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

2010 Final Crab SAFE

Compiled by

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of the Bering Sea and Aleutian Islands

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Fisheries of the Bering Sea and Aleutian Islands Regions

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Introduction

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

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

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF&G and the National Marine Fisheries Service (NMFS). This SAFE report is presented to the North Pacific Fishery Management Council (NPFMC) and is available to the public on the NPFMC web page at: http://fakr.noaa.gov/npfmc/membership/plan_teams/CRAB_team.htm. Under a process approved in 2008 for revised overfishing level (OFL) determinations, 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 September 13-16, 2010 in Seattle, WA to review the final stock assessments as well as Annual Catch Limits analysis and related issues, in order to provide the recommendations and status determinations contained in this SAFE report. This final 2010 Crab SAFE report builds upon review and recommendations from the draft Crab SAFE report reviewed in May 2010. This SAFE report will be presented to the Council in October for their annual review of the status of BSAI Crab stocks. Members of the team who participated in this review include the following: Forrest Bowers (Chair), Ginny Eckert (Vice-Chair), André Punt, Jack Turnock, Shareef Siddeek, Bill Bechtol, Karla Bush, Bob Foy, Brian Garber-Yonts, Gretchen Harrington, Doug Pengilly, Bob Foy, Lou Rugolo, Wayne Donaldson, Josh Greenberg, and Diana Stram.

Stock Status Definitions

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

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

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

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

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

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

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

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

Status Determination Criteria

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

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.

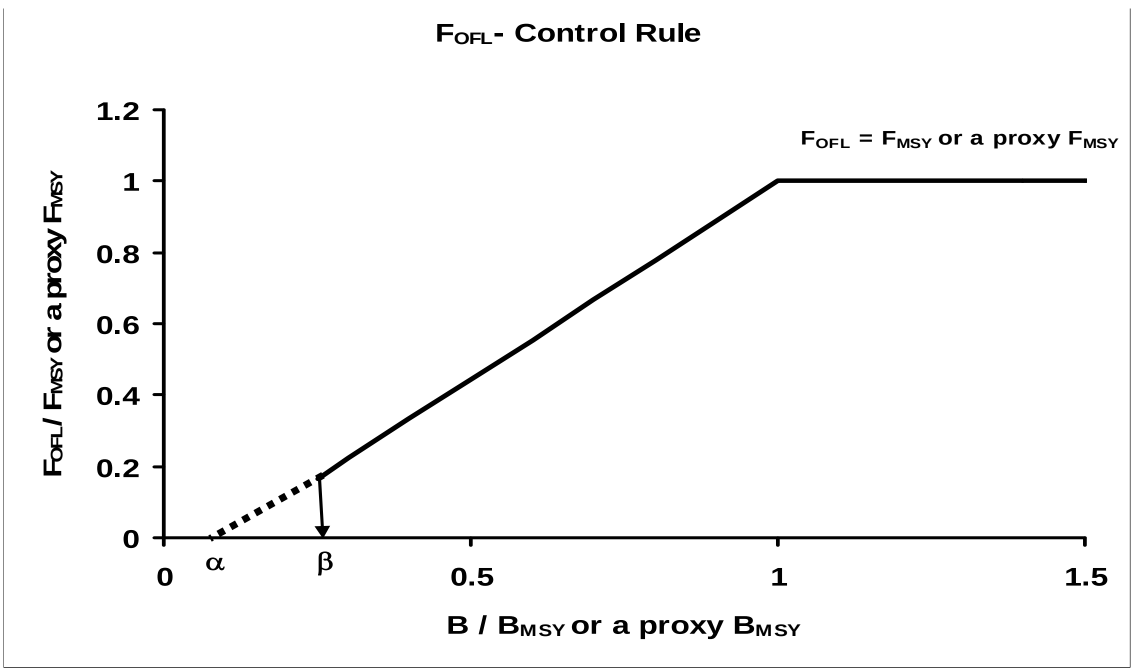

Table 1 Five-Tier System for setting overfishing limits for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.

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

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

† An $F_{OFL} \le F_{MSY}$ will be determined in the development of the rebuilding plan for 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 $0 \leq \beta < 1$.
  - α — a parameter with restriction that $0 \leq \alpha \leq \beta$.
- The maximum value of F_{OFL} is F_{MSY}. $F_{OFL} = F_{MSY}$ when $B > B_{MSY}$.
- F_{OFL} decreases linearly from F_{MSY} to $F_{MSY} \cdot (\beta-\alpha)/(1-\alpha)$ as B decreases from B_{MSY} to $\beta \cdot B_{MSY}$
- When $B \leq \beta \cdot B_{MSY}$, F = 0 for the directed fishery and $F_{OFL} \leq F_{MSY}$ for the non-directed fisheries, which will be determined in the development of the rebuilding plan.
- The parameter, β, determines the threshold level of B at or below which directed fishing is prohibited.
- The parameter, α, determines the value of F_{OFL} when B decreases to $\beta \cdot B_{MSY}$ and the rate at which F_{OFL} decreases with decreasing values of B when $\beta \cdot B_{MSY} < B \leq B_{MSY}$.
  - Larger values of α result in a smaller value of F_{OFL} when B decreases to $\beta \cdot B_{MSY}$.
  - Larger values of α result in F_{OFL} decreasing at a higher rate with decreasing values of B when $\beta \cdot B_{MSY} < B \leq B_{MSY}$.

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, and OFLs. 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 this September report (Table 4). The team has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2011 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 (September 2010 CPT Report).

General recommendations for all assessments

The CPT would like to request SSC input regarding whether we should reconsider whether females should be included in the 'total' catch OFL. 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 s with the breakout estimated at 1.76 t 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 t. 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. Given this concern the assessment authors should list the sources and components of the OFL (similar to the ACL EA, e.g. tables 6-2).

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.

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

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

Ecosystem SAFE overview

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

A summary of the most recent ecosystem trends affecting BSAI crab is summarized below with additional information detailed in the ecosystem consideration indicators chapter.
Recent trends in the 2010 ecosystem indicators (physical & biological trends)

- 2010 was a cold year in the Bering Sea, with extensive winter ice cover, and one of the largest summer cold pool measured since 1999.
- Analysis of ice extent suggests that the northern Bering Sea will remain cold for the foreseeable future. This has important implication for ecosystem and northward spread of species
- A new analysis shows a shift of groundfish survey biomass to the northwest over the last several years. This shift to the northwest has persisted even through recent colder years.
- Very few indicator trends are available for the Aleutian Islands.

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 harvest strategy that aims to allow recovery to the 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 1978-2010 seasons and estimates abundance from 25-29mm to 130-135mm using 5mm size bins. The results of the annual NMFS 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 is based on the same model and estimation framework as the 2009 assessment except that natural mortality and growth are estimated within the model, maturity is a smooth function of size, selectivity and catchability are estimated separately for males and females, the over-weighting of the NMFS survey data has been eliminated, and the “new” survey estimates as well as the BSFRF data in “the study area” for animals of 40mm and larger are used when fitting the model.

Compared with the assessment presented to the CPT in May 2010, the final assessment uses catch and fishery length-frequency data for the 2009/10 season as well as survey abundance and length-frequency data for 2010.

Stock biomass and recruitment trends

Mature male biomass (at the time of mating) peaked between the late-1980s and mid-1990s, declined to a minimum in 2002 and has increased thereafter. The estimates of female mature biomass are higher than during the 2009 assessment, due primarily to the lower estimate of female survey catchability. Recruitment has varied considerably over the period 1979-2010, with the recruitment (at 25mm) in 1986 the highest on record. The recruitment estimates for 2009 and 2010 are the highest since 1992. However, these estimates remain very imprecise.

Tier determination/Plan Team discussion and resulting OFL determination

The CPT recommends that snow crab be in Tier 3 (stock status b), so the OFL is 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 estimate of B_{MSY} from the 2010 assessment is 293.7 million lbs (133.2 thousand t). The MSST is defined as half of the proxy for B_{MSY} (146.8 million lbs/ 66.6 thousand t).

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	146.8	282	48.1	48.1	52.7	73.0
2010/11		225*				97.9

Status and catch specifications (kt) of snow crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07			16.4	16.5	20.4	
2007/08	72.1	98.9	28.6	28.6	35.0	
2008/09	74.1	109.3	26.6	26.5	31.5	35.1
2009/10	66.6	127.7	21.8	21.8	23.9	33.1
2010/11		101.9*				44.4

* Model forecast based on the 2010 assessment under the assumption that the 2010/11 catch equals to the OFL. This value will be updated during the September 2011 assessment when the 2011 survey data and the 2010/11 catch data become available.

The 2009/10 MMB (282 million lbs) exceeds the proxy for MSST (146.8 million lbs) so the stock is not currently overfished. The total catch for 2009/10 (52.7 million lbs) was less than the 2009/10 OFL (73.0 million lbs) so overfishing did not occur during 2009/10. Unlike the 2009 assessment, the 2010 assessment indicates that the MMB did not drop below MSST anytime after 1980.

The CPT notes again that compared to the distribution from surveys, the catch is highly concentrated spatially. This could lead to exploitation rates in the south that exceed the desired rate. In principle, an OFL could be computed for the area in which the fishery operates, for example by applying OFL control rule to the estimated fraction of the population in that area. However, it is not clear how concentrated the stock is at the time of the fishery compared to when the survey takes place.

Rebuilding analysis

Under the current rebuilding plan, this stock had to recover to the B_{MSY} proxy in 2008/09 and 2009/10 to be defined as rebuilt. As the 2008/09 mature male biomass was smaller than B_{MSY}, the stock failed to recover as planned. The estimate of MMB at mating in 2010 was 95.8% of B_{MSY}. The assessment reports the results of projections of MMB relative to the proxy for B_{MSY} for a range of values for the fishing mortality in the directed fishery based on the same methodology that was used in the ACL EA.

Additional Plan Team recommendations

The next assessment should: (a) incorporate the 2010 BSFRF survey data, (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) include the predictions from the May version of the model in the September assessment to evaluate how well the model forecasts biomass, (d) reduce the number of size classes for females, and (e) fit 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), and (e) identify what changes need to be made to the model so that it 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.

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 those seen in the 1970s. The fishery is managed for a total allowable catch (TAC) coupled with restrictions for size (≥ 165.1mm (6.5-in) carapace width), sex (male only), and season (no fishing during mating/molting periods). Prior to 1990, the harvest rate was based on estimated population size and prerecruit and postrecruit abundances, 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-1990s. 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 NMFS 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 September 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. In May 2010, multiple model scenarios were evaluated, including (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. One of these scenarios was selected as the base model for this SAFE, which included constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and included the BSFRF survey data from 2007 and 2008. A variant of this base model was evaluated, which included the CV for the BSFRF data.

Stock biomass and recruitment trends

Model estimates of total survey biomass increased from 176.4 million lbs in 1968 to 720.6 million lbs in 1978, fell to 69.8 million lbs in 1985, generally increased to 198.0 million lbs in 2008, and declined to 180.2 million lbs in 2010. Mature male biomass at mating increased from 61.6 million lbs in 2004 to 89.0 million lbs in 2009 and was 83.1 million lbs in 2010. 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 3a [constant natural mortality ($0.18yr^{-1}$), estimation of additional natural mortality for males during 1980-1984 for females during 1976-1993, BSFRF data].

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 62.7 million lbs. Total catch includes retained male catch and all other bycatch sources.

Status and catch specifications (million 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	89.0	16.0	16.0	18.31	22.56
2010/11		83.1*				23.5

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		NA	7.04	7.14	7.81	
2007/08	20.32	38.96	9.24	9.30	10.54	
2008/09	17.06	39.83	9.24	9.22	10.48	10.98
2009/10	15.56	40.37	7.26	7.26	8.31	10.23
2010/11		37.69*				10.66

*Model forecast based on the 2010 assessment under the assumption that the 2010/11 catch equals to the OFL. This value will be updated during the September 2011 assessment when the 2011 survey data and the 2010/11 catch data become available.

The 2009/2010 MMB exceeds the B_{MSY} proxy of $B_{35\%}$ so the stock is not currently overfished. The total catch for 2009/10 (18.31 million lbs) was less than the 2009/10 OFL (22.56 million lbs) so overfishing did not occur during 2009/10.

Additional Plan Team recommendations

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

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 the EBS Tanner crab because there is no evidence that the EBS Tanner crab is not one stock. Both fisheries were closed from 1997 to 2005 due to low abundance. NMFS declared this stock overfished in 1999 and the Council developed a rebuilding plan. In 2005, abundance increased to a level to support a fishery in the area west of 166^0 W. ADF&G opened both fisheries for the 2006/07 to 2008/09 crab fishing years and to the area east of 166˚ W. longitude only in 2009/10. In 2007, NMFS determined the stock was rebuilt because spawning biomass was above B_{MSY} for two consecutive years.

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

Data and assessment methodology

This stock is surveyed annually by the NMFS EBS trawl survey. Although a stock assessment model has been developed for the eastern portion of the stock, this model is not employed to assess the stock because it does not cover the entire EBS. Area-swept estimates of biomass from the EBS trawl survey are used to estimate biomass of stock components: mature male biomass (MMB), legal male biomass (LMB), and females. The current assessment used NMFS trawl survey data using measured net width (as opposed to assumed fixed-width as in earlier assessments). Fish ticket data are used for computing 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.

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 has risen at a moderate rate from a low of 25.1 million pounds in 1997. Post-1997, MMB at the time of survey increased to 185.2 million pounds in 2007, but has subsequently declined. The survey data continue to show a general overall decline in stock abundance. The MMB projected for February 2011 (26.07 thousand t) is 8% less than MMB in February 2010 (28.44 thousand t). Some moderate sign of recruits in the male and female size frequency at about 25-35 mm CW were shown in the 2010 survey data, but a general decline in abundance of males > 70 mm CW in the 2010 survey raises concerns for near-term future reproductive potential of the stock.

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 no stock assessment model has been developed for the entire EBS stock. Based on the estimated biomass, the stock is at stock status level b. The team recommends that B_{MSY} be 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 equivalently. This equates to a B_{REF} of 83.8 thousand t MMB. The 2009/10 estimate of MMB is 28.44 or 34% of B_{REF}. Hence the stock is estimated to have been in overfished condition. The team recommends that γ=1.0 and M = 0.23yr^{-1}. Under the OFL Control Rule, the 2010/11 F_{OFL}=0.05, equating to a total male and female catch of 1.61 thousand t.

The projected 2010/11 estimate of MMB at the time of mating is 26.07 thousand t, or 31% of B_{REF}.

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 [c]		130.47	2.98	2.12	6.94	
2007/08 [c]		151.59	5.62	2.12	8.00	
2008/09 [c]	94.89	118.23	4.30	1.94	4.96	15.52
2009/10	92.37	62.70	1.34 [a/]	1.32	3.73	5.00
2010/11		57.47 [b/]				3.55

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

Year	MSST	Biomass (MMB)	TAC (east + west)	Retained Catch	Total Catch	OFL
2006/07 [c]		59.18	1.35	0.96	3.15	
2007/08 [c]		68.76	2.55	0.96	3.63	
2008/09 [c]	43.04	53.63	1.95	0.88	2.25	7.04
2009/10	41.90	28.44	0.61 [a/]	0.60	1.69	2.27
2010/11		26.07 [b/]				1.61

a/ Only the area east of 166 deg. W opened in 2009/10; TAC was 1.85 million lbs.
b/ Projected 2009/10 MMB at time of mating after extraction of the estimated total catch OFL.
c/ biomass and threshold values based on fixed net width

In 2009/10, Tanner crab MMB was below the MSST at the time of the 2009 survey, below MSST at the time of the 2009/10 fishery, and below MSST at the time of mating in mid-February 2010. Overfishing did not occur during the 2009/10 fishing year because total catch losses (1.69 thousand t) did not exceed the total catch OFL (2.27 thousand t). The 2009/10 MMB at the time of mating was 38% of B_{REF}. The 2009/10 Tanner crab MMB was estimated to be below MSST. In 2010 at the time of the survey, Tanner crab MMB declined further relative to 2009 and once again was estimated to be below MSST. The stock is projected to remain below MSST in 2011, even if there is zero retained catch in 2010/11

Additional Plan Team recommendations

Alternatives for the time period for computing B_{REF} should be discussed with rationale provided for each alternative period in the May 2011 assessment.

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

ADF&G has not published harvest regulations for the Pribilof Islands red king crab fishery. 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. Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through1998 resulted in poor fishery performance during those seasons with annual harvests below the GHL. The Pribilof red king crab fishery was not open from 1999 to 2008/09 uncertainty with estimated red king crab survey abundance, and concerns for incidental catch and mortality of Pribilof blue king crab(an overfished and very depressed stock). Prior to the closure, the 1998/99 harvest was 0.544 million pounds. The non-retained catches (with application of bycatch mortality rates) from pot and groundfish bycatch estimates of red king crab ranged from 0.009 to 0.424 million pounds during 1991/92 – 2009/10.

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; this year's assessment is again based on trends in MMB at mating time inferred from NMFS annual trawl survey for 1980-2010 and commercial catch and observer data. The revised time-series of historical NMFS trawl survey abundance estimates were used in this assessment. The 2009/2010 assessments of non-retained catch from all groundfish fisheries were 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. An F_{OFL} for 2009/10 was 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 0.18yr^{-1}. As suggested by CPT and SSC, the stock assessment considered the period 1991/92-2009/10 for estimating mean MMB as a proxy $B_{MSY,}$ This F_{OFL} was applied to the projected legal male biomass at the time of the fishery to determine the total (male) catch OFL. Total crab removal (retained, and directed and non-directed bycatch losses) with legal male biomass and MMB were 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 1980-2010. The estimate of MMB from the 2010 survey was 5.44 million pounds. Recruitment is not well understood for Pribilof red king crab. Pre-recruitment indices have remained relatively consistent in the past 10 years, although pre-recruits may not be well assessed with the survey. The point estimates of stock biomass from the survey in recent years has decreased since the 2007 survey with a substantial decrease in all size classes in 2009, but the stock increased in 2010 relative to 2009. The 2010 size frequency for males shows a decrease in the number of old shell and very old shell legal sized males in comparison to 2008 shell conditions, but an increase when compared to 2009. 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 in Tier 4 and γ be set to 1.0.

Historical status and catch specifications (million lbs) 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	14.69[A]	Closed	0	0.015	
2008/09	4.39	11.06[B]	Closed	0	0.021	3.32
2009/10	4.22	4.46[C]	Closed	0	0.006	0.50
2010/11		5.44[D]				0.77

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		6.29	Closed	0	0.01	
2007/08	1.96	6.66[A]	Closed	0	0.007	
2008/09	1.99	5.02[B]	Closed	0	0.01	1.51
2009/10	1.91	2.02[C]	Closed	0	0.003	0.23
2010/11		2.47[D]				0.35

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

Overfishing did not occur during 2009/10. The 2010/11 MMB was 5.44, which was above 2009/10 MSST, but below MMB_{MSY}. Therefore, the stock was assigned to Tier 4b for OFL calculation.

Additional plan team recommendations

1. Because of high variability in abundance, CPT recommended that consideration be given to basing estimates of MMB on moving averages of survey biomass when computing OFLs.
2. The CPT is looking forward to reviewing the new CSA model in 2011 .

5 Pribilof Islands blue king crab

Fishery information relative to OFL setting.

The Pribilof blue king crab fishery began in 1973, with peak landings of 11.0 million lbs during 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 from 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. 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 2010 NMFS bottom-trawl survey, the estimated total mature-male biomass decreased to 0.71 million lbs from 1.28 million lbs in 2009. The 2010/11 MMB at mating is projected to be 0.63 million lbs which is about 7% 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, i.e. excluding the period 1985/1986-1989/1990. This range was chosen because it eliminates periods of extremely low abundance that may not be representative of the production potential of the stock. B_{MSY} is estimated as 9.28 million pounds.

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

The OFL for 2010/11 was set at 0.004 million lbs, the average catch between 1999/00 and 2005/06.
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	1.13	closed	0	0.001	0.004
2010/11		0.63*				0.004

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		0.15	closed	0	0.0002	
2007/08		0.30	closed	0	0.0023	
2008/09	2.10	0.11	closed	0	0.0005	0.0018
2009/10	2.10	0.51	closed	0	0.0005	0.0018
2010/11		0.29*				0.0018

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

The total catch for 2009/10 (0.0013 million lbs) was less than the 2009/10 OFL (0.004 million lbs) so overfishing did not occur during 2009/10. The 2010/11 projected MMB estimate of 0.63 million lbs is below the proxy for MSST so the stock continues to be in an overfished condition.

Additional Plan Team recommendations

A revised rebuilding plan is under development. Initial review of this analysis will occur at the October 2010 Council meeting. .

1. Because of high variability in abundance, CPT recommended that consideration be given to basing estimates of MMB on moving averages of survey biomass when computing OFLs.
2. The CPT is looking forward to reviewing the new CSA model in 2011.

6 St. Matthew blue king crab

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. The fishery developed when 10 U.S. vessels harvested 1.202 million pounds during 1977/78. Harvests peaked in 1983/84 when 9.454-million pounds were landed. The fishery was fairly stable from 1986/87 to 1990/91, with a mean annual harvest of 1.252-million pounds. The mean catch increased to 3.297-million pounds during the period from 1991 to 1998.

This fishery was declared overfished and closed in 1999 when the stock size estimate was below the MSST. In November of 2000, Amendment 15 to the FMP was approved to implement a rebuilding plan for the St. Matthew Island blue king crab stock. The rebuilding plan included a harvest strategy established in regulation by the Alaska Board of Fisheries and an area closure to control bycatch as well as gear modifications. In 2008 and 2009, the MMB was above B_{MSY} for two years and was declared rebuilt in 2009.

The fishery re-opened in 2009/10 with a TAC of 1.167-million pounds and 0.461-million pounds of retained catch were harvested. Commercial crab fisheries near St. Matthew Island were scheduled in the fall and early winter to reduce the potential for bycatch from handling mortalities due to molting and mating crabs. Some bycatch has been observed of non-retained St. Matthew blue king crab in the St. Matthew blue king crab fishery, the eastern Bering Sea snow crab fishery, and groundfish fisheries. Based on limited observer data, bycatch of sublegal male and female crabs from the directed blue king crab fishery off St. Matthew Island was relatively high when the fishery was prosecuted in the 1990s, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs. The recent 2009/10 fishery had lower observed bycatch in the directed fishery than historical estimates.

Data and assessment methodology

A four-stage catch-survey analysis (CSA) is used to assess the male component of the stock. The CSA incorporates the following data: (1) commercial catch data from 1978 to 2009/2010; (2) annual trawl survey data from 1978 to 2010; (3) triennial pot survey data from 1995 to 2007; and (4) bycatch data in the groundfish trawl fishery from 1989 to 2006 and in the groundfish fixed-gear fishery from 1996 to 2008. 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 1978–2010 NMFS annual summer trawl survey for stations within the St. Matthew Section. Trawl survey data provided estimates of density (number/nm^2) at each station for males in four size and shell-condition categories that were used in the assessment: 105–119 mm carapace length (CL); 90–104 mm CL; new-shell 120–133 mm CL; and old-shell ≥120 mm CL and new-shell ≥134 mm CL) males.

Pot survey data are from the July–August 1995, 1998, 2001, 2004 and 2007 ADF&G triennial pot surveys for Saint Matthew Island blue king crab. The pot survey samples areas of important habitat for blue king crab, particularly females, that the NMFS trawl survey cannot sample. Data used are from only the 96 stations fished in common during each of the five surveys. The CPUE (catch per pot lift) indices from those 96 stations for the male sex and shell-condition categories listed above were used in the assessment. ADF&G conducted a pot survey in 2010. However, data from that survey were not available for use when fitting the model.

NMFS observer data was used to estimate groundfish trawl and fixed-gear bycatch. Bycatch composition data were not available so total biomass caught as bycatch was estimated by summing blue king crab biomass from federal reporting areas 524 and 521 according to gear type.

The CSA uses a maximum likelihood approach to estimate male crab biomass and abundance. The model links crab abundance in four crab stages based on a growth matrix, estimated mortalities, and molting probabilities. The four stages are prerecruit-2s (90-104 mm CL), prerecruit-1s (105-119 mm CL), recruits (newshell 120-133 mm CL), and postrecruits (oldshell ≥ 120 mm CL and newshell ≥ 134 mm CL).

Stock biomass and recruitment trends

MMB has fluctuated substantially over three periods. MMB increased during the first period (1978 to 1981) from 7.6 to over 17.6 million lbs, followed by a steady decrease to 2.9 million lbs. in 1985. The second period had a steady increase from the low in 1985 to 13.3 million lbs. in 1997 followed by a rapid decrease to 2.8 million lbs. in 1999. The third period had a steady increase in all size classes from the low in 1999 to the present high of over 12.76 million lbs. in 2009/2010. For 2010/11, the biomass has increased dramatically.

Based on data through 2009/10 and modeled according to the "Scenario 1" assessment model, the stock is estimated to have been above B_{MSY} during 2008/09 and 2009/10 and is projected to be above B_{MSY} in 2010/11. 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 slightly 2009/10 and increased dramatically in 2011/2012.

Like stock biomass, estimated recruitment is generally strong in recent years, with estimated 2010 recruitment to the model markedly higher than that for any other year.

Tier determination/Plan Team discussion and resulting OFL determination

The CPT and SSC recommends that the stock be in Tier 4, with gamma (γ)=1 used for calculating F_{OFL}, and stock status level a. The CPT and SSC concur with the author recommended Scenario 1 model (i.e., same as used for 2009/10, with M fixed at 0.18yr^{-1} for 1978–1998, 2000–2009 and estimated for 1999 and Q fixed at 1.0). The B_{MSYproxy} varies as a function of years used to calculate average MMB. The time period for estimating B_{MSYproxy} is 1989/90 to 2009/10 because the stock was harvested at extremely high rates before 1986 and this time period incorporates stock abundance during rebuilding. The B_{MSYproxy} during this time period is 6.861 million lbs.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		7.1	closed	closed	0.67	
2007/08		9.7	closed	closed	0.35	
2008/09	4.0	10.74	closed	closed	0.20	1.63 [retained]
2009/10	3.4	12.76	1.17	0.46	0.53	1.72 [total male catch]
2010/2011		15.29*				2.29 [total male catch]

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07		3.22	closed	closed	0.3	
2007/08		4.39	closed	closed	0.16	
2008/09	1.81	4.87	closed	0.09	0.09	0.74 [retained]
2009/10	1.52	5.79	0.53	0.20	0.25	0.78 [total male catch]
2010/2011		6.94				1.04 [total male catch]

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

The total catch for 2009/10 (0.55 million lbs) was less than the 2009/10 OFL (1.72 million lbs) so overfishing did not occur during 2009/10. Likewise, the 2009/2010 MMB (12.76 million pounds) is above the MSST (3.4 million lbs.) so the stock is not overfished.

Additional Plan Team recommendations

For the May 2011 assessment the Team recommends that the authors:

- Analyze why some parameters in Table 11 appear not to change from initial values. This is necessary because there is considerable unexpected variation in the time-trajectories of MMB as the end-point of the assessment is changed (see figure 12).
- Calculate $F_{35\%}$ and B35% as proxies for FMSY and BMSY perhaps using the methodology employed in the ACL EA for the May model.
- Add a more detailed description of model changes as an appendix to the May 2011 model.
- Incorporate the 2010 ADF&G pot survey data.

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 B_{MSY} proxy and the CPT chose gamma =1.0 to derive the F_{MSY} proxy.
Estimated B_{MSY} proxy, F_{MSY} proxy and retained catch limit in 2010 are:
B_{MSY} proxy = 3.1173 million lbs,
F_{MSY} 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	0.43	0.71 [B]
2010	1.56	5.44[C]	0.40	0.42		0.73 [C]

Status and catch specifications (kt)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL
2006		1.64	0.20	0.20	0.22	
2007		2.00	0.15	0.14		
2008	0.81	2.38[A]	0.19	0.18		0.31[A]
2009	0.70	2.64[B]	0.17	0.18		0.32[B]
2010	0.71	2.47[C]				0.33[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

Total catch in 2009 was less than the OFL thus overfishing did not occur. 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

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.

Thus, the SSC recommends the following method to calculate a total catch OFL for AIGKC:

$$OFL_{TOT(4)} = (1+RATE_{96/97\text{-}08/09})\bullet OFL_{RET(85/86\text{-}95/96)} + MGF_{96/97\text{-}08/09} = 11.0 \text{ million lbs}$$

where:

$RATE_{96/97\text{-}08/09}$ = mean annual rate = (bycatch mortality in crab fisheries)/(retained catch) over the period 1996/97-2008/09.

$OFL_{RET(85/86\text{-}95/96}$ = mean annual retained catch over the period 1985/86-1995/96, and

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

The SSC recommended that this time period be frozen to stabilize the control rule.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL (retained)
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	5.91		9.18 [retained]
2010/11	NA	NA				11.0 [total catch]

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL (retained)
2006/07	NA	NA	2.59	2.37	2.63	
2007/08	NA	NA	2.59	2.50	2.81	
2008/09	NA	NA	2.72	2.58	2.86	4.16 [retained]
2009/10	NA	NA	2.72			4.16 [retained]
2010/11	NA	NA				11.0 [total catch]

No overfished determination is possible for this stock given the lack of biomass information. Retained catch in 2009/10 was below the retained catch OFL thus overfishing did not occur.

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.

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 SSC recommended 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)	GHL	Retained Catch	Total Catch	OFL
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			0.17 (retained)
2011	NA	NA				0.18

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

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL
2007	NA	NA	0.07	0		
2008	NA	NA	0.07	0	0	
2009	NA	NA	0.07	0	0.0005	0.08 [retained]
2010	NA	NA	0.07	0		0.08 [retained]
2011	NA	NA				0.08

No overfished determination is possible for this stock given the lack of biomass information. Overfishing did not occur in 2009.

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
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			0.12

A-based on 1984/85-07/08 mean retained catch

Status and catch specifications (kt) of Adak RKC.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2006/07	NA	NA	Closed	0	0.002	NA
2007/08	NA	NA	Closed	0	0.005	NA
2008/09	NA	NA	Closed	0	0.01	0.21[A] [retained]
2009/10	NA	NA	Closed	0		0.23[A] [retained]
2010/11	NA	NA	Closed			0.05[B]

A-based on 1984/85-07/08 mean retained catch

No overfished determination is possible for this stock given the lack of biomass information. Retained catch did not exceed the retained catch OFL for this stock thus overfishing did not occur.

Table 3 Crab Plan Team recommendations September 2010 millions lbs.
(Note diagonal fill indicated parameters not applicable for that tier level)

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2011[2] MMB	2011 MMB / MMB_{MSY}	γ	Mortality $(M)yr^{-1}$	2010/11 OFL mill lbs
1	EBS snow crab	3	b	0.91	293.7	1979-current [recruitment]	225	0.76		Male- estimated(0.29) Female – 0.23	97.9
2	BB red king crab	3	a	0.32	62.7	1995-current [recruitment]	83.1	1.33		0.18 default , estimated otherwise[3]	23.5
3	EBS Tanner crab	4	b	0.05	183.6	1969-1980 [survey]	57.48	0.31	1.0	0.23	3.55
4	Pribilof Islands red king crab	4	b	0.11	8.44	1991-current [survey]	5.44	0.64	1.0	0.18	0.77
5	Pribilof Islands blue king crab	4	c	0.0[4]	9.28	1980-1984; 1990-1997 [survey]	0.63	0.07	1.0	0.18	0.004
6	St. Matthew Island blue king crab	4	a	0.18	6.80	1989-current [model estimate]	15.29	2.23	1.0	0.18 (1978-98, 2000-08); 1.8 (1999)	2.29 [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				SSC Formula[5] [total catch]					11.0
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 Additional mortality males: two periods-1980-1985; 1968-1979 and 1986-2008. Females three periods: 1980-1984; 1976-1979; 1985 to 1993 and 1968-1975; 1994-2008. See assessment for mortality rates associated with these time periods.

Table 4. Stock status in relation to status determination criteria 2009/10
(Note diagonal fill indicates parameters not applicable for that tier level)

Chapter	Stock	Tier	MSST	B_{MSY} or $B_{MSYproxy}$	2010[1] MMB	2010 MMB / MMB_{MSY}	2009/10 OFL mill lbs [retained]	2009/10 Total catch
1	EBS snow crab	3	146.8	293.6	281.5	0.96	73.0	52.7
2	BB red king crab	3	34.3	68.5	89.0	1.39	22.6	18.3
3	EBS Tanner crab	4	92.37	189.76	62.7	0.33	5.0	3.73
4	Pribilof Islands red king crab	4	4.39	8.44	4.46	0.53	0.50	0.006
5	Pribilof Islands blue king crab	4	4.64	9.01	1.13	0.24	0.004	0.001
6	St. Matthew Island blue king crab	4	3.48	6.95	12.76	1.83	1.72 [total male catch]	0.53
7	Norton Sound red king crab	4	1.54	3.12	5.83	1.9	0.73 [retained]	0.43
8	AI golden king crab	5					9.18 [retained]	5.9 [retained]
9	Pribilof Island golden king crab	5					0.17 [retained]	0 [retained]
10	Adak red king crab	5					0.12 [retained]	0 [retained]

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

Stock Assessment of eastern Bering Sea snow crab

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September 16, 2010

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 2009/10 fishing year (95.8% of $B_{35\%}$). The total mature survey biomass in 2010 was 302,400 t which is also below (72% of Bmsy) the Bmsy (418,150 t) in place under the rebuilding plan implemented in 2000. Based on this finding, the snow crab stock has not rebuilt within the required 10 year rebuilding time period specified in the FMP. NMFS has notified the Council that the snow crab stock has failed to make adequate progress towards rebuilding.

Observed survey mature male biomass increased from 141,300 t in 2009 to 157,310 t in 2010. Observed survey mature female biomass also increased from 103,800 t in 2009, to 145,099 t in 2010. The 2010 estimate of males greater than 101 mm was 135.0 million, an increase from 125.9 million in 2009. Observed survey numbers of small crab increased in 2010 from 2009, indicating a possibly above average recruitment.

Model estimates of mature male biomass at mating increased from 105,974 in 2007/8 to 122,329 t in 2008/9, to 127,711 t in 2009/10 (95.8% 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 2009/10 fishery was 21,785 t compared to the 2008/9 fishery retained catch of 26,560 t. The total catch in the 2009/10 fishery was estimated at 23,870 t below the OFL of 33,100 t.

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%.

The assessment model used for this assessment is the model recommended by the CPT and the SSC in June 2010 ("Model 5" of the May 2010 assessment). The assessment model estimates natural mortality for male crab in the model (M= 0.29), estimates growth parameters for males and females, and estimates a smooth function for the probability of maturing. The model uses the "new" survey data that has measured net widths to estimate abundance instead of a 50ft fixed net width. The 2009 study area data from BSFRF and NMFS was added to the assessment model as an additional survey for estimation of survey selectivity. Maximum survey selectivity (Q) for the 1989 to present time period was estimated at 0.75.

The OFL for 2010/11 was estimated at 44,400 t, an increase from the 2009/10 OFL of 33,100 t, due to the change in assessment models and a small increase in observed survey biomass in 2010. The retained portion of the 2010/11 OFL is 39,200 t.

The MMB projected for 2010/11 when fishing at the F35% control rule is 101,900 t with an OFL of 44,400 t (Fofl = 0.91). The MMB projected for 2010/11 when fishing at 75% F35% control rule, is 81% of B35%. Projected total catch fishing at 75% F35% control rule is 37,600 t and retained catch 33,300 t. Projected catch fishing at the rebuilding strategy (ADFG strategy) for 2010/11 was 22,200 t of total catch and 19,400 t of retained catch.

Year	Bmsy [a] proxy (1000t)	MSST (1000t)	Biomass (MMB) (1000t)	TAC (1000t)	Retained Catch (1000t)	Total Catch[b] (1000t)	OFL (1000t)
2005/06				16.7	16.8	19.5	NA[c]
2006/07				16.4	16.5	20.4	NA
2007/08	144.1	72.1	98.9	28.6	28.6	35.0	NA
2008/09	148.2	74.1	109.3	26.6	26.5	31.5	35.1
2009/10	133.2	66.6	127.7	21.8	21.8	23.9	33.1
2010/11			101.9 [d]				44.4

[a] Bmsy proxy for 2009/10 based Sept 2010 assessment.
[b] 50% mortality applied to pot discard mortality, 80% mortality applied to groundfish bycatch.
[c] The first year of implementation of the OFL was 2008/09.
[d] projected MMB at mating on February 15, 2011 fishing at the Fofl.

Changes to the Model

Changes to the model 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 female crab and M estimated in the model for male crab, 4) Separate survey selectivities estimated for males and females (SSC recommendation) (Table 12).

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. The 2010 survey biomass and length frequency data were added to the model. Fishery length frequency and catch data for the 2009/10 fishery were added to the model. Groundfish bycatch data for 2009/10 were added to the model.

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 April SSC 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).

May 2010 CPT comments

After much discussion, the bulk of the CPT supported model 5, which became the recommended model.

Authors response to May CPT

Model 5 results were presented to the SSC June meeting and incorporated into the rebuilding and ACL analysis.

June 2010 SSC comments

The SSC concurs with the CPT that Model 5 provides the best overall fit and supports the use of this model for stock status determinations and specifications.

The SSC offers the following comments and suggestions for further model improvements during the next assessment cycle:

- *The SSC agrees with the recommendations of the CPT on page 9 of the SAFE Introduction. Specifically, the consequences of not placing penalties on M should be explored in Model 5 and/or other models. For model runs that constrain M, a clear rationale for the constraint should be provided.*

- *With regard to selectivity, we encourage further exploration of changes to the model that improve the fit to other data components if selectivity is fixed at the Somerton curve or that result in a more realistic selectivity curve if selectivity is estimated.*
- *Catchability (q) for females in model 5 is considerably lower than for males; therefore a discussion about the biological basis that may explain this difference should be included if catchabilities are estimated separately.*
- *The model currently estimates both q and M and it would be useful to include a plot of the bivariate distribution of M against q. This would help clarify the influence of q and M in the model to test the contention that q and M are less confounded in this kind of model than is typically the case in age-structured assessments (as per CPT minutes).*
- *We encourage and look forward to the further development of a spatial model for snow crab that may help resolve issues such as selectivity, poor fits to some length-frequency data, differential fishing mortalities, and the possibility of differential contribution to recruitment of local populations.*
- *The SSC requests some discussion and clarification on the possible influence of using NMFS survey data from within the "study area" (where experimental trawling was done) twice in the analysis: once to fit selectivities for the entire trawl survey area and once to fit selectivities within the "study area".*
- *Improvements in the snow crab model continue to be hampered by a lack of basic biological data on the stock and we encourage continued research on reproductive potential, movement, aging, growth, and other biological parameters.*

Authors Response to June 2010 SSC Comments

The model recommended by the CPT in May 2010 and the SSC in June 2010 is used in the current assessment. Alternative models and other model exploration will be presented at the May 2011 CPT meeting, which will include the 2010 side by side survey data collected by BSFRF and NMFS.

INTRODUCTION

Snow crab (*Chionoecetes opilio*) are distributed on the continental shelf of the Bering Sea, Chukchi Sea, and in the western Atlantic Ocean as far south as Maine. In the Bering Sea, snow crab are common at depths less than about 200 meters. The eastern Bering Sea population within U.S. waters is managed as a single stock; however, the distribution of the population may extend into Russian waters to an unknown degree.

FISHERY HISTORY

Snow crab were harvested in the Bering Sea by the Japanese from the 1960s until 1980 when the Magnuson Act prohibited foreign fishing. Retained catch in the domestic fishery increased in the late 1980's to a high of about 149,110 t in 1991, declined to 29,820 t in 1996, increased to 110,410 t in 1998 then declined to 15,200 t in the 1999/2000 fishery (Table 1, Figure 1). Due to low abundance and a reduced harvest rate, retained catches from 2000/01 to 2006/07 ranged from a low of about 10,860 t to 16,780 t. The retained catch for the 2007/08 fishery increased to 28,600 t and was 26,560 t in 2008/09 due to increasing biomass. The retained catch for the 2009/10 fishery was 21,820 t. The total catch for the 2009/10 fishery was estimated at 23,780 t, which was below the 75% F35% control rule value determined in the September 2009 assessment at 27,180 t (retained catch 22,910 t) and below the 2009/10 OFL of 33,100 t total catch.

Discard from the directed pot fishery was estimated from observer data since 1992 and ranged from 11% to 64% (average 33%) of the retained catch of male crab biomass (Table 1). Female discard catch is very low and not a significant source of mortality. In 1992 trawl discard mortality was about 1,950 t, increased to about 3,550 t in 1995, then declined to about 0900 t to 1,500t until 1999. Trawl bycatch in 2008 and 2009 was 300 t and 680 t respectively. Discard in groundfish fisheries from highest to lowest snow crab bycatch is the yellowfin sole trawl fishery, flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery and the Pacific cod hook and line and pot fisheries.

