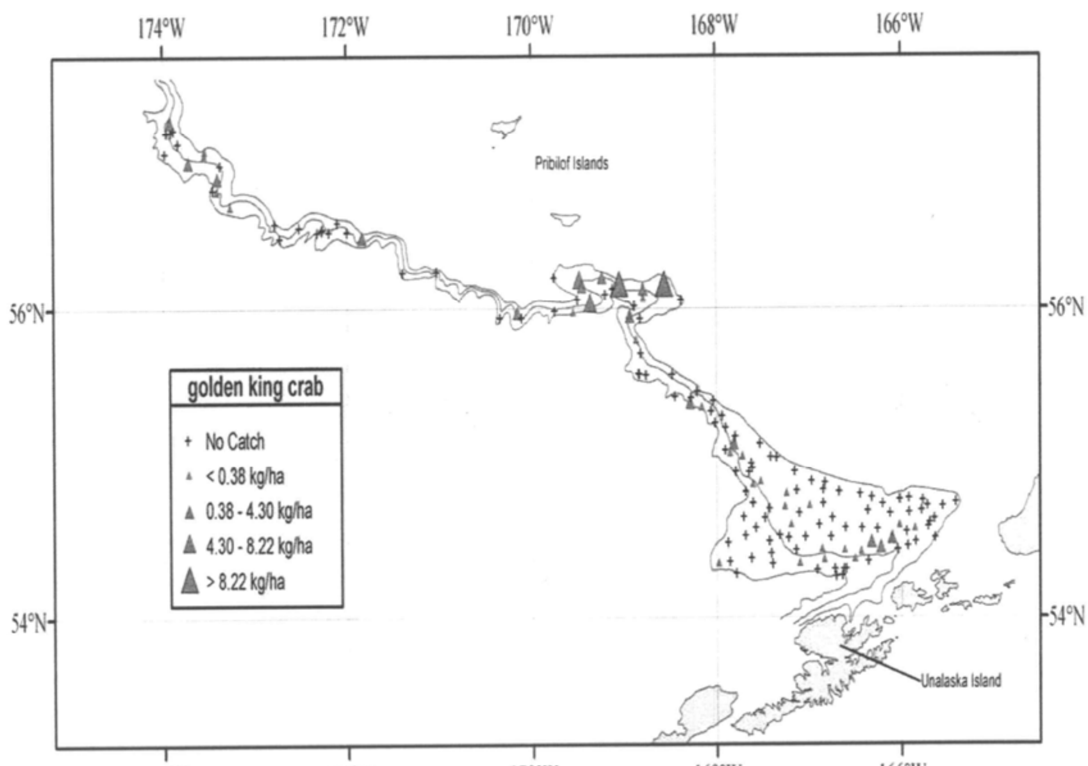


Figure 2. Distribution and relative abundance of golden king crabs from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey. Relative abundance is categorized by no catch, sample CPUE less than the mean CPUE, between the mean CPUE and two standard deviations above the mean CPUE, 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).

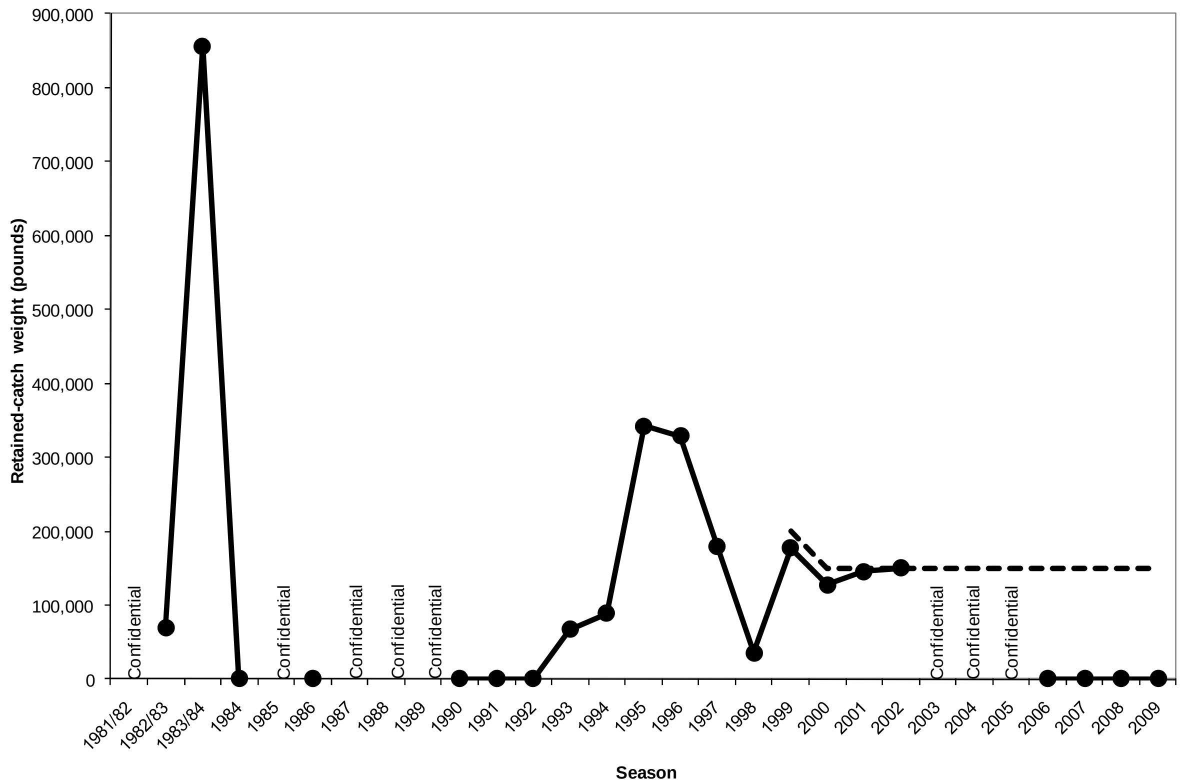


Figure 3. Retained catch (pounds; filled circles and solid line) during the 1981/82 through 2009 Pribilof Islands golden king crab fishery seasons compared with the GHL established for the fishery during the 1999–2009 seasons (dashed line; see Table 1).

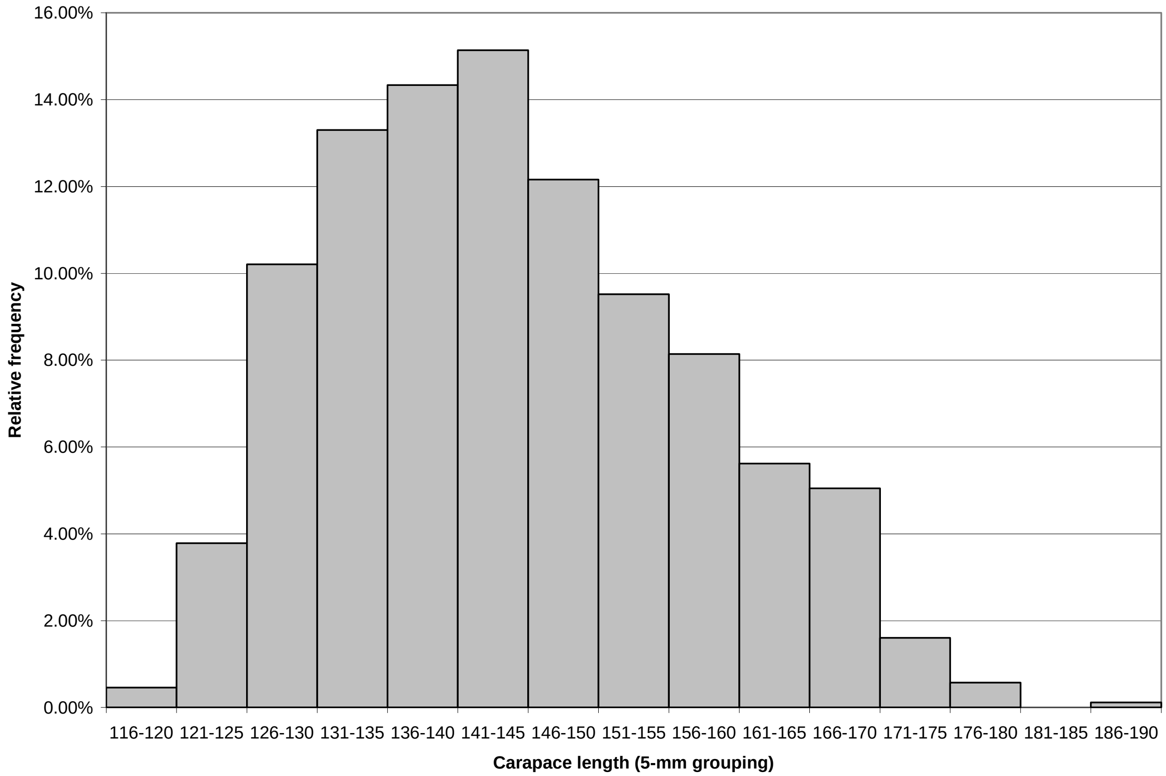


Figure 4. Relative frequency distribution for carapace length (mm) of retained golden king crabs sampled by season during the 2002 Pribilof Islands golden king crab fishery (N= 872; data from ADF&G shellfish observer database, Kodiak, April 2008).

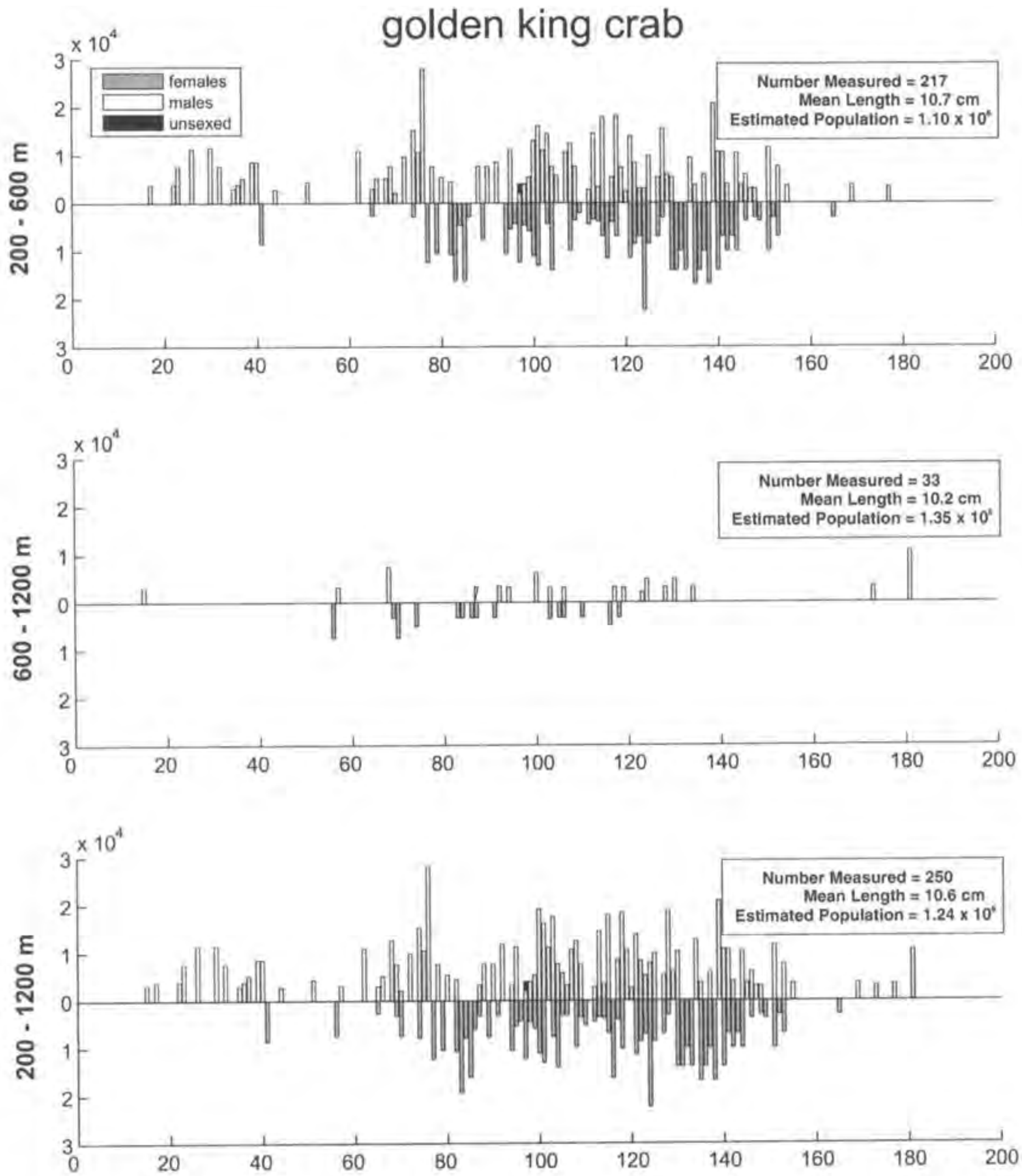


Figure 5. Size composition of the estimated golden king crab population from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey (all areas) by depth zone. The abscissa is scaled as total carapace length in millimetres and the ordinate represents the estimated total population.