Size frequency data and catch per pot have been collected by observers on snow crab fishery vessels since 1992. Observer coverage was 10% on catcher vessels larger than 125 ft (since 2001), and 100% coverage on catcher processors (since 1992).

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

Several modifications to pot gear have been introduced to reduce bycatch mortality. In the 1978/79 season, pots used in the snow crab fishery first contained escape panels to prevent ghost fishing. Escape panels consisted of an opening with one-half the perimeter of the tunnel eye laced with untreated cotton twine. The size of the cotton laced panel to prevent ghost fishing was increased in 1991 to at least 18 inches in length. No escape mechanisms for undersized crab were required until the 1997 season when at least one-third of one vertical surface had to contain not less than 5 inches stretched mesh webbing or have no less than four circular rings of no less than 3 3/4 inches inside diameter. In the 2001 season the escapement for undersize crab was increased to at least eight escape rings of no less than 4 inches placed within one mesh measurement from the bottom of the pot, with four escape rings on each side of the two sides of a four-sided pot, or one-half of one side of the pot must have a side panel composed of not less than 5 1/4 inch stretched mesh webbing.

Harvest rates

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

The realized retained catch typically exceeded the GHL historically, resulting in exploitation rates for the retained catch (using survey numbers) ranging from about 60% to 100% for most years (Figure 2). The exploitation fraction is calculated using the abundance for male crab over 101 mm estimated from the survey data reduced by the natural mortality from the time of the survey until the fishery occurs, approximately 7 months later, since the late 1980's. The historical GHL calculation did not include the correction for time lapsed between the survey and the fishery. In 1986 and 1987 the exploitation rate exceeded 1.0 because some crabs are retained that are less than 102 mm, discard mortality of small crabs is also included, and survey catchability may be less than 1.0. The exploitation fraction was derived using the total catch divided by the mature male biomass estimated from the model, ranged from 10% to 60% (Figure 3). The exploitation fraction estimated by dividing the total catch by the model estimate of the crabs over 101 mm ranged from about 15% to 85% (Figure 3). The total exploitation rate on males > 101 mm was 50% to 85% for 1988 to 1994 and 50% to 60% for 1998 and 1999 (year when fishery occurred).

Prior to adoption of Amendment 24, B_{MSY} (921.6 million lbs (418,150 t)) was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (NPFMC 1998). MSST was defined as 50% of the B_{MSY} value (MSST=460 million lbs of total mature biomass (209,074 t)). The harvest strategy since 2000/1 used a retained crab harvest rate on the mature male biomass of 0.10 on levels of total mature biomass greater than ½ MSST (230 million lbs), increasing linearly to 0.225 when biomass is equal to or greater than B_{MSY} (921.6 million lbs) (Zheng et al. 2002). The GHL was actually set as the number of retained crab allowed in the harvest, calculated by dividing the GHL in lbs by the average weight of a male crab > 101 mm. If the GHL in numbers was greater than 58% of the estimated number of new shell crabs greater than 101 mm plus 25% of the old shell crab greater than 101 mm, the GHL is capped at 58%. If natural mortality is 0.2, then this actually results in a realized exploitation rate cap for the retained catch of 66% at the time of the fishery, occurring approximately 7 months after the survey. The fishing mortality rate that results from this harvest strategy depends on the relationship between mature male size numbers and male numbers greater than 101 mm. The maximum full selection fishing mortality rate is close to 1.0 at the maximum harvest rate of 0.225 of mature male biomass.

DATA

Data Sources

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from 1978 to the 2009/10 season were used in this analysis. Observers were placed on directed crab fishery vessels starting in 1990. Size frequency data on the total catch (retained plus discarded) in the directed crab fishery were available from 1992 to 2009/10. Total discarded catch was estimated from observer data from 1992 to 2009/10 (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 2009/10. 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	1978/79-2009/10
Discarded male and female crab pot fishery size frequency	1992/3-2009/10
Trawl fishery bycatch size frequencies by sex	1991-2009
Survey size frequencies by sex and shell condition (“new” survey data)	1978-2010

Retained catch estimates	1978/79-2009/10
Discard catch estimates from snow crab pot fishery	1992/93-2009/10 from observer data
Trawl bycatch estimates	1973-2009/10
Total survey biomass estimates and coefficients of variation ("new" survey data)	1978-2010
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.

The total mature biomass (all sizes of morphometrically mature males and females) estimated from the survey declined to a low of 82,100 t in 1985, increased to a high of 809,600 t in 1991 (includes northern stations after 1989), then declined to 140,900 t in 1999, when the stock was declared overfished (Table 2 and Figure 4). The mature biomass increased in 2000 and 2001, mainly due to a few large catches of mature females. The survey estimate of total mature biomass was 208,000 t in 2008, increasing to 245,000 t in 2009 and 302,400 t in 2010.

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

Survey mature female biomass increased from 103,800t in 2009 to 145,100t in 2010.

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

Survey Size Composition

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

Survey abundance by size for males and females indicate a moderate level of recruitment moving through the stock and resulting in the recent increase in abundance. (Figures 6 through 8). In 2009 small crab (<50mm) increased in abundance relative to 2008. The 2010 length frequency data show high abundance in the 40 to 50 mm range. 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 9). In 2003 and 2004 the ice edge was farther north than past years, allowing some fishing to occur as far north as 60-61^o N. Catch in the 2006/07 fishery was similar to recent years (Figure 10) with most catch south of 58 ^{o} N. and west of the Pribilof Islands between about 171^o W and 173^o W. The pattern of catch was similar to previous years for the 2008/09 fishery however, about 3,580 t of retained catch was taken east and south of the Pribilof Islands at 168 to 167 ^{o} longitude and 55.5 to 56.6 ^{o} latitude which has not occurred in recent years (Figure 11). About 93% of the retained catch came from south of 58.5^o N.

The distribution of males and females in 2009 are shown in Figures 12-18. Males > 77 mm (approximately mature males) are mostly distributed between the Pribilof Islands and St. Matthew Island (Figure 12). 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 14). Small males (<78 mm) and immature females were distributed mainly north of St. Matthew Island (Figures 12 and 15). Mature old shell females with no eggs comprised 8% of old shell mature females, primarily from only one tow (Figure 17). 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 16). 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 18).

Survey data from 2010 estimated a larger abundance of small crab than in 2009 (male and female) mostly in the northern part of the survey area (Figures 19 and 24). Large males (>101mm) were distributed similar to 2009, however, farther south than in previous years (Figure 21). Mature females with less than or equal to half clutch of eggs were mostly in the northern part of the survey area above 58 ^{o} N (Figure 24).

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

Ernst, et al. (2005) found the centroids of survey summer distributions have moved to the north over time (Figures 26 and 27). In the early 1980's the centroids of mature female distribution were near 58.5 ^{o} N, in the 1990's the centroids were about 59.5 ^{o} N. The centroids of old shell male distribution was south of 58 ^{o} N in the early 1980's, moved north in the late 1980's and early 1990's then shifted back to the south in the late 1990's. The distribution of males>101 mm was about at 58 ^{o}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 28, see Somerton et al 2010 for more details). The abundance estimated by the BSFRF survey in the study area was 66.9 million male crab >=100 mm compared to 36.7 million for the NMFS tows (Table 3). The NMFS abundance of females >=50mm (121.5 million) was greater than the BSFRF abundance estimate in the study area (113.6 million) (Table 3).

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

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

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 32).

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 33). 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 33). 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 female crab in the model. Male natural mortality estimated in the model with a prior constraint of mean M=0.23 with a se = 0.054 estimated from using the 95% CI of +-1.7 years on maximum age estimates from dactal wear and tag return analysis in Fonseca, et al. (2008).

Molting probability

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

Male Tanner and snow crabs that do not molt (old shell) may be important in reproduction. Paul et al. (1995) found that old shell mature male Tanner crab out-competed new shell crab of the same size in breeding in a laboratory study. Recently molted males did not breed even with no competition and may not breed until after about 100 days from molting (Paul et al. 1995). Sainte-Marie et al. (2002) states that only old shell males take part in mating for North Atlantic snow crab. If molting precludes males from breeding for a three month period, then males that are new shell at the time of the survey (June to July), would have molted during the preceding spring (March to April), and would not have participated in mating. The fishery targets new shell males, resulting in those animals that molted to maturity and to a size acceptable to the fishery of being removed from the population before the chance to mate. Animals that molt to maturity at a size smaller than what is acceptable to the fishery may be subjected to fishery mortality from being caught and discarded before they have a chance to mate. However, new shell males will be a mixture of crab less than 1 year from terminal molt and 1+ years from terminal molt due to the inaccuracy of shell condition as a measure of shell age.

Crabs in their first few years of life may molt more than once per year, however, the smallest crabs included in the model are probably 3 or 4 years old and would be expected to molt annually. The growth transition matrix was applied to animals that grow, resulting in new shell animals. Those animals that don't grow become old shell animals. Animals that are classified as new shell in the survey are assumed to have molted during the last year. The assumption is that shell condition (new and old) is an accurate measure of whether animals have molted during the previous year. The relationship between shell condition and time from last molt needs to be investigated further. Additional radiometric aging for male and female snow crab shells is being investigated to improve the estimate of radiometric ages from Orensanz (unpub. data).

Mating ratio and reproductive success

Full clutches of unfertilized eggs may be extruded and appear normal to visual examination, and may be retained for several weeks or months by snow crab. Resorbtion of eggs may occur if not all eggs are extruded resulting in less than a full clutch. Female snow crab at the time of the survey may have a full clutch of eggs that are unfertilized, resulting in overestimation of reproductive potential. Male snow crab are sperm conservers, using less than 4% of their sperm at each mating. Females also will mate with more than one male. The amount of stored sperm and clutch fullness varies with sex ratio (Sainte-Marie 2002). If mating with only one male is inadequate to fertilize a full clutch, then females will need to mate with more than one male, necessitating a sex ratio closer to 1:1 in the mature population, than if one male is assumed to be able to adequately fertilize multiple females.

The fraction barren females and clutch fullness observed in the survey increased in the early 1990’s then decreased in the mid- 1990’s then increased again in the late 1990’s (Figures 34 and 35). 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 36 and 37). 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 38). 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'.
$Z^s_{l'}$	Natural and fishing mortality by sex s and length bin l'
PM^s_l	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 and which were released in late May of 1980. Forty-nine tagged crabs were recovered in the Tanner crab fishery in the spring of 1981 of which only 5 had increased in carapace width. It is not known if the tags inhibited molting or resulted in mortality during molting, or the extent of tag retention. One crab was recovered after 15 days in the 1980 fishery, which apparently grew from 108 mm to 123 mm carapace width. One crab was recovered in 1982 after almost 2 years at sea that increased from 97 to 107 mm.

Growth data from 14 male crabs collected in March of 2003 that molted soon after being captured were used to estimate a linear function between premolt and postmolt width (Lou Rugolo unpublished data, Figure 39). 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 40),

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

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. The 2010 assessment model estimates the growth parameters in the model using the observed values as constraints, with standard errors estimated from Canadian growth data.

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),

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

$\alpha_{s,l'}$ 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 ($NMN^s_{t,l}$),

$$NMN_{t,l}^{s} = PM_{l}^{s} \sum_{L=l_1}^{l'} G_{l',l}^{s} \, e^{-Z_{l'}^{s}} N_{t-1,l'}^{s}$$

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

$$NMO_{t,l}^{s} = e^{-Z_{l}^{s,old}} NMO_{t-1,l}^{s} + e^{-Z_{l}^{s,new}} NMN_{t-1,l}^{s}$$

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.

$$B_t = \sum_{L=1}^{lbins} (NMO_{tm,l}^{males} + NMN_{tm,l}^{males}) \, W_l^{males}$$

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 41).

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

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 42).

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

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 9.

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

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

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.

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

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

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

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

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

Growth parameters were estimated in the model using a penalty which assumes a normal distribution,

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

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

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

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

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

There were a total of 280 parameters estimated in the model (Table 8) for the 33 years of data (1978-2010). The 96 fishing mortality parameters (one set for the male catch, one set for the female discard catch, and one set for the trawl fishery bycatch) estimated in the model were constrained so that the estimated catch fit the observed catch closely. There were 33 recruitment parameters estimated in the model, one for the mean recruitment, 32 for each year from 1979 to 2010 (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. One parameter for male natural mortality and 3 growth parameters were also estimated.

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 8). 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 2010, April 2010 and June 2010 Council meetings (Turnock 2010) and also at the March 2010 and May 2010 Crab Plan Team meetings. In this analysis likelihood profiles were examined for different assumptions regarding survey catchability and natural mortality. The model presented in this analysis is the model recommended by the CPT in May 2010 and the SSC in June 2010.

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.

The model in this assessment (September 2010) 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. The model also estimates natural moratlity for male crab and growth parameters for male and female crab. Survey selectivities for the BSFRF and NMFS data in the study area are also estimated separately for males and females. Small crab (<40mm) were removed from 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.

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.

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

The temporal autocorrelation error (ε_t) was estimated as,

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

ρ_R	temporal autocorrelation coefficient for recruitment, set at 0.6.

Recruitment variability and autocorrelation were estimated using recruitment estimates from the stock assessment model. Steepness (h) and R_0 were estimated by setting Bmsy and Fmsy equal to B35% and F35% using a Beverton and Holt spawner recruit curve.

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

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

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

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

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

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

RESULTS

The total mature biomass increased from about 410,700 t in 1978 to the peak biomass of 908,800 t in 1990. Biomass declined sharply after 1997 to about 287,400 t in 2003. Total mature biomass increased to 333,600 t in 2008 then declined to 323,800 t in 2010 (Table 4 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 43). Parameter estimates are listed in Table 8. 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 43, 44, 45 and 46 respectively.

Mature male and female biomass show similar trends (Table 3, Figures 47 and 49). Model estimates of mature male biomass increased from 134,600 t in 2005 to 179,900 t in 2009, and then declined to 170,000 t in 2010. Observed survey mature male biomass increased from 141,300 t in 2009 to 157,300 t in 2010. Model estimates of mature female biomass has an increasing trend from 394,500 t in 2002 to 506,800 t in 2010. Mature female biomass observed from the survey increased from 103,800 t in 2009 to 145,100 t in 2010, due to what appears to be an above average recruitment.

Estimated female mature biomass for the current model (survey Q = 0.75) with "new" survey data and other changes was higher than from the September 2009 assessment (Figure 48). Estimated male biomass is higher compared to the September 2009 assessment due to a lower survey Q. The use of the "new" survey data in the current assessment, which is in general lower than the "old" survey data used in the September 2009 assessment does not result in as high an increase in model estimated male biomass as would be expected from the lower survey Q (Figure 50). The fits to the length frequency data and biomass estimates for the BSFRF and NMFS data within the 2009 study area are shown in Figures 74 and 75.

Fishery selectivities and retention curves were estimated using ascending logistic curves (Figures 41 and 51). Selectivities for trawl bycatch were estimated as ascending logistic curves (Figure 52). Plots of model fits to the survey size frequency data are presented in Figures 53 and 55 by sex for shell conditions combined with residual plots in Figures 54 and 56. A summary of the fit across all years for male and female length frequency data indicates a very good fit overall (Figure 57). 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.

Maximum survey selectivity (Q) for crab for the period 1978 to 1981 was estimated at 1.0 (males) and 0.81 (females), for the period 1982 to 1988 at 0.72 (males) and 0.58 (females) and 0.75 (males) and 0.61 (females) for 1989 to the present (Figures 42 and 73 and Table 8). The September 2009 assessment Q for the 1989 to present period was estimated at the maximum bound of 1.0 for all crab (Turnock 2010). The maximum survey selectivity estimated using the 2009 study area by Somerton (2010) was 0.76 at 140 mm for male crab (Figure 73).

The estimated number of males > 101mm generally follows the observed survey abundance estimates (Figure 58). 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 and 137.6 million in 2010. The estimated 95% confidence interval for the observed survey large males in 2009 was +/-29% of the estimate. Model estimates of large males were 158.0 million crab in 2008, 166.9 million crab in 2009 and 154.6 million crab in 2010.

Two main periods of above average recruitment were estimated by the model, in 1979-1981, 1983 (fertilization year) and in 1987 (Figure 59). Recruits are 25mm to about 40 mm and may be about 4 years from hatching, 5 years from fertilization (Figure 60, although age is approximated). Lower than average recruitments were estimated from 1989 to 1997 and in 2000 to 2004. The 1998-1999 and 2004-2005 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 slightly above average recruitment, however, the last few years recruitments have higher uncertainty. The recruitment from the 2004 year class has entered the mature female biomass and resulted in the increase in biomass in 2010 from 2009. 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 61 through 65. Fits to the trawl fishery bycatch size frequency data are in Figures 66 through 68.

Fishing mortality rates ranged from 0.16 to 2.89 (Figure 69 and Table 4). Fishing mortality rates ranged from 0.72 to 2.89, 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 0.27 to 0.78, with an average of 0.43.
Mature male biomass at mating in 2009/10 estimated from the model was at 95.8% (127,711 t) of B35% (133,200 t) (Figure 71).

Likelihood values for the current model are shown in Table 11.

Harvest Strategy and Projected Catch

Current Rebuilding Harvest Strategy

The harvest strategy described here is the current rebuilding strategy adopted in December 2000 in Amendment 14 and first applied in the 2000/01 fishing season (NPFMC 2000). Harvest strategy simulations are reported by Zheng et al. (2002) based on a model with structure and parameter values different than the model presented here. The harvest strategy by Zheng et al. (2002) was developed for use with survey biomass estimates. Prior to the passage of Amendment 24, Bmsy was defined as the average total mature survey biomass for 1983 to 1997. MSST was defined as ½ Bmsy. The harvest strategy consists of a threshold for opening the fishery (104,508 t (230.4 million lbs) of total mature biomass (TMB), 0.25*Bmsy), a minimum GHL of 6,804 t (15 million lbs) for opening the fishery, and rules for computing the GHL.

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

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

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

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

Retained Catch = E * MMB.

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

Overfishing Control Rule

Amendment 24 to the FMP introduced revised the definitions for overfishing. The information provided in this assessment is sufficient to estimate overfishing based on Tier 3b. The overfishing control rule for tier 3b is based on spawning biomass per recruit reference points (NPFMC 2007) (Figure 76).

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

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

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

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

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

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

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% was estimated at 1.24, higher than in September 2009 (F35%=0.703), due to changes in the model (higher M for male crab, growth estimated and lower survey Q). B35% was estimated at 133,246 t, lower than in September 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 2010 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 2010 mature male biomass projected forward to the time of mating time (Feb. 2011), 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 41).

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. MMB in 2008/09 (97,300 t) was below B35% (149,200 t, estimated from the September 2009 assessment) and the estimated MMB in 2009/10 was 95.8% of the current B35% (133,246 t) (Figure 71).

Projections were run for multipliers on the F35% control rule of 0.75, 0.65, 0.55 and 0.45. The rebuilding strategy implemented in 2000 was also run for comparison. Steepness of the Beverton and Holt spawner recruit curve used in projections was estimated at 0.738 and R_0 at 1.207 billion crab, by equating F35% with Fmsy and B35% with Bmsy. Rebuilding is defined as MMB at mating above B35% for 1 year. When rebuilding occurs then the rebuilding strategy switches to 0.8 F35% as a proxy for the ACL. The rebuilding strategy (ADFG harvest strategy) does not switch when rebuilt.

The changes to the assessment model in this assessment (September 2010) have resulted in higher estimates of biomass, higher estimate of F35% and lower estimate of B35% compared to the September 2009 assessment. The rebuilding strategy implemented in 2000/01 was developed for use with observed survey data and includes reference points based on observed survey data, not based on the current (September 2010) assessment model. If this strategy is applied as it has been in the past several years to the model estimate of survey biomass (which will be lower than model estimated biomass due to Q=0.75), then projected catches will be lower than the 75% F35% control rule catches (Tables 7a-f). The total catch projected for 2010/11 fishing at 75% F35% was 37,600 t compared to the rebuilding strategy total catch of 22,200 t (using survey biomass estimated by the assessment model).

Median biomass values are projected to decline slightly or stay level depending on the rebuilding strategy in the next few years, then increase due partly to the near average recruitments estimated in the last two years (2009 and 2010) that will grow into the mature male biomass. The probability of rebuilding fishing at 75% F35% is above 0.50 in 2014/15 (prob. = 0.85), although the probability of rebuilding is 0.475 in 2013/14. The stock rebuilds one year sooner fishing at 65% F35% (2013/14, prob. = 0.59). The probability of rebuilding is 0.82 in 2013/14 fishing at the 2000/01 rebuilding strategy.

Conservation concerns

- The Bering Sea snow crab stock has failed to rebuild in the required 10 year time period. While MMB was estimated at 95.8% of B35% in 2009/2010, the stock is projected to decline over the next several years.

- The last two years of recruitment estimates are near or slightly above average, however, the most recent estimates of recruitment have high uncertainty.

- 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.

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Table 1. Catch (1,000 t) for the snow crab pot fishery and groundfish trawl bycatch. Retained catch for 1973 to 1981 contain Japanese directed fishing. Observed discarded catch is the total estimate of discards before applying mortality. Discards from 1992 to 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			1.48	0.07	25.23	1978	2.46		
1979-80	34.04			2.57	0.08	36.70	1979	1.98		
1980-81	30.37			5.49	0.07	35.98	1980	1.44	17.9-41.3	
1982	13.32			4.88	0.05	18.26	1981	0.60	7.3-10.0	
1983	11.85			2.76	0.06	14.67	1982	0.24	7.17	
1984	12.17			1.32	0.05	13.52	1983	0.31	22.23	
1985	29.95			2.39	0.05	32.40	1984	0.33	44.46	
1986	44.46			3.35	0.05	47.89	1985	0.29	25.86	
1987	46.24			4.59	0.08	50.90	1986	1.23	25.59	
1988	61.41			11.13	0.11	72.63	1987	0.00	50.23	
1989	67.81			15.63	0.12	83.56	1988	0.44	59.89	
1990	73.42			15.59	0.15	89.15	1989	0.51	63.43	
1991	149.11			28.66	0.16	178.05	1990	0.39	142.92	
1992	143.06	43.65	186.71	31.55	0.18	174.87	1991	1.95	151.09	
1993	104.71	56.65	161.37	27.97	0.35	132.96	1992	1.84	94.01	
1994	67.96	17.66	85.62	9.90	0.24	77.77	1993	1.81	48.00	
1995	34.14	13.36	47.50	6.60	0.18	40.85	1994	3.55	25.27	
1996	29.82	19.10	48.92	9.73	0.07	39.62	1995	1.35	23.00	
1997	54.24	24.68	78.92	10.65	0.22	65.32	1996	0.93	53.09	
1998	110.41	19.05	129.46	11.21	0.05	125.64	1997	1.50	102.50	
1999	88.02	15.50	103.52	8.00	0.05	96.26	1998	1.02	84.48	
2000	15.20	1.72	16.92	1.31	0.04	16.43	1999	0.61	12.93	
2001	11.46	2.06	13.52	1.00	0.04	12.55	2000	0.53	12.39	
2002	14.85	6.27	21.12	1.90	0.04	16.96	2001	0.39	13.97	
2003	12.84	4.51	17.35	1.96	0.04	14.91	2002	0.23	11.62	
2004	10.86	1.90	12.77	1.15	0.04	12.01	2003	0.76	9.44	
2004/2005	11.29	1.69	12.98	0.90	0.04	12.21	2004	0.96	9.48	
2005/2006	16.78	4.52	21.30	1.64	0.04	18.54	2005	0.37	16.74	
2006/2007	16.50	5.90	22.39	2.40	0.04	19.02	2006	0.84	16.42	
2007/2008	28.60	8.42	37.02	4.41	0.05	33.04	2007	0.44	28.58	
2008/2009	26.56	6.86	33.42	3.11	0.05	29.77	2008	0.30	26.59	35.07
2009/2010	21.82	4.09	25.91	1.93	0.04	23.78	2009	0.68	21.80	33.10

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
2010	145.1	157.3	302.4	137.6

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

Year	Biomass (1000t 25mm+)	numbers (million crabs 25mm+)	female mature biomass(1000t)	Male mature biomass(1000t)	Total mature biomass (1000t)	Number of males >101mm (millions)	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	612.9	10,076.6	208.4	202.3	410.7	183.7	*	133.4	5.1	0.35	0.16
1979	648.7	9,985.6	246.7	164.6	411.3	134.9	1,079.7	90.5	6.9	0.83	0.29
1980	694.4	9,822.4	311.3	124.4	435.7	74.9	1,050.8	64.5	8.1	1.93	0.37
1981	729.7	8,986.4	347.3	118.5	465.8	48.6	706.1	79.4	7.0	1.08	0.20
1982	748.5	7,470.8	337.4	174.2	511.7	109.8	260.8	126.2	5.4	0.35	0.11
1983	779.6	8,079.1	303.0	259.0	562.1	234.1	1,147.1	192.8	4.1	0.16	0.07
1984	816.5	9,472.0	280.3	301.9	582.3	296.7	1,609.8	203.2	3.8	0.32	0.14
1985	868.5	11,491.2	283.5	291.9	575.4	282.4	2,100.7	190.9	3.8	0.51	0.20
1986	1,022.7	16,259.4	313.4	262.0	575.4	222.8	3,718.6	164.0	4.1	0.72	0.24
1987	1,109.2	13,518.0	387.2	264.0	651.2	187.2	514.7	156.0	4.3	1.36	0.33
1988	1,289.7	17,539.9	418.0	301.2	719.1	201.0	3,603.8	172.7	4.0	1.52	0.35
1989	1,330.4	13,653.8	462.2	366.8	829.0	258.4	126.5	227.9	3.7	1.12	0.30
1990	1,298.2	11,058.8	456.4	452.4	908.8	369.8	327.4	214.3	3.7	2.10	0.49
1991	1,093.9	9,115.8	412.5	401.1	813.6	309.0	442.0	174.8	3.9	2.89	0.55
1992	1,065.0	16,234.7	354.3	311.3	665.6	217.6	4,751.4	151.8	4.0	2.78	0.52
1993	1,026.0	14,171.9	393.3	265.4	658.6	189.6	933.2	151.7	4.3	1.62	0.35
1994	1,032.0	12,282.2	430.2	227.3	657.5	112.4	719.7	151.8	4.3	1.17	0.22
1995	1,038.5	9,752.6	426.1	253.6	679.7	115.2	156.2	183.2	3.9	0.91	0.19
1996	1,006.7	7,663.4	378.5	360.4	738.9	272.3	87.9	247.8	3.3	0.70	0.22
1997	883.4	6,094.5	317.1	436.3	753.4	424.1	130.9	248.5	3.1	1.02	0.35
1998	670.8	5,917.9	260.3	322.9	583.1	293.0	692.8	177.5	3.4	1.17	0.36
1999	515.1	5,611.1	225.2	202.5	427.7	155.8	582.1	152.7	3.6	0.29	0.10
2000	459.0	4,758.7	206.2	163.6	369.8	119.1	210.3	117.7	3.8	0.30	0.10
2001	417.8	4,057.6	187.2	138.0	325.3	92.0	188.4	99.1	4.0	0.52	0.15
2002	394.5	4,075.3	164.8	130.7	295.5	91.0	473.4	95.7	3.8	0.45	0.14
2003	405.4	5,084.9	148.4	138.9	287.4	115.4	971.8	104.6	3.5	0.28	0.10
2004	436.5	5,928.7	150.0	140.2	290.3	122.2	1,003.0	104.9	3.6	0.27	0.10
2005	453.9	5,277.8	164.6	134.6	299.2	107.6	353.0	94.8	3.8	0.49	0.16
2006	477.0	5,325.6	169.3	136.9	306.1	99.9	633.3	97.0	3.6	0.53	0.17
2007	477.3	4,340.9	167.8	161.3	329.1	128.9	124.8	106.0	3.4	0.78	0.25
2008	453.4	4,050.8	155.0	178.5	333.6	158.0	372.0	122.3	3.1	0.55	0.20
2009	472.6	6,094.3	141.3	179.9	321.2	166.9	1,501.7	127.7	3.0	0.40	0.16
2010	506.8	6,888.4	153.8	170.0	323.8	154.6	1,105.2				

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

Tables 7a-f. Projections using a multiplier on the F35% control rule for 2010/11 to 2019/20 fishery seasons. Median total catch (ABC_{tot} 1000t), median retained catch (C_{dir} 1000 t), Percent mature male biomass at time of mating relative to B35%, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is full selection fishing mortality and exploitation rate is total male catch relative to mature male biomass at the time of the fishery. $B_{35\%}$ = 133,246 t. $F_{35\%}$ = 1.24. All projections have rebuilding strategy (multiplier) in effect until rebuilt, then strategy switches to a 0.8 multiplier.

a) 75% $F_{35\%}$ sigma b = 0.2

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Prob Rebuilding(1 yrs)**	**Full Selection Fishing Mortality**
2010/11	37.6(29,47.1)	33.3(25.6,41.6)	81.1(71.9,90)	0	0.73
2011/12	26.5(16.6,41.5)	22.8(14.1,35.7)	75.7(64.6,86.4)	0	0.64
2012/13	25.8(15.2,39)	20.6(12.2,31)	80.1(67.2,94)	0.008	0.7
2013/14	41.4(24.4,55.7)	32.8(19.7,43.8)	99.4(80.3,124.1)	0.475	0.84
2014/15	59.4(37.7,78.8)	49.6(32.2,65.4)	118.9(90.1,174.7)	0.854	0.88
2015/16	65.7(39.5,121.6)	55.6(34.1,98.3)	127.8(86.2,227.1)	0.888	0.91
2016/17	68.5(29.9,161.6)	57.8(25.6,137.1)	130.3(77.4,285.2)	0.896	0.91
2017/18	67.4(22.9,171.9)	57(19.6,148.2)	130.4(69.1,300.9)	0.915	0.92
2018/19	65(18.6,171.3)	54.6(15.8,148.4)	130.7(63.1,298.5)	0.931	0.9
2019/20	64.9(16.3,171.1)	54.3(13.9,148.2)	133.1(60.4,308.3)	0.941	0.89

b) 65% F35% sigma b = 0.2

Year	**ABC$_{tot}$ (1000t)**	**C$_{dir}$ (1000t)**	**Percent MMB/ $B_{35\%}$**	**Prob Rebuilding(1 yrs)**	**Full Selection Fishing Mortality**
2010/11	34.5(26.5,43.3)	30.5(23.4,38.3)	83.3(73.6,92.6)	0	0.65
2011/12	25.2(15.7,39.9)	21.7(13.3,34.5)	78.4(67.3,89.3)	0.001	0.58
2012/13	24.6(14.4,37.1)	19.8(11.6,29.7)	82.8(69.8,96.9)	0.023	0.63
2013/14	39.1(22.9,51.9)	31.1(18.5,41.3)	103(84.1,128.3)	0.591	0.75
2014/15	55.3(35.6,74.8)	46.3(30.6,62.2)	124.1(95.4,179.6)	0.912	0.77
2015/16	74.3(38.9,146.4)	63.2(33.7,119.6)	127(89.3,221.8)	0.937	1.01
2016/17	79.8(31.6,180.7)	67.3(27.2,150.3)	123.5(77.4,264.8)	0.941	1.11
2017/18	73.4(23.9,186.7)	60.8(20.3,160.1)	121.4(68.1,273.2)	0.95	1.11
2018/19	68.7(18.5,181.6)	57.1(15.8,155.2)	120.8(61.5,273.5)	0.962	1.08
2019/20	67.6(16.8,185.8)	56.3(14.3,154.2)	121.7(57.8,283)	0.967	1.08

c) 55% F35% sigma b = 0.2

Year	**ABC$_{tot}$ (1000t)**	**C$_{dir}$ (1000t)**	**Percent MMB/ $B_{35\%}$**	**Prob Rebuilding(1 yrs)**	**Full Selection Fishing Mortality**
2010/11	31(23.7,39)	27.3(20.8,34.5)	85.6(75.6,95.5)	0.011	0.57
2011/12	23.6(14.6,37)	20.4(12.4,32)	81.4(70.2,92.7)	0.012	0.51
2012/13	23.3(13.5,34.5)	18.9(10.9,27.8)	86.1(72.8,100.3)	0.058	0.56
2013/14	35.9(21.2,47.3)	29(17.2,38)	107.2(88.5,133.2)	0.72	0.65
2014/15	50.7(33.5,75.7)	42.7(28.8,62)	130.2(101.3,183.2)	0.961	0.66
2015/16	82.3(39.2,151.3)	70.6(33.8,123.6)	129.3(92.1,222.5)	0.973	1.03
2016/17	81.3(33.6,182.1)	68.4(29.2,152)	124(77,266.6)	0.975	1.12
2017/18	73.4(24.4,187.5)	61.1(21,160.6)	121.6(67.6,274.3)	0.98	1.11
2018/19	68.6(19.1,181.9)	56.9(15.8,155.4)	120.6(61.6,274.6)	0.984	1.09
2019/20	68.7(16.8,186.5)	56.8(14.3,154.3)	121.8(57.3,285)	0.985	1.09

d) 45% F35% sigma b = 0.2

Year	ABC_{tot} (1000t)	C_{dir} (1000t)	Percent MMB/ $B_{35\%}$	Prob Rebuilding(1 yrs)	Full Selection Fishing Mortality
2010/11	27.1(20.6,34.3)	23.8(18.1,30.2)	88.3(77.7,98.7)	0.029	0.48
2011/12	21.7(13.2,33)	18.8(11.2,28.8)	85.1(73.5,96.8)	0.034	0.44
2012/13	21.7(12.4,31.5)	17.7(10,25.8)	90(76.9,103.5)	0.134	0.48
2013/14	32.1(19.3,43.2)	26.2(15.6,34.9)	112.2(93.5,137.3)	0.852	0.54
2014/15	45.5(31,95.9)	38.6(26.4,79.5)	136.1(107.6,190.1)	0.989	0.56
2015/16	88.8(39,155.9)	76.4(34,126.9)	129.7(93.4,225.5)	0.99	1.11
2016/17	81.4(36,183.7)	68.6(31.4,153)	123.6(76.4,266.6)	0.992	1.14
2017/18	73.4(25.3,187.8)	61.4(21.5,161.1)	122.2(67.1,275.3)	0.993	1.12
2018/19	69.2(19.3,182.2)	57.7(16.4,155.4)	121.1(60.2,275.4)	0.993	1.1
2019/20	69.2(17.1,187.3)	57(14.3,155)	122.4(57.2,287)	0.993	1.1

e) Rebuilding strategy (ADFG harvest strategy) using model estimate of survey biomass, sigma b = 0.2

Year	ABC_{tot} (1000t)	C_{dir} (1000t)	Percent MMB/ $B_{35\%}$	Prob Rebuilding(1 yrs)	Full Selection Fishing Mortality
2010/11	22.2(17.5,27.6)	19.4(15.2,24.2)	91.7(79.9,103.4)	0.126	0.38
2011/12	21.5(12.9,37.2)	18.7(11,32.5)	87.6(74.4,100.3)	0.135	0.42
2012/13	24.8(14.2,35.1)	20.4(11.5,29.1)	90.3(77,103.8)	0.182	0.54
2013/14	34.1(18.8,59.3)	27.7(15.1,47.7)	109.9(92.2,132.3)	0.821	0.58
2014/15	47.2(23.6,87.4)	40(19.8,72.2)	134.5(107.8,178.9)	0.993	0.6
2015/16	53(25,128.7)	46.2(21.4,103.8)	147.4(111.9,225.9)	0.996	0.61
2016/17	56.7(21.8,164.4)	49.1(18.6,139.1)	153.1(102.6,287)	0.998	0.63
2017/18	58(19.8,169.8)	49.7(17.1,145.9)	156.4(92.9,308)	0.998	0.62
2018/19	56.2(16.5,163.7)	47.6(14.1,140.4)	156.5(84.4,316.4)	0.998	0.6
2019/20	55.2(15.4,166.4)	46.9(13.2,142.1)	159.8(80.1,329.1)	0.998	0.61

f) No catch, sigma b = 0.2

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Prob Rebuilding(1 yrs)**	**Full Selection Fishing Mortality**
2010/11	0(0,0)	0(0,0)	106.9(91.8,122.2)	0.778	0
2011/12	0(0,0)	0(0,0)	115.5(99.2,132.1)	0.944	0
2012/13	0(0,0)	0(0,0)	128.2(110.3,146.8)	0.996	0
2013/14	0(0,0)	0(0,0)	162.8(139.6,192.5)	1	0
2014/15	0(0,0)	0(0,0)	209.8(176.8,273.5)	1	0
2015/16	0(0,0)	0(0,0)	245.9(189.9,380.8)	1	0
2016/17	0(0,0)	0(0,0)	272.8(183.6,511.1)	1	0
2017/18	0(0,0)	0(0,0)	292.2(173,617.7)	1	0
2018/19	0(0,0)	0(0,0)	304.9(163.2,670.1)	1	0
2019/20	0(0,0)	0(0,0)	323.5(155.6,703.1)	1	0

Table 8. Parameters values (excluding recruitments, probability of maturing and fishing mortality parameters).

Parameter	Value	S.D. for estimated parameters	Estimated(Y/N)
Natural Mortality immature and mature females	0.23		N
Natural Mortality immature and mature males	0.29	0.0080	Y
Female intercept (a) growth	8.015	0.2538	Y
Male intercept(a) growth	8.015	0.2538	Y
Female slope(b) growth	1.01	0.0072	Y
Male slope (b) growth	1.12	0.0046	Y
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	0.158	0.0040	Y
Fishery selectivity total males length at 50%	106.27		Y
Fishery selectivity retention curve males slope	0.33	0.0121	Y
Fishery selectivity retention curve males length at 50%	96.18	0.1578	Y
Pot Fishery discard selectivity female slope	0.219	0.0083	Y
Pot Fishery discard selectivity female length at 50%	85.89	1.2982	Y
Trawl Fishery selectivity slope	0.077	0.0030	Y
Trawl Fishery selectivity length at 50%	117.9	4.7341	Y
Survey Q 1978-1981 male (female)	1.0 (0.81)	0.00	Y
Survey 1978-1981 length at 95% of Q	63.6	3.14	Y
Survey 1978-1981 length at 50% of Q	42.3	1.52	Y
Survey Q 1982-1988 male (female)	0.72 (0.58)	0.05	Y
Survey 1982-1988 length at 95% of Q	68.9	4.44	Y
Survey 1982-1988 length at 50% of Q	41.9	1.66	Y
Survey Q 1989-present	0.75	0.04	Y
Survey 1989-present, length at 95% of Q	52.4	2.65	Y
Survey 1989-present length at 50% of Q	35.1	0.96	Y
Female Survey Q 1989-present	0.61	0.0287	Y
Female Survey 1989-present, length at 95% of Q	51.28	3.2760	Y
Female Survey 1989-present length at 50% of Q	33.04	1.1453	Y
Male BSFRF Study area Q (availability)	0.35	0.08	Y
Male BSFRF Study area length at 95% of Q	75.51	4.99	Y
Male BSFRF Study are length at 50% of Q	64.05	2.46	Y

Table 8 cont.. Parameters values for the base model (Model 1), excluding recruitments, probability of maturing and fishing mortality parameters.

Male NMFS Study area Q	0.26	0.0594	Y
Male NMFS Study area length at 95% of Q	100.0	0.0019	Y
Male NMFS Study are length at 50% of Q	77.74	1.47	Y
Female BSFRF Study area Q (availability)	0.17	0.0632	Y
Female BSFRF Study area length at 95% of Q	68.23	5.56	Y
Female BSFRF Study are length at 50% of Q	57.36	3.14	Y
NMFS Study area female Q	0.15	0.0329	Y
Female NMFS Study area length at 95% of Q	58.76	2.71	Y
Female NMFS Study are length at 50% of Q	51.68	1.34	Y
Fishery cpue q	0.0009	0.0008	Y

Table 9. 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 10. Model estimated recruitments (male) and mature male biomass at survey time with standard deviations. Recruits enter the population at the beginning of the year.

Survey year	Recruit (male,millions)	S.D.	MMB at survey (1000 tons)	S.D.
1978			133.4	8.8
1979	1079.7	221.2	90.5	6.0
1980	1050.8	219.5	64.5	4.7
1981	706.1	179.6	79.4	5.6
1982	260.8	115.5	126.2	9.0
1983	1147.0	195.1	192.8	13.1
1984	1609.8	264.4	203.2	14.6
1985	2100.7	320.4	190.9	14.7
1986	3718.6	358.7	164.0	12.6
1987	514.7	187.2	156.1	11.1
1988	3603.8	225.8	172.7	11.1
1989	126.5	50.4	227.9	12.7
1990	327.4	58.0	214.3	11.0
1991	442.0	87.0	174.8	9.2
1992	4751.4	366.6	151.9	8.5
1993	933.2	146.2	151.7	8.6
1994	719.8	97.7	151.8	9.3
1995	156.2	45.6	183.2	11.6
1996	87.9	29.4	247.8	14.7
1997	130.9	44.6	248.5	15.2
1998	692.8	100.7	177.5	12.9
1999	582.1	91.2	152.7	10.8
2000	210.3	52.5	117.7	8.4
2001	188.4	52.6	99.1	7.7
2002	473.4	85.0	95.7	7.4
2003	971.9	133.6	104.6	7.5
2004	1003.0	135.0	104.9	7.2
2005	353.0	91.9	94.8	6.8
2006	633.3	104.6	97.0	7.1
2007	124.8	46.8	106.0	8.3
2008	372.0	88.1	122.3	10.0
2009	1501.7	258.7	127.7	10.9
2010	1105.2	333.9		

Table 11. Likelihood values.

Likelihood Component	Value
Recruitment	33.331
ret fishery length	-1943.46
total fish length	700.734
female fish length	183.405
survey length	3464.3
trawl length	229.017
BSFRF length	-97.5945
NMFS study area length	-82.1107
M prior	11.6696
maturity smooth	26.1068
growth a	8.57495
growth b	0.142086
BSFRF biomass	0.153199
NMFS study area biomass	0.155793
fishery cpue	0.162415
retained catch	2.88731
discard catch	99.3278
trawl catch	8.1605
female discard catch	5.75378
survey biomass	147.618
F penalty	55.3572
Initial numbers at length	592.2067
Total likelihood	3445.898

Table 12. Changes in the September 2010 model and data from the September 2009 model and data.

Model Scenario	Description
Data	"New" survey data (with measured net width), no extra weight on survey biomass, BSFRF 2009 survey data added (small crab <40 mm removed from length freqencies)
Parameters estimated	logistic curves used for 2009 study area survey selectivity, Bering sea separate survey selectivities males and females, probability of maturing estimated for males and females Male M estimated with prior, Growth per molt parameters for males and females estimated with priors

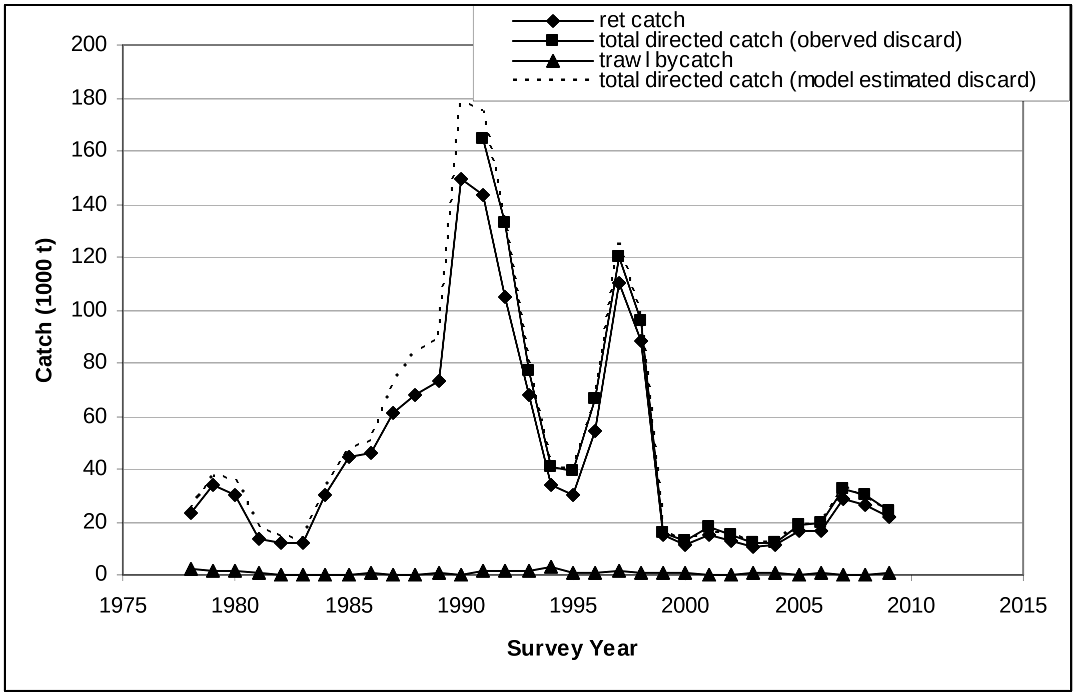

Figure 1. Catch (1000 t) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch is retained catch plus discarded catch after 50% discard mortality was applied. Discard catch was estimated from observer data 1992 to present. Discard for 1978 to 1991 was estimated in the model. Trawl bycatch is male and female bycatch from groundfish trawl fisheries with 80% mortality applied.

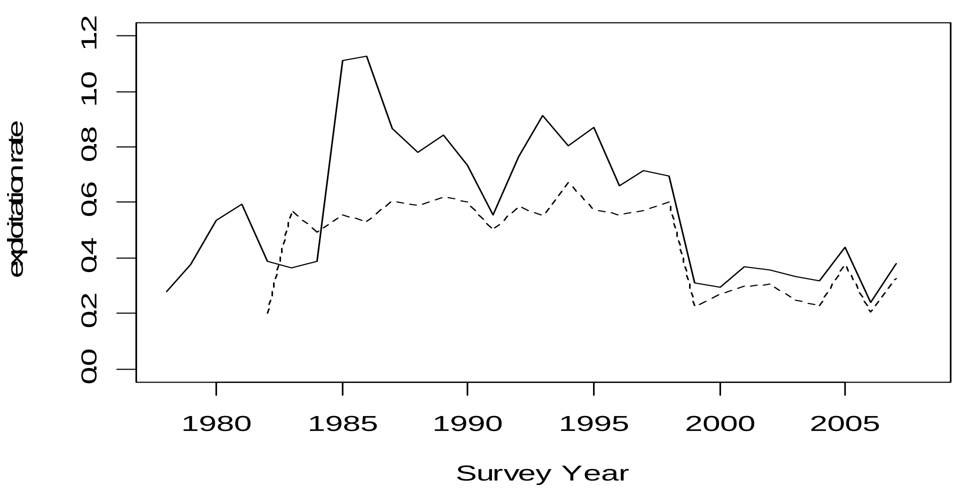

Figure 2. Exploitation rate estimated as the preseason GHL divided by the survey estimate of large male biomass (>101 mm) at the time the survey occurs (dotted line). The solid line is the retained catch divided by the survey estimate of large male biomass at the time the fishery occurs. Year is the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

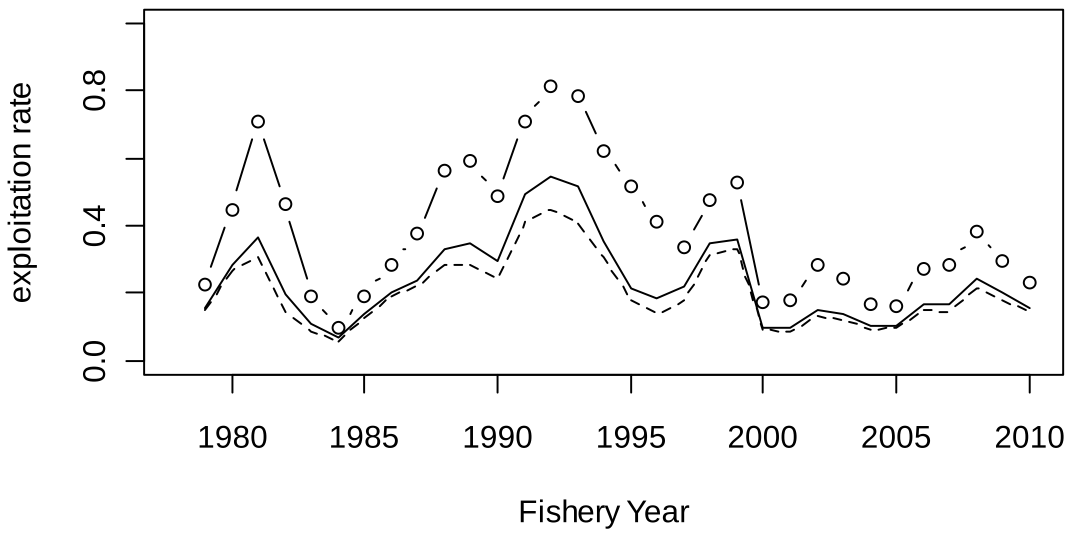

Figure 3. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line is total and dotted line is retianed). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the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

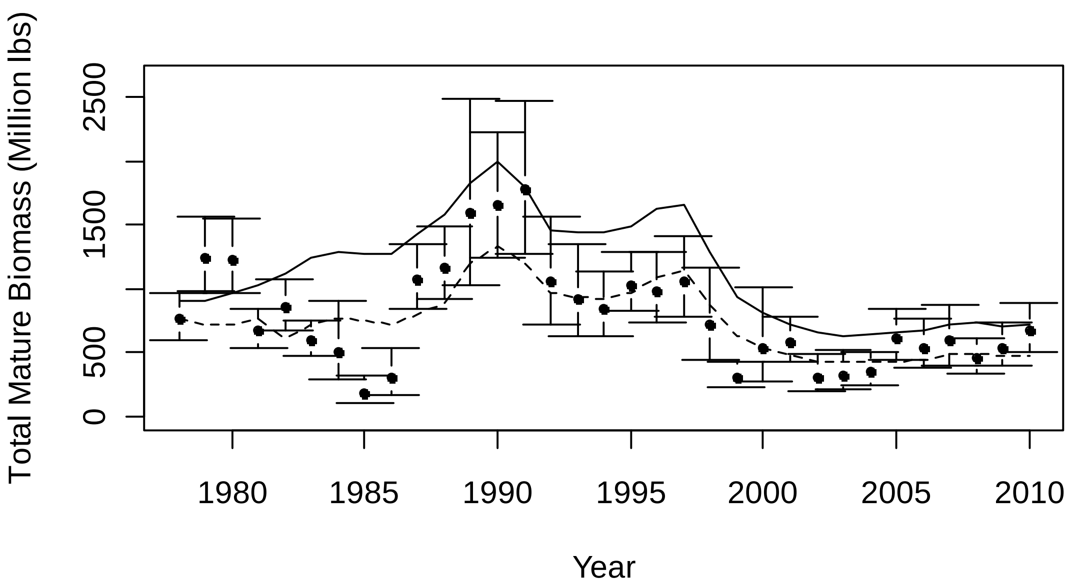

Figure 4. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

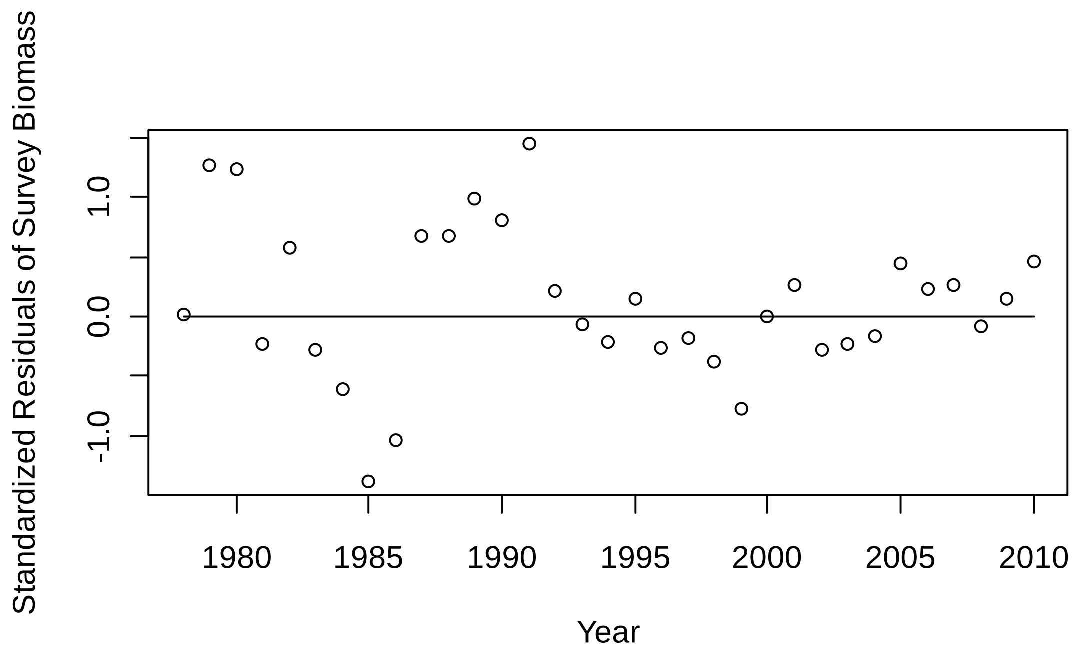

Figure 5. Standardized residuals for model fit to total mature biomass from Figure 4.

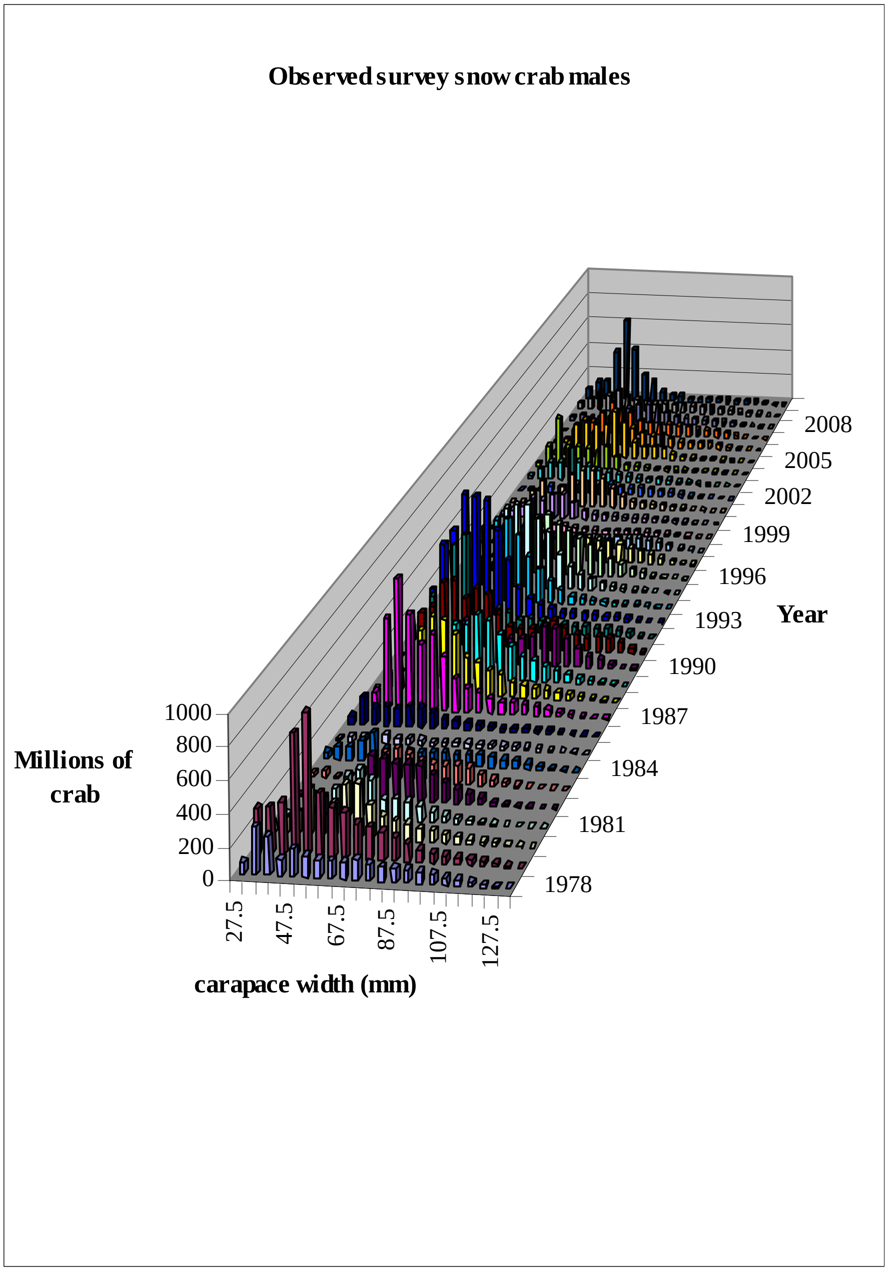

Figure 6. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

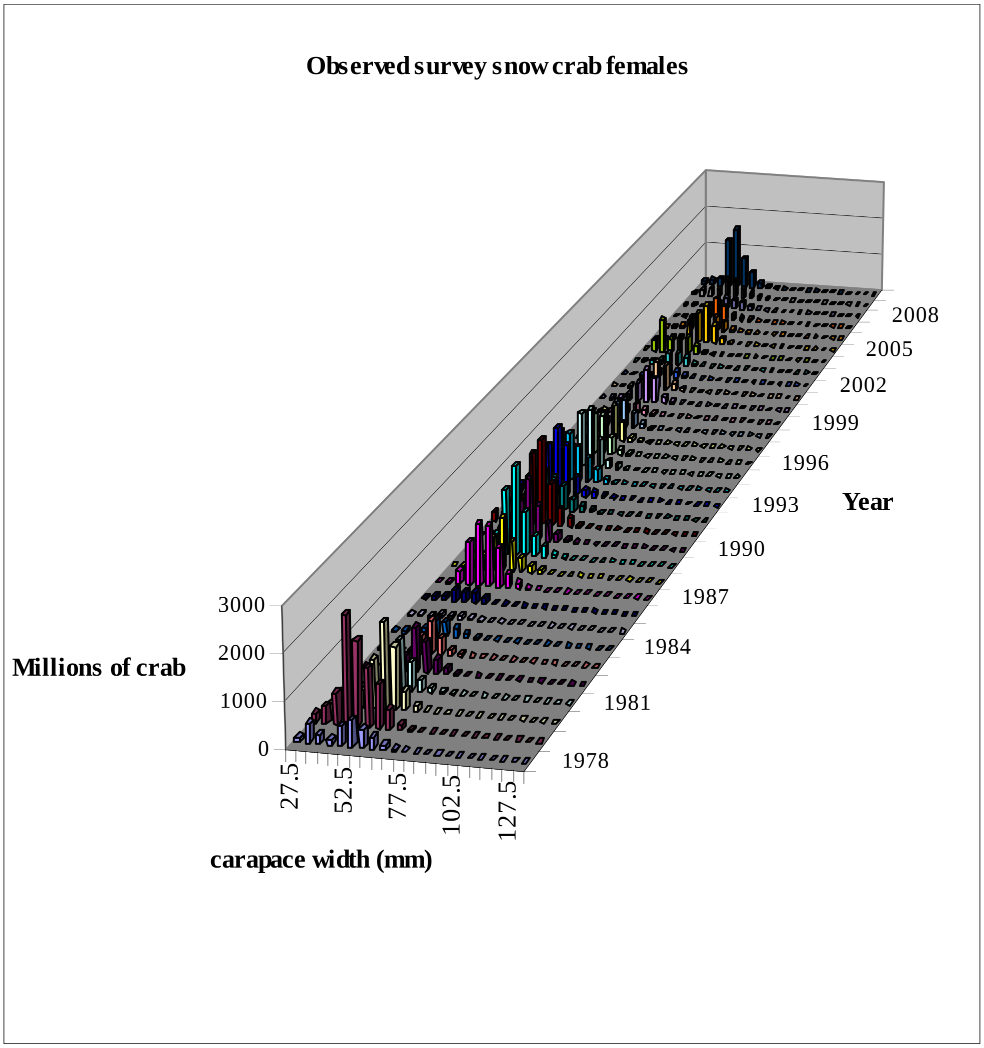

Figure 7. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

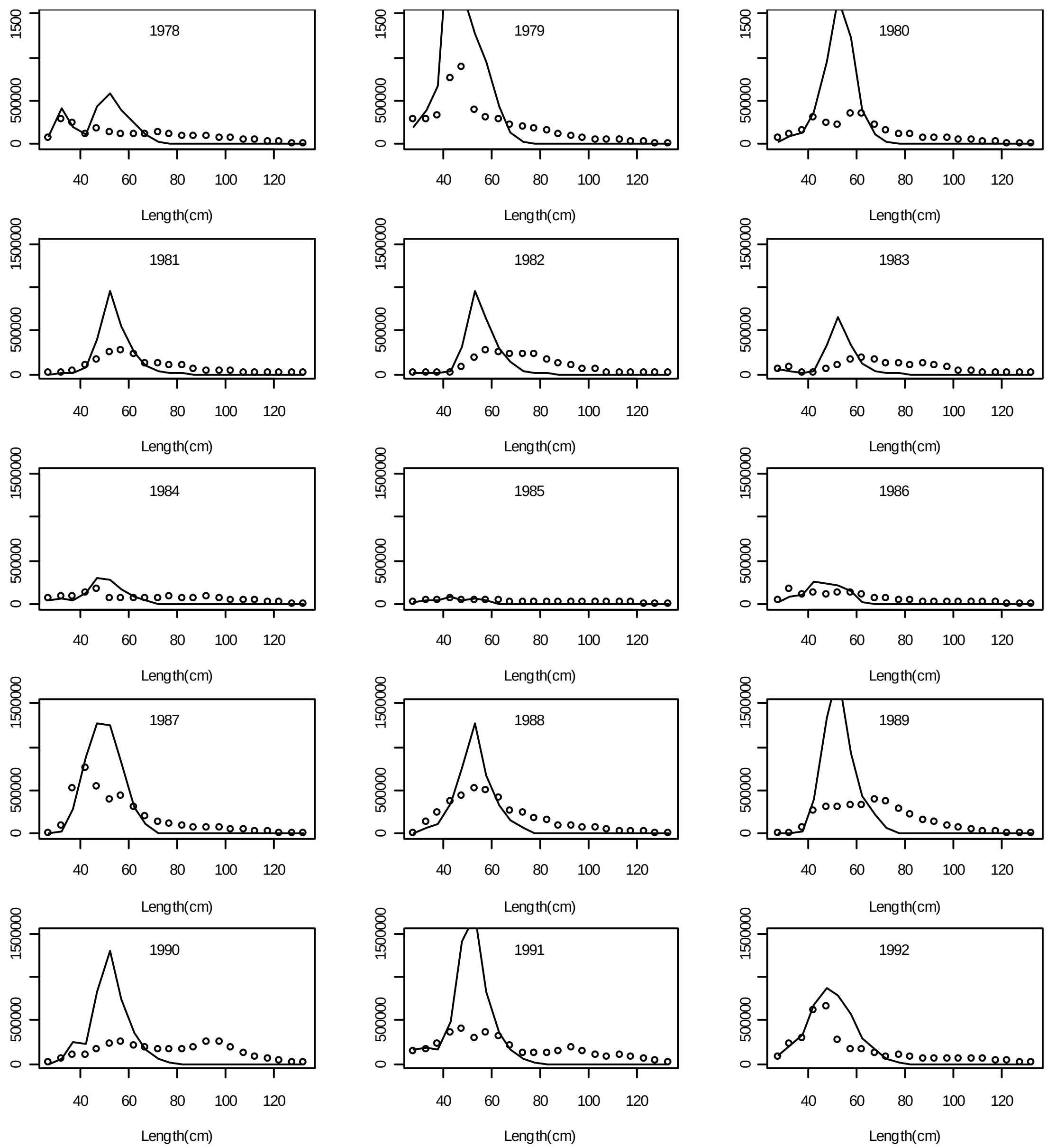

Figure 8. Observed survey numbers 1978 to 1992 by length, males circles, females solid line.

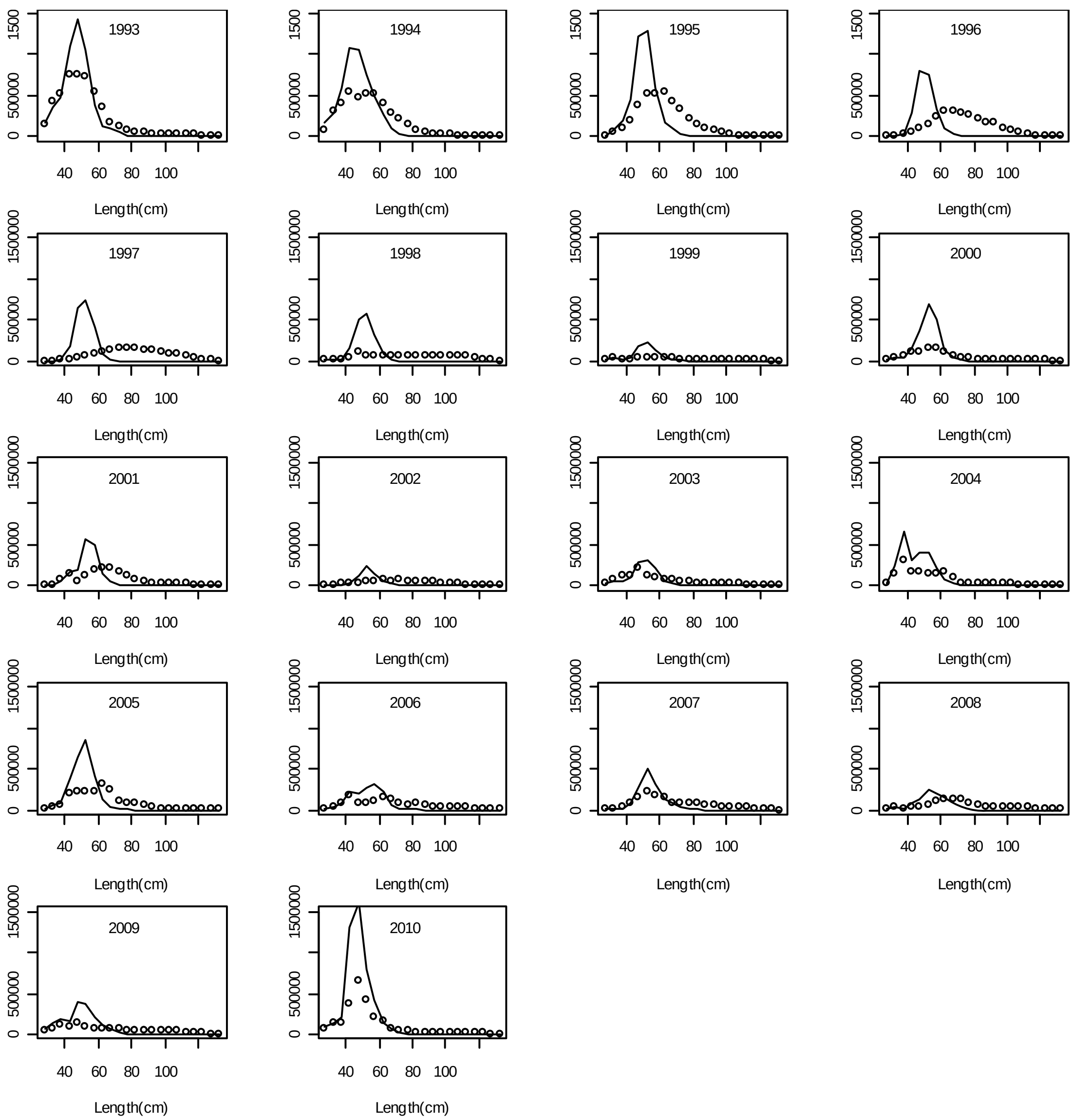

Figure 8 continued. Observed survey numbers 1993 to 20010 by length, males circles, females solid line.

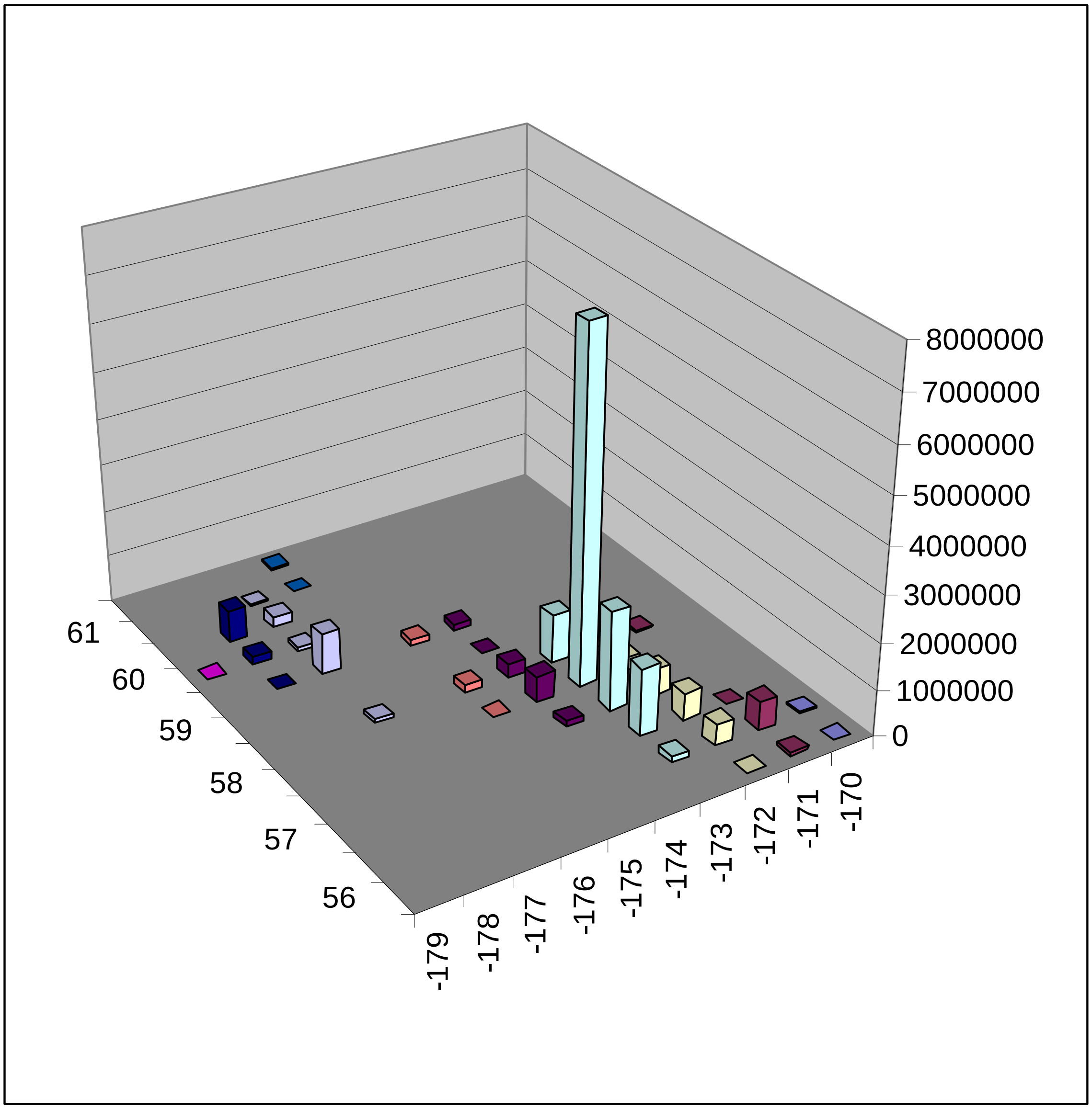

Figure 9. 2003/04 pot fishery retained catch in numbers by statistical area. Longitude in negative degrees. Areas are 1 degree longitude by 0.5 degree latitude.

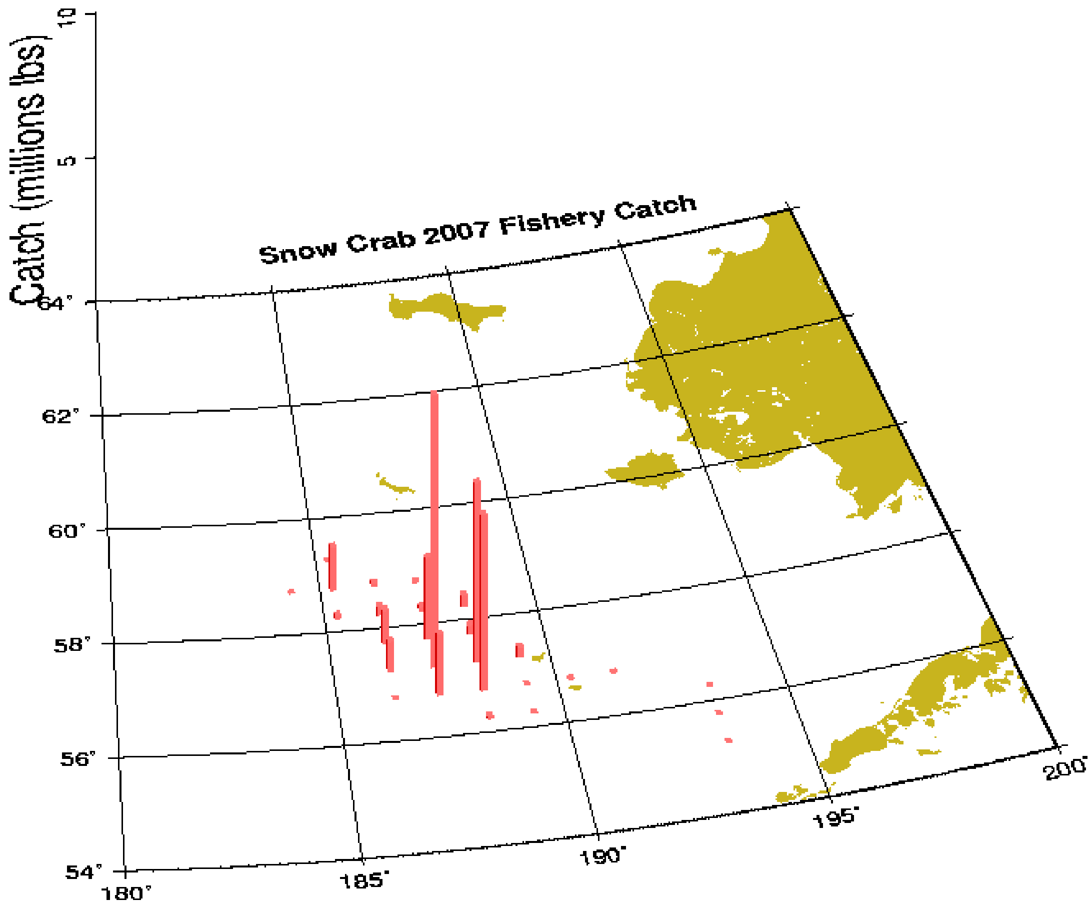

Figure 10. 2006/07 snow crab pot fishery retained catch(million lbs) by statistical area. Longitude increases from west to east (190 degrees = 170 degrees W longitude). Areas are 1 degree longitude by 0.5 degree latitude.

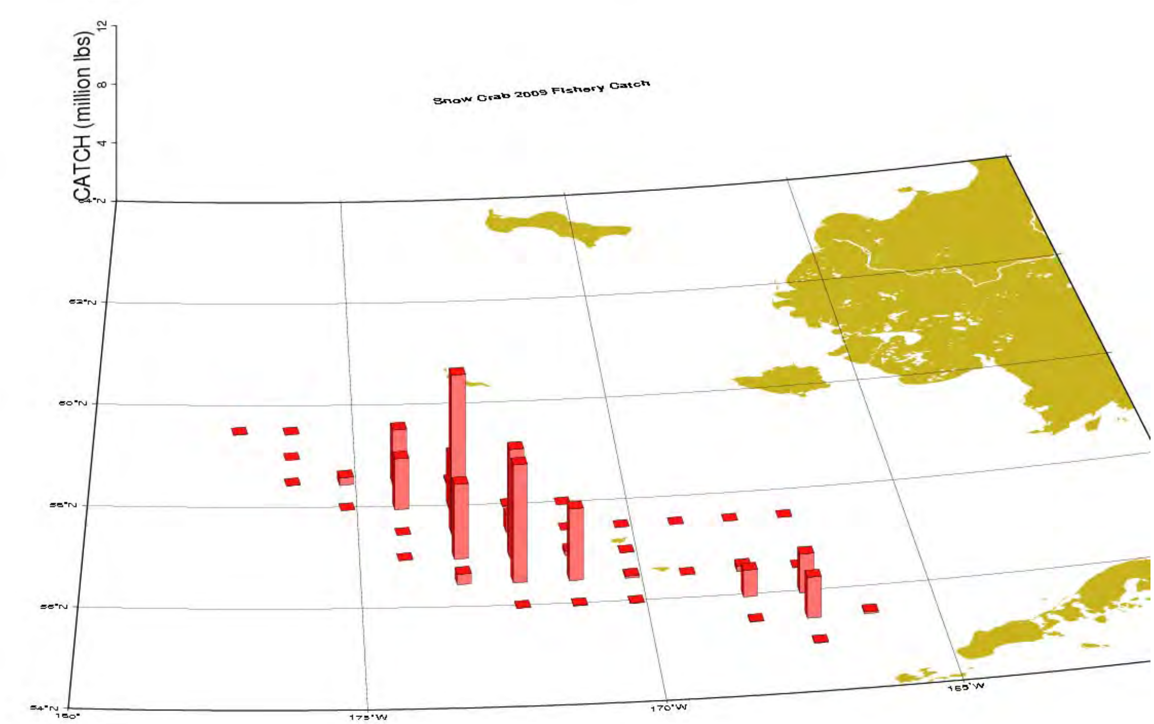

Figure 11. 2008/09 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

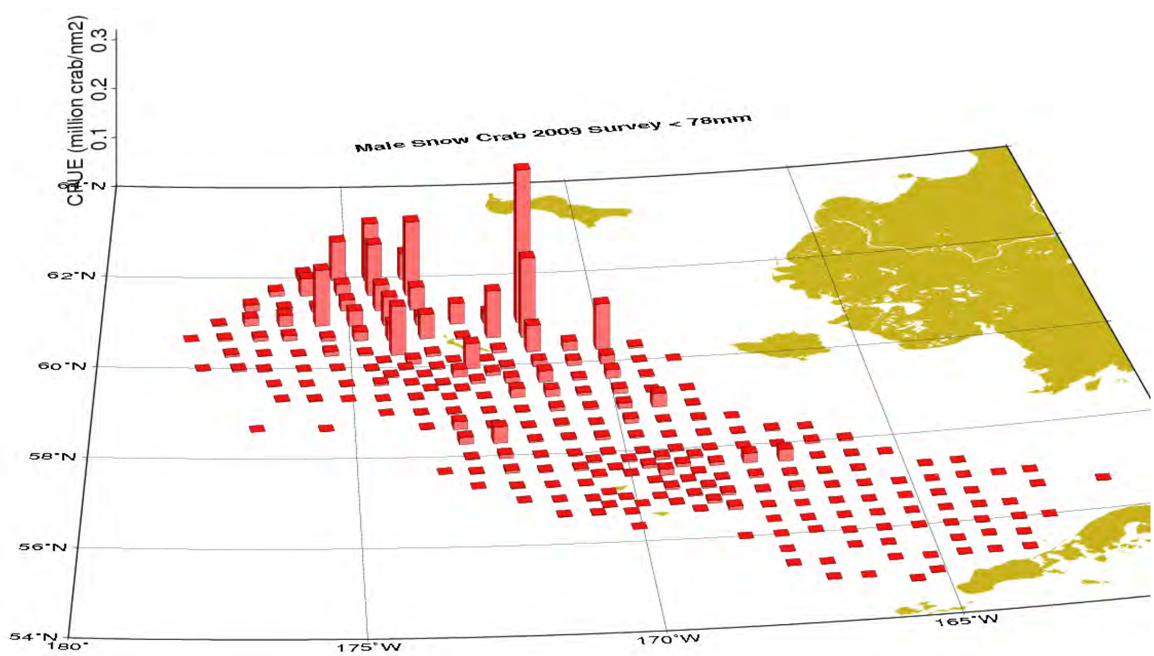

Figure 12. 2009 Survey CPUE (million crab per nm2) of males < 78 mm by tow.