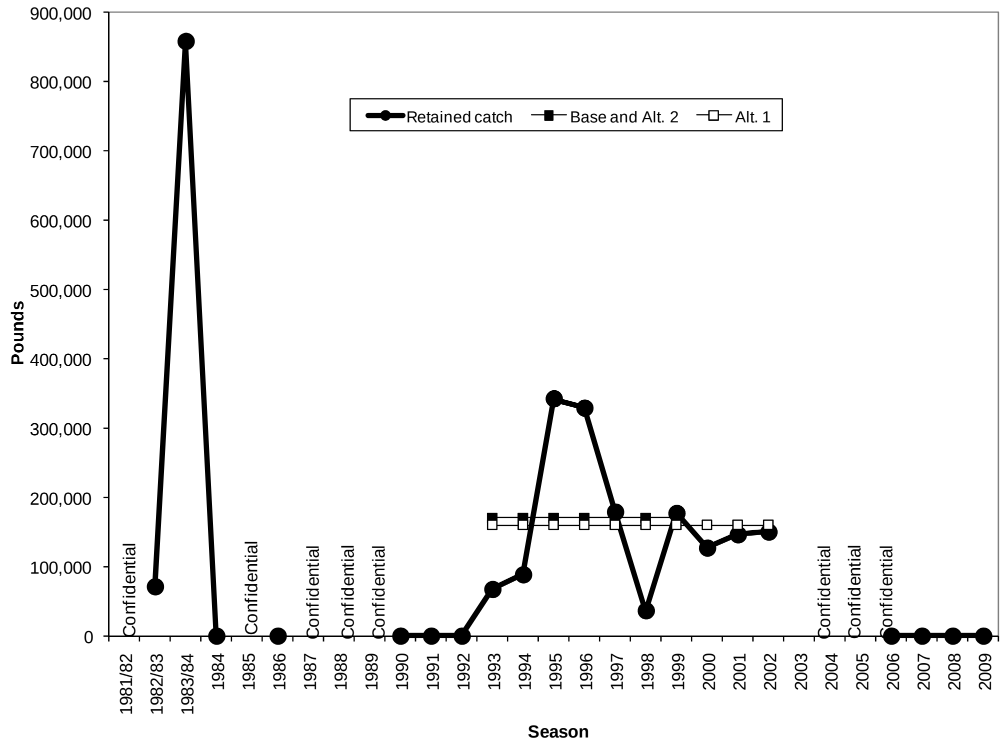


Figure 6. Alternative retained-catch OFLs (Base and Alternatives 1–2) compared with actual historical fishery retained catch for the Pribilof Islands golden king crab fishery, 1981/82–1983/84 and 1984–2009 (see Table 1 and section E.3.b).

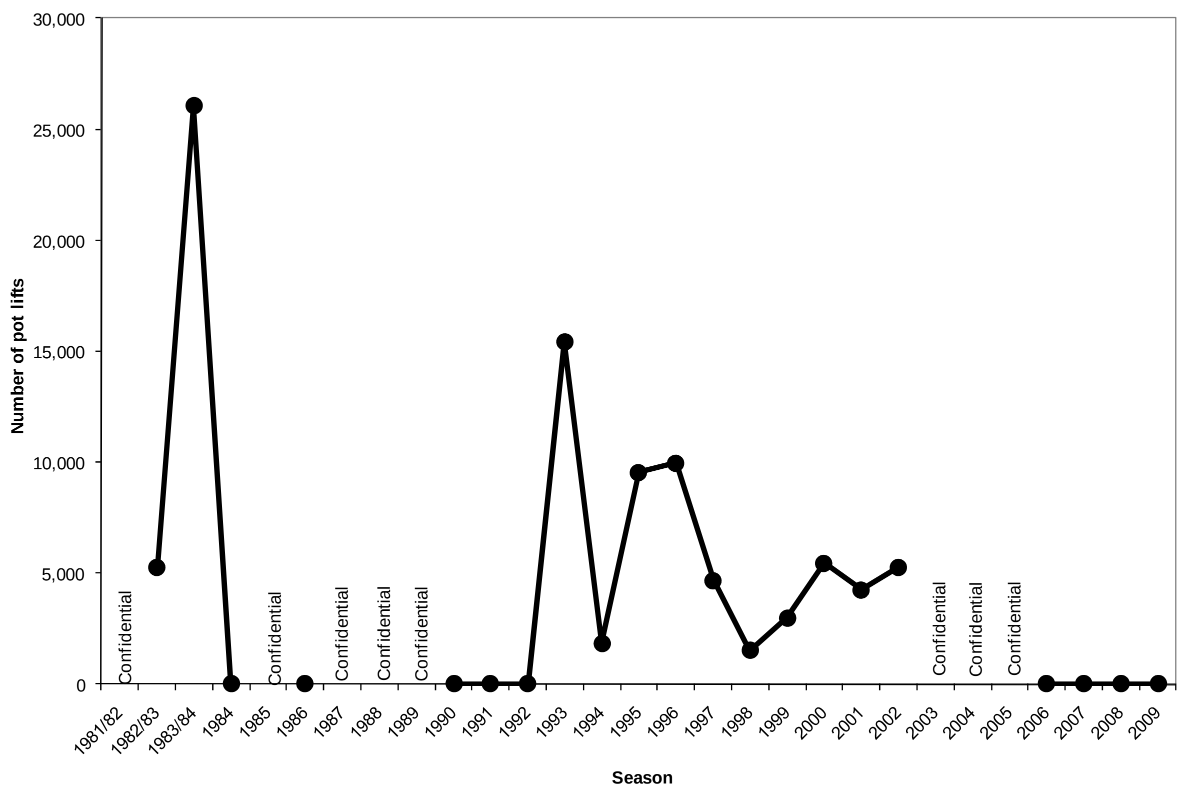


Figure 7. Number of pot lifts performed in the Pribilof District golden king crab fishery, 1981/82–1983/84 and 1984–2009 (see Table 1).

Adak Red King Crab

May 2010 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-million pounds. 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, but the retained catch during the 1995/96 season was only 0.039-million pounds. 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 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 (2002/03) and 0.479-milliion pounds (2003/04). The fishery has been closed through the 2009/10 season since the end of the 2003/04 season. Non-retained catch of red king crabs 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 1995/96–2008/09 seasons averaged 0.003-million pounds in crab fisheries and 0.023-million pounds during groundfish fisheries. Estimated weight of annual total fishery mortality during 1995/96–2008/09 averaged 0.116-million pounds; the average annual retained catch during that period was 0.090-thousand pounds.

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 2006 provided no evidence of strong recruitment. Red king crabs captured during the November 2009 pot survey conducted by ADF&G were predominately larger, matured-sized crabs and the size distribution of captured males provided no expectations for near-term recruitment of legal males (Gish 2010). In comparison to the results from the same stations fished during the 2006 Petrel Bank pot survey, the catch of red king crabs during the 2009 survey occurred in a more limited area and the catch of legal males was lower. Limited (18 pot lifts) exploratory catch-and-release fishing for red king crabs 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 crabs in four areas west of Petrel Bank between 178°00' E longitude and 175°30' E longitude; that limited effort yield a catch of one legal-sized male red king crab (J. Alas, ADF&G, *pers. comm.*).

5. Management performance:
No overfished determination (i.e., MSST) is possible for this stock given the lack of biomass information. Overfishing did not occur during the 2008/09 fishing year. See table, below.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a,c]
2006/07	N/A	N/A	Closed	0	0.004	N/A
2007/08	N/A	N/A	Closed	0	0.011	N/A
2008/09	N/A	N/A	Closed	0	0.014	0.46
2009/10	N/A	N/A	Closed	0	TBD	0.50
2010/11	N/A	N/A	TBD			0.50

a. Millions of pounds.
b. Includes handling mortality of discarded bycatch.
c. Retained-catch OFL.

6. Basis for the OFL: See table, below.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality
2009/10	5	1984/85-2007/08[a]	0.18[b]
2010/11	5	1984/85-2007/08[a]	0.18[b]

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.

7. **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:**
    - Retained catch data from the closed 2009/10 directed fishery season (0 pounds) has been added.
    - Data on non-retained bycatch during crab and groundfish fisheries during 1995/96–2008/09 has been updated with data from the 2008/09 Aleutian Islands golden king crab fishery.
    - Estimates of bycatch mortality during 1992/93–1994/95 groundfish fisheries are presented in addition to those for 1995/96–2008/09.

3. **Changes to the assessment methodology:** None.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:**
    - The OFL for 2009/10 was 0.50-million pounds of retained catch and was estimated by the average annual retained catch (including deadloss) for the period 1984/85–2007/08. The recommended retained-catch OFL for 2010/11 is the same: 0.50-million pounds, estimated as the average retained catch (including deadloss) for the period 1984/85–2007/08.

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 2009: *"The timing for final assessments for Tier 5 stocks should be done annually in May and only brought back to the CPT as an agenda item in September should there be new information over the summer and/or modification to CPT recommendations from the SSC."*
        - Response: That is being done.
    - SSC, June 2009: *"The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number a number of years that are common across groups of species or areas."*
        - Response: The stock assessment author has not addressed this question yet and does not recall a larger discussion on this by the CPT as whole.
    - CPT, September 2009: None that I could find.
    - SSC, October 2009: *"The SSC offers these general comments to all stock assessment authors: (1) at the beginning of each SAFE chapter, summarize the SSC and Plan team requests to the author (and response to each) to assure that these requests are not overlooked, … and (2) each assessment should clearly state what is new and not new from the previous assessment. (3) All assessment authors should structure their assessment documents following the guidelines established by the crab plan team."*
        - Response: It is done.

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

- CPT, May 2009: *"The team recommends establishing an OFL for this stock consistent with the approach recommended by the SSC last year (as retained catch and freezing years considered through 2007/08)."*
    - Response: That is the approach taken in this assessment.
- SSC, June 2009: None – this stock was not addressed at the June 2009 meeting.
    - Response: None.

- CPT, September 2009: *"The author will re-examine the available bycatch data for possible inclusion in the OFL calculation for the 2010 assessment. However, recent data are not comparable to past data..."*
    - Response: Estimates of bycatch mortality during the 1992/93–1994/95 groundfish fisheries are presented in addition to the total fishing mortality estimates for 1995/96–2008/09. Correlations among bycatch mortality estimates by source and retained catch are examined. However, this assessment follows the approach to calculating the OFL for 2010 that was recommended by the CPT in May 2009. It is true that recent data are often not comparable to past data.
- SSC, Oct '09: *"The SSC requests that the author incorporates the results of the ADF&G systematic survey of the Petrel Bank area in the 2010 SAFE chapter. The SSC agrees with the CPT recommendations of a tier 5 designation and establishment of a retained catch OFL of 0.5 million pounds based on average catch using the year of 1984/85 to 2007/08. It was also noted that there are concerns over the level of groundfish bycatch for this stock, which may need to be addressed."*
    - Response:
        - Results from the 2009 survey are reported, but stock is still treated as Tier 5.
        - 1984/85-2007/08 period is the "Base" option for this Tier 5 assessment.
        - 1992/93-2008/09 bycatch in groundfish fisheries from areas 541, 542, and 543 is reported.

C. Introduction

1. **Scientific name:** *Paralithodes camtschaticus*, Tilesius, 1815

2. Description of general distribution:

The general distribution of red king crabs 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 crabs 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 crabs 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 (2008, page 4) 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 crabs 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 crabs (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 crabs 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 crabs 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 crabs:

> 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 crabs (79–109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crabs 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 crabs. 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 crabs specifically in the Adak Area. Among the red king crabs 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 crabs 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 crabs 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. <u>Brief summary of management history</u>:

A complete summary of the management history is provided in Bowers et al. (2008, pages 6–11). The domestic fishery for red king crabs in the Adak Area began with the 1960/61 season (Bowers et al. 2008). Retained catch of red king crabs in the Aleutians west of 172º W longitude averaged 11.60-million pounds during the 1960/61–1975/76 seasons, with a peak harvest of 21.19-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 (Bowers et al. 2008; Figure 3). 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 1.04-million pounds; the peak harvest during that period was 1.98-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 4). 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 (Bowers et al. 2008). 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 0.51-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
2004/05–2009/10	• 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 crabs may be commercially fished only with king crab pots (as defined in 5 AAC 34.050). Pots used to fish for red king crabs 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 crabs 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 2008). Fishing for red king crabs 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 crabs 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 5,000 pounds and west of 179° E longitude with a GHL of 10,000 pounds, but was closed between 179° W longitude and 179° E longitude.
- ADF&G-Industry pot surveys for red king crabs 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 2008, 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 2008) with a GHL of 500,000 pounds. Additionally, an ADF&G-Industry pot survey for red king crabs 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. Summary of new information:

- Retained catch data from the closed 2009/10 directed fishery season has been added; the retained catch was 0 pounds.
- Data on non-retained bycatch during crab and groundfish fisheries during 1995/96–2008/09 has been updated with data from the 2008/09 Aleutian Islands golden king crab fishery; the update changes the bycatch estimates only slightly from the 2009 assessment.
- Estimated bycatch mortality of red king crabs during federal groundfish fisheries in reporting areas 541, 542, and 543 for the 1992/93–1994/95 seasons are presented in addition to those for 1995/96–2008/09; the estimated bycatch for 1992/93 (and hence the bycatch mortality estimate) is suspiciously low.

2. Data presented as time series:

a. Total catch and b. Information on bycatch and discards:

- The 1960/61–2007/08 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; Table 1 does not include data for the closed (0 retained catch, 0 effort) 2008/09–2009/10 seasons. Although summaries of these data at the geographical level of ADF&G statistical area are presently available back to the 1980/81 season, the conventions for defining and naming statistical areas changed between the 1984/85 and 1985/86 seasons. The statistical areas as defined and named from 1985/86 to present can be directly related to 1º degree longitude by 30' latitude areas, allowing for partitioning and mapping the data geographically.
- The 1960/61–2009/10 time series of retained catch (pounds of landed crabs) is presented graphically in Figure 2.
- The 1995/96–2008/09 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 crabs 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 crabs 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 crabs at sea, including catcher-processor vessels. Due to the limited number of observed vessels, the observer data from the directed Adak red king crab fishery in the 1990/91 and 1992/93–1994/95 seasons (Table 3) and golden king crab fishery in the 1993/94 and 1994/95 seasons are confidential. During the 1995/96–2004/05 seasons, observers were required on all vessels fishing for king crabs 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 crabs 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 crabs 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 1992/93–2008/09 time series of estimated weight of bycatch and estimate bycatch mortality of red king crabs 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 4. The bycatch estimate for 1992/93 is suspiciously low relative to the 1.29-million pound retained catch during that season (Table 1). Following Foy and Rugolo (2009), the handling 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.
- The 1995/96–2008/09 time series of estimated weight of total fishery mortalities of red king crabs in the Adak Area, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries, is provided in Table 5. Bycatch mortality was estimated by applying assumed handling mortality rates to the estimates of bycatch in Tables 2 and 4. Following Siddeek et al. (2009), the handling mortality rate of king crabs captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2. Following Foy et al. (2009), the handling 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.
- The 1995/96–2008/09 time series of estimates weight of total fishery mortalities of red king crabs in the Adak Area, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries (Table 5) is presented graphically in Figure 5.
- The 1992/93–2008/09 time series of bycatch mortality weights in crab and groundfish fisheries are plotted as a function of retained catch in Figure 6 (correlation coefficients are in Table 6).

c. Catch-at-length:

None presented; see D.4.

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:

The size- frequency distribution, by sex, of red king crabs captured during the 2006 and 2009 ADF&G pot survey for red king crabs in the Petrel Bank area are presented and compared in Figure 7. Data are from 117 stations (468 pot lifts) covering an area of approximately 761 nmi^2 (2,732 km^2) that were fished in common during both surveys. Each station consisted of four pots arrayed approximately 0.125 nmi (0.23 km) apart. Each pot measured 7 ft x 7 ft x 2.8 ft (2.1 m x 2.1 m x 0.9 m), was fitted with 2.75-in (70-mm) stretch mesh on all webbing, and had two opposing tunnel openings measuring 8 in x 36 in (0.2 m x 0.9 m); see Gish 2007, 2010. Data from the 2006 and 2009 ADF&G pot surveys in the Petrel Bank area provide the only such data from a standardized survey for Adak red king crabs that are available (similar data are not available from the 1975–1977 surveys).

f. Other data time series:

Data on CPUE (number of retained crabs per pot lift) during the red king crab in the Adak Area are available for the 1972/73–2009/10 seasons (see Table 1). That time series is plotted with the weight of retained catch in Figure 8. Data from the closed (0 pounds retained catch) 2009/10 season are not included in the graph, whereas data from the 1998/99 season (during which fishing was restricted to be outside of the Petrel Bank area) and the 2000/01 and 2001/02 ADF&G-Industry surveys are included in the graph.

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 crabs by Vining et al. (2002) based on information received from recoveries during commercial fisheries of tagged red king crabs 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 crabs 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; 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 crabs 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 bycatch of red king crabs in the Adak red king crab and Adak and Dutch Harbor golden king crab fisheries during 1988/89–1994/95.
- Observer data on size distribution (exclusive of use to estimate weight) and geographic distribution of bycatch of red king crabs in the Adak red king crab fishery and the

Adak/Aleutian Islands golden king crab fishery, 1988/89–2008/09 (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 is available 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, but were not presented due to "age" of the data and because data from the 1999/2000 season or the 2000/01–2001/02 seasons were 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:

Subsections a–i are not applicable to a Tier 5 sock.

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. Accordingly, it has been recommended by NPFMC (2007) and by the CPT and SSC in 2008 that the Adak Area red 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" (Amendment 24). Additionally, Amendment 24 states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, would be based on the best scientific information available and provide the appropriate risk aversion for stock conservation and utilization goals."

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 (Amendment 24; Federal Register/Vol. 73, No. 116, 33926) and the CPT in September 2009 recommended examining a total-catch OFL. Hence alternative configurations for the Tier 5 model are limited to: 1) a retained-catch versus total-catch OFL, and 2) alternative time periods for computing the average catch (whether retained or total). Nonetheless, the CPT in May 2009 and SSC in October 2009 recommended a retained-catch OFL for 2009/10. The important questions to resolve when choosing from among alternative time periods for computing average catch (whether retained or total) as an estimate of OFL are:

1. Over what time period in the history of the fishery was the retained catch "representative of the production potential of the stock?"
2. In choosing the time period, what available information should be used when considering "the required risk aversion for stock conservation?"
3. In choosing the time period, what available information should be used when considering "utilization goals?"

Considerations in choosing the time period that is “representative of the production potential of the stock” include the choice of a time period that represents prevailing environmental conditions. In that regard NPFMC (2007) suggested using the years post-1984 to calculate a retained-catch OFL; that suggestion was based on an assumed 8-year lag between hatching and growth to legal size and a environmental “regime shift” that occurred in 1976/77. The changes in distribution of fishery effort and catch that have occurred during the history of the fishery (see section C.5 and Figure 4) may also be indicative of changes in prevailing environmental conditions over the Adak Area.

Changes in management practices over the history of the fishery (e.g., establishment of GHLs and fishery or area closures; see section C.5) that can constrain or otherwise affect the annual retained catch are also an important consideration here. From the comparison between the retained catch with the GHLs in Figure 3, it would appear that, except for seasons when the fishery was closed and the 2002/03 and 2003/04 seasons, the catch during the 1973/74–1995/96 seasons was generally not constrained by a GHL or upper limit of a GHL range. In that regard, NPFMC (2007) suggested excluding fishery data after 1994 from computation of a retained-catch OFL because, since 1995, “… the fishery was closed, fishing effort was less than 10% of the average, or fishing was allowed in only a small part of the fishing ground.” On the other hand, the SSC in June 2008 recommended including data after the 1994/95 season because “… periods of high and low catches, including periods when the fishery was closed because of conservation concerns [because] [t]hese catches likely reflect fluctuations in stock abundance.”

Data availability is another consideration. Retained catch data for the Adak red king crab fishery is available back to the 1960/61 season, but for the 1960/61–1983/84 seasons the data can only be summarized for the areas west and east of 172º W longitude (recall that the Adak Area as defined here is the Aleutian Islands area west of 171º W longitude; see sections C.5 and D.2). Hence, although average retained catch can be computed with data including that from the 1960/61–1983/84 seasons, the average catch from that period would not include whatever catch occurred between 171º W longitude and 172º W longitude. Data availability also affects the choice of whether a retained-catch OFL or a total-catch OFL is used for this stock because estimates of annual total fishery mortality are available only back to the 1995/96 season (see section D.2).

When considering time periods intended to represent “the production potential of the stock,” an additional fundamental question to resolve is, “Does ‘the production potential of the stock’ mean:

1. ‘the production potential of the stock’ under current environmental conditions, regardless of the actual current condition of the stock itself?

   or

2. ‘the production potential of the stock’ at the current condition of the stock?”

The answer to that question is needed to determine whether the time period chosen is limited only to the more recent past or includes years in the more distant past that may not be representative of the stock’s current condition. The size frequency distribution of retained catch during the most recent fishery seasons (2002/03 and 2003/04; see Figure 6 in Pengilly 2009) and results of the 2006 and 2009 ADF&G pot surveys (Gish 2007, 2010) indicate that recruitment to the stock has been poor during this decade. Hence catch data in the more distant past is likely not representative of the stock's current productivity. However, the basis for the SSC's June 2008 recommendation on the 2008/09 OFL for this stock (i.e., that it was intended to "be a more appropriate proxy for the long-term average production potential") aligns most with the first interpretation of what is meant by "the production potential of the stock."

With regard to considering "the required risk aversion for stock conservation" when determining the OFL, the SSC in June 2008 suggested that, "The OFL should be the most appropriate proxy for MSY, and risk aversion is more appropriately applied when setting harvest levels." Note that that suggestion again aligns most with the first interpretation, above, of what is meant by "the production potential of the stock."

Guidance for considering "utilization goals" has been lacking except for the SSC (June 2008) noting that a larger retained-catch OFL, as opposed to a bycatch-only OFL for this stock, would "… allow continued ADF&G-Industry surveys, which have taken as much as 154,000 lbs."

3. <u>Model Selection and Evaluation</u>:

a. <u>*Description of alternative model configurations:*</u>

Three alternative configurations for computing average retained catch to estimate a retained-catch OFL for 2009/10 were considered and are described in the table below (The "Base" and Alternatives 1–2). Each alternative follows the recommendation of the SSC (June 2008, October 2009) to include years of fishery closures and the CPT (May 2009) to freeze the years considered at 2007/08.

Model	Retained-vs. Total-catch	Time Period (n of years)	Description/Comments
Base	Retained	1984/85–2007/08 (24)	• Determined the 2009/10 OFL • Addresses "lack of rationale for excluding the 1984/85 catch" when determining the 2008/09 OFL (SSC, October 2008) • 1984/85 season is first that Adak Area is defined as west of 171° W longitude • Corresponds roughly with assumed 8-year lag from hatching to legal size and 1976/77 "regime shift" (NPFMC 2007)
Alt. 1	Retained	1977/78–2007/08 (31)	• 1977/78 is first season after 1976/77 closure; longer time period than Base or • 1976/77 season is a "break" between high retained catches of 1960s–early 1970s and lower retained catches beginning in 1977/78. • Retained catch for 1977/78–1983/84

			seasons is for area west of 172º W longitude
Alt. 2	Retained	1960/61–2007/08 (48)	• Longest time period possible • Average catch during 1960/61–1975/76 is 10X greater than for 1977/78–1995/96 • Retained catch for 1960/61–1983/84 seasons is for area west of 172º W longitude

b. ***<u>Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed</u>:***

See the table, below.

Model	Retained-vs. Total-catch	Time Period (n of years)	Resulting OFL (millions of pounds)
Base	Retained	1984/85–2007/08 (24)	0.50
Alt. 1	Retained	1977/78–2007/08 (31)	0.67
Alt. 2	Retained	1960/61–2007/08 (48)	4.30

c. ***<u>Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models</u>:***

All alternatives assume that retained catch is indicative of stock productivity without any regard to harvest restraints (GHLs, TACs, fishery closures, etc) that were imposed by management during the history of the fishery. The reality of that assumption was discussed in section E.2–Model Description.

Alternative 2 is the simplest alternative in that it computes only the mean of the retained catch with minimum assumptions on changes in potential productivity of the stock over the history of the fishery and minimum assumptions on area that the reported catch occurred in. Alternative 2 is judged by the assessment author to be an unrealistic retained-catch OFL given the history of the fishery.