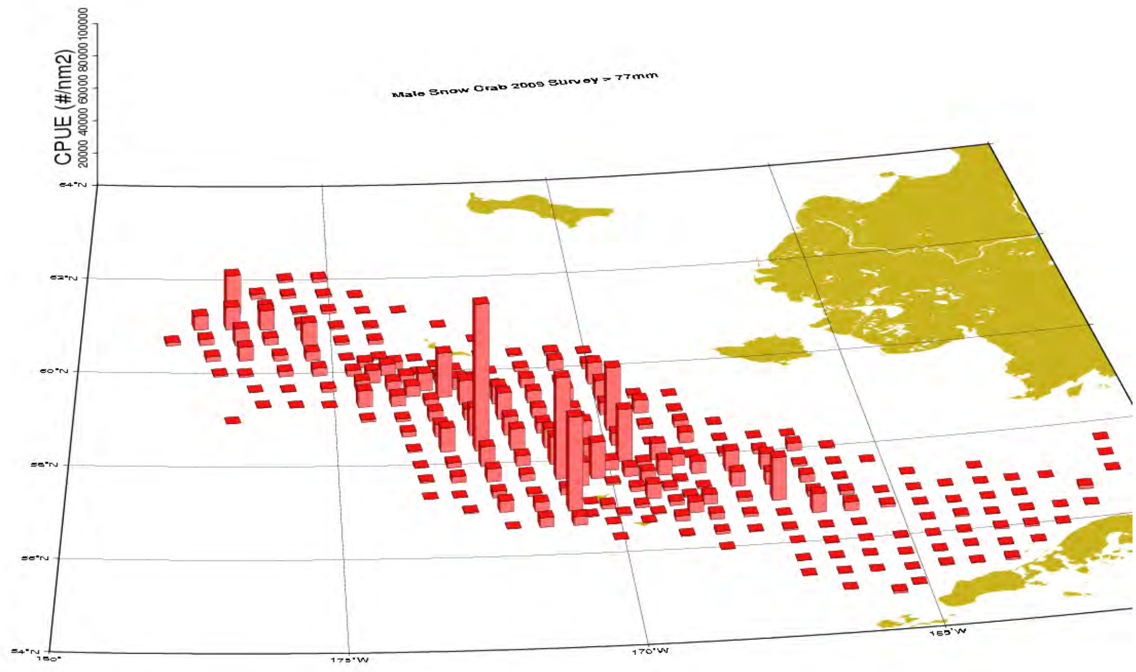

Figure 13. 2009 Survey CPUE (number per nm2) of males > 77 mm by tow.

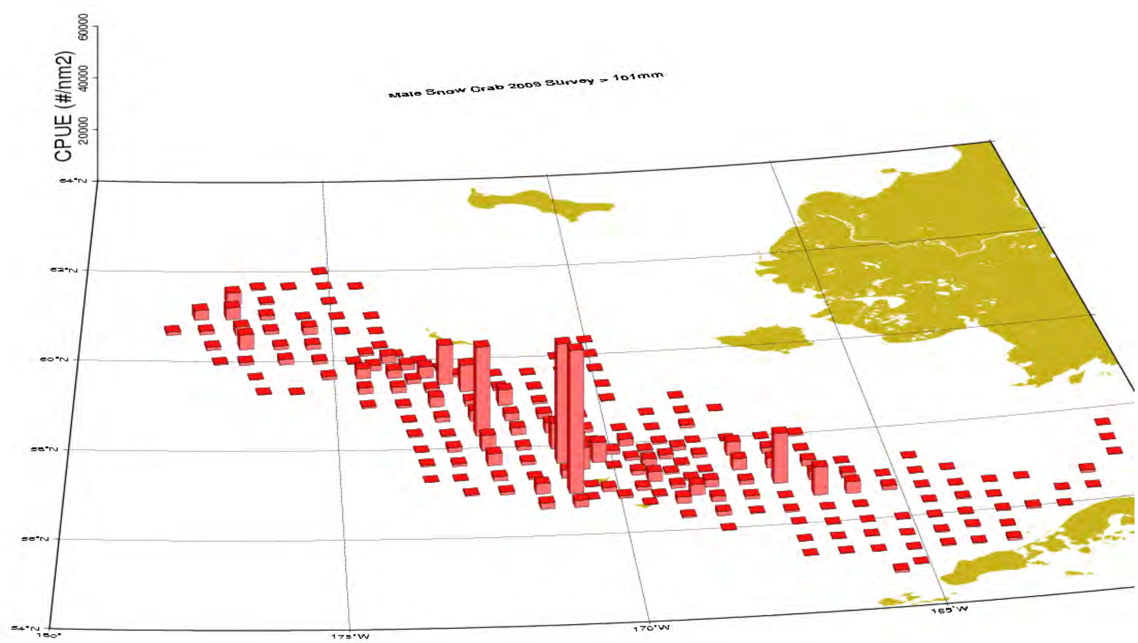

Figure 14. 2009 Survey CPUE (number per nm2) of males > 101 mm by tow.

Figure15. Snow crab 2009 survey immature female cpue.

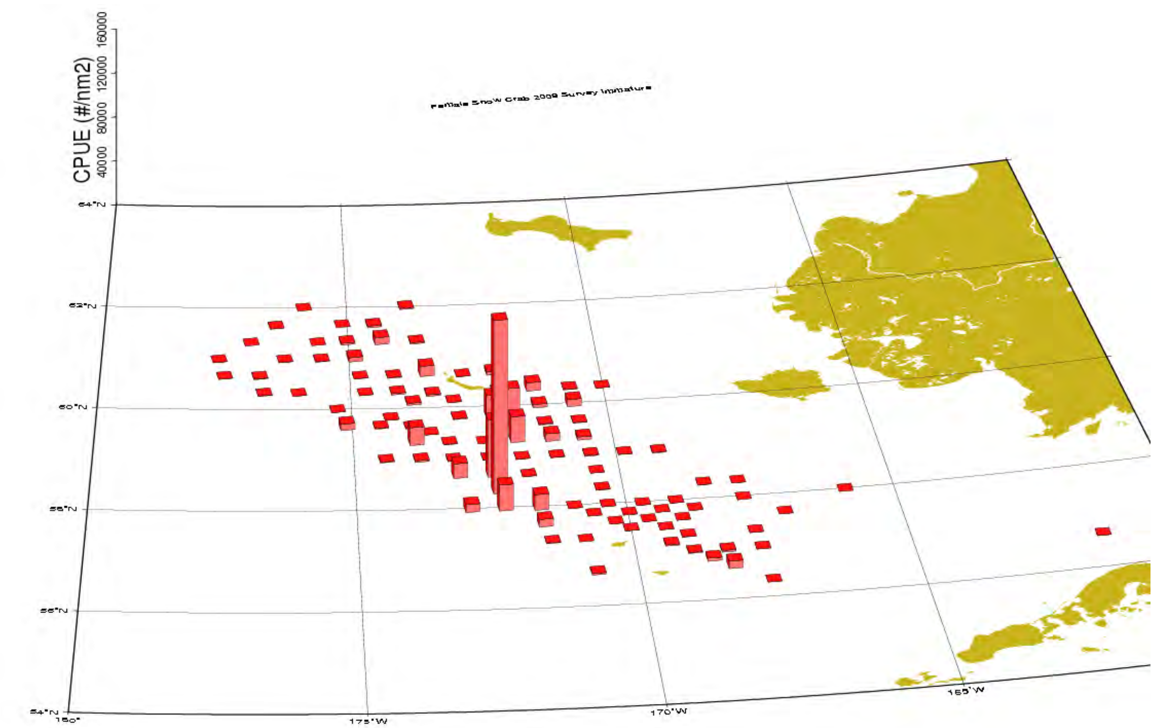

Figure 16. 2009 survey snow mature females cpue with less than or equal to half clutch of eggs.

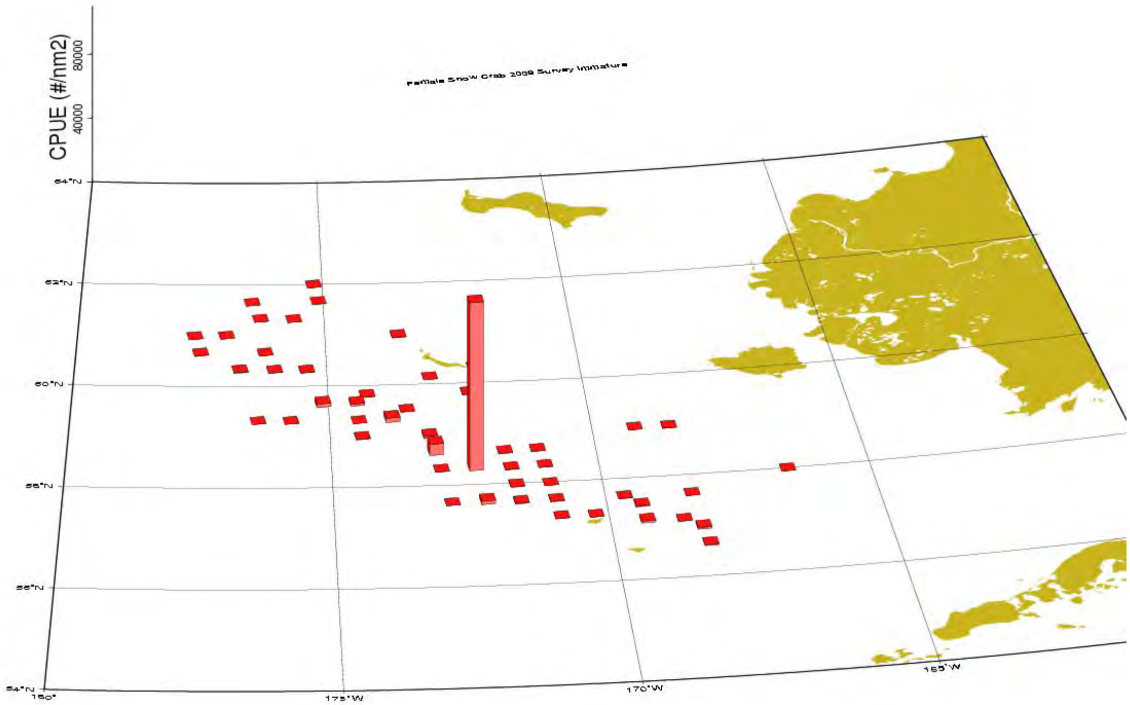

Figure 17. 2009 survey mature females with no eggs. Note scale not the same as other plots.

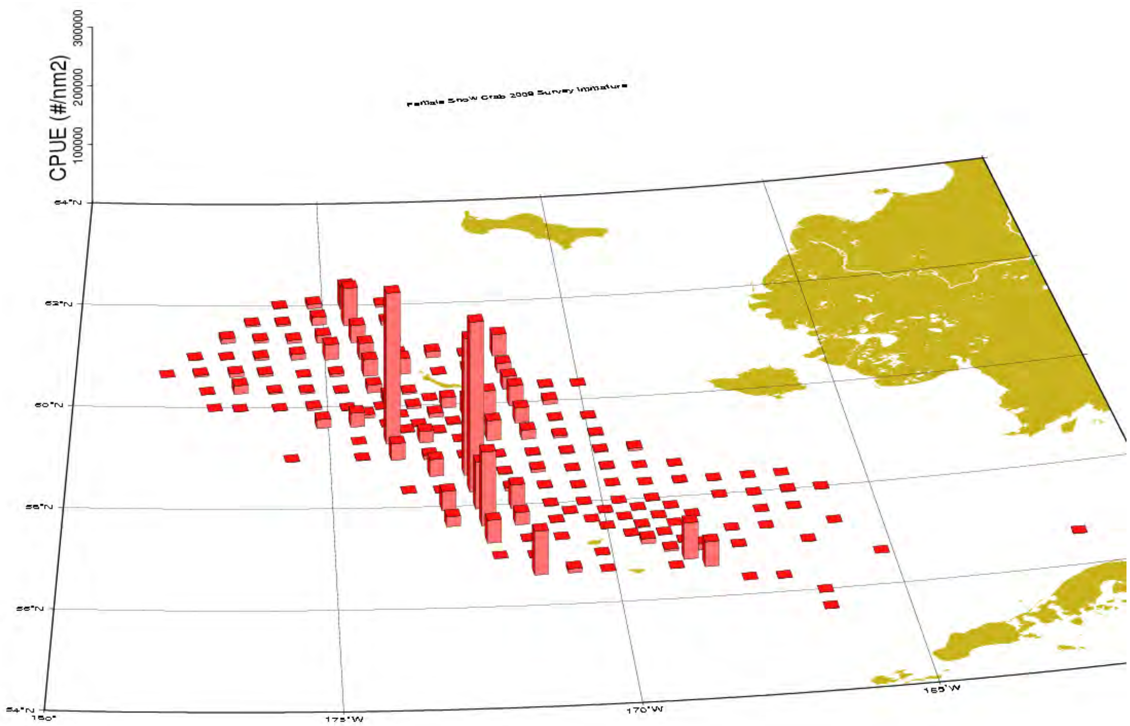

Figure 18. 2009 survey female survey cpue by haul for mature females with eggs. Scale not same as other plots.

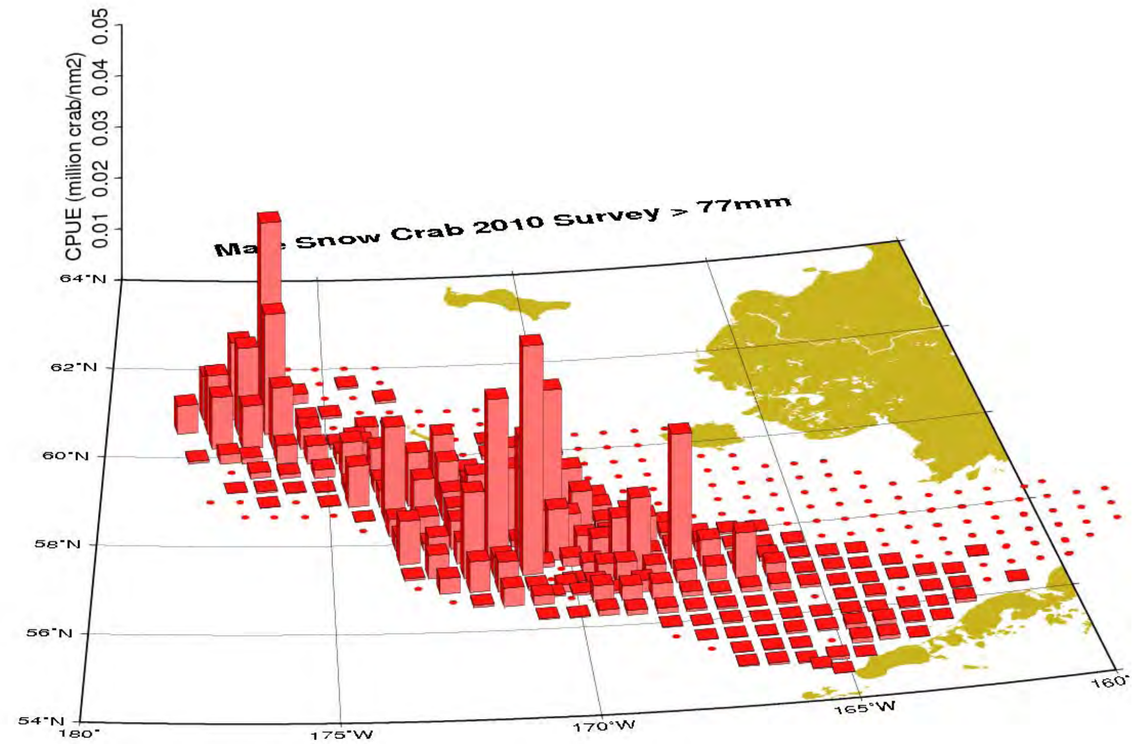

Figure 19. 2010 Survey CPUE (million crab per nm2) of males > 77 mm by tow. Filled circles are tows with 0 cpue.

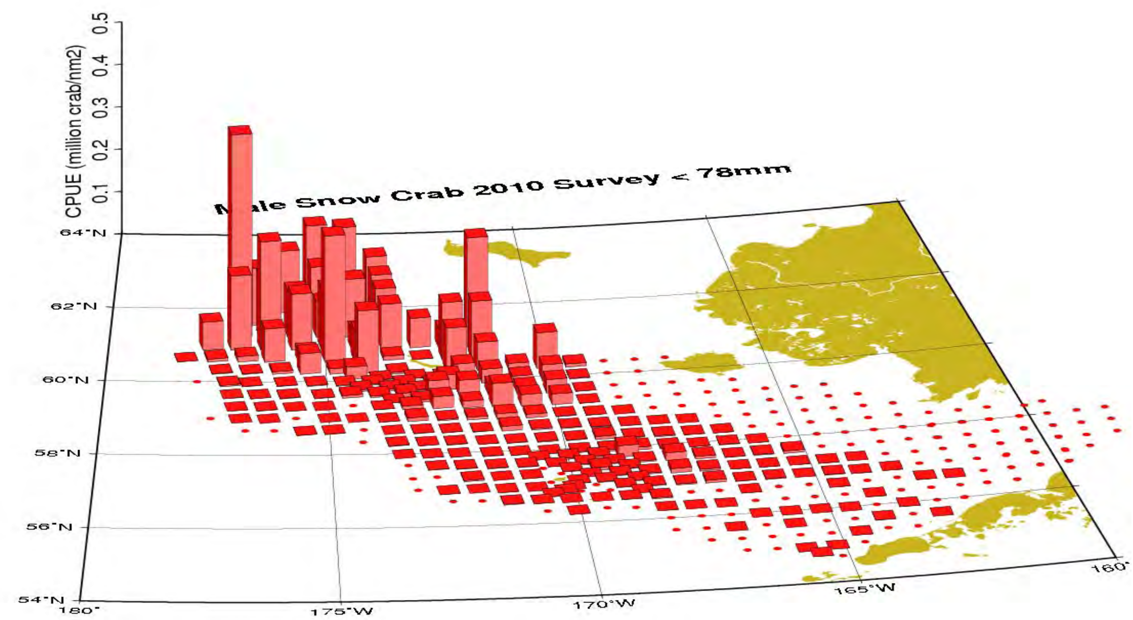

Figure 20. 2010 Survey CPUE (million crab per nm2) of males < 78 mm by tow. Filled circles are tows with 0 cpue.

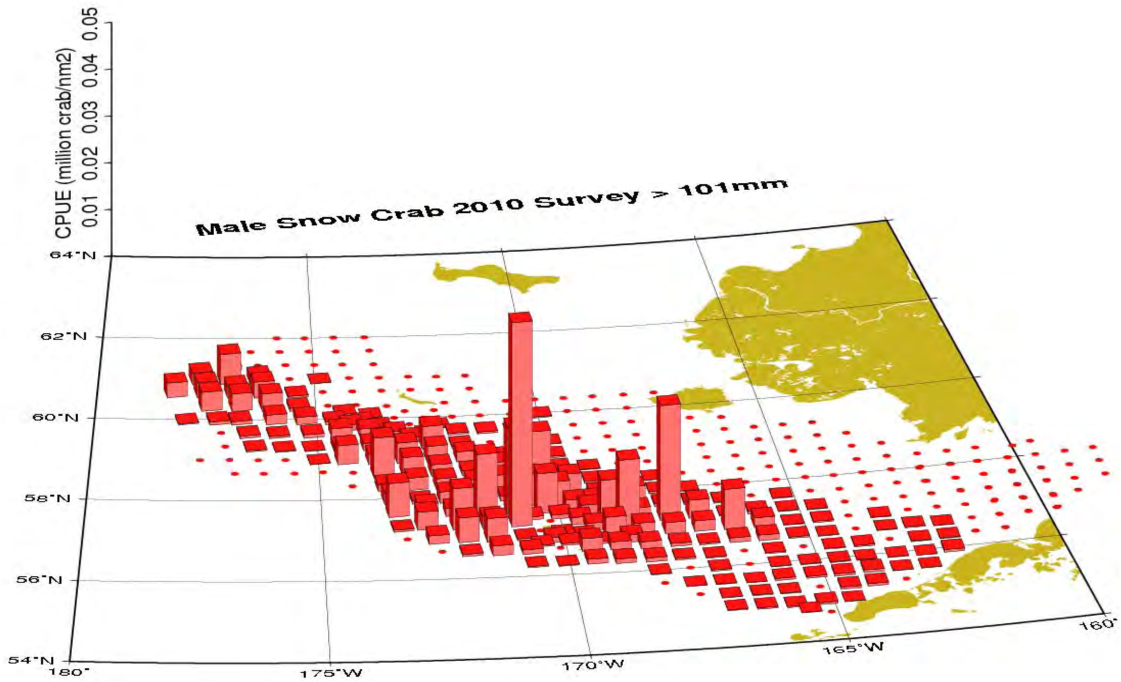

Figure 21. 2010 Survey CPUE (million crab per nm2) of males > 101 mm by tow. Filled circles are tows with 0 cpue.

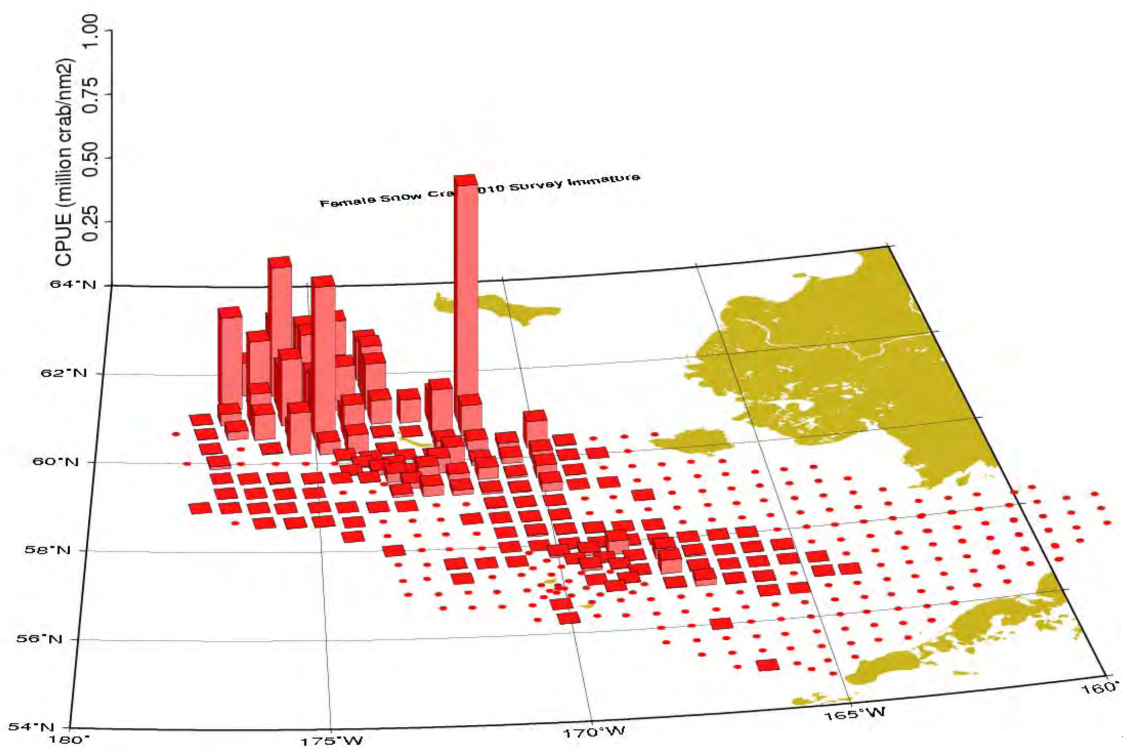

Figure 22. 2010 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

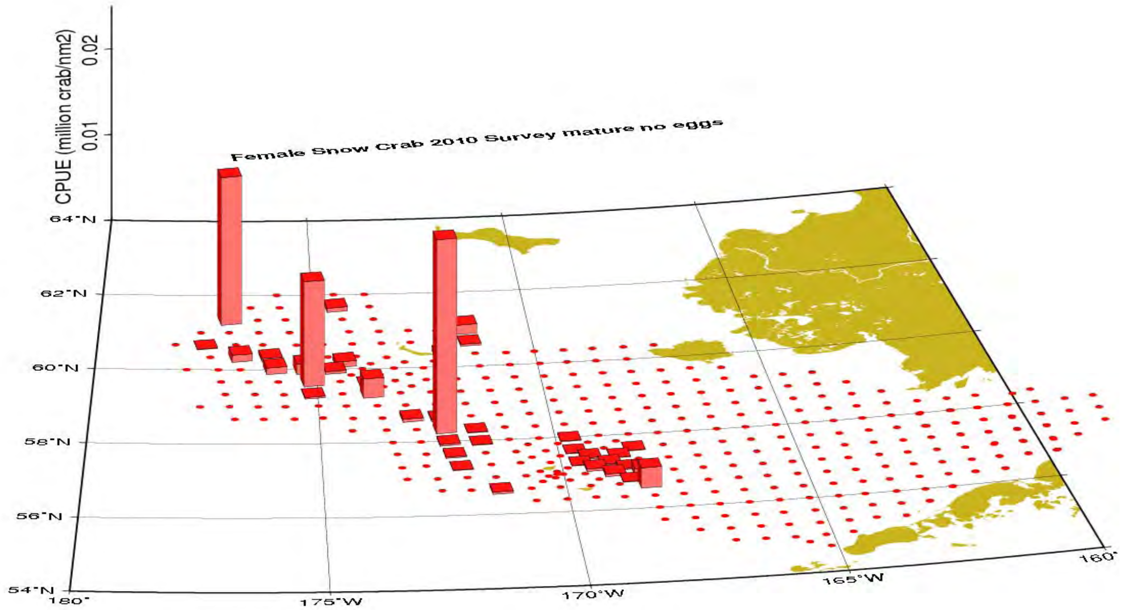

Figure 23. 2010 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

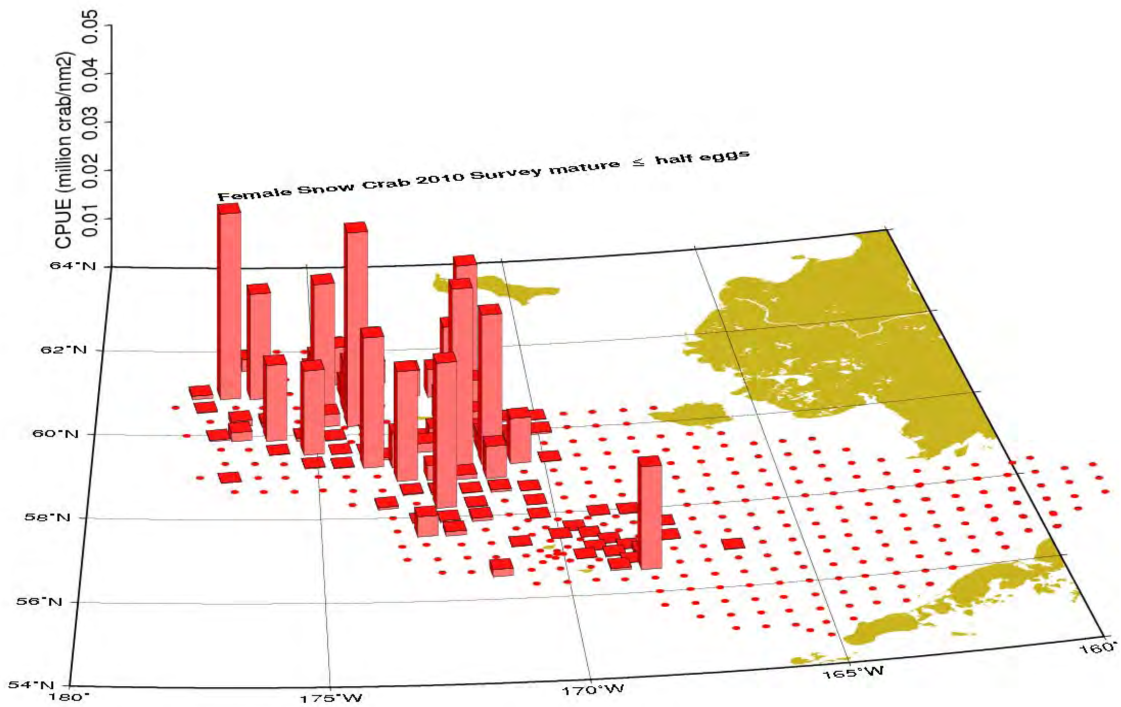

Figure 24. 2010 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

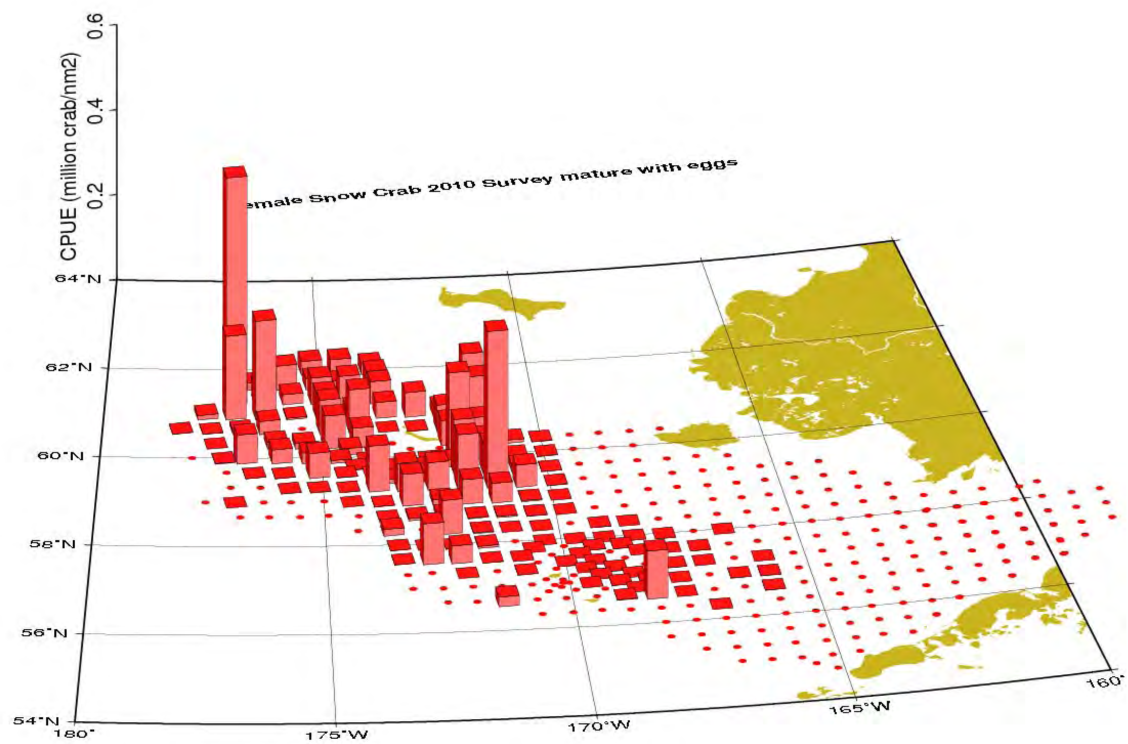

Figure 25. 2010 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

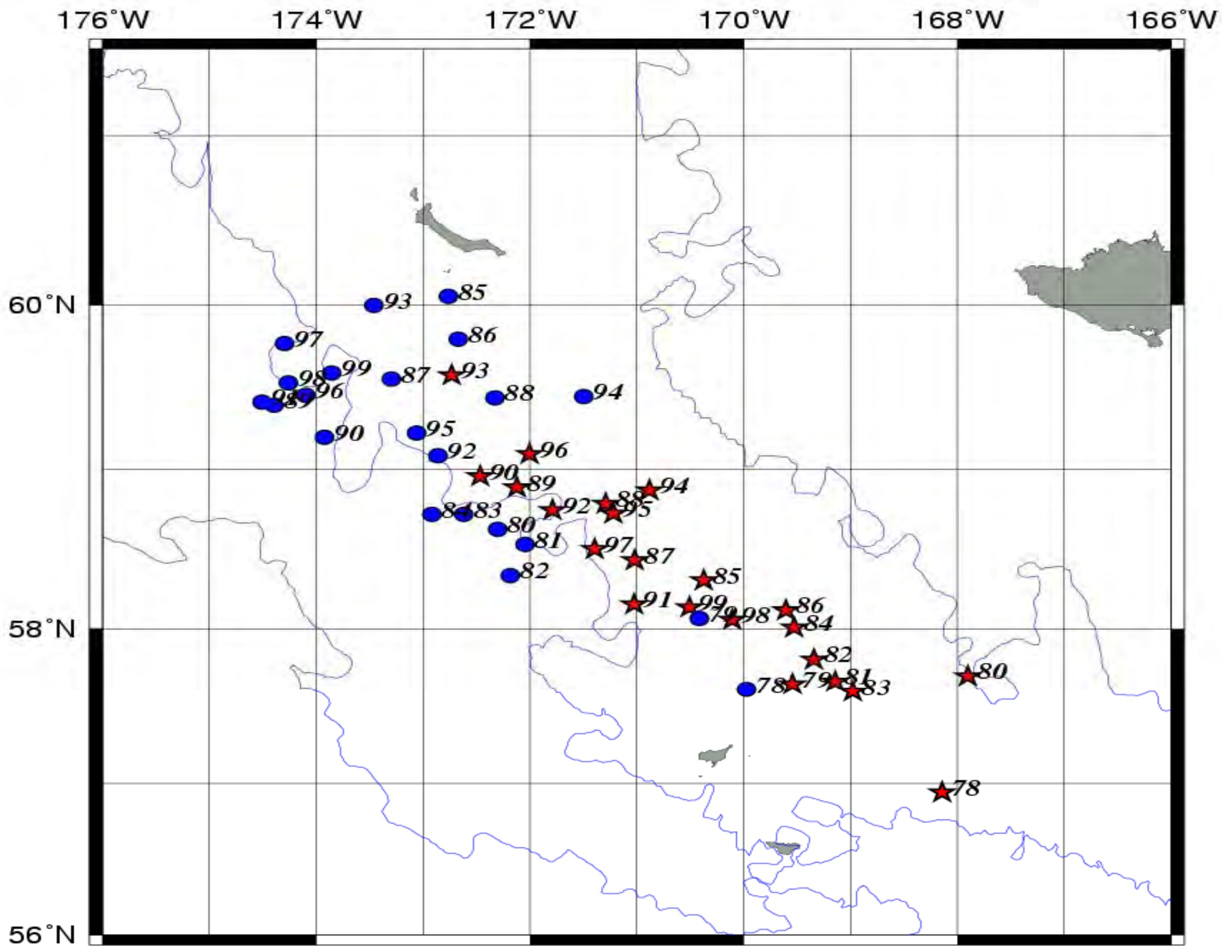

Figure 26. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars (Ernst, et al. 2005).

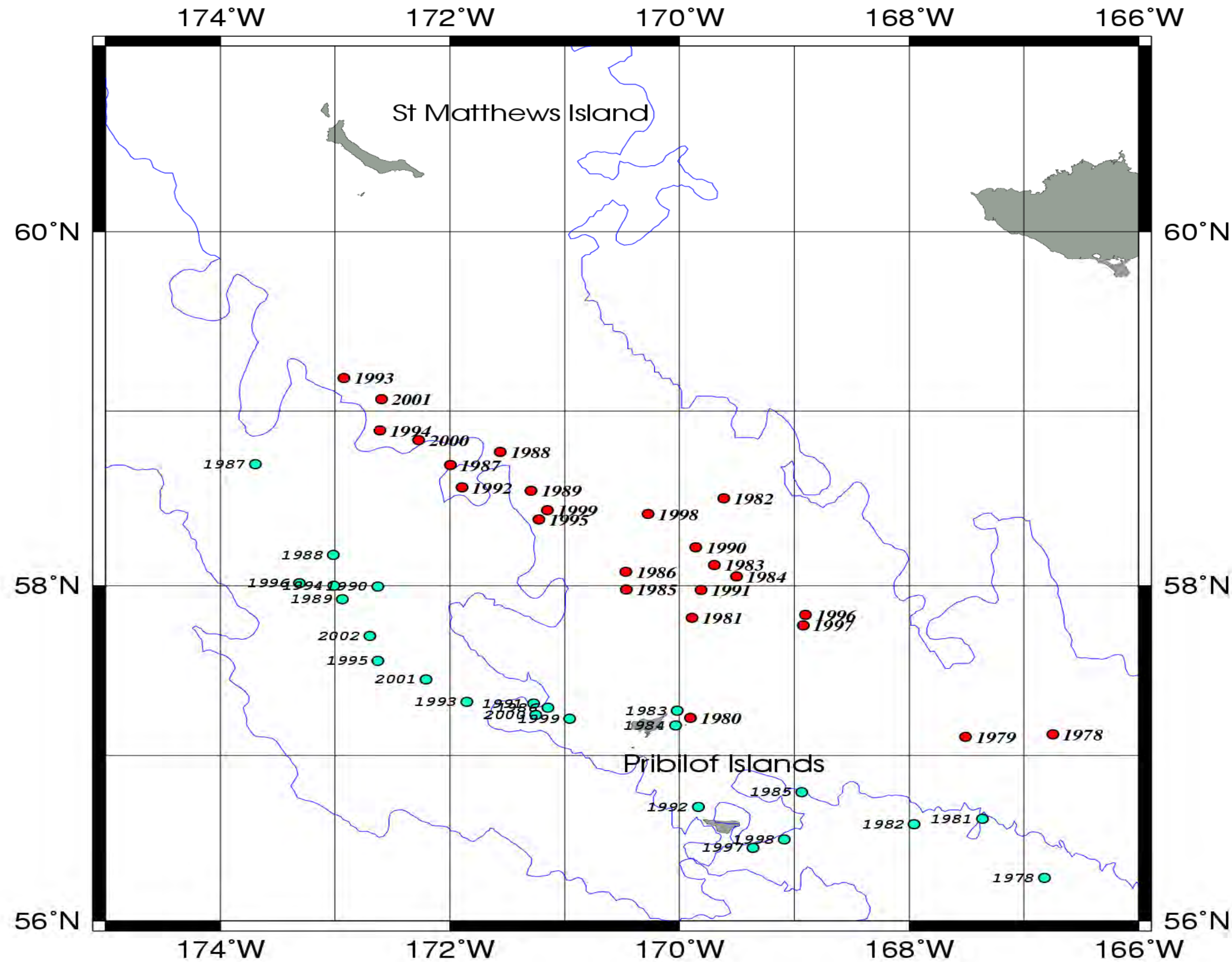

Figure 27. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green) (Ernst, et al. 2005).

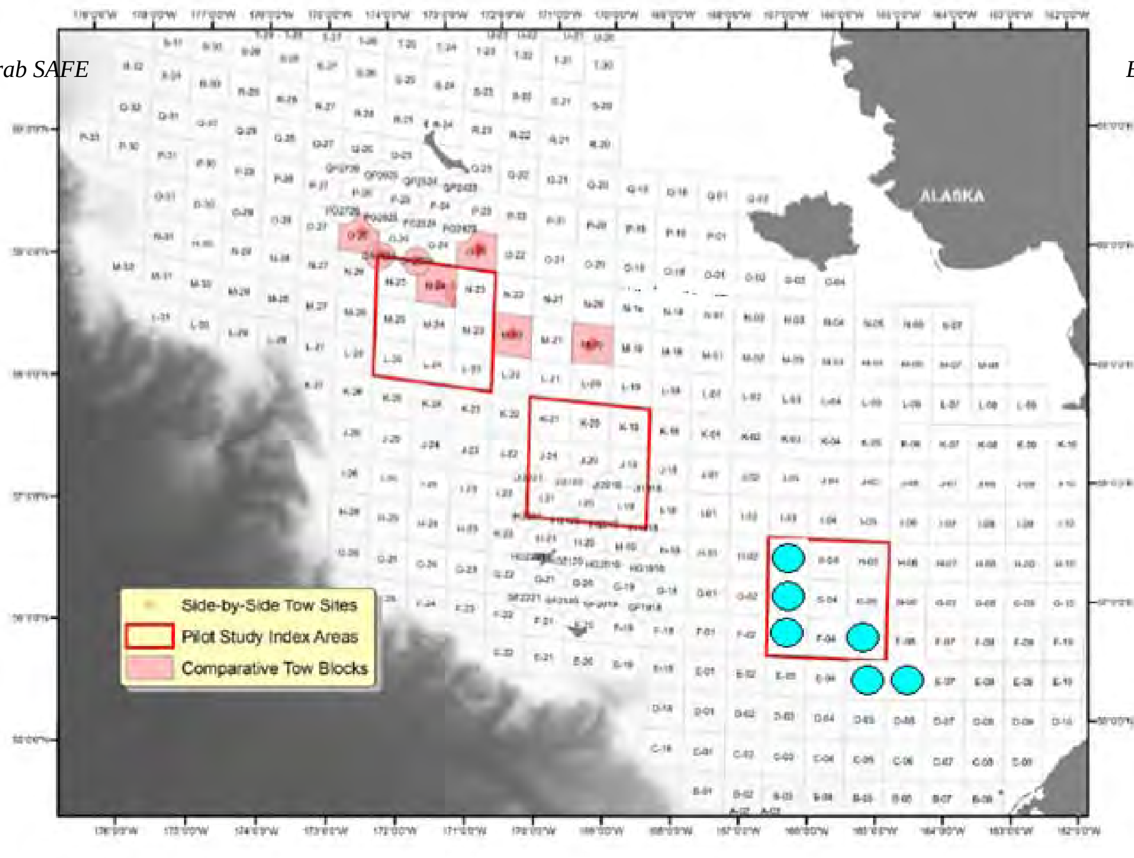

Figure 28. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas are the blue circles.

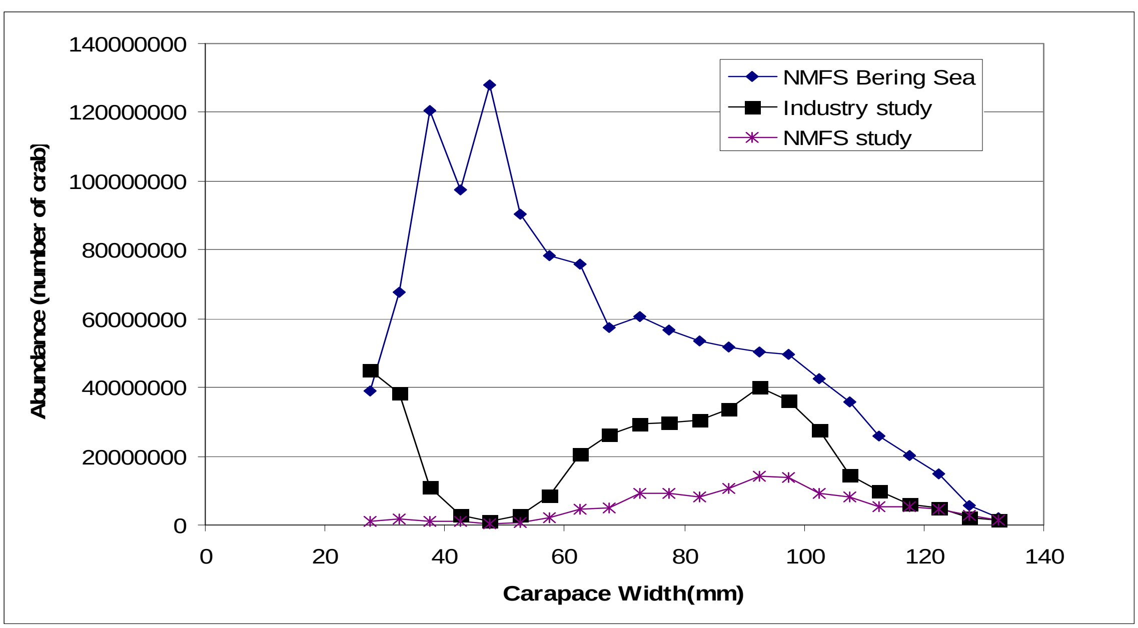

Figure 29. Abundance estimates of male snow crab by 5 mm carapace width(>=25mm) for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the study area.

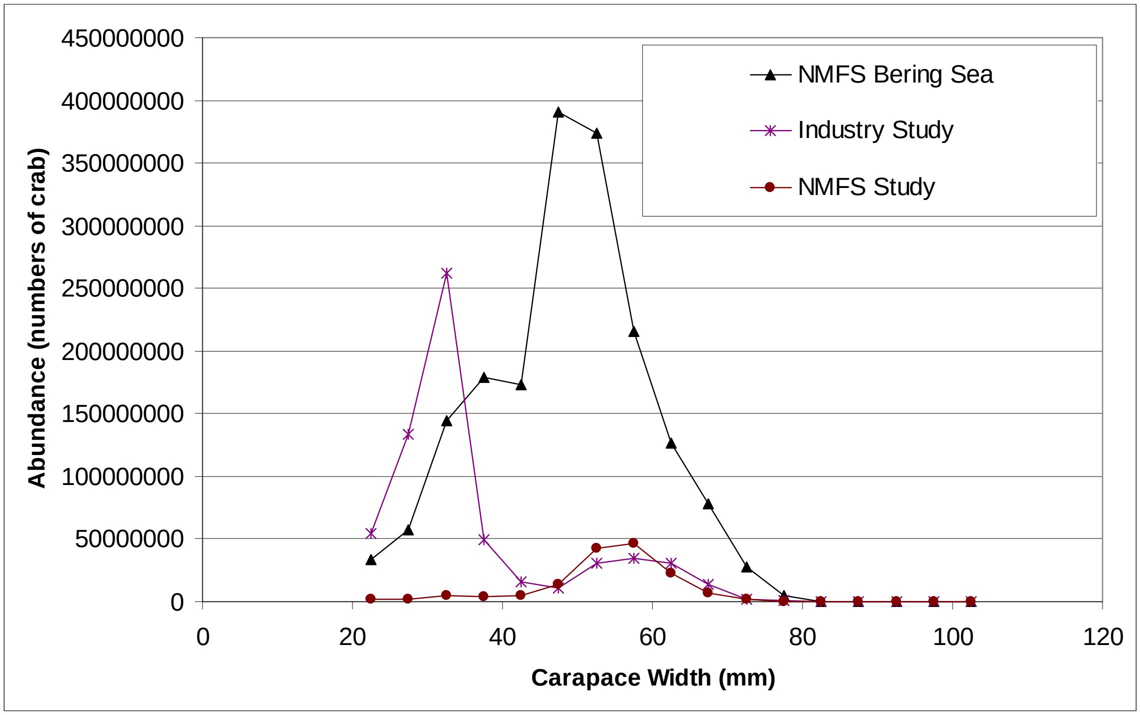

Figure 30. Abundance estimates of female snow crab by 5 mm carapace width for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the study area.

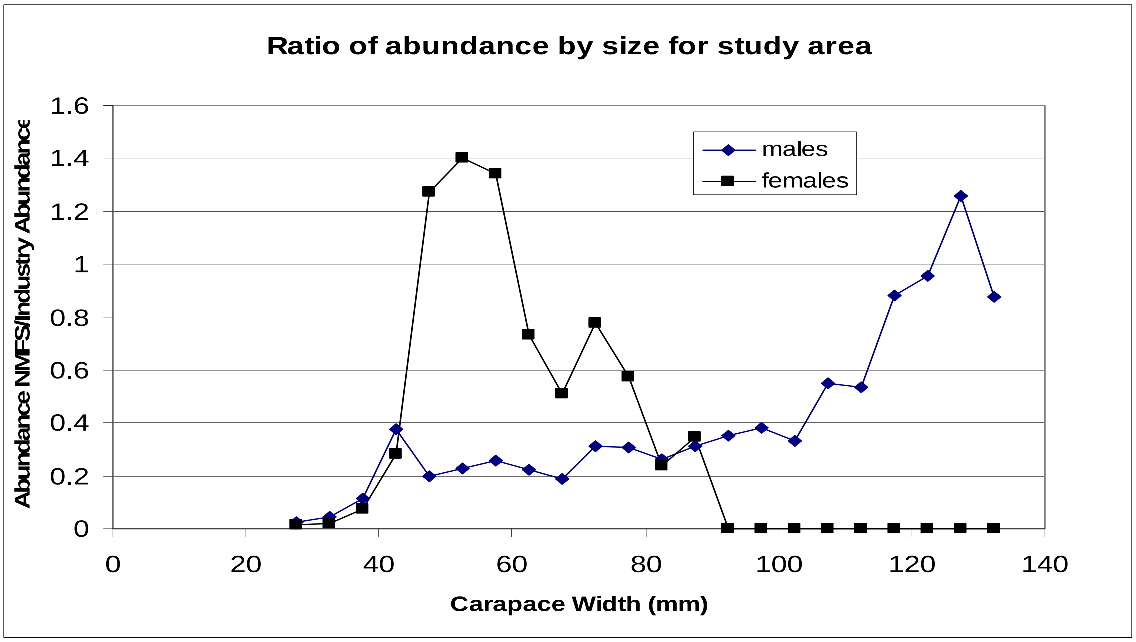

Figure 31. Ratio of abundance in the study area from the NMFS net to the BSFRF net for male and female crab.

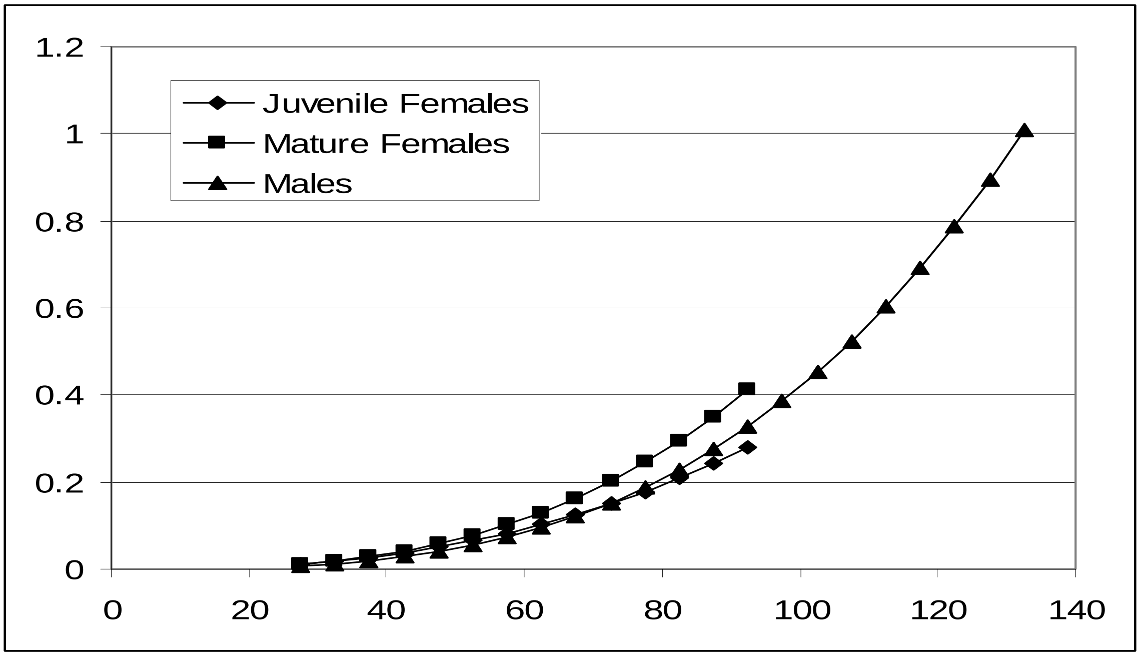

Figure 32. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

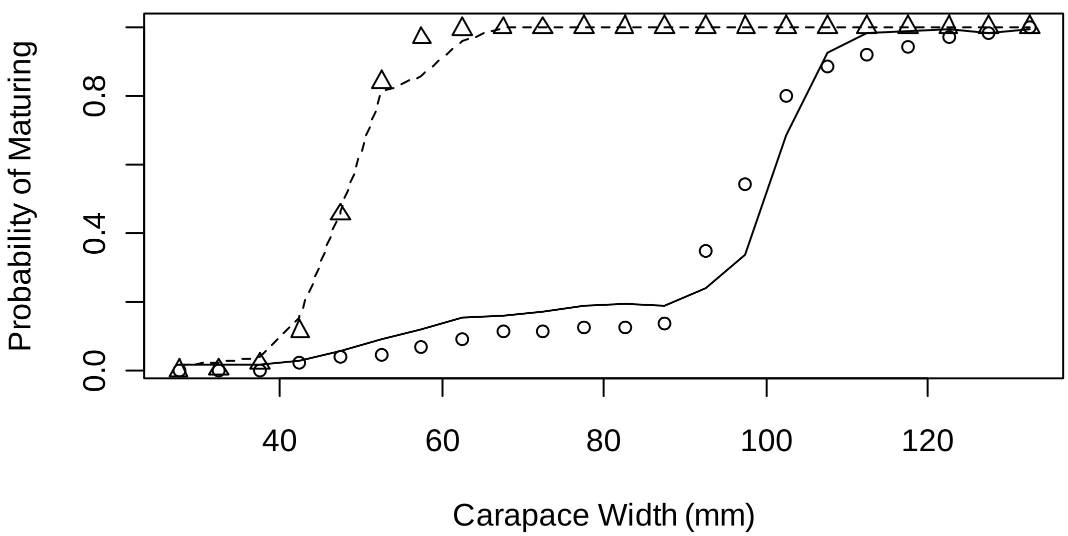

Figure 33. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (<u>not</u> the average fraction mature). Triangles are values for females used in the 2009 assessment. Circles are values for males used in the 2009 assessment.

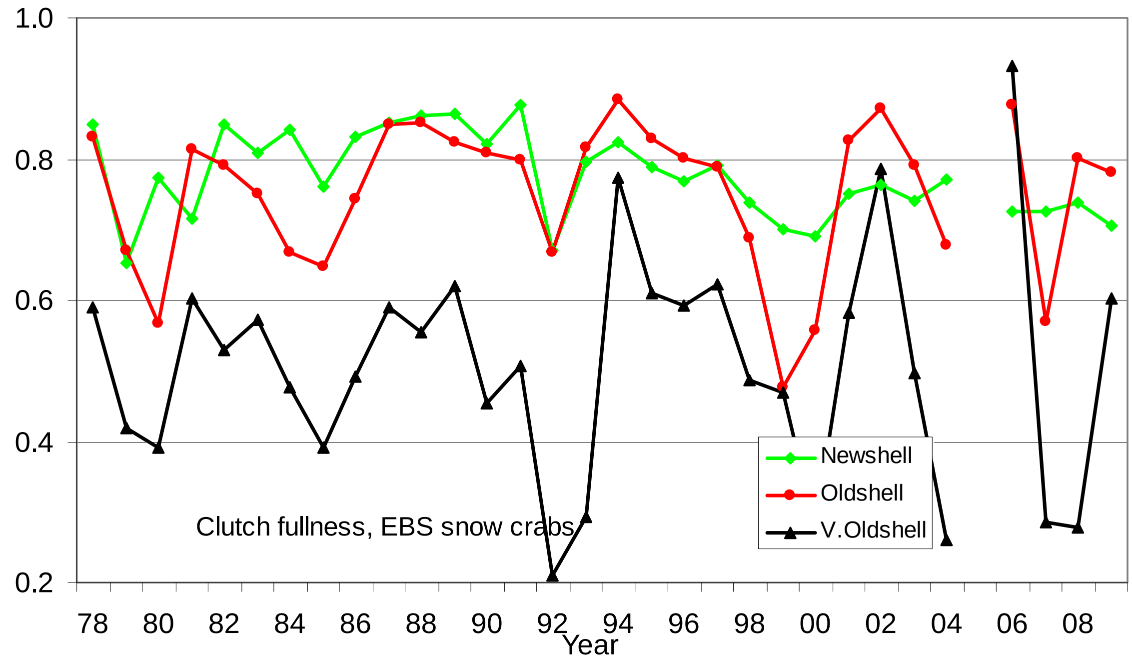

Figure 34. Clutch fullness for Bering Sea snow crab survey data by shell condition for 1978 to 2009.

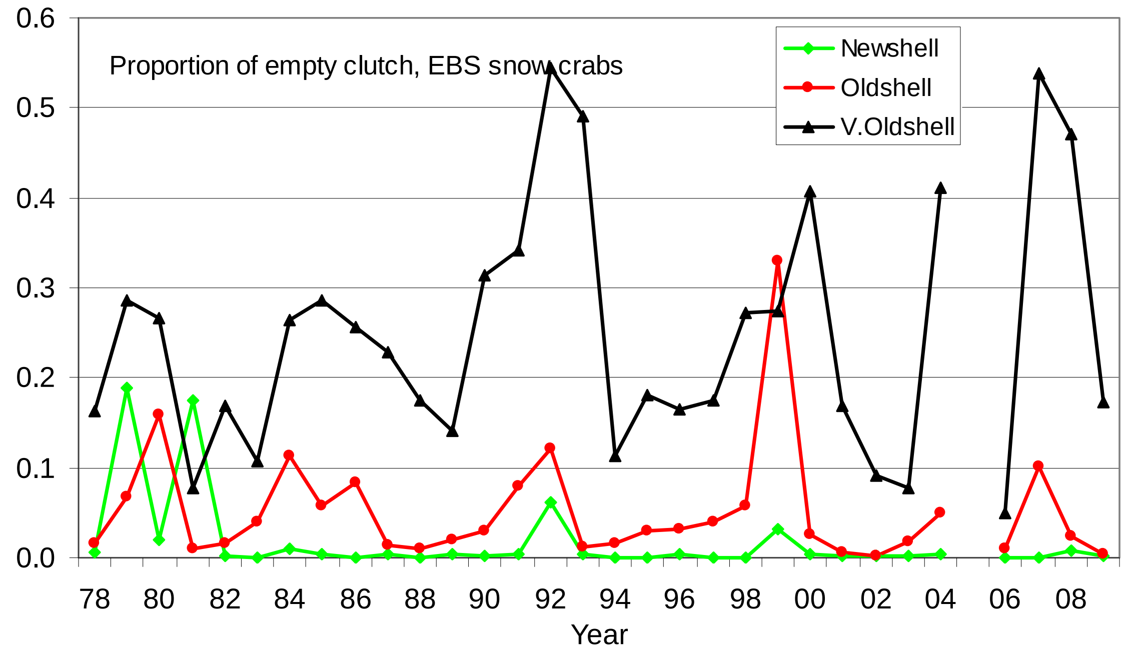

Figure 35. Proportion of barren females by shell condition from survey data 1978 to 2009.

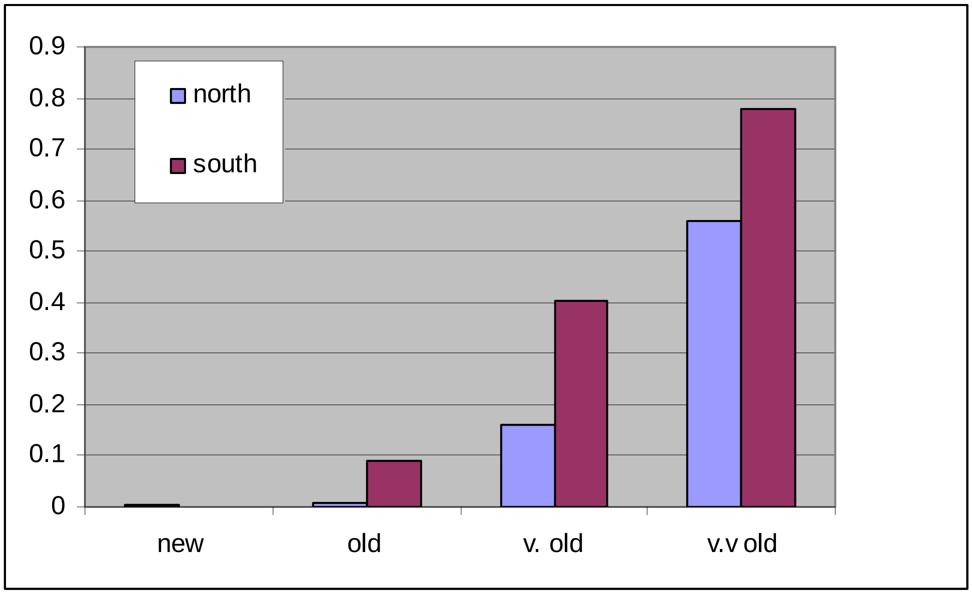

Figure 36. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

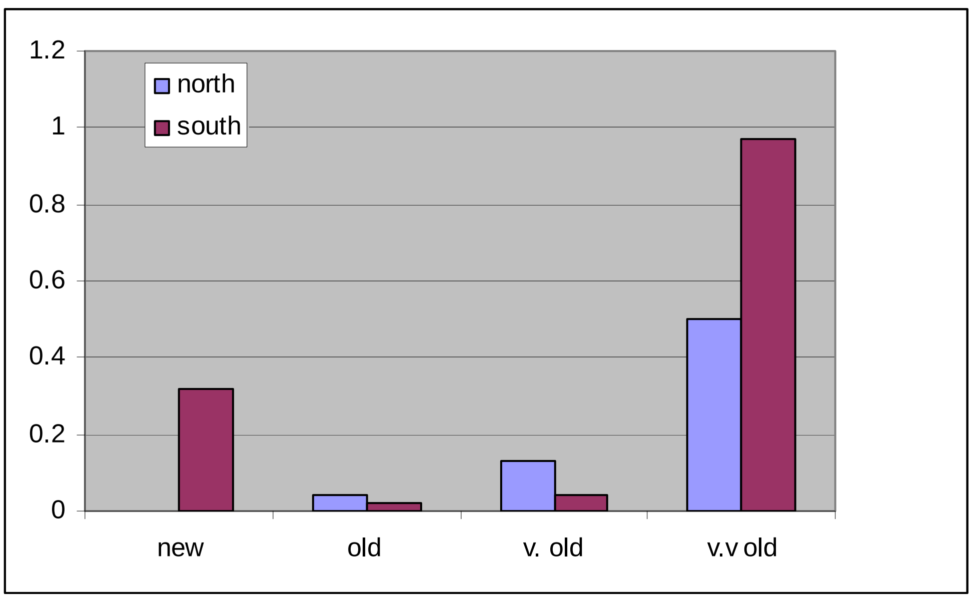

Figure 37. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

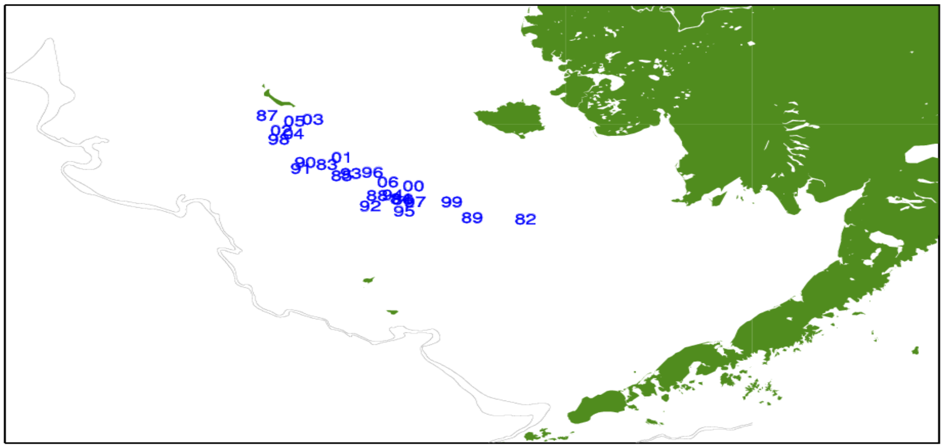

Figure 38. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

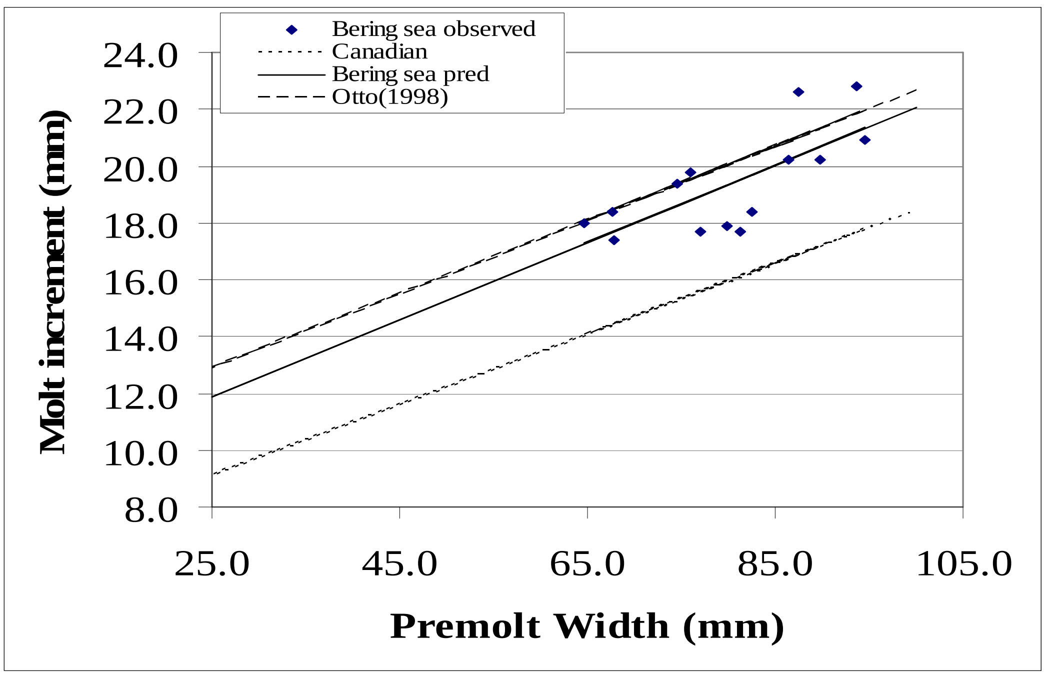

Figure 39. Growth increment as a function of premolt size for male snow crab. Points labeled Bering Sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering Sea pred is the predicted line from the Bering Sea observed growth, which is used as a prior for the growth 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.

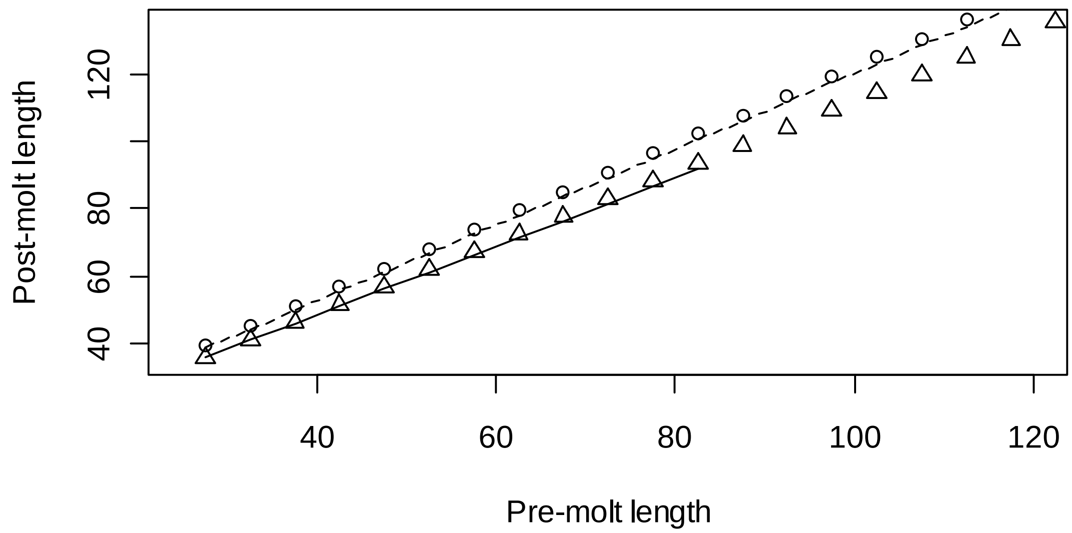

Figure 40. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the model. Circles are the observed growth curve.

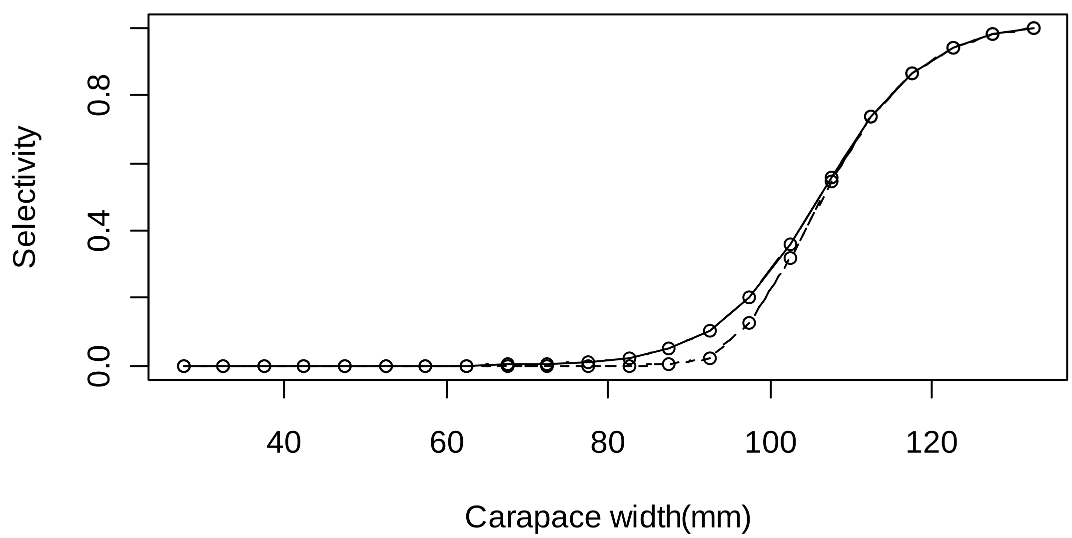

Figure 41. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

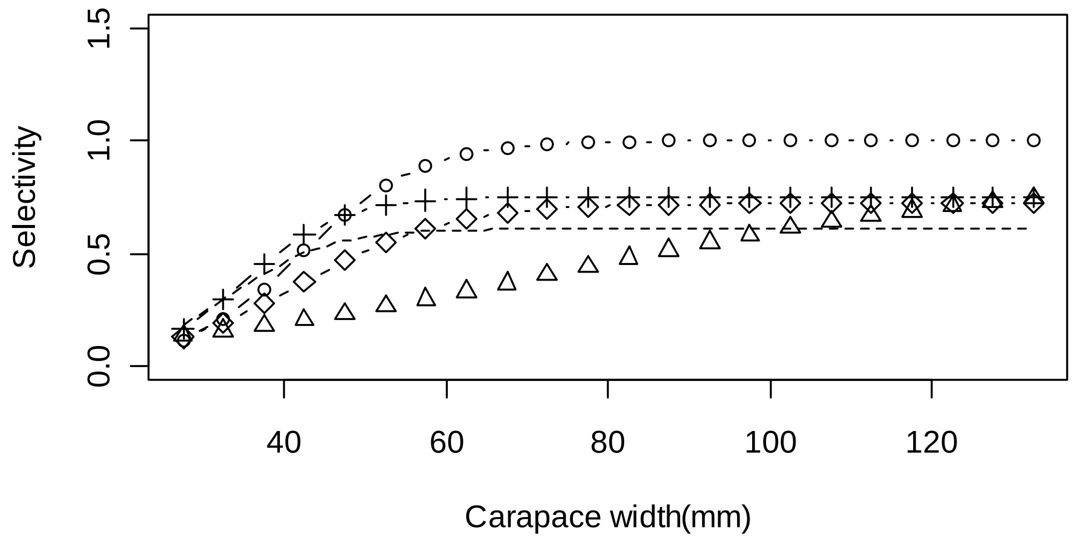

Figure 42. Survey selectivity curves for female (dotted lines) and male snow crab (solid lines) estimated by the model for 1978-1981(circles), for 1982 to 1988 (diamonds), and 1989 to present (pluses). Survey selectivities estimated by Somerton from 2009 study area data (2010) are the triangles.

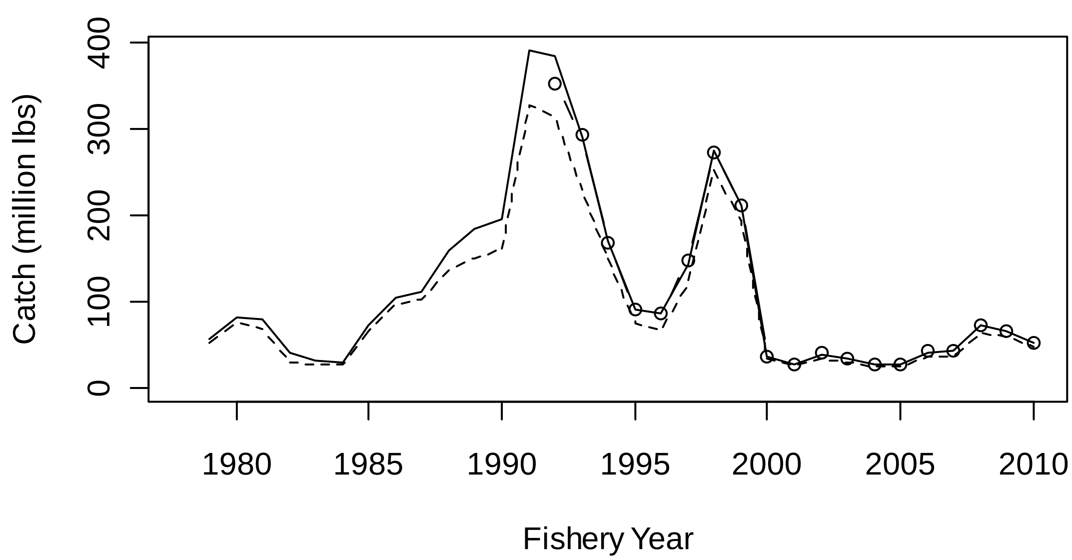

Figure 43. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 50% mortality of discarded crab) and observed retained catch (dotted line) for 1979 to 2008 fishery seasons.

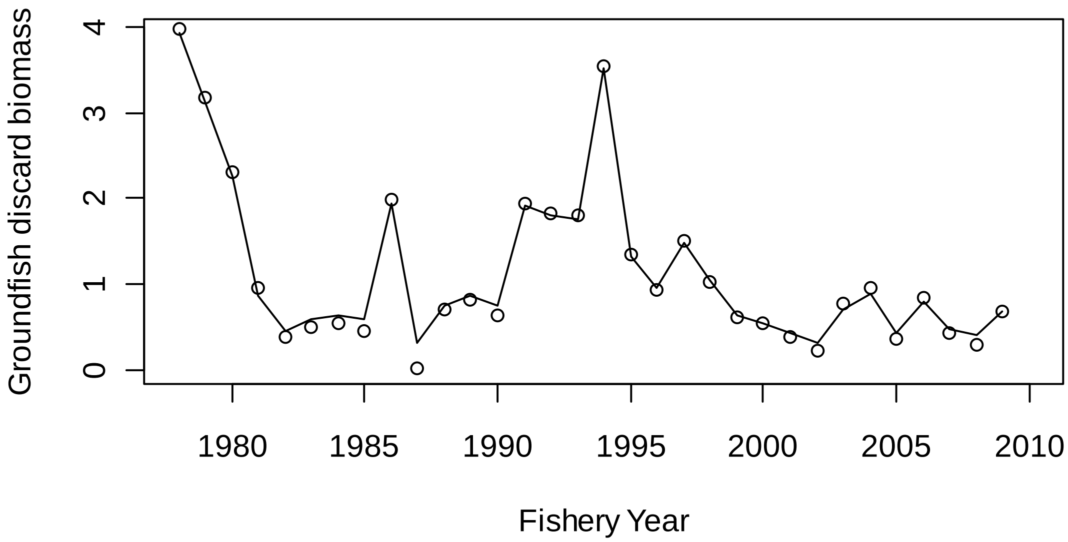

Figure 44. Model fit to groundfish bycatch from 1978 to 2009. Circles are observed catch, line is model estimate.

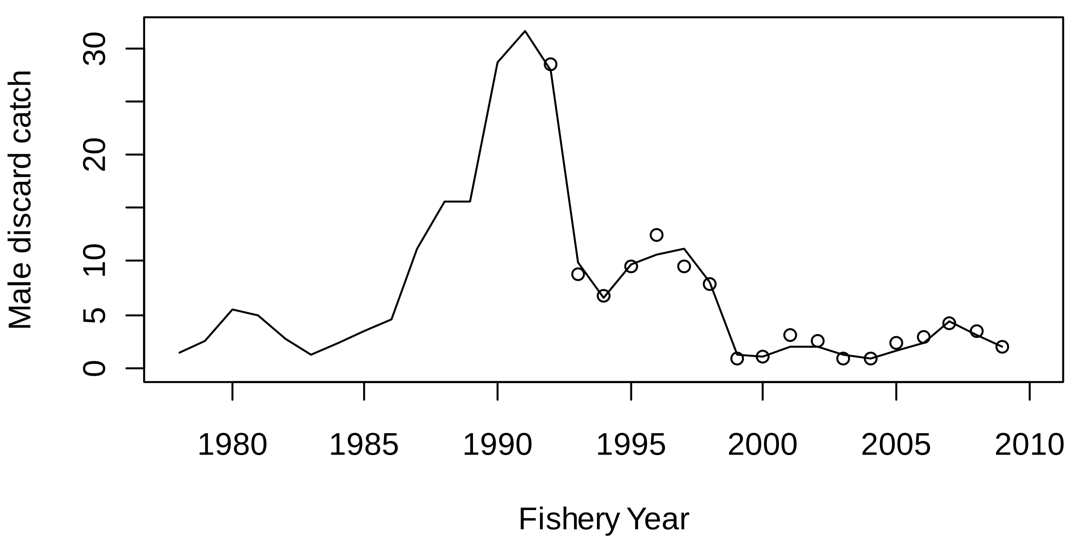

Figure 45. Model fit to male directed discard catch for 1992 to 2009 and estimated male discard catch from 1978 to 1991.

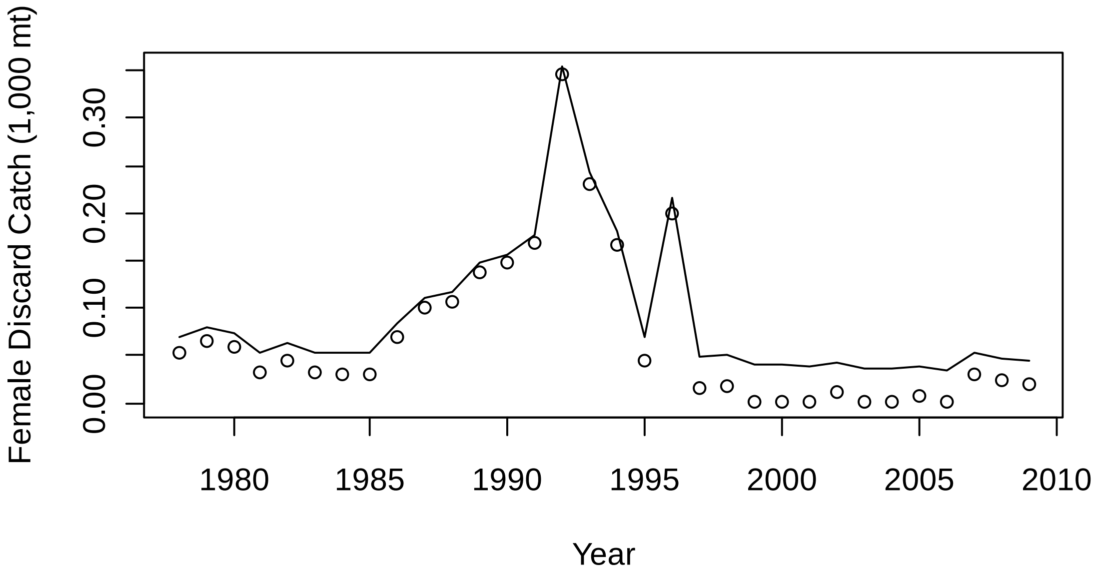

Figure 46. Model fit to female discard bycatch in the directed fishery from 1992 to 2009 and model estimates of discard from 1978 to 1991.