Alternative 1 adds more realism by taking large-scale changes in retained catch during the fishery history as evidence of large-scale changes in stock productivity. A large scale change in retained catch occurred in the history of the fishery, with the fishery closure in 1976/77 marking the demarcation; average annual retained catch during 1960/61–1975/76 was 11.60-million pounds, whereas the average annual retained catch during 1977/78–2007/08 was 0.67-million pounds. Alternative 1 still ignores changes in the boundaries defining the Adak Area that occurred between 1983/84 and 1984/85. Moreover, retained catch data is available only at the level of "west of 172° W longitude" for the period 1977/78–1979/80 and at the level of statistical areas that are difficult to partition geographically for the period 1980/81–1984/85.

The Base makes no assumptions on the area of retained catch by using only retained-catch data reported for the area west of 171° W longitude during 1984/85–2007/08, although the 1984/85 data is retrievable only at the level of statistical areas that are difficult to partition geographically. On the other hand, the Base does not attempt to specifically address the potential effects on productivity of a 1976/77 `regime shift, although the difference in that regard may considered be negligible.

The Base is judged by the author to provide the best retained-catch OFL among alternatives in that it maintains a reasonably long time period (24 years) without ignoring large-scale changes in fishery performance, assumed effects due to a 1976/77 regime, and changes in management boundaries.

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?:***

- Estimates of total retained catch (pounds) during a season are from fish ticket landings recorded at landings and are assumed here to be correct.
- Estimates of bycatch during crab fisheries are based on data obtained by pot lifts sampled by observers. The bycatch estimates (in terms of number of crabs captured per pot lift by sex-size class) have high precision (CVs<10%) and the sampling and estimation generally is accurate to within 6% (Barnard and Burt 2008).
- Estimates of biomass of bycatch use a length-to-weight estimator for red king crabs provided in NPFMC (2007) applied to the size distribution of crabs in pot lifts sampled by observers. The length-to-weight estimator is assumed to be accurate and the size distribution of sampled crabs is assumed to accurately reflect the size distribution of all crabs that occur as bycatch during the crab fisheries.
- The handling mortality rates used to estimate bycatch mortality are those that have been judged as credible for other assessments (Siddeek 2009, Foy and Rugolo 2009).

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. ***<u>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)</u>:*** Not applicable.

c. ***<u>Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible)</u>:*** Infromation requested for this subsection is not applicable to a Tier 5 stock. Alternative retained-catch OFLs are graphed relative to actual retained catch during history of fishery in Figure 9.

d. ***<u>Evaluation of the fit to the data</u>:*** Not applicable for Tier 5 stock.

e. ***<u>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)</u>:*** Not applicable for Tier 5 stock.

f. ***<u>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.)</u>:*** Not applicable for Tier 5 stock.

F. Calculation of the OFL

1. **<u>Specification of the Tier level and stock status level for computing the OFL:</u>**

- Recommended as Tier 5: Retained-catch OFL estimated by average retained catch over a specified period (as recommended by CPT in May 2009; see section B.2).
- Recommended time period for computing retained-catch OFL: 1984/85–2007/08.
  - The time period follows the May 2009 recommendation of the CPT by freezing the end of the time period considered at 2007/08 (see section B.2). The inclusion of 1984/85 in the time period acknowledges the SSC's October 2008 opinion that there was a lack of rationale for not including 1984/85 in the time period used for the 2008/09 OFL (1985/86–2007/08). The time period 1984/85–2007/08 provides the longest time period through 2007/08 during which retained-catch data can be retrieved from the area west of 171° W longitude (as the Adak Area is now defined). This time period excludes the pre-1976/77 period, during which time the average retained catch was 11.60-million pounds – an order of magnitude greater than the annual retained catch in any year following 1976/77. Given the level of precision about the assumed time from hatching to legal size (8 years; NPFMC 2007) and the assumed timing at which a mid-1970s regime shift occurred in the Adak Area (1976/77; NPFMC 2007), this time period also reasonably accommodates the attempt to base the chosen time period on prevailing environmental conditions.

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). According to Amendment 24 of the FMP, itself:

> For Tier 5 stocks, the historical performance of the fishery is used to set OFLs in terms of retained catch. The OFL represents the average retained catch from a time period determined to be representative of the production potential of the stock. The time period selected for computing the average catch, hence the OFL, would be based on the best scientific information available and provide the appropriate risk aversion for stock conservation and utilization goals. In Tier 5, the OFL is specified in terms of an average catch value over 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.
>
> For most Tier 5 stocks, only retained catch information is available so the OFL will be estimated for the retained catch portion only, with the corresponding overfishing comparison on the retained catch only. In the future, as information improves, the OFL calculation could include discard losses, at which point the OFL would be applied to the retained catch plus the discard losses from directed and non-directed fisheries.

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	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a,c]
2006/07	N/A	N/A	Closed	0	0.004	N/A
2007/08	N/A	N/A	Closed	0	0.011	N/A
2008/09	N/A	N/A	Closed	0	0.014	0.46
2009/10	N/A	N/A	Closed	0	TBD	0.50
2010/11	N/A	N/A	TBD			0.50

a. Millions of pounds.
b. Includes handling mortality of discarded bycatch.
c. Retained-catch OFL.

4. Recommendation for F_{OFL}, OFL total catch (or OFL retained catch) for the coming year:

Recommended OFL = 0.50-million pounds, retained-catch.

G. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

H. 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 (October 2008; see section B.2) 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 crabs 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 crabs 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, *pers. comm.*).

Trawl surveys are preferable relative to pot surveys for providing density estimates, but crab pots may be the only practical gear for sampling king crabs 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 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.

I. Ecosystem Considerations

1. Ecosystem Effects on Stock:

a. ***<u>Prey availability/abundance trends (historically and in the present and foreseeable future)</u>:*** Existence and availability of such information is not known to the author.

b. ***<u>Predator population trends (historically and in the present and foreseeable future)</u>:*** Existence and availability of such information is not known to the author.

c. ***<u>Changes in habitat quality (historically and in the present and foreseeable future)</u>:*** Existence and availability of such information is not known to the author.

2. Fishery Effects on the Ecosystem

a. Fishery-specific bycatch of HAPC biota marine mammals and birds, and other sensitive non-target species:

A summary of bycatch during the 2002/03–2003/04 Adak red king crab fisheries are provided in Tables 7 and 8. Note that, due to closure of the fishery, there was no bycatch in the fishery during 2004/05–2009/10.

b. ***<u>Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components</u>:***

Existence and availability of such information is not known to the author. Note that, the fishery – when opened – since the 1990s has been concentrated in the Petrel Bank area, typically at depths of 60–90 fathoms (110–165 m; see section C.2). Due to closure of the fishery, there has been no effect during 2004/05–2008/09.

c. Fishery-specific effects on amount of large size target crab:

The fishery can only retain males ≥ 6.5-inches carapace width. Bycatch of sublegal males has been low relative to catch of legal males in the most recent seasons (see Table 2), presumably due to low availability of sublegal males. Hence the fishery, when prosecuted, would be expected to decrease the amount of large size males. However, without background information on the available biomass of large size males, the magnitude of the effect cannot be estimated. Note that, due to closure of the fishery, there has been no effect during 2004/05–2009/10.

d. ***<u>Fishery-specific contribution to discards</u>:***

Estimated contribution of discards of red king crabs of the Adak red king crab fishery relative to the Aleutian Islands golden king crab fishery during 1995/96–2008/09 is provided in Table 2. See Table 4 for comparison with the estimated bycatch of Adak red king crabs in federal groundfish fisheries during 1992/93–2008/09. Note that, due to closure of the fishery, there has been no contribution from the directed fishery during 2004/05–2009/10.

e. **<u>Fishery-specific effects on age-at-maturity and fecundity of the target species</u>:**

Existence and availability of such information is not known to the author. Note that, due to closure of the fishery, there has been no effect during 2004/05–2009/10.

f. ***Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance):***

Number of pot lifts per season during 1969/70–2009/10 is plotted in Figure 10. Note that the geographic distribution of fishery effort has changed during this time period and that the fishery has been concentrated in the Petrel Bank area since 1990/91 (see section C.5).

J. Literature Cited

Alaska Department of Fish and Game (ADF&G). 1978. Westward Region shellfish report to the Alaska Board of Fisheries, April 1978. Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak.

Barnard, D. R. and R. Burt. 2004. Alaska Department of Fish and Game summary of the 2002 mandatory shellfish observer program database for the general and CDQ crab fisheries. Alaska Department of Fish and Game, Regional Information Report No. 4K04-27, Kodiak.

Barnard, D. R. and R. Burt. 2008. Alaska Department of Fish and Game summary of the 2006/2007 mandatory shellfish observer program database for the rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 08-17, Anchorage.

Blau, S. F. 1990. Size at maturity of female red king crabs (*Paralithodes camtschatica*) in the Adak Management Area, Alaska. Pages 105–116 *in* Proceedings of the International Symposium on King and Tanner Crabs, Anchorage, Alaska, USA, November 28–30, 1989. Alaska Sea Grant College Program Report No. 90-04, Fairbanks.

Blau, S. F. 1993. Overview of the red king crab surveys conducted in the Adak management area (R), Alaska 1969–1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K93-10, Kodiak.

Bowers, F. R., W. Donaldson, and D. Pengilly. 2002. Analysis of the January-February and November 2001 Petrel bank red king crab commissioner's permit surveys. Alaska Department of Fish and game, Division of Commercial Fisheries, Regional Information Report 4K02-11, Kodiak.

Bowers, F. R., K. Herring, E. Russ, J. Shaisnikoff, and H. Barnart. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, 2007/08. Pages 5–75 *in* Bowers, F. R., M. Schwenzfeier, K. Milani, B. Failor-Rounds, K. Milani, M. Salmon, K. Herring, J. Shaishnikoff, E. Russ, R. Burt, and H. Barnhart. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2007/08. Alaska Department of Fish and Game, Fishery Management Report No. 08-73, Anchorage.

Burt, R. and D. R. Barnard. 2005. Alaska Department of Fish and Game summary of the 2003 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 05-05, Anchorage. Alaska Department of Fish and Game, Division of Comercial Fisheries, Fishery Research Bulletin No. 92-02. Juneau.

Donaldson, W. E., and W. K. Donaldson. 1992. A review of the history and justification for size limits in Alaskan king, Tanner, and snow crab fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin No. 20-02, Juneau.

Foy, R. J., and L. Rugolo. 2009. Draft 2009 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions. May 2009. http://www.fakr.noaa.gov/npfmc/membership /plan_teams/CPT/509chapters/PIBKC509.pdf

Granath, K. 2003. Analysis of the November 2002 Adak, Atka, and Amlia Islands red king crab commissioner's permit survey. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K03-33, Kodiak.

Gish, R. K. 2007. The 2006 Petrel Bank red king crab survey. Alaska Department of Fish and Game, Fishery Management Report No. 07-44, Anchorage.

Gish, R. K. 2010. The 2009 Petrel Bank red king crab pot survey: Results for red king crab. Alaska Department of Fish and Game, Regional Information Report No. 4K10-XX, Kodiak.

McMullen, J. 1967. Breeding king crabs *Paralithodes camtschatica* located in ocean environment. J. Fish. Res. Board. Can. 24(12): 2627–2628.

McMullen, J. 1969. Effects of delayed mating in the reproduction of king crab *Paralithodes camtschatica*. J. Fish. Res. Board. Can. 26(10): 2737–2740.

McMullen, J. and H. Yoshihara. 1971. King crab research: Alaska Peninsula-Aleutian Islands Area. *In*: ADF&G. 1971. King crab management report to the Board of Fish and Game, April 1971 meeting. Kodiak.

National Marine Fisheries Service (NMFS). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668, August 2004.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Nyblade, C.F. 1987. Phylum or subphylum Crustacea, class Malacostraca, order Decopoda, Anomura. In: M.F. Strathman (ed), Reproduction and development of marine invertebrates on the northern Pacific Coast. Univ. Wash. Press, Seattle, pp.441-450.

Otto, R. S., R. A. MacIntosh, and P. A. Cummiskey. 1990. Fecundity and other reproductive parameters of female red king crab (*Paralithodes camtschatica*) in Bristol Bay and Norton Sound, Alaska. Pages 65–90 *in* Proceedings of the International Symposium on King and Tanner Crabs, Anchorage, Alaska, USA, November 28–30, 1989. Alaska Sea Grant College Program Report No. 90-04, Fairbanks.