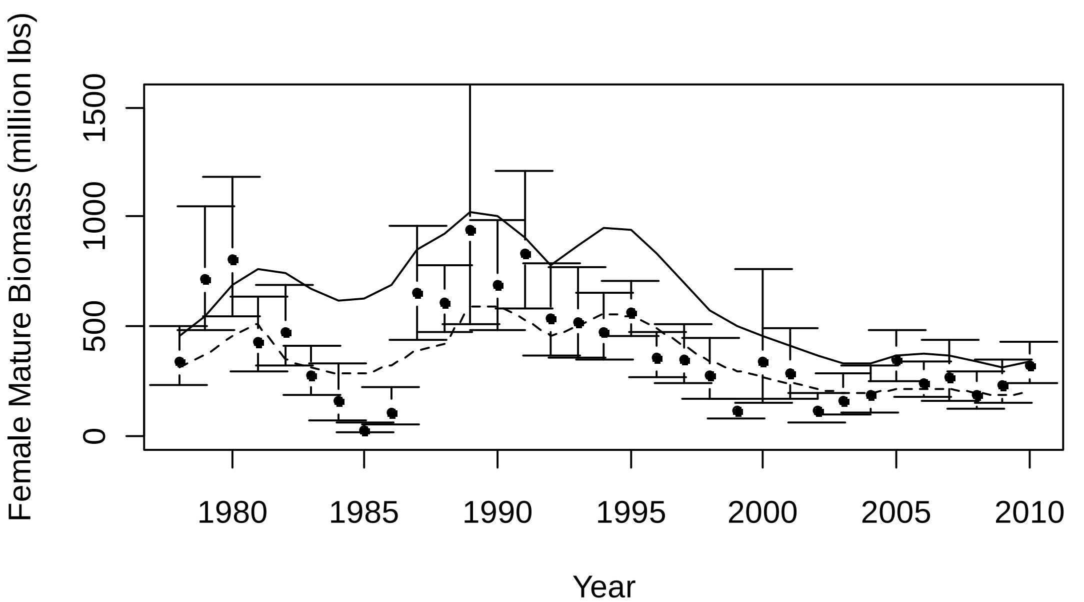

Figure 47. Population female mature biomass (millions of pounds, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

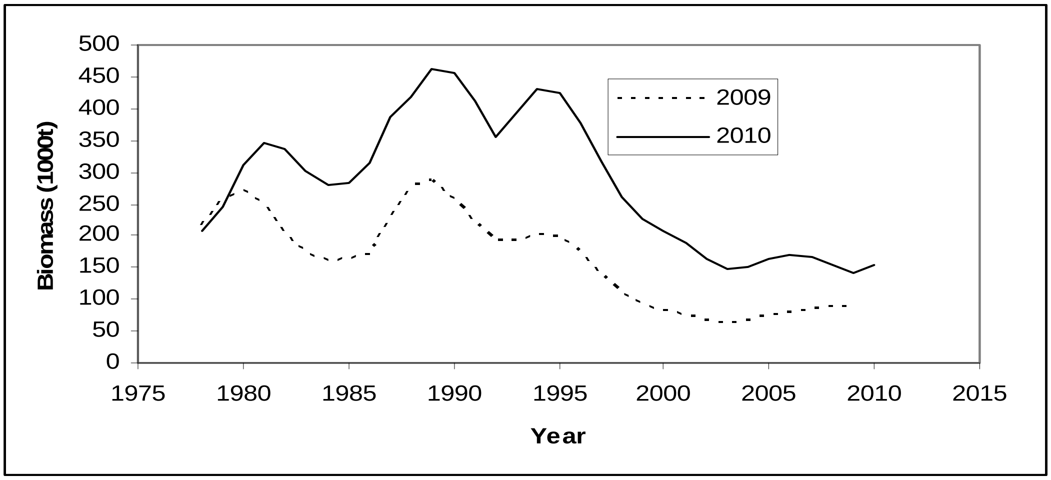

Figure 48. Population female mature biomass from the September 2009 and September 2010 assessment.

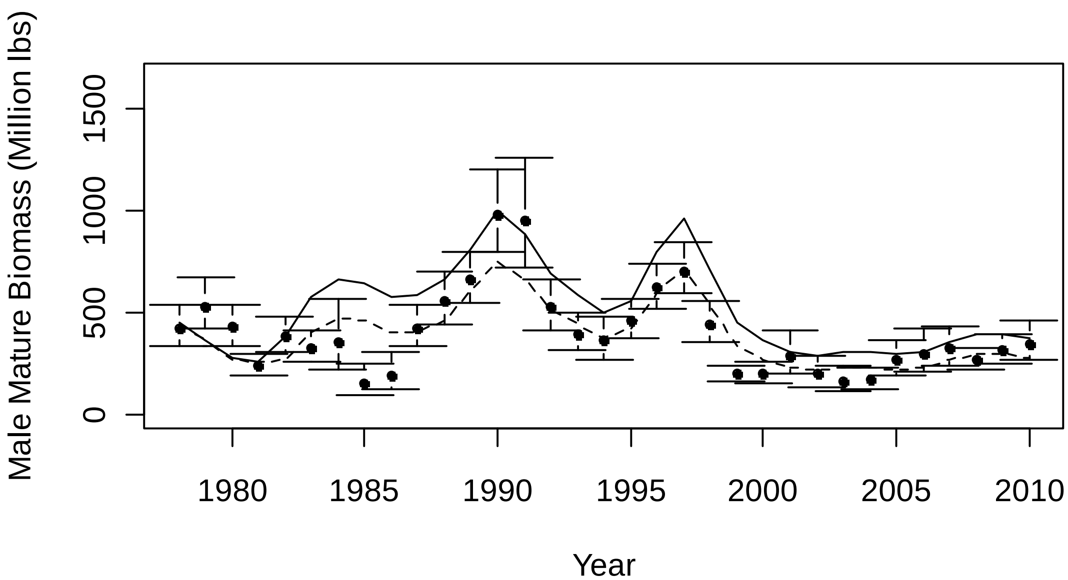

Figure 49. Population male mature biomass (millions of pounds, solid line), model estimate of survey male mature biomass (dotted line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

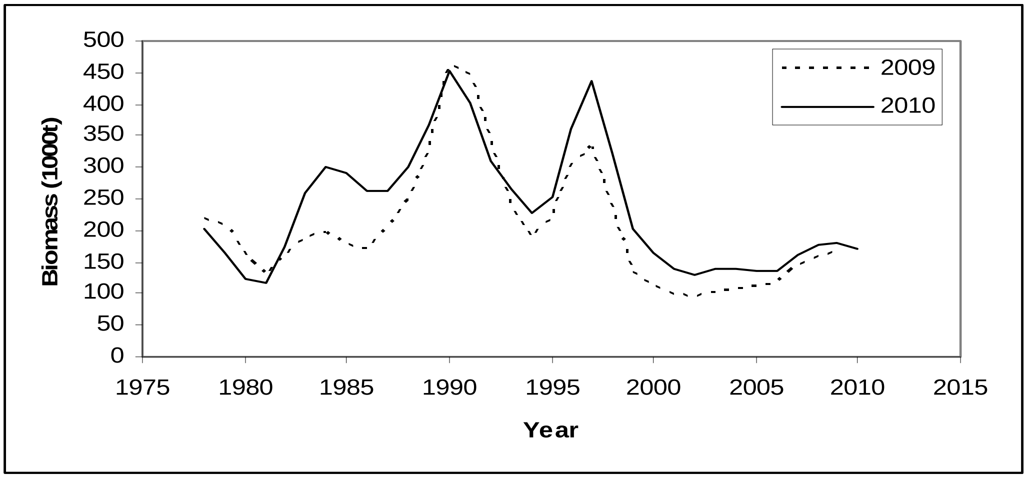

Figure 50. Population male mature biomass from the September 2009 assessment and the September 2010 assessment.

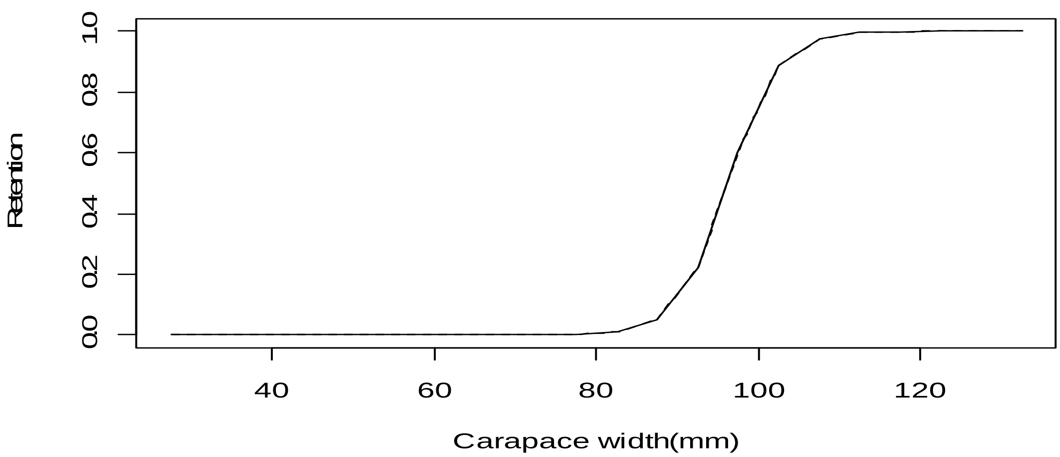

Figure 51. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

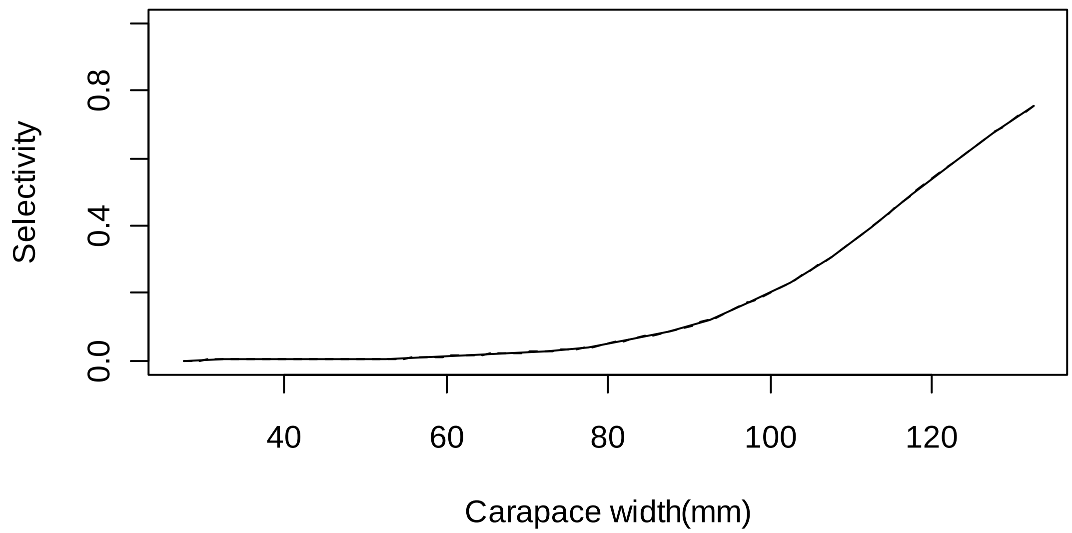

Figure 52. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

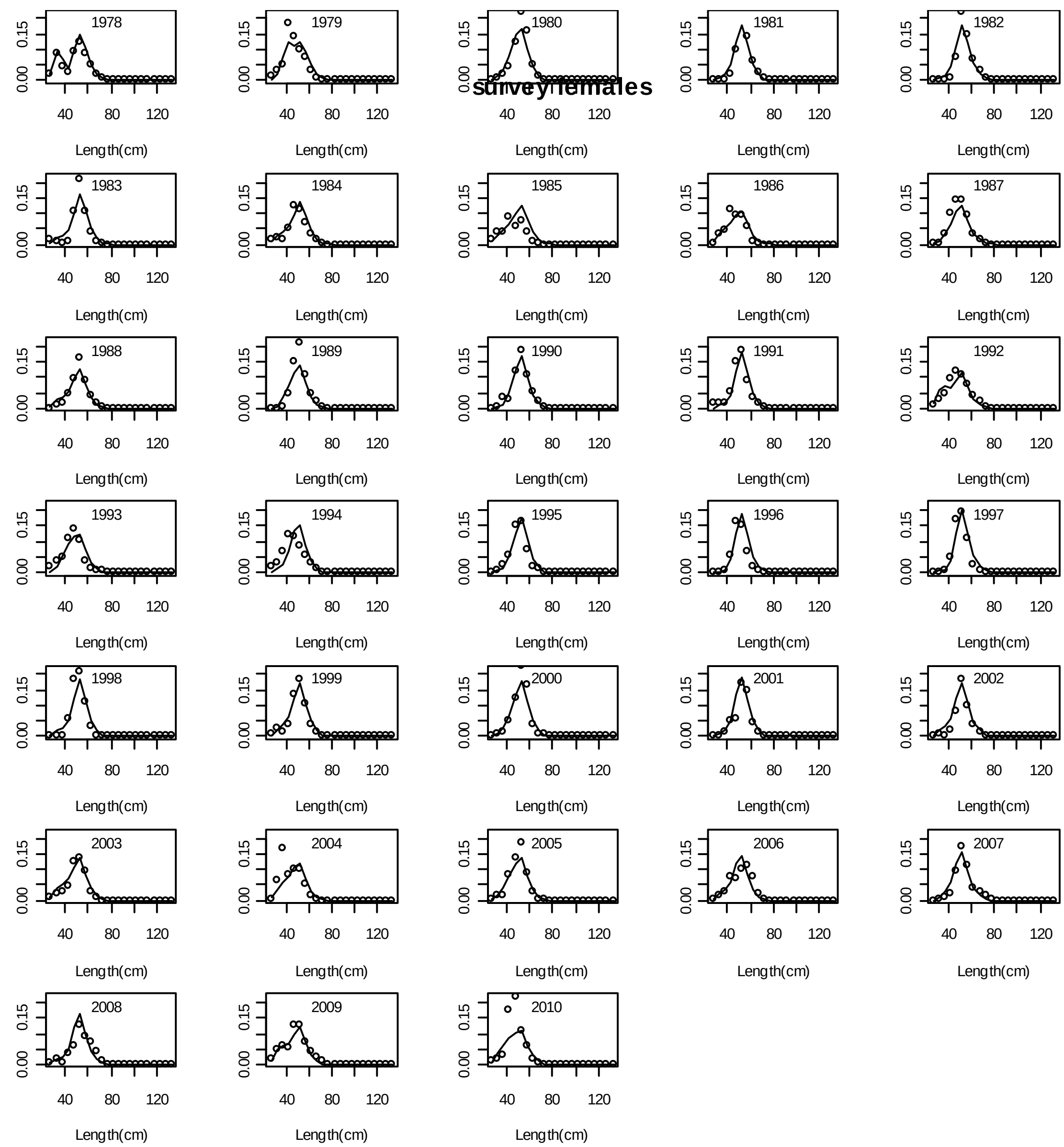

Figure 53. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

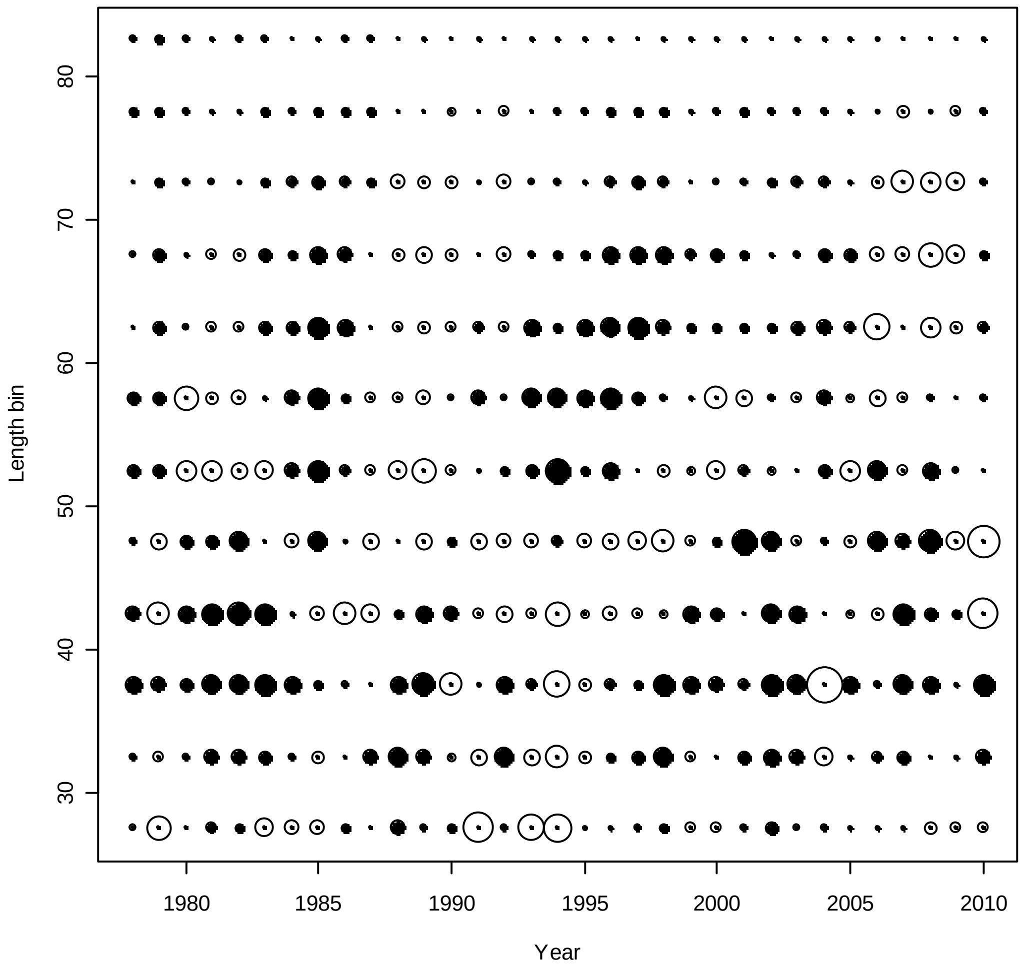

Figure 54. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

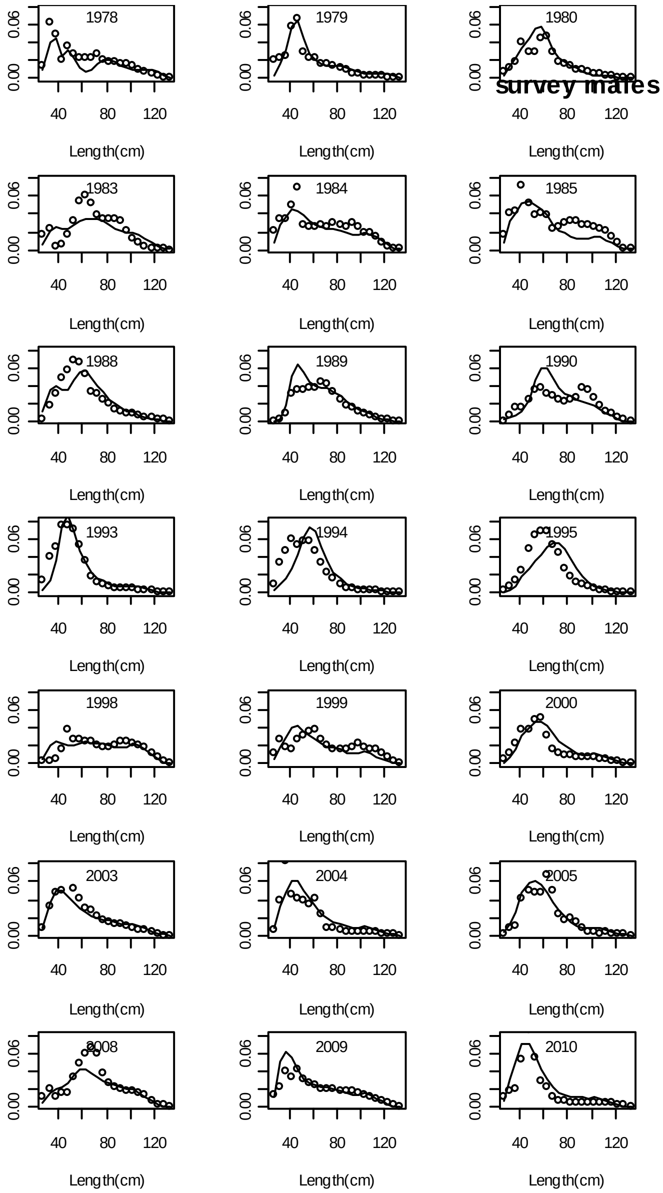

Figure 55. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

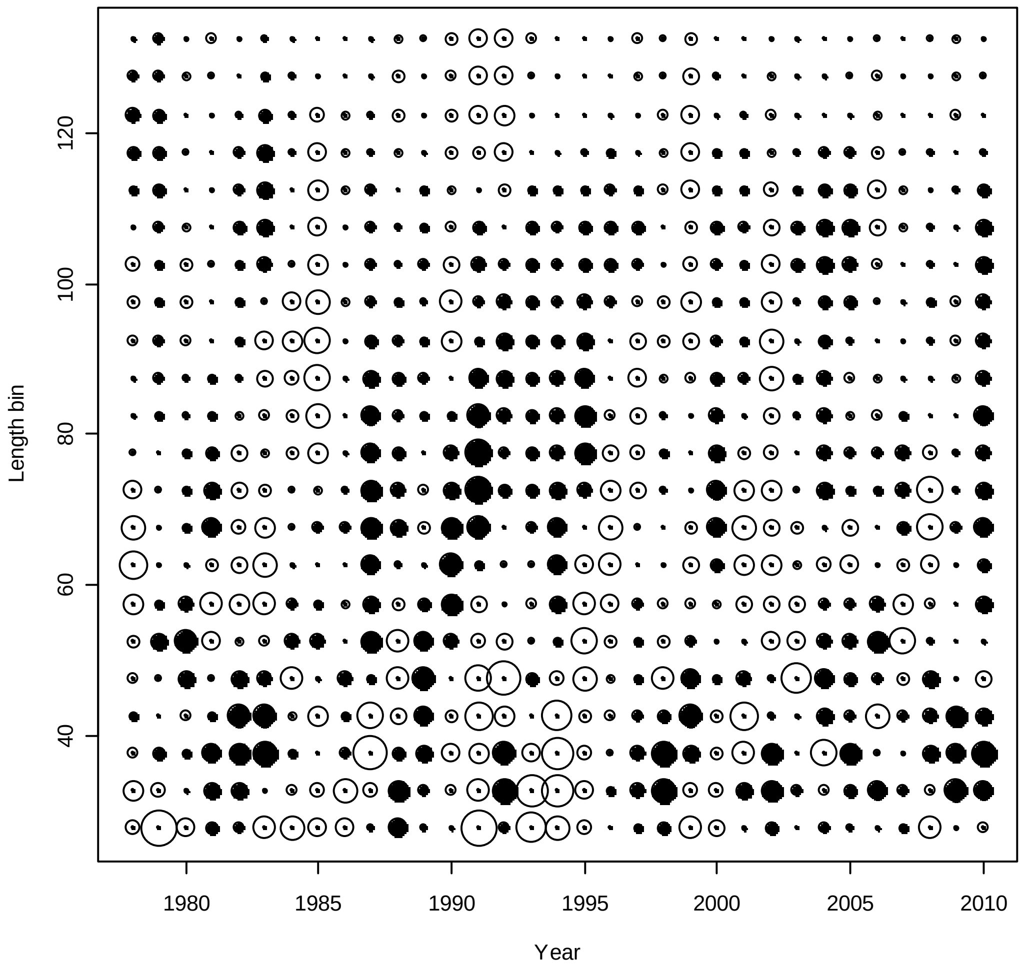

Figure 56. Residuals for fit to survey male size frequency. . Filled circles are negative residuals (predicted higher than observed).

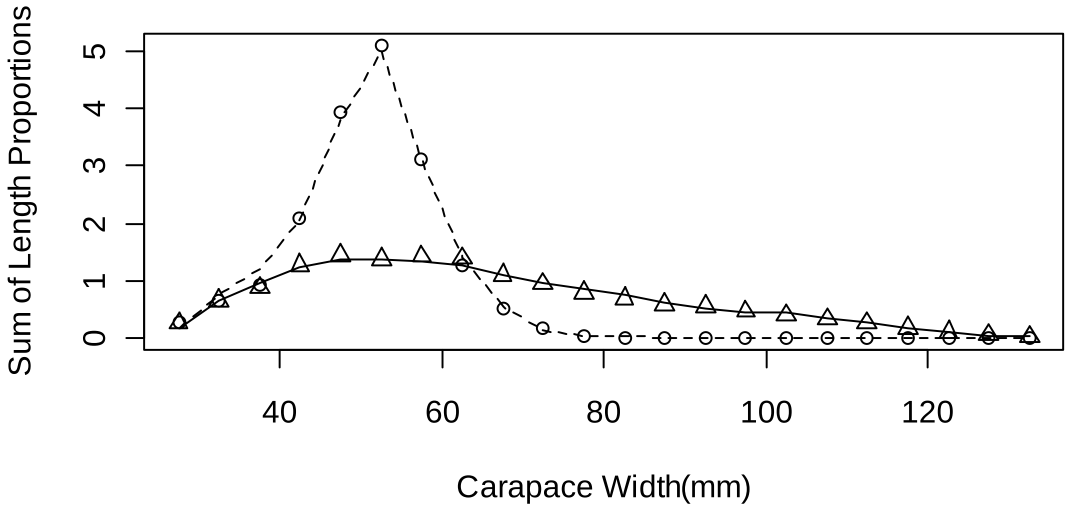

Figure 57. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

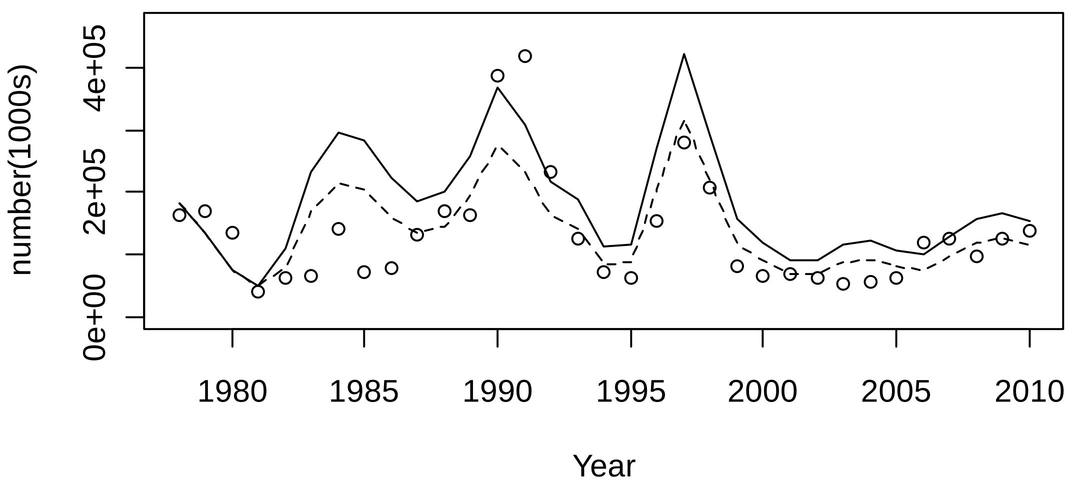

Figure 58. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

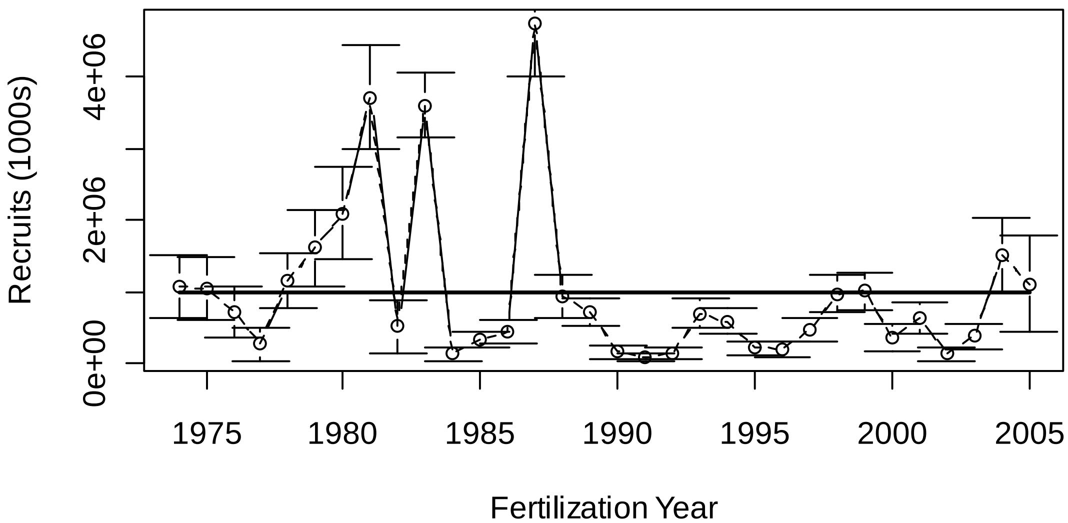

Figure 59. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

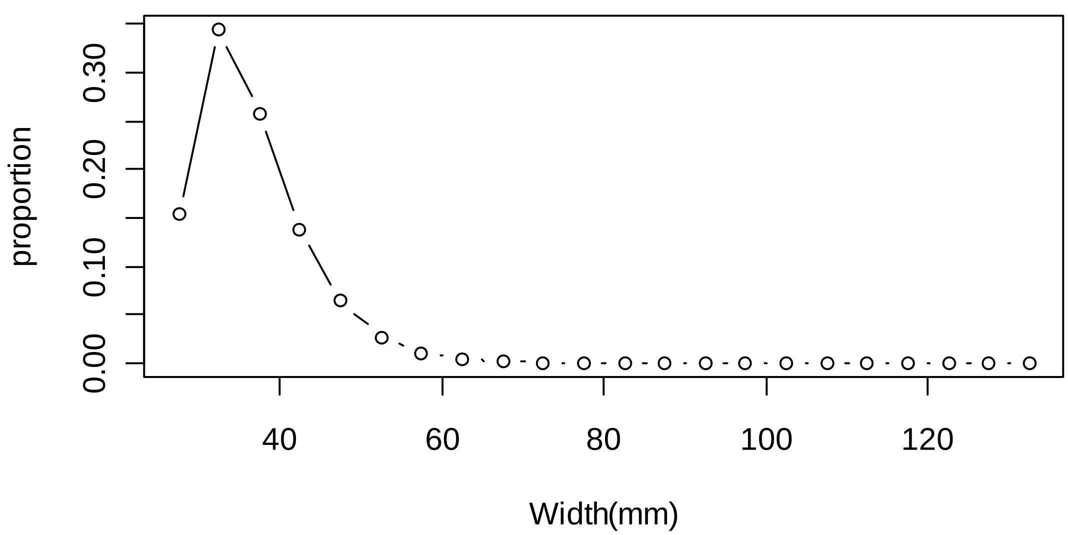

Figure 60. Distribution of recruits to length bins estimated by the model.

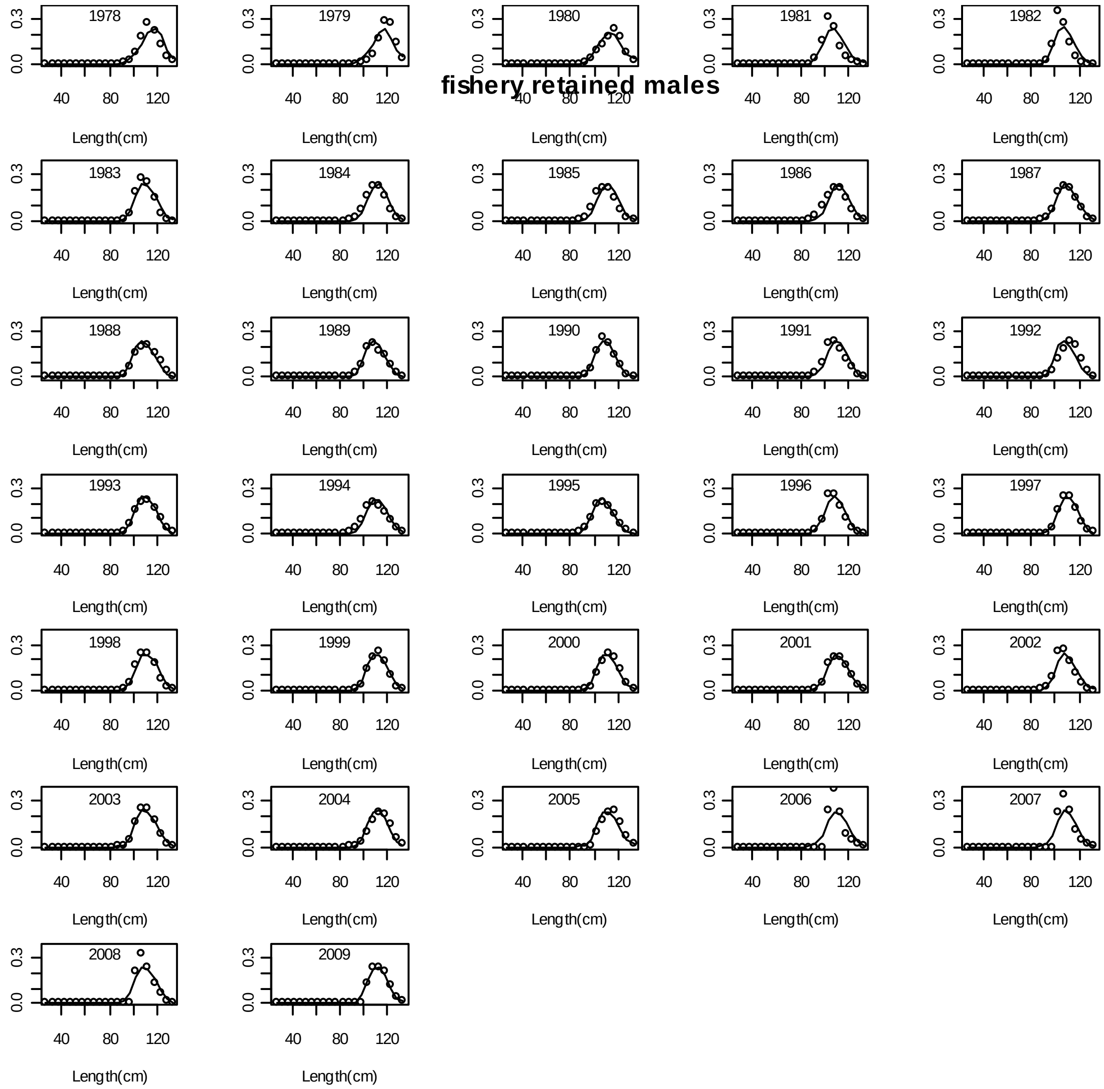

Figure 61. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

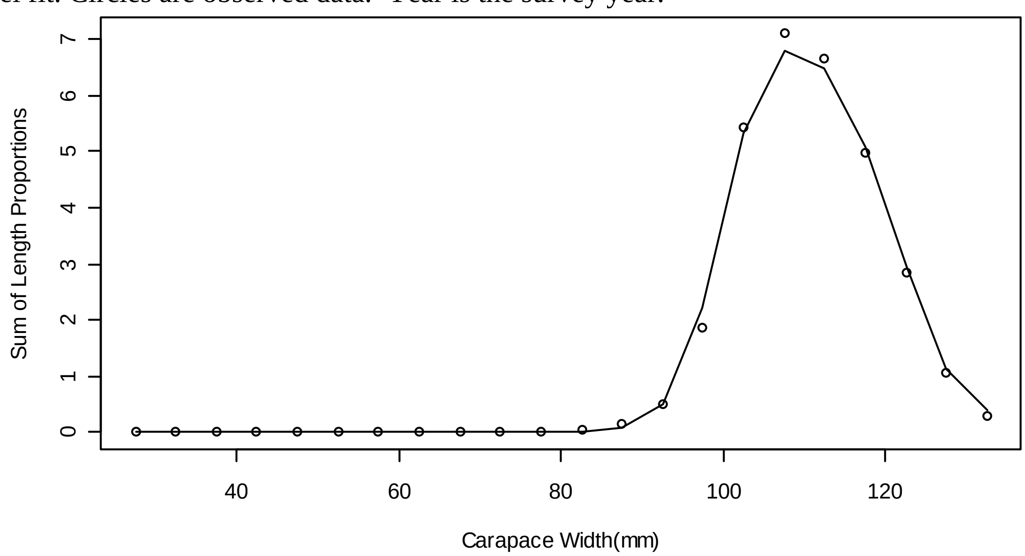

Figure 62. Summary fit to retained male length.

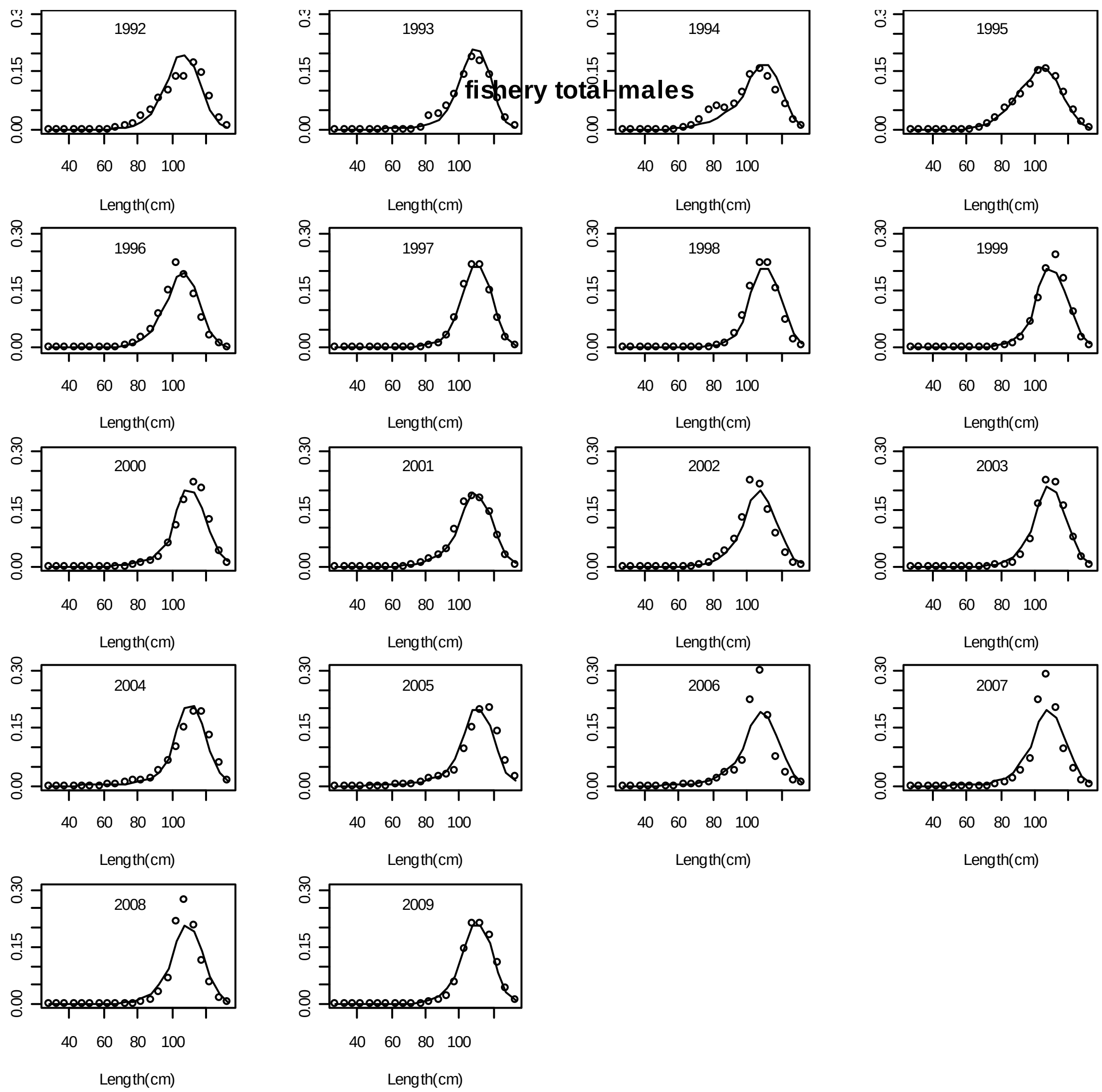

Figure 63. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

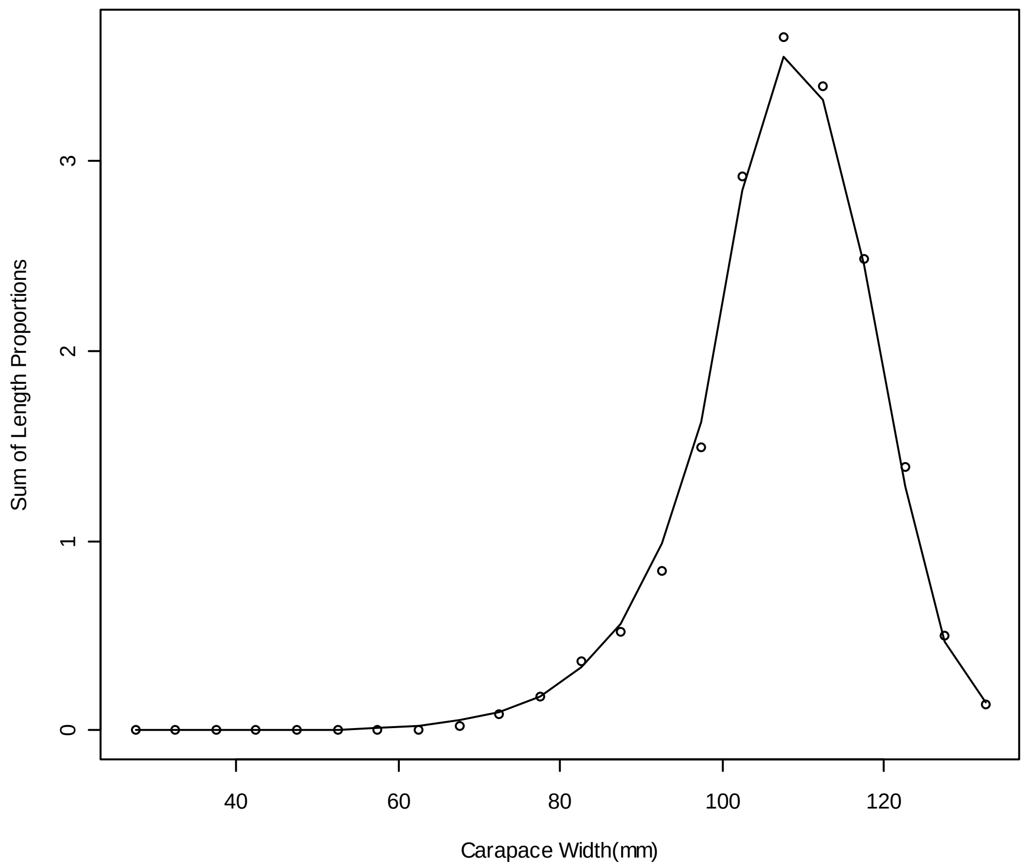

Figure 64. Summary fit to total length frequency male catch.