Pengilly, D. 2009. Adak red king crab: September 2009 Crab SAFE Report Chapter. Pages 605–644 *in*: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions (2009 Crab SAFE), September 2009. North Pacific Fishery Management Council, Anchorage, AK.

Powell, G. C., and R. B. Nickerson. 1965. Reproduction of king crabs *Paralithodes camtschatica* (Tilesius). J. Fish. Res. Board Can. 22(1):101–111.

Powell, G. C., D. Pengilly, and S. F. Blau. 2002. mating pairs of red king crabs (*Paralithodes camtschaticus*) in the Kodiak Archipelago, Alaska, 1960–1984. Pages 225–245 *in* Crabs in cold-water regions: Biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks. 876 pp.

Powell, G. C., B. Shafford, and M. Jones. 1973. Reproductive biology of young adult king crabs *Paralithodes camtschaticus* (Tilesius) at Kodiak, Alaska. Proc. Natl. Shellfish. Assoc. 63:77–87.

Seeb, L., and C. Smith. 2005. Red king crab and snow-Tanner crab genetics. Bering Sea Crab Research II, Project 2. Final Comprehensive Performance Report for NOAA Award NA16FN2621. October 2005. ADF&G, Juneau.

Siddeek, M.S.M., L. J. Watson, D. R. Barnard, and R. K. Gish. 2009. Draft Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Stock Assessment Model Development. May 2009. http://www.fakr.noaa.gov/npfmc/membership/plan_teams/CPT/509chapters/GKCModel509.pdf.

Wallace, M. M., C. J. Pertuit, and A. R. Hvatum. 1949. Contribution to the biology of the king crab (*Paralithodes camtschatica* Tilesius). U. S. Fish Wildl. Serv. Fish. Leafl. 340. 55 pp.

Vining, I., S. F. Blau, and D. Pengilly. 2002. Growth of red king crabs from the central Aleutian Islands, Alaska. Pages 39–50 *in* Crabs in cold-water regions: Biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks. 876 pp.

Table 1. Aleutian Islands, Area O, red king crab commercial fishery data, 1960/61–2007/08, 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. 2008); though not included in this table, note that the fishery was closed for the 2008/09–2009/10 seasons.

		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					Average			
		Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1974/75	East of 172° W	87	372	1,812,647	71,821	13,991,190	7.7	25		
	West of 172° W	36	97	532,298	32,620	2,774,963	5.2	16	148.6	NA
	TOTAL		**469**	**2,344,945**	**104,441**	**16,766,153**	**7.1**	**22**		
1975/76	East of 172° W	79	369	2,147,350	86,874	15,906,660	7.4	25		
	West of 172° W	20	25	79,977	8,331	411,583	5.2	10	147.2	NA
	TOTAL		**394**	**2,227,327**	**95,205**	**16,318,243**	**7.3**	**23**		
1976/77	East of 172° W	72	226	1,273,298	65,796	9,367,965 [f]	7.4	19		
	East of 172° W	38	61	86,619	17,298	830,458 [g]	9.6	5	NA	NA
	West of 172° W	FISHERY CLOSED								
	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	FISHERY CLOSED								
	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	FISHERY CLOSED								
	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					FISHERY CLOSED				
	West of 171° W	35	82	156,097	29,095	868,828	5.6	5	152.2	0
1986/87	East of 171° W	FISHERY CLOSED								
	West of 171° W	33	69	126,204	29,189	712,543	5.7	4	NA	800
1987/88	East of 171° W	FISHERY CLOSED								
	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.

Season	Locale	Number of Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Average Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1988/89	East of 171° W	F I S H E R Y C L O S E D								
	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	F I S H E R Y C L O S E D								
	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	F I S H E R Y C L O S E D								
	West of 171° W	7	34	146,903	10,674	828,105	5.6	14	148.1	0
1991/92	East of 171° W	F I S H E R Y C L O S E D								
	West of 171° W	10	35	165,356	16,636	951,278	5.8	10	149.8	0
1992/93	East of 171° W	F I S H E R Y C L O S E D								
	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	F I S H E R Y C L O S E D								
	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	F I S H E R Y C L O S E D								
	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	F I S H E R Y C L O S E D								
	West of 171° W	4	12	6,880	1,986	38,941	5.7	3	153.6	235
1996/97		F I S H E R Y C L O S E D								
1997/98		F I S H E R Y C L O S E D								
1998/99	West of 174° W	3	6	749	102	5,900	7.9	7	NA	0
1999/2000		F I S H E R Y C L O S E D								
2000/01[i]	Petrel Bank[j]	1	3	11,299	496	76,562	6.8	23	161.0	0
2001/02[k]	Petrel Bank[j]	4	5	22,080	564	153,961	7.0	39	159.5	82
2002/03	Petrel Bank[j]	33	35	68,300	3,786	505,642	7.4	18	162.4	1,311
2003/04	Petrel Bank[j]	30	31	59,828	5,774	479,113	8.0	10	167.9	2,617
2004/05 - 2007/08		F I S H E R Y C L O S E D								

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 crabs 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).

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 crabs in the Adak Area during commercial crab fisheries by season for the 1995/96–2008/09 seasons (from Pengilly 2009, updated with estimates for 2008/09 by W. Gaeuman, ADF&G, 28 April 2010).

	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[a]	38,941	0	20,669	27,624	0	2,047	314	50,654
1996/97[b]	0	0	0	0	3,292	2,024	666	5,982
1997/98[b]	0	0	0	0	178	579	179	936
1998/99[b,c]	5,900	-	-	-	747	138	186	-
1999/00[b]	0	0	0	0	161	756	93	1,010
2000/01[b]	76,562	0	771	374	365	274	35	1,819
2001/02[b]	153,961	174	6,574	8,369	19,995	0	364	35,476
2002/03[b]	505,642	1,658	6,027	17,432	21,738	355	512	47,722
2003/04[b]	479,113	631	6,597	7,962	9,425	6,352	6,686	37,653
2004/05[b]	0	0	0	0	2,143	210	0	2,353
2005/06[b]	0	0	0	0	189	0	49	239
2006/07[b]	0	0	0	0	323	117	50	491
2007/08[b]	0	0	0	0	615	1,819	561	2,995
2008/09	0	0	0	0	220	20	97	337
Average	90,009	189	3,126	4,751	4,242	1,049	699	13,436
CV of Mean	52%	70%	54%	51%	47%	43%	66%	42%

a. Non-retained bycatch estimates by D. Pengilly using bycatch number estimates in Boyle et al. 1996, 1997 and size frequency data in ADF&G crab observer database, Kodiak, 12 August 2009.

b. Sources for non-retained bycatch weight estimates for 1996/97–2007/08 are as were listed in Table 5 of the Adak Red King Crab chapter of the 2008 SAFE.

c. Data on non-retained bycatch of red king crabs during the red king crab fishery not available (see Moore et al. 2000).

Table 3. Vessel participation and number of observed vessels in the Adak red king crab fishery since initiation of crab fishery observer program in the 1988/89 season through the 1994/95 season. During 1988/89–1994/95 observers were deployed only on catcher-processor vessels. Since 1995/96 season, observers have been required on all vessels fishing for red king crabs in the Aleutian Islands.

Fishery Season	Vessel Effort	Vessels Observed	Comments
1988/89	73	11	-
1989/90	56	10	-
1990/91	7	2	Data confidential
1991/92	10	3	-
1992/93	12	2	Data confidential
1993/94	11	1	Data confidential
1994/95	20	1	Data confidential

Table 4. Estimated annual weight (pounds) of discarded bycatch of red king crabs (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), 1992/93–2008/09 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office through R. Foy AFSC, Kodiak Laboratory, 7 August 2009).

Season	Fixed Gear	Trawl Gear	Mortality
1992/93	65	42	66
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
Mean	7,444	25,931	24,467
CV of Mean	29%	25%	22%

Table 5. Estimates of total fishery mortality (pounds) for red king crabs in the Adak Area, 1995/96–2008/09, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries.

		Bycatch mortality		
Season	Retained Catch	Crab Fisheries[a]	Groundfish Fisheries[b]	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	48,932
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
Mean, 1995/96–2007/08	96,932	3,000	23,935	123,867
CV of Mean	52%	37%	23%	43%
Mean, 1995/96–2008/09	90,009	2,791	23,198	115,997
CV of Mean	52%	37%	22%	43%

a. Bycatch mortality during crab fisheries was computed by applying an assumed handling mortality rate of 0.2 to the estimates of total bycatch weight in the "Total non-retained" column of Table 2.

b. Bycatch mortality during groundfish fisheries was computed by applying an assumed handling mortality rate of 0.5 to the estimates of bycatch weight in the "Fixed Gear" column of Table 4 and an assumed handling mortality rate of 0.8 to the estimates of bycatch weight in the "Trawl Gear" column of Table 4.

c. 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 during the 1998/99 red king crab fishery by the ratio of bycatch mortality to retained catch during the 1995/96 crab fisheries.

Table 6. Table of coefficients of linear correlation among retained catch (RETCATCH, N=17 yrs), estimated bycatch mortality in crab fisheries (CRABBYMORT, N=13 yrs), estimated bycatch mortality in groundfish fisheries (GFBYMORT, N=17 yrs), and estimated total bycatch mortality (TOTBYMORT, N=13 yrs) for Adak red king crabs during 1992/93–2008/09 (see Tables 1, 4, and 5 for source data).

	RETCATCH	CRABBYMORT	GFBYMORT	TOTBYMORT
RETCATCH	1.000			
CRABBYMORT	0.721	1.000		
GFBYMORT	0.440	0.471	1.000	
TOTBYMORT	0.529	0.609	0.987	1.000

Table 7. Summary of contents of 596 pot lifts sampled by observers during the 2002/03 Adak ("Petrel Bank") red king crab fishery (total fishery pot lifts was 3,786).

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
Anthomastus sp.	5	0	0	0	0
arrowtooth flounder	1	0	0	0	0
Atka mackerel	39	0	0	0	0
basket star	2	0	0	0	0
bivalve unident.	4	0	0	0	0
Brittle star unident.	3	0	0	0	0
Coral unident.	6	0	0	0	0
Cyclohelia sp.	1	0	0	0	0
dusky rockfish	1	0	0	0	0
giant octopus	23	0	0	0	0
golden king crab	0	17	31	4	0
graceful decorator crab	2	0	0	0	0
hair crab	0	19	136	31	0
hairy triton (or Oregon triton)	1	0	0	0	0
hermit crab unident.	22	0	0	0	0
Hind's scallop (or reddish scallop)	125	0	0	0	0
hybrid C. opilio	0	1	0	0	0
hydrocoral unident.	6	0	0	0	0
hydroid unident.	25	0	0	0	0
leech unident.	1	0	0	0	0
mussel unident.	2	0	0	0	0
northern rockfish	1	0	0	0	0
Pacific cod	13	0	0	0	0
Pacific halibut	4	0	0	0	0
Pacific lyre crab	2403	0	0	0	0
Pribilof neptune (or Pribilof whelk)	7	0	0	0	0
Primnoidae Group I	20	0	0	0	0
red king crab	0	1028	364	8337	8303
red-tree coral	1	0	0	0	0
rockfish unident.	1	0	0	0	0
scallop unident.	1479	0	0	0	0
sculpin unident.	107	0	0	0	0
sea anemone unident.	3	0	0	0	0
sea cucumber unident.	3	0	0	0	0
sea urchin unident.	4	0	0	0	0
skate unident.	7	0	0	0	0
snailfish unident.	1	0	0	0	0
snail unident.	4	0	0	0	0
soft coral unident.	7	0	0	0	0
sponge unident.	58	0	0	0	0
starfish unident.	30	0	0	0	0
stony coral unident.	21	0	0	0	0
Stylaster sp.	4	0	0	0	0
Tanner crab	0	162	93	0	0
tunicate unident.	2	0	0	0	0
weathervane scallop	354	0	0	0	0
yellow Irish lord	120	0	0	0	0

Table 8. Summary of contents of 932 pot lifts sampled by observers during the 2003/04 Adak ("Petrel Bank") red king crab fishery (total fishery pot lifts was 5,774).

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
Alaska plaice	1	0	0	0	0
Anthomastus sp.	6	0	0	0	0
arrowtooth flounder	2	0	0	0	0
Atka mackerel	196	0	0	0	0
basket star	8	0	0	0	0
bivalve unident.	41	0	0	0	0
Black coral unident.	2	0	0	0	0
brittle star unident.	557	0	0	0	0
bryozoan unident.	112	0	0	0	0
Calcigorgia sp.	2	0	0	0	0
Caryophyllia sp.	2	0	0	0	0
chiton unident.	2	0	0	0	0
circumboreal toad crab	4	0	0	0	0
Clavularia sp.	6	0	0	0	0
Coral unident.	6	0	0	0	0
Cup coral unident.	12	0	0	0	0
Cyclohelia sp.	35	0	0	0	0
Distichopora sp.	6	0	0	0	0
dusky rockfish	5	0	0	0	0
Errinopora sp.	1	0	0	0	0
flatfish unident.	3	0	0	0	0
giant octopus	20	0	0	0	0
golden king crab	0	126	2	11	2
great sculpin	2	0	0	0	0
hair crab	0	36	257	47	0
hairy triton (or Oregon triton)	5	0	0	0	0
hermit crab unident.	24	0	0	0	0
Hind's scallop (or reddish scallop)	847	0	0	0	0
hybrid C. bairdi	0	0	1	0	0
hydrocoral unident.	148	0	0	0	0
invertebrate unident.	2	0	0	0	0
jellyfish unident.	7	0	0	0	0
Kamchatka coral (or bubblegum coral)	12	0	0	0	0
leech unident.	13	0	0	0	0
lyre whelk	1	0	0	0	0
northern rockfish	4	0	0	0	0
Pacific cod	22	0	0	0	0
Pacific halibut	8	0	0	0	0
Pacific lyre crab	4071	0	0	0	0
Pacific ocean perch	2	0	0	0	0
Pacific oyster	1	0	0	0	0
Primnoidae Group I	11	0	0	0	0
Primnoidae unident.	2	0	0	0	0
prowfish	1	0	0	0	0
red king crab	0	2186	787	9327	9315
rockfish unident.	3	0	0	0	0
rock sole unident.	4	0	0	0	0
scale worm unident.	4	0	0	0	0
scallop unident.	930	0	0	0	0

-Continued-

Table 8. page 2 of 2.

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
sculpin unident.	99	0	0	0	0
sea anemone unident.	10	0	0	0	0
sea cucumber unident.	6	0	0	0	0
sea spider unident.	1	0	0	0	0
sea urchin unident.	8	0	0	0	0
skate unident.	14	0	0	0	0
snailfish unident.	2	0	0	0	0
snail unident.	7	0	0	0	0
soft coral unident.	6	0	0	0	0
spinyhead sculpin	4	0	0	0	0
sponge unident.	351	0	0	0	0
starfish unident.	45	0	0	0	0
Stylaster sp.	124	0	0	0	0
Tanner crab	0	54	64	0	0
tube worm unident.	8	0	0	0	0
tunicate unident.	16	0	0	0	0
walleye pollock	12	0	0	0	0
weathervane scallop	110	0	0	0	0
worm unident.	21	0	0	0	0
yellowfin sole	1	0	0	0	0
yellow Irish lord	326	0	0	0	0

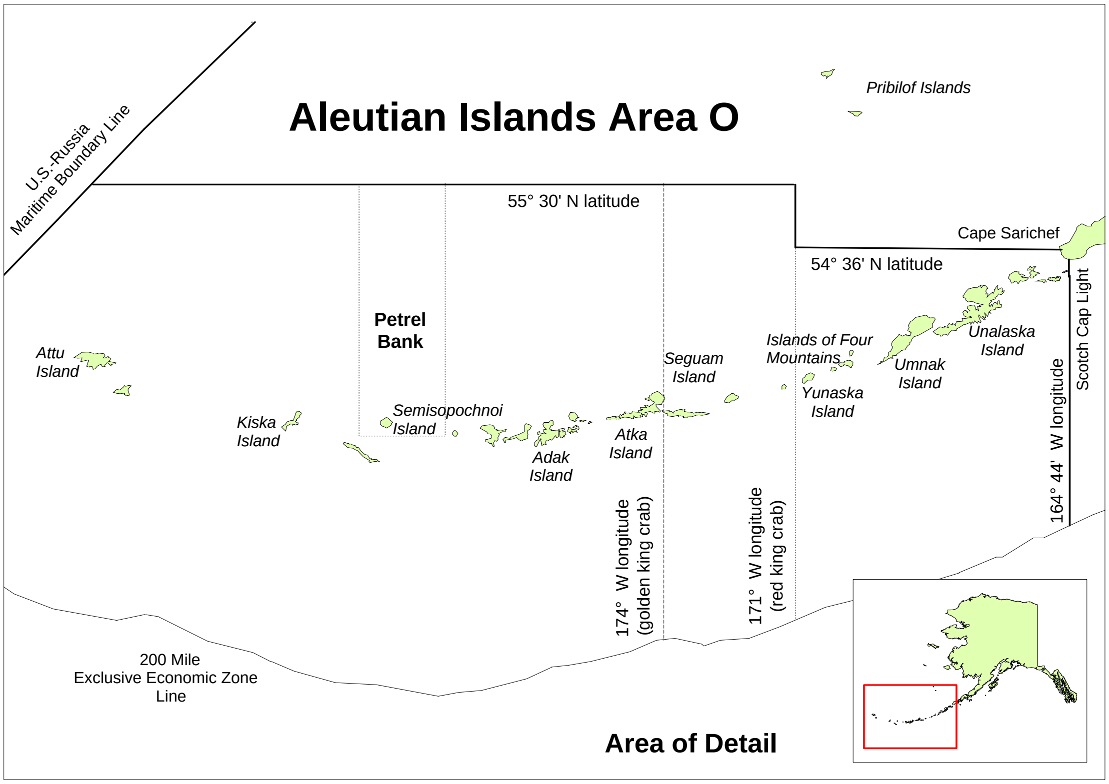


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Bowers et al 2008).

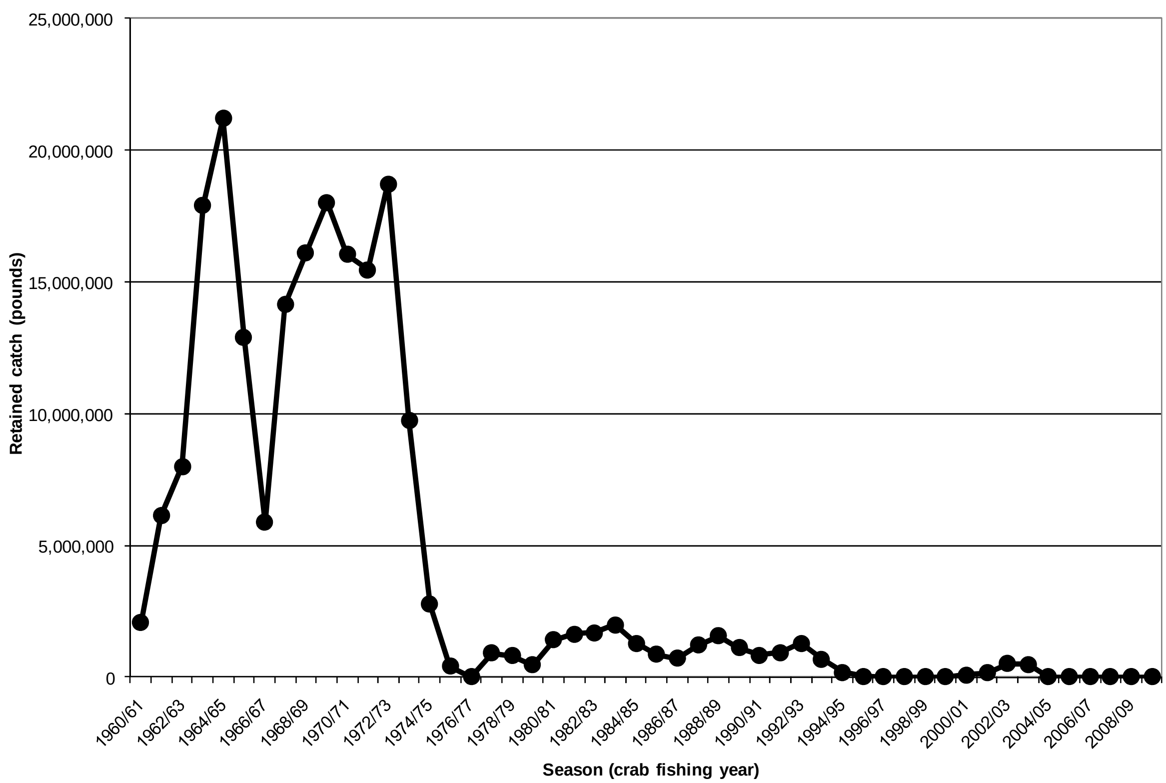


Figure 2. Retained catch in the Adak red king crab fishery, 1960/61–2009/10 (catch is for the area west of 172° W longitude during 1960/61–1983/84 and for the area west of 171° W longitude during 1984/85–2009/10; see Table 1).

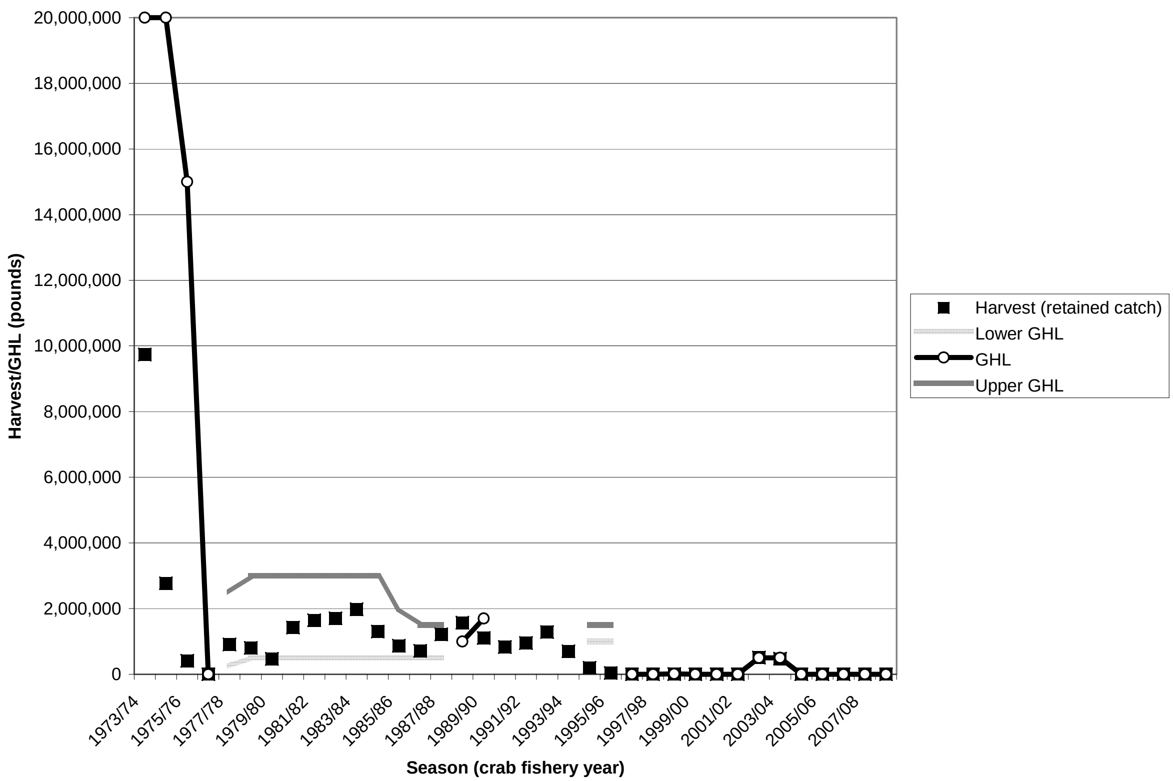


Figure 3. Guideline harvest levels (GHL, pounds) for the 1973/74–2008/09 Adak red king crab fishery seasons, with retained catch (harvest, pounds); the 2009/10 fishery was closed and retained catch was 0 pounds; the retained catch graphed for the 2000/01–2001/02 seasons does not include the catch retained during ADF&G-Industry surveys of the Petrel Bank area; the 1973/74–1975/76 GHL also included incidental catch of golden king crabs (from Tables 1-1 and 1-2 in Bowers et al. 2008).

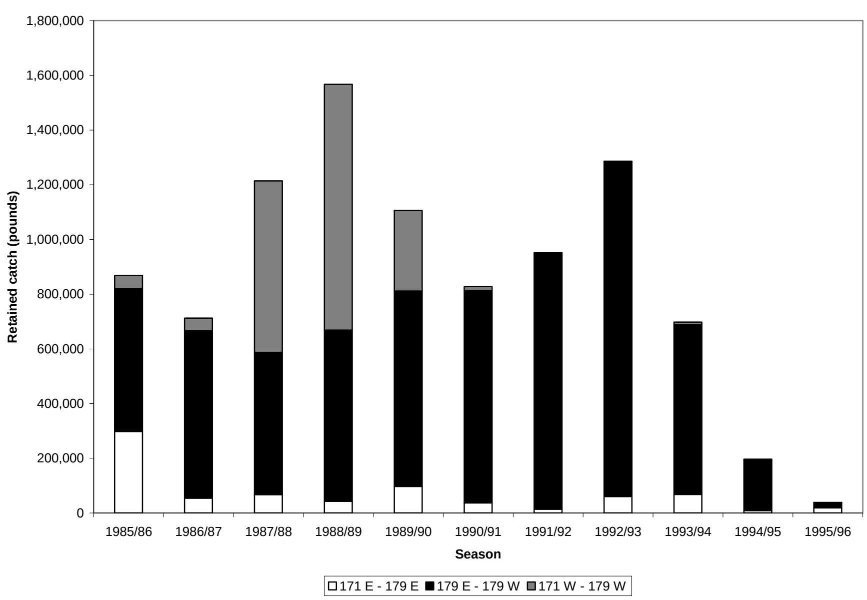


Figure 4. Retained catch (pounds) in the Adak red king crab fishery for the 1984/85–1995/96 seasons, partitioned into three longitudinal zones (171º W longitude to 179º W longitude, 179º W longitude to 179º E longitude, and 179º E longitude to 171º E longitude; from ADF&G fish ticket summary provided by F. Bowers, ADF&G).

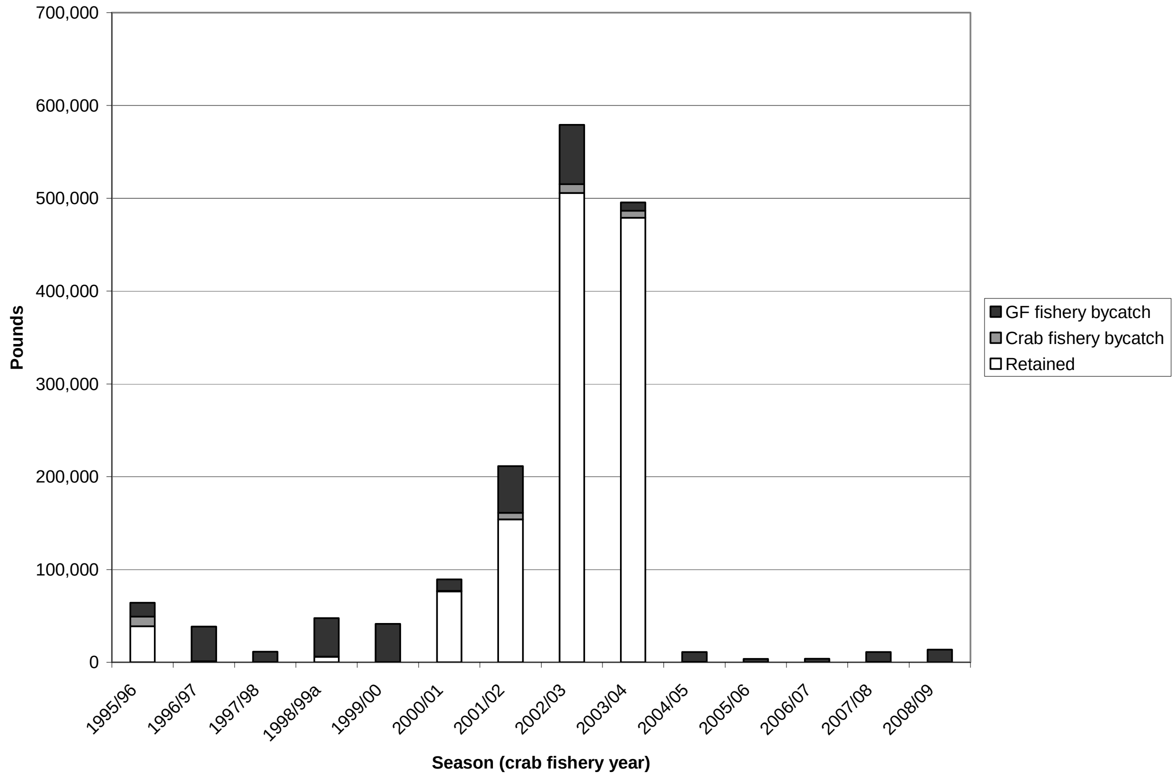


Figure 5. Estimates of total fishery mortality (pounds) for red king crabs in the Adak Area, 1995/96–2008/09, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries (see Table 5).

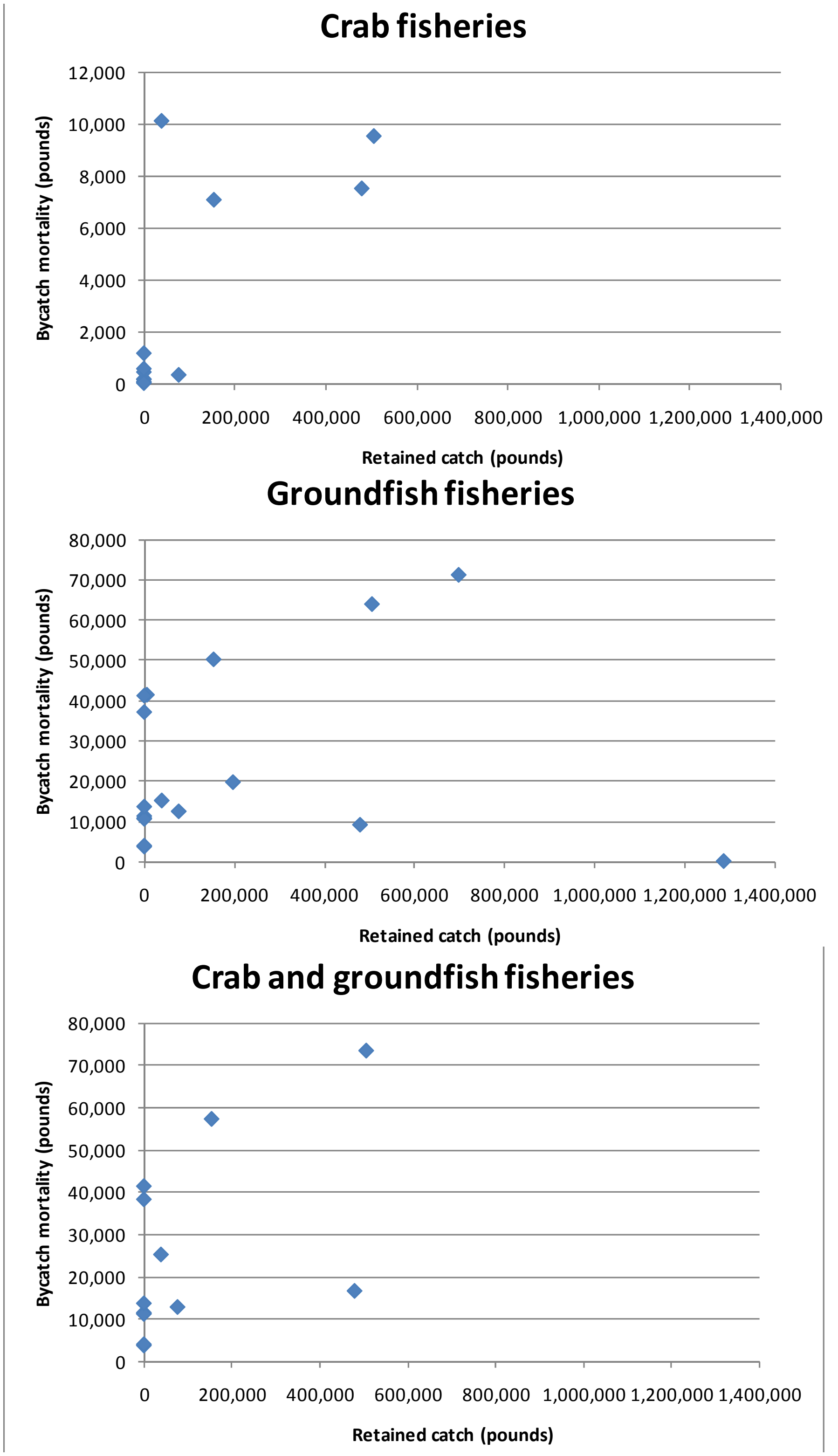


Figure 6. Estimated bycatch mortality of Adak red king crabs in crab fisheries (top panel), groundfish fisheries (middle panel), and crab and groundfish fisheries combined (bottom panel) as a function of the retained catch in the directed Adak red king crab fishery.

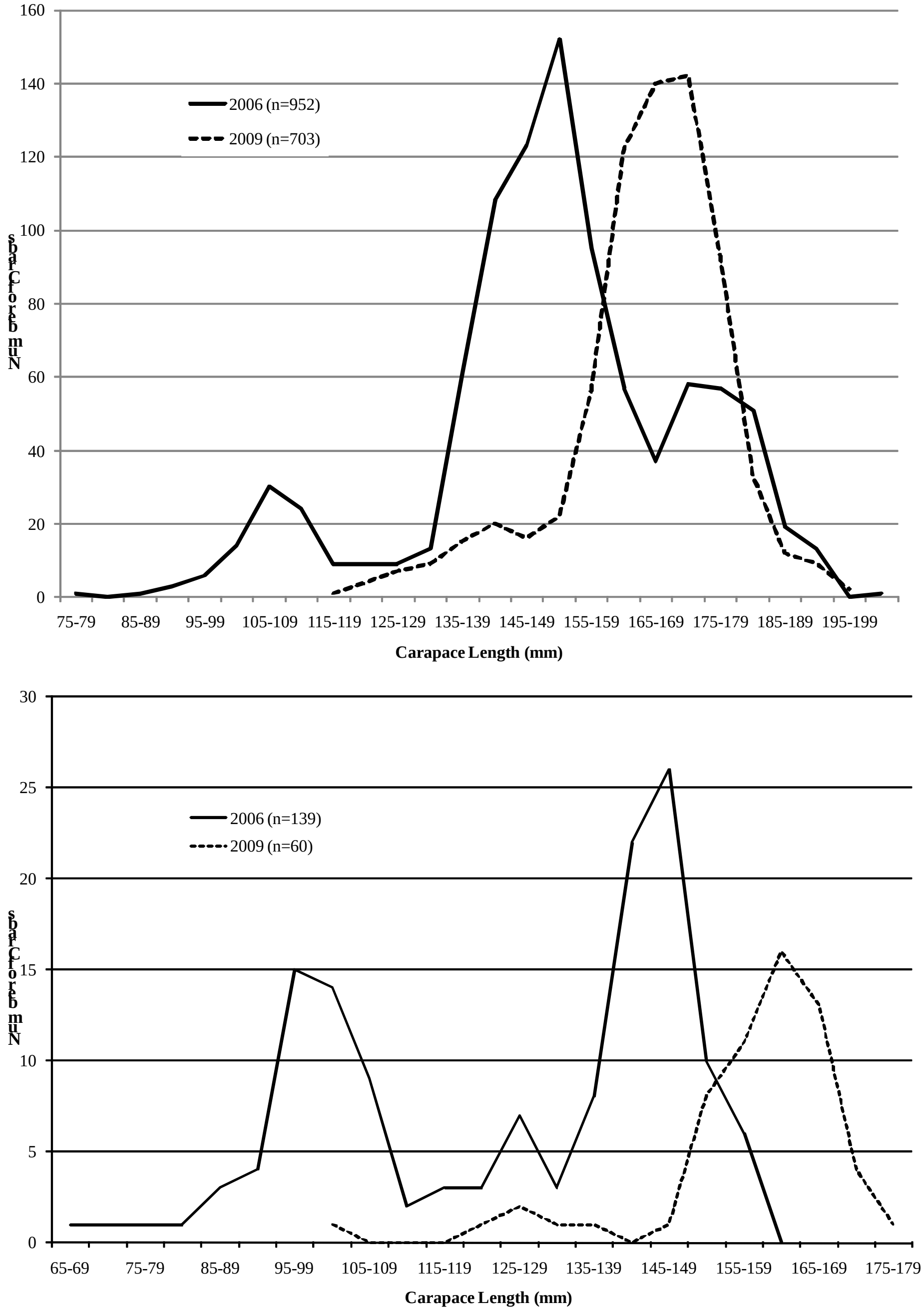


Figure 7. The size-frequency distributions of male (top panel) and female (bottom panel) red king crabs by 5-mm carapace length groups captured during the 2006 and 2009 ADF&G pot surveys for red king crabs in the Petrel Bank area (from Gish 2010).

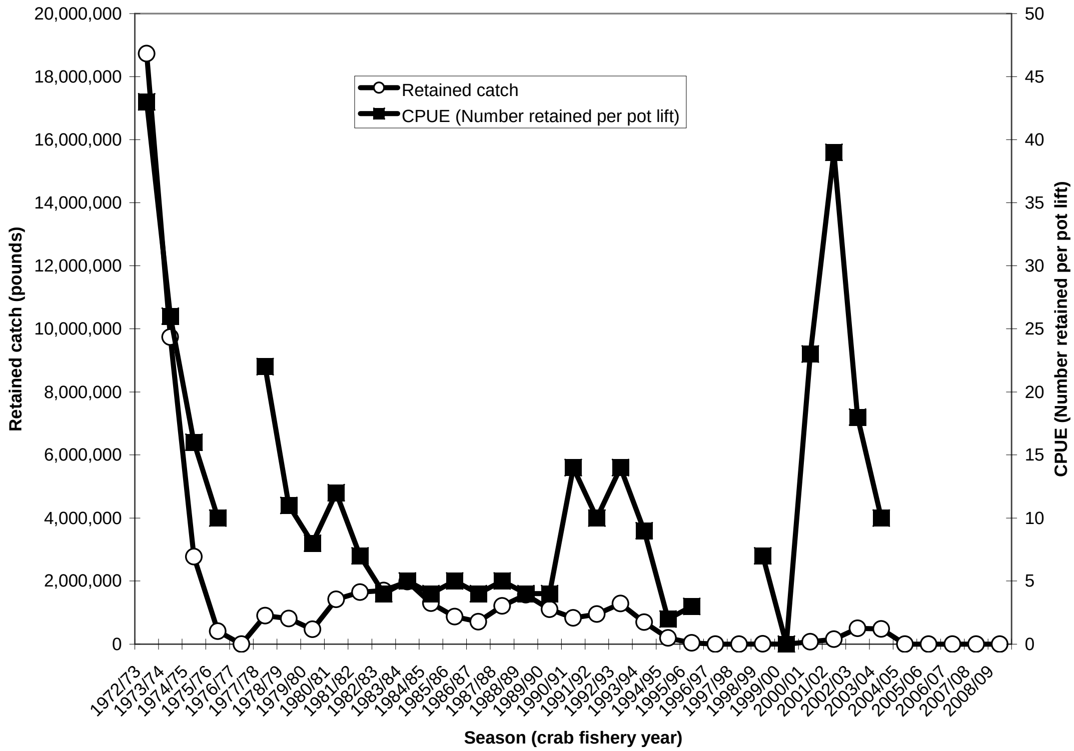
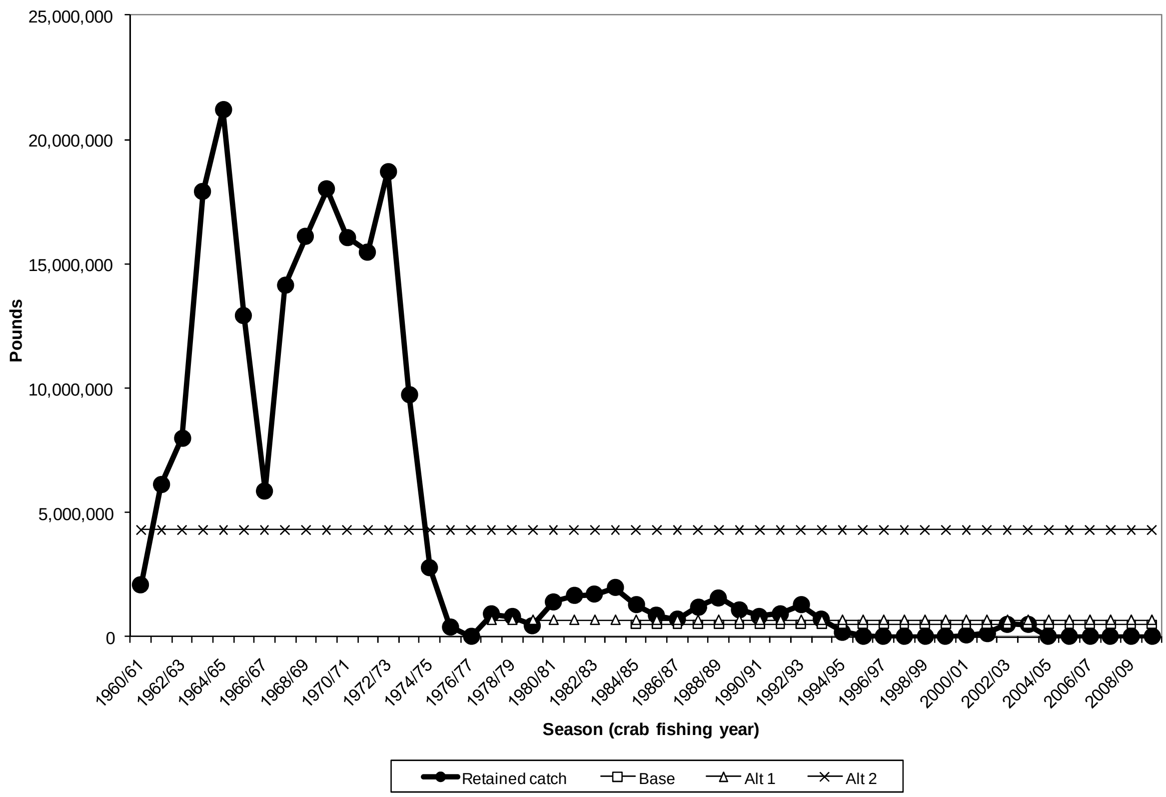


Figure 8. Retained catch (pounds) and CPUE (number of retained crabs per pot lift) of red king crabs during the 1972/73–2008/09 fishery seasons for red king crabs in the Adak Area (see Table 1); data from the closed (0 pounds retained catch) 2009/10 season are not included in the graph. Data for the 1972/73–1983/84 seasons are from the area west of 172º W longitude; data since the 1984/85 season are from the area west of 171º W longitude. Fishing was closed in the Petrel Bank area (i.e., between 179º W longitude and 179º E longitude) for the 1998/99 season, whereas fishing was restricted to the Petrel Bank area during the 2000/01–2003/04 seasons. The 2000/01 and 2001/02 data are from the 2000/01 and 2001/02 ADF&G-Industry surveys of the Petrel Bank area that were performed under provisions of a commissioner's fishery permit.



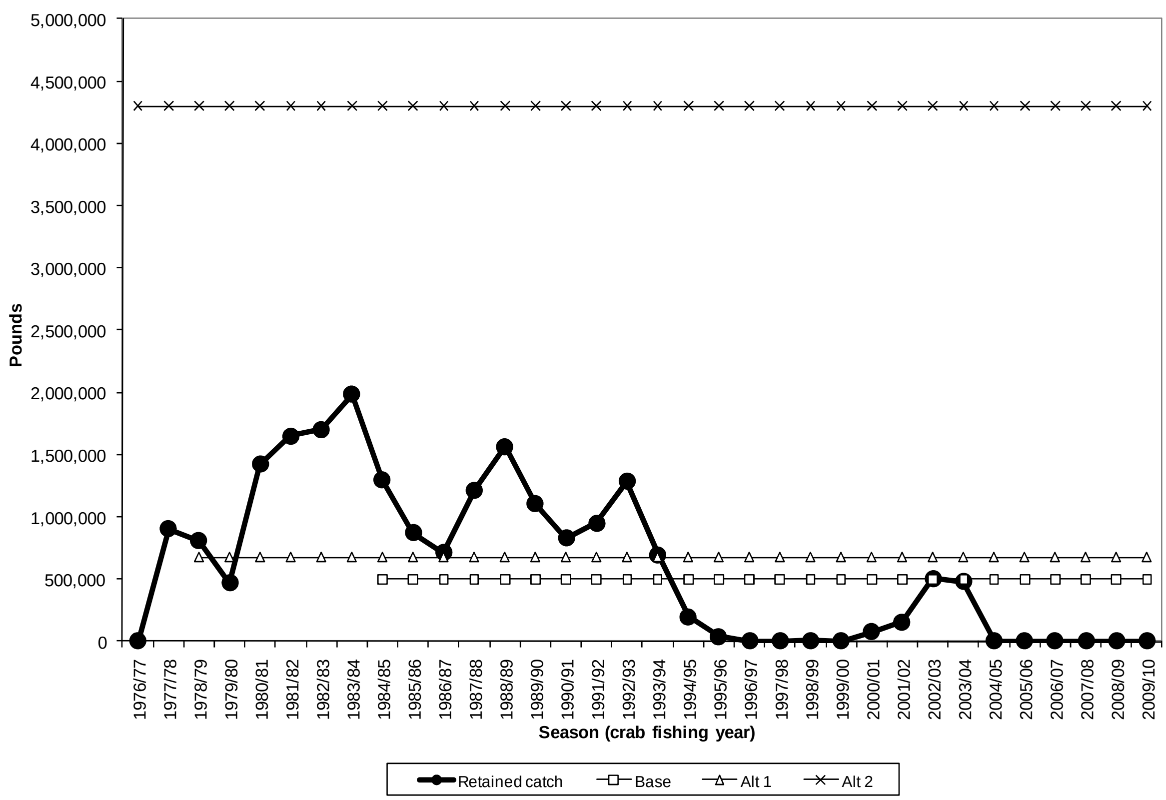


Figure 9. Alternative retained-catch OFLs (Base and Alternatives 1–2) compared with actual historical fishery retained catch for the Adak red king crab fishery, 1960/61–2009/10 in the top panel and 1976/77–2009/10 in the bottom panel (see Table 1 and section E.3.b).

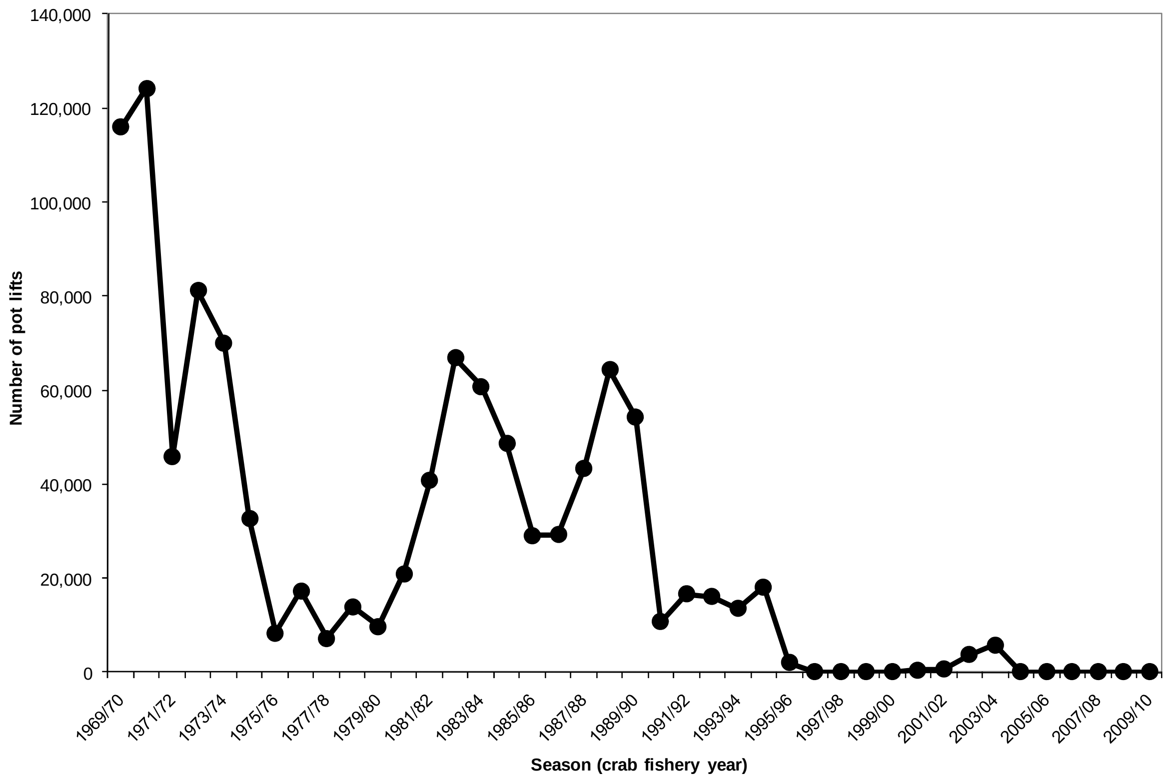


Figure 10. Number of pot lifts performed in the Adak red king crab fishery, 1969/70–2009/10 (see Table 1).