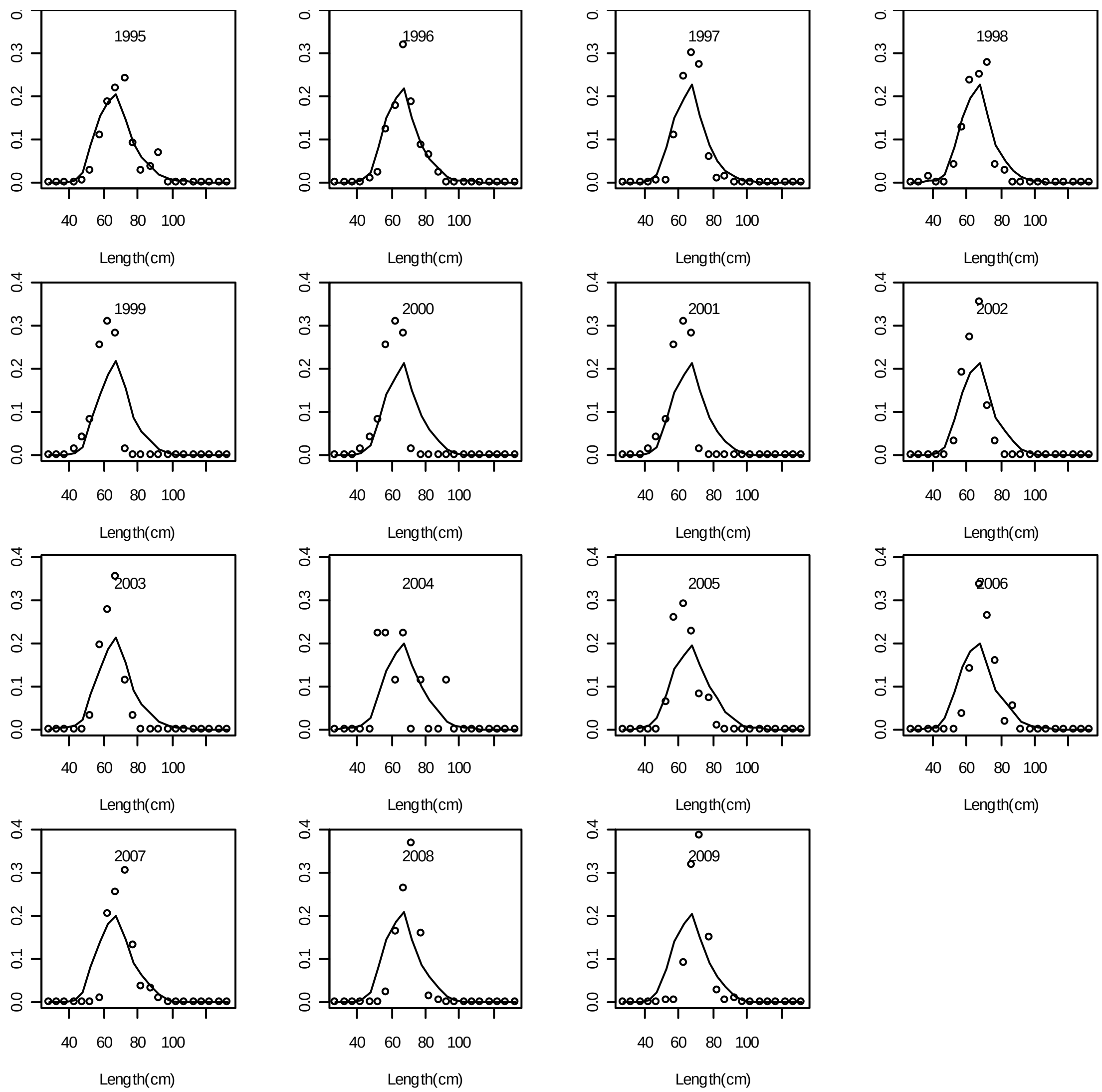

Figure 65. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

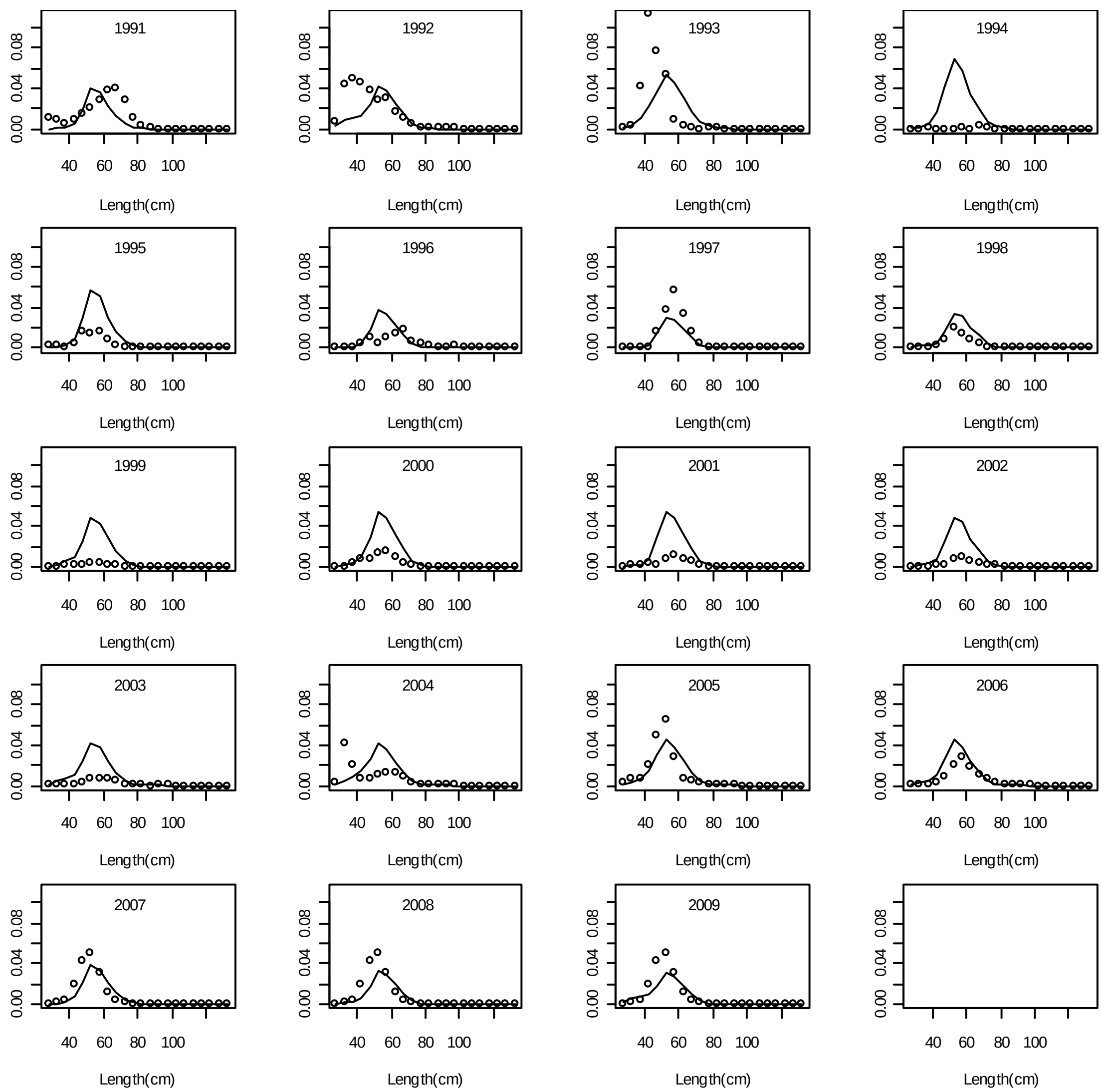

Figure 66. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

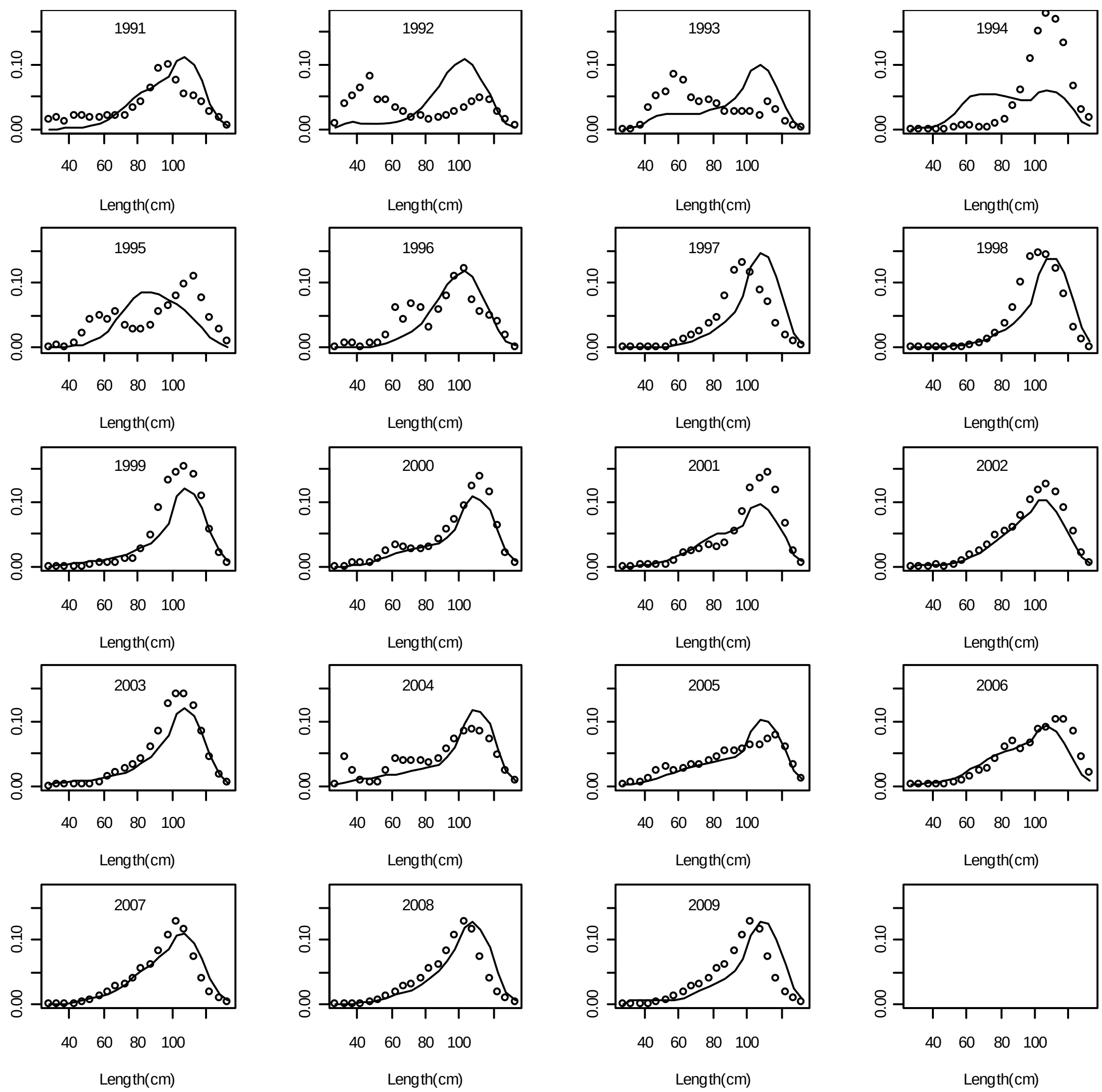

Figure 67. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

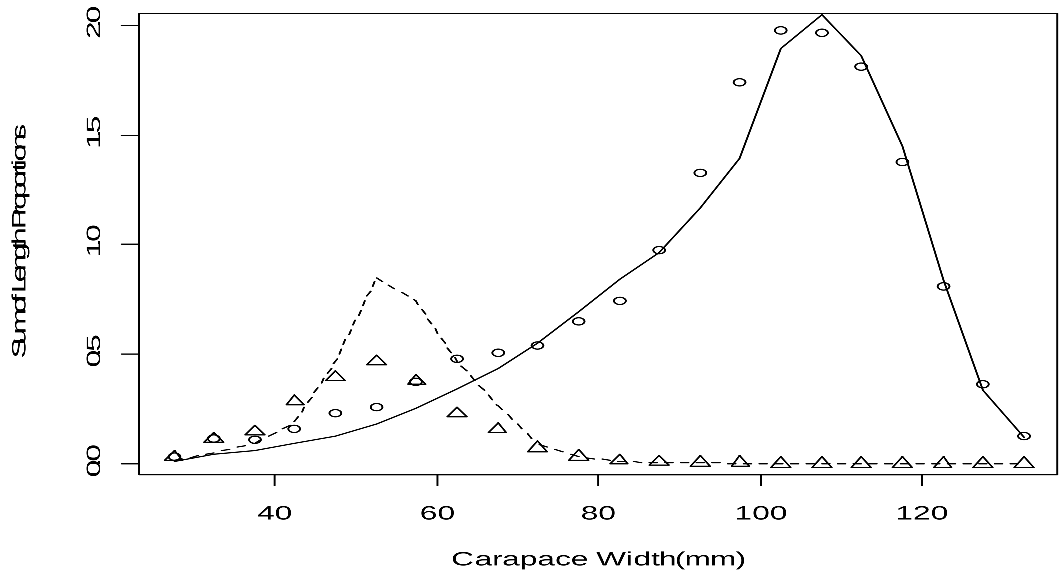

Figure 68. Summary fit to groundfish length frequency.

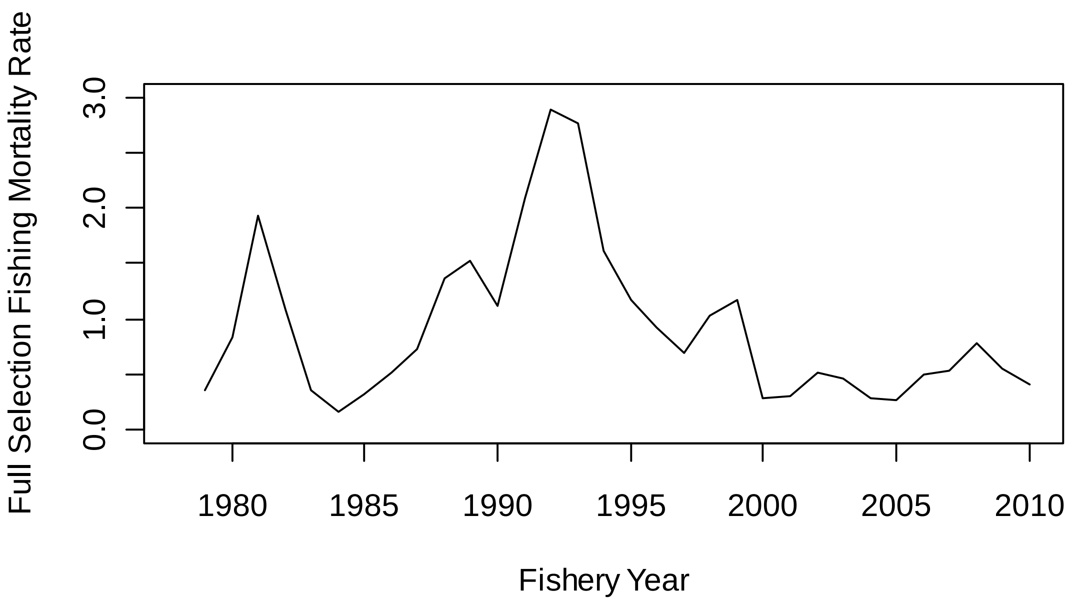

Figure 69. Full selection fishing mortality estimated in the model from 1979 to 2010 fishery seasons (1978 to 2009 survey years).

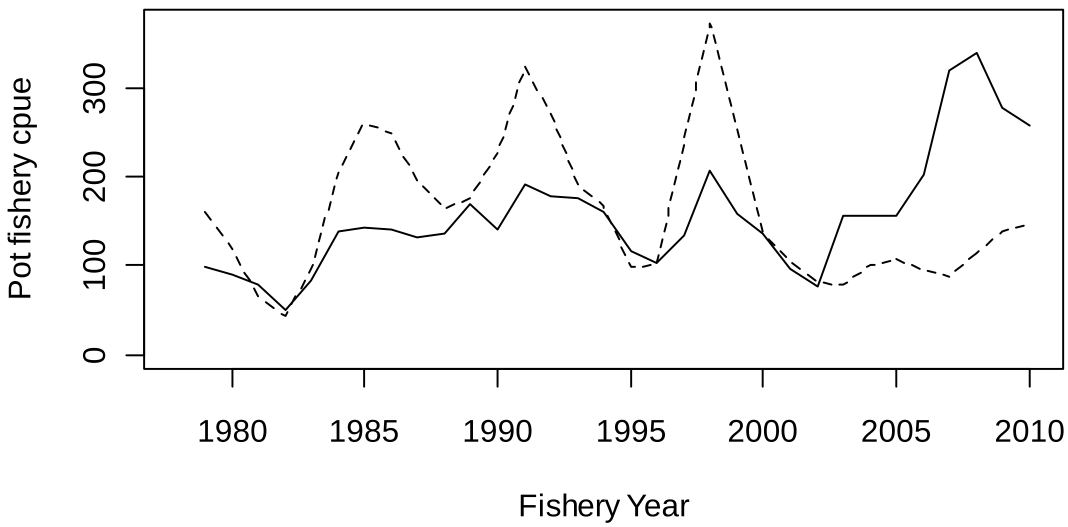

Figure 70. Fit to pot fishery cpue for retained males. Solid line is observed fishery cpue, dotted line model fit.

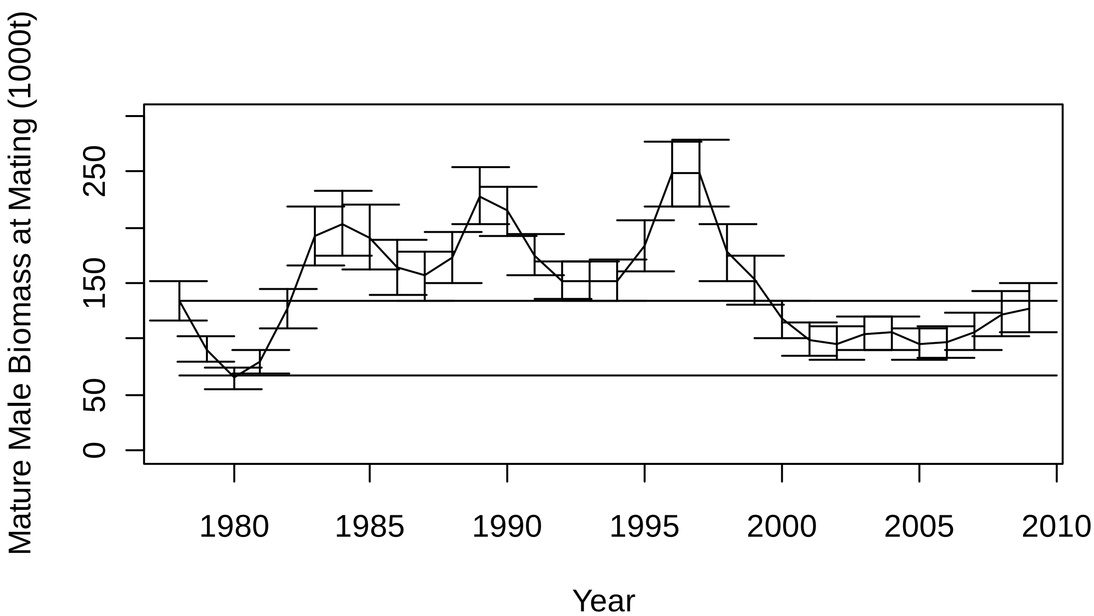

Figure 71. Mature Male Biomass at mating with 95% confidence intervals. Top horizontal line is B35%, lower line is ½ B35%.

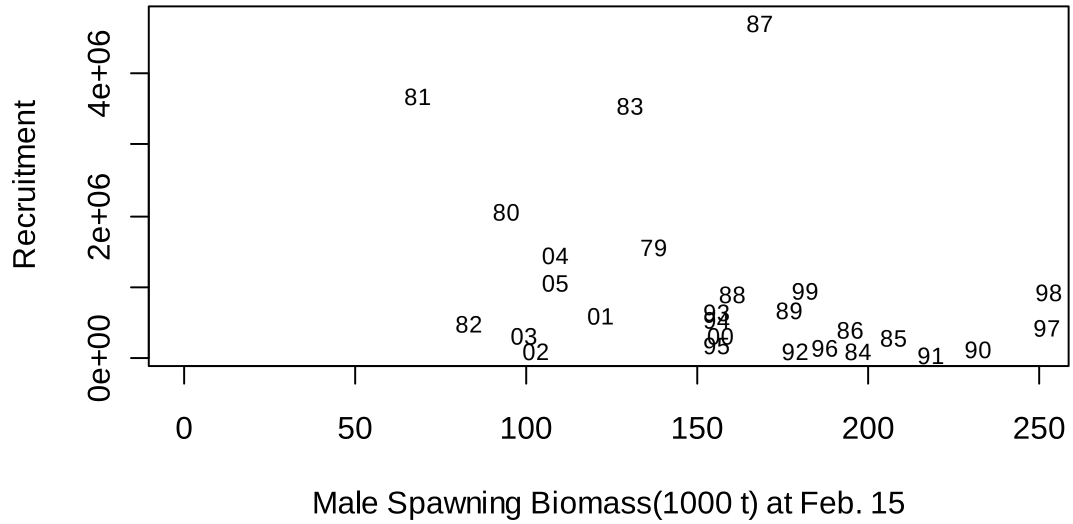

Figure 72. Spawner recruit estimates using male mature biomass at time of mating (1000s tons). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

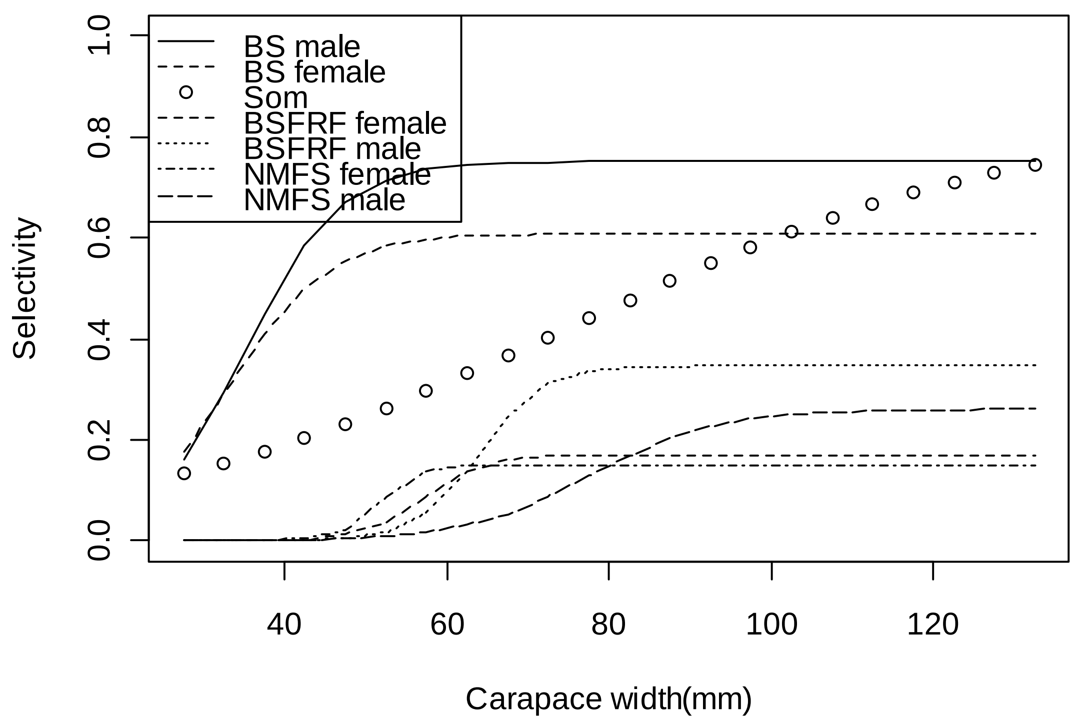

Figure 73. Survey selectivity curves entire Bering Sea survey for female (upper dashed line) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton from 2009 study area data (2010) are the circles. Lower lines are survey selectivities in the study area for BSFRF male and female crab and NMFS male and female crab.

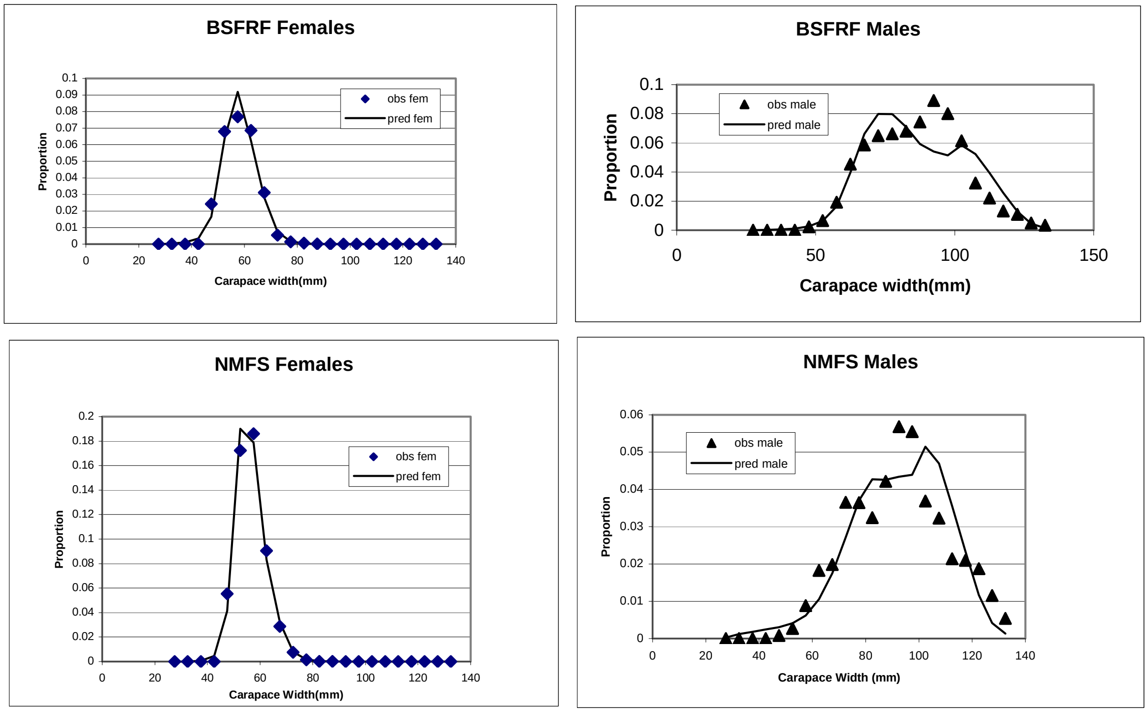

Figure 74. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

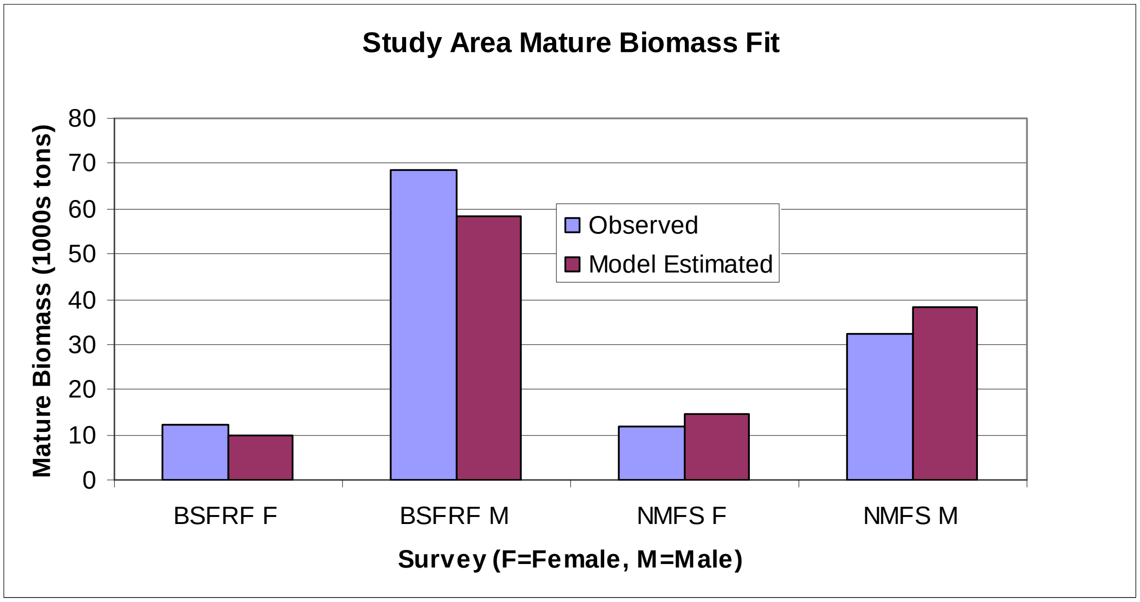

Figure 75. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

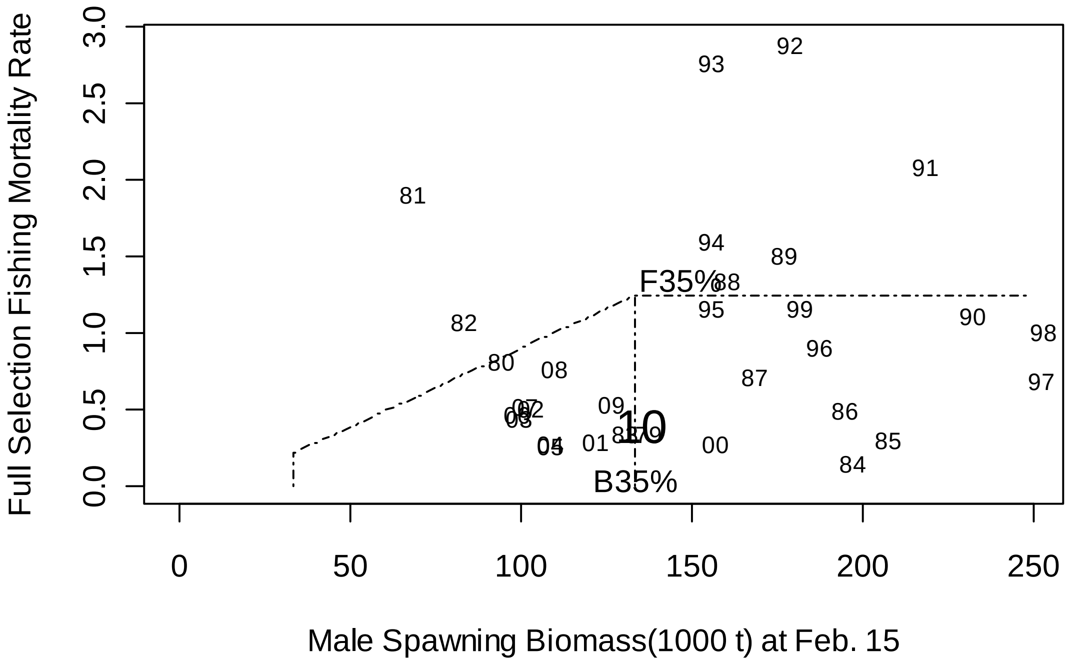

Figure 76. Fishing mortality estimated from fishing years 1979 to 2009/10 (labeled 10 in the plot). The OFL control rule (F35%) is shown for comparison. The pre-2000 target F was about 1.1. The vertical line is B35%, estimated from the product of spawning biomass per recruit fishing at F35% and mean recruitment from the stock assessment model.

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2010

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Executive Summary

1. Stock: red king crab (RKC), *Paralithodes camtschaticus,* in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades. Catches during recent years were among the high catches in last 15 years. The retained catch was about 4 million lbs (1,814 t) 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 4.4 times more abundant in 2010 than in 1985 and mature males being 2.8 times more abundant in 2010 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 1985-2010, 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
2006/07		82.0[A]	15.5	15.7	17.2	N/A
2007/08	37.6	85.9[B]	20.4	20.5	23.2	N/A
2008/09	34.3	96.4[C]	20.4	20.3	23.1	24.2
2009/10	31.4	99.6[D]	16.0	16.0	18.3	22.6
2010/11		83.1[E]	NA	NA	NA	23.5

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 and updated with 2008/09 catch
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2009 and updated with 2009/10 catch
E – Calculated from the assessment reviewed by the Crab Plan Team in September 2010

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	96.4	1.27	0.33	1995–2008	0.18
2009/10	3a	68.5	99.6	1.39	0.32	1995–2009	0.18
2010/11	3a	62.7	83.1	1.33	0.32	1995-2010	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 and 2009 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 1.857 during 1968-1977 and 0.356 during 1978-2010.

A. Summary of Major Changes

1. Change to management of the fishery: None.

2. Changes to the input data:

a. Catch and bycatch were updated through August 2010 and the 2010 summer trawl survey data were added.

3. Changes to the assessment methodology:

None.

4. Changes to assessment results:

Male abundance from the 2010 summer trawl survey was lower than expected. Estimated mature male abundance and biomass in 2010 were about 7% lower than those in 2009. Estimated crab abundance and biomass during recent five years were slightly lower than those estimated in 2009.

B. Responses to SSC and CPT Comments

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

Response to CPT Comments (from May 2010)

"Each stock assessment author should remove the ecosystem section of their chapter and provide it to Liz Chilton for incorporation into the ecosystem consideration chapter."

The ecosystem section of the report has been removed and provided to Liz Chilton.

Response to SSC Comments (from June 2010)

"The SSC requests that the Crab Plan Team and stock assessment authors for red king crab chapters either justify differences between stocks in handling mortality rates for crab pot discards, or adopt a single rate. In order to have greater consistency between assessments, the SSC recommends that catch statistics reported in the executive summary section contain both metric tons and pounds (millions).

It would be useful to consider presenting results from the newly developed projection models for stocks during the next assessment cycle. For example, the SSC notes that the projection model for Pribilof red king crab could be interpreted as an indication that the stock is approaching an overfished condition. This information should be provided in the SAFE when the assessments are finalized in the fall, even though OFL determinations will be based on Tier 4 considerations."

Recent catches reported in the executive summary section were given in both millions of pounds and metric tons. Pot handling mortality rates for Bristol Bay red king crab and Norton Sound red king crab are assumed to be 0.2. Pot handling mortality rates for red king crab are estimated to be <0.06 from several studies. A higher value (0.2) is used to account for some uncertainties.

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

Response to CPT Comments (from May 2010)

"*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 BMSY time frames. The assessment author should provide alternatives and comment on the appropriateness of each."

The CPT and SSC comments on *likelihood profiles, Bayesian approach, effective sample sizes, CIE comments* will be addressed in May 2011. Alternative definitions for *Bmsy* time frames and detailed results on different scenarios will also be presented 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 re-examined. 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 constraints, the main effort focused on model scenarios in the May 2010 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 2010)

"The SSC agrees that Model 3 is suitable for basing stock status determination after the summer survey data are incorporated later this year. This model estimates additional natural mortality for males and females, uses the BSFRF survey, and does not estimate molting parameters. However, the SSC notes that Model 5, which sets additional mortality for females to 0, has a higher likelihood. This should not be possible, because Model 5 has one less parameter. This needs to be rechecked. It may be that these sex-specific differences in additional natural mortality are not needed. Also, the SSC recommends that the authors consider using AIC for model comparison for the sake of parsimony. (This can only be done when the same data are used."

Model 5 has the lowest log likelihood (55180) among all models (ranging from 55180 to 55806). AIC may be used for model comparison in May 2011.

"The SSC concurs with the CPT that the stock is in Tier 3. The SSC also agrees with the selected range of years, 1995 to the current year, for average recruitment and $B_{35\%}$. The SSC agrees with the authors' plan to continue to refine the model in terms of likelihood profiles for M and q, sensitivity to data weighting, use of Bayesian methods, and other topics described on pages 137 – 142 of the May 2010 SAFE."

These will be addressed in May 2011.

"The SSC notes that the time periods used for estimating survey selectivity do not match the time periods used for estimating survey catchability q. This does not seem realistic, since shifts in gear would be expected to influence both selectivity and q. The SSC requests that the authors examine a model with common time periods for q and selectivity. "

The survey catchability is not estimated except during 1970-1972. The catchability from the double-bag experiment was used for all periods except 1970-1972. The authors tried to estimate three sets of survey catchability and selectivity; however, parameter confounding seems to be a problem with estimating too many sets of survey catchability. There seems to be a gear problem with the surveys in 1970-1972, so a separate set of catchability and selectivity was estimated.

"On page 165, the author states that one explanation of the extra female mortality during 1976 through 1979 and 1985 through 1993 was increased bycatch (among other things). If the primary cause of the additional mortality is thought to be bycatch mortality, then this should be modeled as female fishing mortality, rather than natural mortality, because the fishery impact would be over a discrete season, rather than an entire year. At a minimum, it should clarify and justify how the additional mortality was modeled."

Extra mortality seems to be an issue worth further investigation in the future.

"On the bottom of page 166, the SSC notes that the pot male fishing mortality rate in the SAFE is not correct. This value should be 0.2. "

The handling mortality rate is 0.2. However, the pot female fishing mortality rate is about 2% of those for males.

"The SSC notes that the values for 2009/10 OFL in the SAFE chapter and the ACL document do not match. The author should explain the reason for the difference."

We think that we finally got them almost the same. The difference is from the earlier version of the ACL analysis, which has some different initial conditions and weightings.

"For the Ecosystem Considerations chapter, the importance of king crab consumption of fish discards should be examined. This has been observed in the Barents Sea, where king crab distribution overlaps intensive fishing activity (G. Hunt, pers. comm.). Thus, it would be interesting to examine trajectories of crab populations in relation to the amount of groundfish discards."

This is an interesting observation. We will explore this issue in the future.

"If time permits, it would be useful for the CPT and SSC to see the CIE review report at their September/October 2010 meetings."

We attach the CIE review reports here. We will discuss the approach with the CPT on how to address the CIE comments.

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 constraints, 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 the EFH analysis.

C. Introduction

1. Species

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

2. General distribution

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

3. Stock Structure

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

4. Life History

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

RKC larval duration and juvenile crab growth are dependent on temperature (Stevens 1990; Stevens and Swiney 2007). RKC mature at 5–12 years old, depending on stock and temperature (Stevens 1990) and may live >20 years (Matsuura and Takeshita 1990), with males and females attaining a maximum size of 227 and 195 mm carapace length (CL), respectively (Powell and Nickerson 1965). For management purposes, females >89 mm CL and males > 119 mm CL are assumed to be mature for Bristol Bay RKC. Juvenile RKC molt multiple times per year until age 3 or 4, thereafter molting continues annually in females for life and in males until maturity. After maturing, male molting frequency declines.

5. Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States (Bowers et al. 2008). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974 (Bowers et al. 2008). The Russian fleet fished for RKC from 1959 through 1971. The Japanese fleet employed primarily tanglenets with a very small proportion of catch from trawls and pots. The Russian fleet used only tanglenets. United States trawlers started to fish for Bristol Bay RKC in 1947, and effort and catch declined in the 1950s (Bowers et al. 2008). The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t), worth an estimated $115.3 million ex-vessel value (Bowers et al. 2008). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades (Table 1). After the stock collapse in the early 1980s, the Bristol Bay RKC fishery took place during a short period in the fall (usually lasting about a week), with the catch quota based on the stock assessment conducted in the previous summer (Zheng and Kruse 2002). As a result of new regulations for crab rationalization, the fishery was open longer 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).

6. Fisheries Management

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

D. Data

1. Summary of New Information

New data include commercial catch and bycatch in 2009/2010 and the 2010 summer trawl survey.

2. Catch Data

Data on landings of Bristol Bay RKC by length and year and catch per unit effort were obtained from annual reports of the International North Pacific Fisheries Commission from 1960 to 1973 (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the ADF&G from 1974 to 2008 (Bowers et al. 2008). Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Bowers et al. 2008; Burt and Barnard 2006). Sample sizes for catch by length and shell condition are summarized in Table 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.

3. NMFS Survey Data

The NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conduct this multispecies, crab-groundfish survey during the summer. Stations are sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of $\approx$140,000 nm^2. Since 1972 the trawl survey has covered the full stock distribution except nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2009 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 older NMFS abundance estimates (Stevens et al. 1991). In this study, all tow data were used. NMFS re-estimated historic areas-swept in 2008 and re-estimated area-swept abundance as well, using all tow data. 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, 2006-2010: the standard survey that was performed in late May and early June (about two weeks earlier than historic surveys) in 1999 and 2000 and the standard survey that was performed in early June in 2006-2010 and resurveys of 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), 32 stations (2007-2009) and 23 tows (2010) with high female density that was performed in late July, about six weeks after the standard survey. The resurveys were necessary because a high proportion of mature females had not yet molted or mated prior to the standard surveys (Figure 6). Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000 because most mature females had not molted prior to the standard surveys. As in 2006, area-swept estimates of males >89 mm CL, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different between the standard survey and resurvey (P=0.74, 0.74 and 0.95) based on paired t-tests of sample means. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 are significantly different between the standard survey and resurvey (P=0.03) based on the t-test. 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).

4. Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay red king crab in 2007 and 2008 with a small-mesh trawl net and 5-minute tows. The surveys occurred at similar times with the NMFS standard surveys and covered about 97% of the Bristol Bay area. Few Bristol Bay red king crab were outside of the BSFRF survey area. Because of small mesh size, the BSFRF surveys 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 male abundances were estimated to be 22.331 and 19.747 million in 2007 and 2008 with a CV of 0.0634 and 0.0765.

E. Analytic Approach

1. History of Modeling Approaches

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, the ADF&G developed a length-based analysis (LBA) in 1994 that incorporates multiple years of data and multiple data sources in the estimation procedure (Zheng et al. 1995a). Annual abundance estimates of the Bristol Bay RKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995 (Figure 1). An alternative LBA (research model) was developed in 2004 to include small size groups for federal overfishing limits. The crab abundance declined sharply during the early 1980s. The LBA estimated natural mortality for different periods of years, whereas the research model estimated additional mortality beyond a basic constant natural mortality during 1976-1993. In this report, we present only the research model that was fit to the data from 1968 to 2010.

2. Model Description

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

b-f. See appendix.

g. Critical assumptions of the model:

   i. The 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).

   ii. Survey and fisheries selectivities are a function of length and were constant over shell condition. Selectivities are a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Four different survey selectivities were estimated: (1) 1968-69 (surveys at different times), (2) 1970-72 (surveys without a footrope chain), (3) 1973-1981, and (4) 1982-2009 (modifying approaches to surveys).

   iii. Growth is a function of length and did not change over time for males. For females, three growth increments per molt as a function of length were estimated based on sizes at maturity (1968-1982, 1983-1993, and 1994-2010). Once mature, female red king crabs grow with a much smaller growth increment per molt.

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

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

vi. Survey catchability (Q) was estimated to be 0.896, based on a trawl experiment by Weinberg et al. (2004). Q was assumed to be constant over time except during 1970-1972. Q during 1970-1972 was estimated in the model.

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

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

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

3. Model Selection and Evaluation

a. Alternative model configurations:

Only one base scenario was run for this report. It is scenario 3 from the May SAFE report: 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. We called this scenario 3a because we also added and estimated a CV for BSFRF data, which we called scenario 3b. Unless indicated, the tables and figures are all for scenario 3a.

b. Progression of results: NA.

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

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

e. Sample sizes for length composition data. Estimated sample sizes and effective sample sizes are summarized in tables.

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

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

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

i. Model evaluation is provided under Results, below.

4. Results

a. Effective sample sizes and weighting factors.

i. 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 7. 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.

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

b. Tables of estimates.

   i. Parameter estimates are summarized and provided in Tables 5 and 6.

   ii. Abundance and biomass time series are provide in Table 7.

   iii. Recruitment time series are in Table 6.

   iv. Time series of catch/biomass are in Tables 1 and 4.

   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 8). 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).

c. Graphs of estimates.

   i. Selectivities and molting probabilities by length are provided in Figures 8 and 9.

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

   Estimated molting probabilities during 1968-2009 (Figure 9) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell 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.

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

   Estimated survey biomass, mature male and female abundances without additional CV for the BSFRF data (scenario 3a) and with additional CV (scenario 3b) are generally similar except the male abundance and biomass in recent years (Figure 10). With additional CV, estimated male abundance and biomass are higher than without additional CV. Estimated additional CV value tends to be very large (>2.0), which makes the BSFRF data to be almost no influence on the abundance estimates. Since the estimated large CV is not realistic, we set an upper bound of 0.6 for this CV.

   The model did not fit the mature crab abundance directly and depicted the trends of the mature abundance well (Figure 10). Estimated mature crab 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 4.4 times more abundant in 2010 than in 1985 and mature males being 2.8 times more abundant in 2010 than in 1985 (Figure 10).

iii. Estimated recruitment time series are plotted in Figure 11.

iv. Estimated harvest rates are plotted against mature male biomass in Figure 12.

The average of estimated male recruits from 1995 to 2010 (Figure 11) and mature male biomass per recruit were used to estimate $B_{35\%}$. Alternative periods of 1968-present and 1985-present were compared in our previous report. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 12). Before the current harvest strategy was adopted in 1996, many fishing mortalities were above $F_{35\%}$ (Figure 12). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, 2007 and 2008 but below the $F_{35\%}$ limits in the other years.

Estimated full pot fishing mortalities ranged from 0.00 to 1.07 during 1968-2009 with estimated values over 0.40 during 1968-1981, 1986-1987, 1990-1991, 1993, and 1998 (Table 6, Figure 12). Estimated fishing mortalities for pot female bycatch and trawl bycatch were generally less than 0.06.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships (Figure 13a). Annual stock productivities are illustrated in Figure 13b.

Stock productivity (recruitment/mature male biomass) was much higher before the 1976/1977 regime shift: the mean value was 1.857 during 1968-1977 and 0.356 during 1978-2010.

Egg clutch data collected during summer surveys may provide information about mature female reproductive conditions. Although egg clutch data are subject to rating errors as well as sampling errors, data trends over time may be useful. Proportions of empty clutches for newshell mature females >89 mm CL were high in some years before 1990, but have been low since 1990 (Figure 14). The highest proportion of empty clutches (0.2) was in 1986, and 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 14). The average clutch fullness was almost identical for these two periods (Figure 14).

d. Graphic evaluation of the fit to the data.

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

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

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

The model (scenario 3a) fit the fishery biomass data well and the survey biomass reasonably well (Figures 10 and 15). Because the model estimates annual fishing mortality for pot male catch, pot female bycatch, and trawl bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences.

The model also fit the length and shell composition data well (Figures 17-24). Model fit of length compositions in the trawl survey was better for newshell males and females than for oldshell males. The model predicted lower proportions of oldshell males in 1993, 1994, 2002, 2007 and 2008, and higher proportions of oldshell males in 1997, 2001, 2003, 2004, 2006 and 2010 than the area-swept estimates (Figure 18). In addition to size, molting probability may also be affected by age and environmental conditions. Tagging data show that molting probability changed over time (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 21). We explored a logistic selectivity function, but due to the long left tail of the pot male bycatch selectivity, the logistic selectivity function did not fit the data well.

Modal progressions are tracked well in the trawl survey data, particularly beginning in the mid-1990s (Figures 17 and 19). Cohorts first seen in the trawl survey data in 1975, 1986, 1990, 1995, 1999, 2002 and 2005 can be tracked over time. Some cohorts can be tracked over time in the pot bycatch as well (Figure 21), but the bycatch data did not track the cohorts as well as the survey data. Groundfish trawl bycatch data provide little information to track modal progression (Figures 23 and 24).

Residuals of total survey biomass and proportions of length and shell condition, calculated as observed minus predicted, are 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 16). Standardized residuals of proportions of survey newshell males appear to be random over length and year (Figure 25). Residuals of proportions of survey oldshell males were mostly positive or negative for some years (Figure 26). 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 27). Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors. Further study for female growth and availability for survey gears due to different molting times may be needed.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) historical results and (2) the 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. Treating the 2010 estimates as the baseline values, we can also evaluate how well the model had done in the past. The 2010 model results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data.

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

The performance of the 2010 model includes sequentially excluding one-year of data. The model performed well during 2004-2009 (Figure 28).

Overall, both historical results and the 2010 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 2002; Ianelli et al. 2003). Since the most recent model has not been used to set TAC or overfishing limits until 2009, historical implications for management from the stock assessment errors cannot be evaluated at the current time. However, management implications of the ADF&G stock assessment model were evaluated by Zheng and Kruse (2002).

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

The model first fit the data from 1985 to 2004 in 2004. Thus, six historical assessment results are available. The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1000 for survey biomass, 2000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5, 2, and 1 were also applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 29).

In 2005, to improve the fit for retained catch data, the weight for retained catch biomass was increased to 3000 and the weight for retained catch proportions was increased to 6. All other weights were not changed. In 2006, all weights were re-configured. No weights were used for proportion data, and instead, effective sample sizes were set to 500 for retained catch, 200 for survey data, and 100 for bycatch data. Weights for biomasses were changed to 800 for retained catch, 300 for survey and 50 for 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 29).

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 29).

In 2009 and 2010, the model was extended to the data through 1968. No weight factors were used for the NMFS survey biomass in 2009 and 2010.

f. Uncertainty and sensitivity analyses

i. Estimated standard deviations of parameters are summarized in Table 6. Estimated standard deviations of mature male biomass are in Table 7.

ii. Likelihood profiles for mature male biomass, exploitable male abundance and exploitable male biomass in 2010 are illustrated in Figure 30. The confidence intervals are quite narrow for all three values.

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

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

F. Calculation of the OFL

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

3. Specification of the OFL:

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

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

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

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

Where

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

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

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

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

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

Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 1999 to 2009 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 1990-2009. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2007-2009 than in 2005 after the fishing industry minimized discards of legal males. Thus, the average of retained selectivities and discard male selectivities during 2007-2009 were used to represent current trends for per recruit analysis and projections.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1968-2010, 1985-2010, and 1995-2010 (Figure 11). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 13a. We recommend using the average recruitment during 1995-present, which was used in 2008 and 2009 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 1.857 during 1968-1977 and 0.356 during 1978-2004 (Figure 36).

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

Specification of OFL:

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	34.2[D]	99.6[E]	16.0	16.0	TBD	22.6
2010/11	32.4[E]	83.1[E]	NA	NA	NA	23.5

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

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1995-2010, the biological reference points were estimated as follows:

$B_{35\%}$ = 62.696 million lbs, or 28,438 t

$F_{35\%}$ = 0.32

$F_{40\%}$ = 0.26

Based on $B_{35\%}$ and $F_{35\%}$, the retained catch and total catch limits for 2010 were estimated to be:

Retained catch: 21.287 million lbs, or 9,655.474 t,

Total catch: 23.519 million lbs, or 10,667.863 t,

MMB on 2/15/2011: 83.142 million lbs, or 37,712.4 t.

Total catch includes retained catch and all other bycatches.

G. Rebuilding Analyses

NA.

H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:
   a. Information about changes in natural mortality in the early 1980s;
   b. Un-observed trawl bycatch in the early 1980s;
   c. Natural mortality;
   d. Crab availability to the trawl surveys;
   e. Juvenile crab abundance.
2. Research priorities:
   a. Estimating natural mortality;
   b. Estimating crab availability to the trawl surveys;
   c. Surveying juvenile crab abundance in near shore;

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

I. Projections and Future Outlook

1. Projections

Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections was a random selection from estimated recruitments during 1995-2010. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2010. The 2010 abundance was randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three scenarios of fishing mortality for the directed pot fishery were used in the projections:

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

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

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

Each scenario was replicated 1000 times and projections made over 10 years beginning in 2010 (Table 8).

As expected, projected mature male biomasses are much higher without the directed fishing mortality than under the other scenarios. At the end of 10 years, projected mature male biomass is above $B_{35\%}$ for the $F_{40\%}$ scenario and similar to $B_{35\%}$ for the $F_{35\%}$ scenario (Table 8; Figure 31). Projected retained catch for the $F_{35\%}$ scenario is higher than those for the $F_{40\%}$ scenario (Table 8, Figure 32). Due to the poor recruitment during recent years, the projected biomass and retained catch are expected to decline during the next few years.

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a starting declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 33). Most individuals from the 1997 year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and will continue to recruit to the legal population next year (Figure 33). However, no strong cohorts have been observed in the survey data after this cohort (Figure 33). 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.

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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	1.910	0.149	0.218	18.310

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

Year	GHL Range	GHL Mid-point	Actual 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	16,708	50,017	6,024		
2010	1,344	1,633					

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 3a).

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	5
Fixed initial (1968) length composition parameters	56
Total number of fixed parameters	83
Free growth parameters	4
Initial abundance (1968)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	43
Female recruitment deviations	43
Natural and fishing mortality parameters	4
Survey catchability parameters	2
Pot male fishing mortality deviations	44
Bycatch mortality from the Tanner crab fishery	6
Pot female bycatch fishing mortality deviations	22
Trawl bycatch fishing mortality deviations	36
Free selectivity parameters	28
Total number of free parameters	236
Total number of fixed and free parameters	319

Negative log likelihood components

Length compositions---retained catch	-1024.680
Length compositions---pot male discard	-760.741
Length compositions---pot female discard	-1963.540
Length compositions---survey	-51723.100
Length compositions---trawl discard	-1699.290
Length compositions---Tanner crab discards	-161.881
Pot discard male biomass	163.488
Retained catch biomass	48.618
Pot discard female biomass	0.126
Trawl discard	7.989
Survey biomass	75.092
Recruitment variation	163.725
Sex ratio of recruitment	0.060
Total	-56870.600

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

	Recruits				F for Directed Pot Fishery				F for Trawl	
Year	Females	S. dev.	Males	S.dev.	Males	S.dev.	Females	S.dev.	Est.	S.dev.
Mean	16.189	0.022	16.189	0.022	-2.040	0.033	0.011	0.001	-4.682	0.074
1968					2.099	0.011				
1969	-0.293	0.110	0.968	0.066	2.078	0.059				
1970	0.604	0.116	0.919	0.098	1.798	0.062				
1971	-0.348	0.099	2.081	0.051	1.478	0.066				
1972	0.718	0.224	0.065	0.174	1.545	0.069				
1973	-0.489	0.119	1.600	0.057	1.297	0.073				
1974	0.192	0.091	1.582	0.059	1.486	0.069				
1975	0.301	0.061	2.494	0.046	1.331	0.064				
1976	-0.298	0.243	0.699	0.128	1.412	0.066			-0.293	0.080
1977	0.600	0.167	0.517	0.122	1.488	0.066			0.258	0.078
1978	0.572	0.134	0.967	0.098	1.630	0.057			0.179	0.077
1979	0.279	0.131	1.281	0.095	1.692	0.045			0.140	0.077
1980	-0.019	0.123	1.536	0.098	2.099	0.003			0.096	0.077
1981	0.254	0.087	1.266	0.079	1.769	0.061			-0.547	0.076
1982	-0.170	0.046	2.176	0.048	-0.193	0.060			1.105	0.080
1983	-0.226	0.081	1.179	0.054	-10.089	0.415			1.107	0.079
1984	0.174	0.064	1.111	0.044	0.714	0.059			2.000	0.002
1985	0.435	0.188	-1.422	0.143	0.877	0.060			1.332	0.078
1986	0.317	0.061	0.351	0.046	1.523	0.057			0.318	0.077
1987	0.130	0.130	-0.435	0.084	1.232	0.053			-0.206	0.076
1988	-0.321	0.265	-1.509	0.163	0.361	0.048			0.969	0.075
1989	0.415	0.137	-0.786	0.107	0.499	0.046			-0.348	0.075
1990	-0.209	0.096	0.109	0.062	1.148	0.043	1.851	0.112	-0.115	0.075
1991	-0.192	0.115	-0.521	0.075	1.129	0.045	-0.274	0.112	0.126	0.075
1992	-0.167	0.355	-2.494	0.228	0.618	0.046	2.000	0.028	0.246	0.076
1993	-0.360	0.095	-0.578	0.056	1.283	0.049	1.825	0.112	0.649	0.075
1994	-0.247	0.400	-2.746	0.242	-10.535	0.407	1.175	5.438	-0.783	0.076
1995	-0.008	0.037	0.952	0.034	-10.789	0.407	1.376	4.903	-0.787	0.076
1996	-0.016	0.104	-0.453	0.072	0.309	0.043	-3.798	0.170	-0.805	0.076
1997	-0.722	0.407	-2.807	0.245	0.434	0.043	-1.258	0.116	-1.155	0.076
1998	-0.210	0.105	-0.446	0.064	1.143	0.045	1.856	0.114	-0.441	0.074
1999	-0.104	0.060	0.582	0.043	0.696	0.045	-2.334	0.122	-0.303	0.074
2000	-0.053	0.176	-0.727	0.108	0.301	0.044	-0.402	0.117	-0.944	0.075
2001	1.036	0.191	-1.655	0.163	0.289	0.044	0.949	0.116	-0.646	0.075
2002	0.157	0.040	0.979	0.035	0.378	0.044	-2.327	0.124	-0.998	0.075
2003	-0.084	0.180	-0.813	0.116	0.883	0.043	1.025	0.117	-1.213	0.075
2004	0.170	0.091	0.235	0.077	0.712	0.044	0.301	0.117	-0.911	0.075
2005	0.192	0.048	0.927	0.045	1.115	0.046	0.756	0.118	-1.076	0.075
2006	-0.254	0.131	-0.026	0.084	0.800	0.047	-1.630	0.119	-1.163	0.076
2007	-0.474	0.181	-0.372	0.099	1.073	0.051	-0.353	0.119	-1.164	0.077
2008	0.164	0.250	-1.374	0.183	1.077	0.057	-0.549	0.120	-0.930	0.078
2009	-0.380	0.335	-1.670	0.204	0.730	0.061	-0.719	0.121	-1.293	0.081
2010	-0.532	0.393	-1.886	0.241						

Table 6 (continued). 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	0.569	0.016	log_srv_L50, m, 70-72	5.200	0.000
Mf80-84	0.884	0.020	srv_slope, f, 70-72	0.146	0.010
Mf76-79,85-93	0.045	0.006	log_srv_L50, f, 70-72	4.387	0.014
log_betal, females	0.138	0.053	log_srv_L50, m, 73-81	4.391	0.028
log_betal, males	0.718	0.073	srv_slope, f, 73-81	0.064	0.003
log_betar, females	-0.365	0.068	log_srv_L50, f, 73-81	4.424	0.017
log_betar, males	-0.335	0.053	log_srv_L50, m, 82-10	4.558	0.028
Q, females, 70-72	0.172	0.018	srv_slope, f, 82-10	0.039	0.002
Q, males, 70-72	0.886	0.100	log_srv_L50, f, 82-10	4.547	0.019
Q, 68-69, 73-10	NA	NA	log_srv_L50, m, 68-69	4.508	0.015
moltp_slope	0.088	0.003	srv_slope, f, 68-69	0.019	0.002
log_moltp_L50	4.941	0.003	log_srv_L50, f, 68-69	5.037	0.071
log_N68	18.960	0.031	TC_slope, females	0.284	0.067
log_avg_L50, 73-10	4.926	0.001	log_TC_L50, females	4.539	0.013
log_avg_L50, 68-72	4.864	0.005	TC_slope, males	0.293	0.019
ret_fish_slope, 73-10	0.503	0.020	log_TC_L50, males	5.021	0.043
ret_fish_slope, 68-72	0.307	0.036	log_TC_F, males, 91	-2.861	0.358
pot disc.males, φ	-0.249	0.011	log_TC_F, males, 92	-4.027	0.333
pot disc.males, κ	0.003	0.000	log_TC_F, males, 93	-5.166	0.309
pot disc.males, γ	-0.012	0.000	log_TC_F, females, 91	-2.947	0.084
sel_62.5mm, 68-72	1.400	0.000	log_TC_F, females, 92	-4.134	0.084
post disc.fema., slope	0.470	0.195	log_TC_F, females, 93	-4.725	0.083
log_pot disc.fema., L50	4.401	0.012			
trawl disc slope	0.057	0.003			
log_trawl disc L50	5.031	0.048			

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 1968-2010. 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	14.773	8.689	33.703	1.295	61.581	176.441	176.524
1969	14.503	6.210	33.837	1.830	62.857	178.280	192.111
1970	17.576	6.847	45.325	2.626	65.774	79.067	94.888
1971	20.606	8.874	59.795	3.432	73.180	97.475	
1972	26.745	11.723	76.884	4.474	91.274	121.302	110.820
1973	33.557	14.826	103.474	5.369	108.613	417.730	351.646
1974	49.241	20.401	145.179	6.710	113.334	484.766	424.121
1975	54.551	27.731	168.948	7.802	119.765	586.663	461.200
1976	56.842	31.093	172.964	7.738	155.033	670.492	626.366
1977	64.331	32.001	189.935	7.195	194.575	713.718	800.168
1978	82.884	36.457	234.662	7.161	186.750	720.634	710.799
1979	83.895	44.393	232.561	8.315	168.172	690.285	536.477
1980	65.588	41.934	99.124	4.141	159.187	632.176	503.933
1981	24.693	14.940	44.738	2.819	65.212	282.425	247.233
1982	13.085	6.862	33.775	1.843	29.498	156.795	292.355
1983	9.907	5.152	27.494	1.282	18.805	117.909	104.135
1984	8.733	4.161	19.951	0.923	15.726	99.705	331.782
1985	8.807	3.268	28.594	1.076	11.696	69.820	72.763
1986	13.096	5.588	38.138	1.407	16.683	91.041	102.052
1987	15.668	7.354	49.152	1.635	20.592	101.798	145.811
1988	15.922	9.097	58.854	1.766	26.035	107.415	111.488
1989	17.105	10.482	64.528	1.822	25.202	113.963	129.489
1990	17.298	11.229	58.600	1.816	22.631	116.169	116.127
1991	14.003	9.919	47.843	1.758	22.284	105.958	182.621
1992	11.331	7.956	44.320	1.689	22.145	94.618	76.571
1993	12.050	7.407	39.575	1.649	19.790	91.933	103.969
1994	11.504	6.809	51.076	1.688	16.732	80.953	65.674
1995	11.847	8.505	56.662	1.646	15.885	96.183	79.206
1996	11.888	9.112	51.742	1.564	21.160	110.023	90.138
1997	11.310	8.129	47.997	1.510	30.669	115.611	174.149
1998	15.340	7.900	52.174	1.606	29.907	121.441	168.189
1999	17.133	9.196	62.369	1.818	26.272	123.444	123.648
2000	15.528	10.688	63.017	1.864	28.871	127.976	139.183
2001	14.653	10.467	61.300	1.818	32.709	132.544	104.985
2002	16.882	10.221	67.552	1.855	31.667	145.586	142.274
2003	17.768	11.332	65.713	1.908	38.098	154.810	192.746
2004	15.934	10.861	61.636	1.914	46.439	160.610	194.642
2005	18.736	10.455	64.130	2.075	46.567	176.779	212.034
2006	19.688	11.220	71.307	2.369	54.129	186.154	189.854
2007	20.602	12.332	70.825	2.740	61.516	197.810	206.408
2008	23.443	12.565	79.161	3.548	57.536	197.964	219.671
2009	24.430	14.109	88.969	4.392	51.098	190.795	178.893
2010	22.730	15.371	83.142	3.877	44.515	180.151	151.357

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, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2010-2019.

Year	MMB	95% limits of MMB		Catch	95% limits of catch	
No directed fishery						
2010	104.218	96.292	111.677	0	0	0
2011	108.824	100.547	116.612	0	0	0
2012	105.905	97.845	113.481	0	0	0
2013	100.253	92.339	107.955	0	0	0
2014	99.470	86.880	118.797	0	0	0
2015	104.726	81.062	144.500	0	0	0
2016	112.183	77.181	164.518	0	0	0
2017	120.006	75.510	179.022	0	0	0
2018	127.694	74.560	194.158	0	0	0
2019	135.180	74.227	211.917	0	0	0
$F_{40\%}$						
2010	86.472	79.895	92.660	17.922	16.558	19.204
2011	75.212	69.491	80.594	17.677	16.332	18.942
2012	61.098	57.260	65.015	15.108	13.114	16.659
2013	50.784	47.747	54.144	10.276	9.049	11.594
2014	48.262	40.557	61.825	8.169	6.404	11.203
2015	52.063	35.486	84.332	8.134	4.688	12.654
2016	57.137	33.220	93.338	9.210	3.797	16.723
2017	61.517	34.420	100.608	10.485	3.712	18.852
2018	65.026	34.431	107.037	11.566	3.750	20.348
2019	67.945	35.320	114.369	12.422	3.851	21.790
$F_{35\%}$						
2010	82.932	76.624	88.866	21.483	19.849	23.020
2011	69.364	64.087	74.326	20.278	18.736	21.730
2012	55.646	52.255	58.764	15.244	13.207	17.227
2013	46.046	43.305	49.087	10.157	8.966	11.389
2014	44.121	36.656	57.380	8.125	6.286	11.307
2015	48.104	32.194	78.826	8.417	4.586	14.060
2016	53.007	30.429	86.608	9.775	3.774	18.694
2017	56.987	31.834	92.746	11.251	3.762	20.835
2018	59.981	31.737	97.679	12.449	3.900	22.278
2019	62.389	32.631	105.449	13.331	4.065	23.671

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

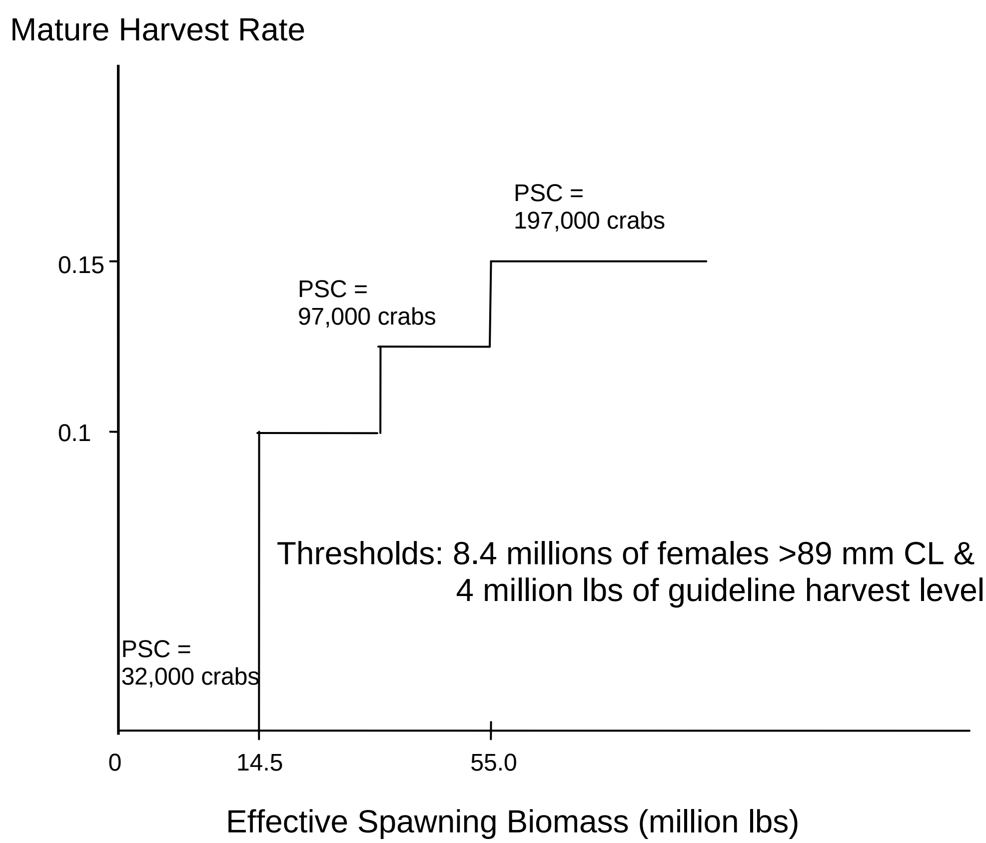


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crabs) of Bristol Bay red king crabs in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates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

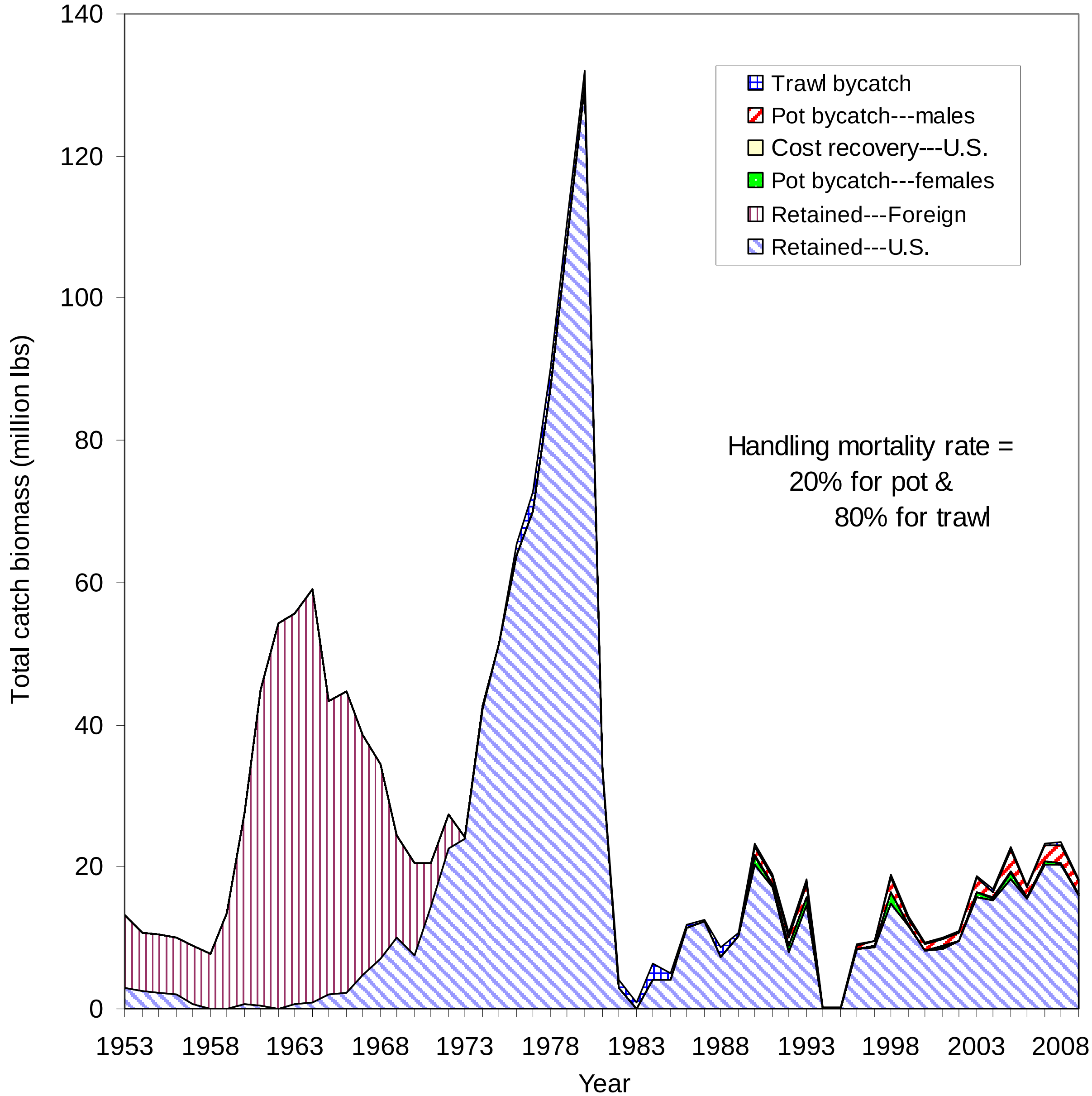


Figure 2. Retained catch biomass and bycatch mortality biomass (million lbs) for Bristol Bay red king crab from 1960 to 2009. Handling mortality rates were assumed to be 0.2 for the directed pot fishery and 0.8 for the trawl fisheries.

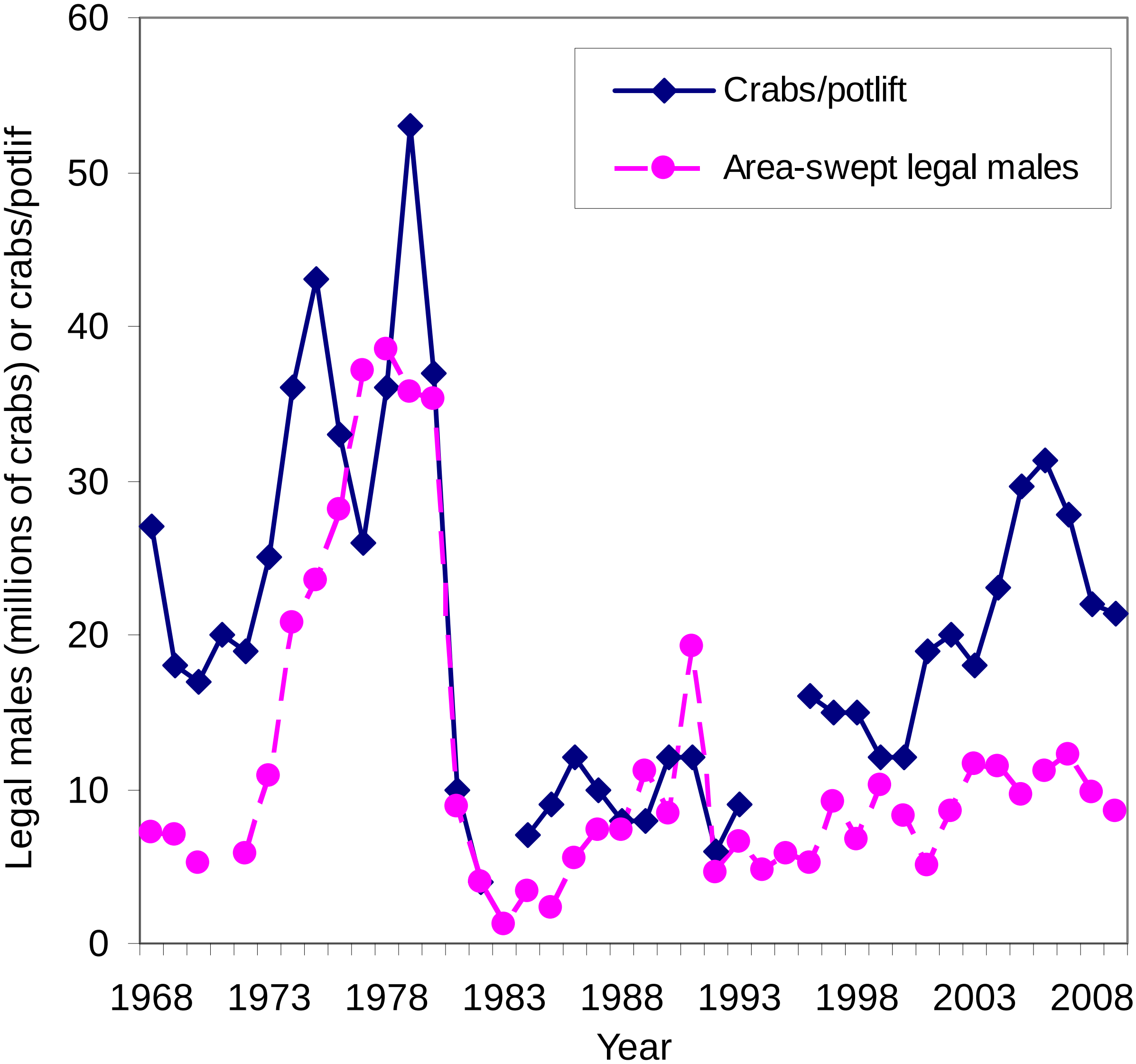


Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2009.

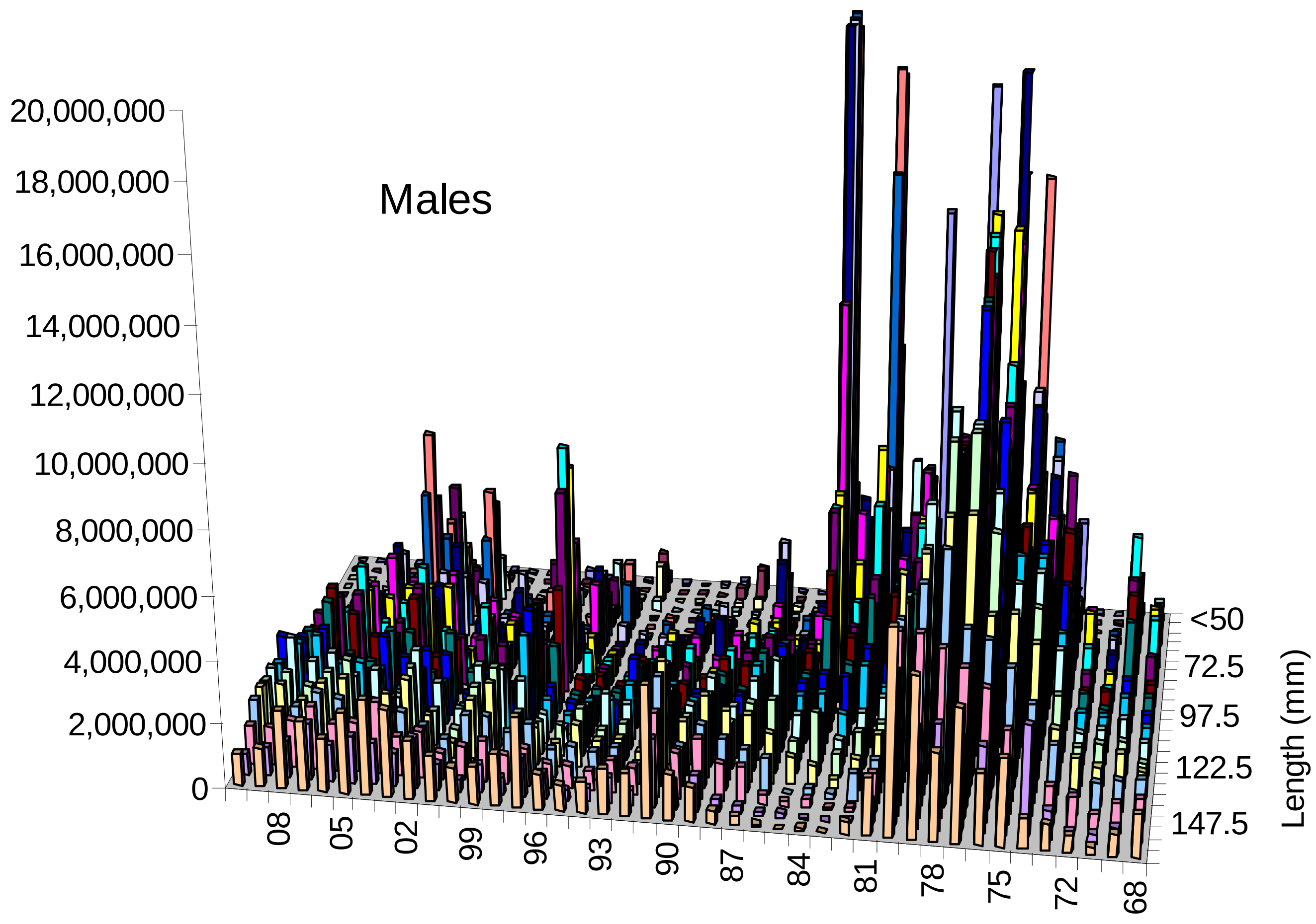


Figure 4. Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2010.

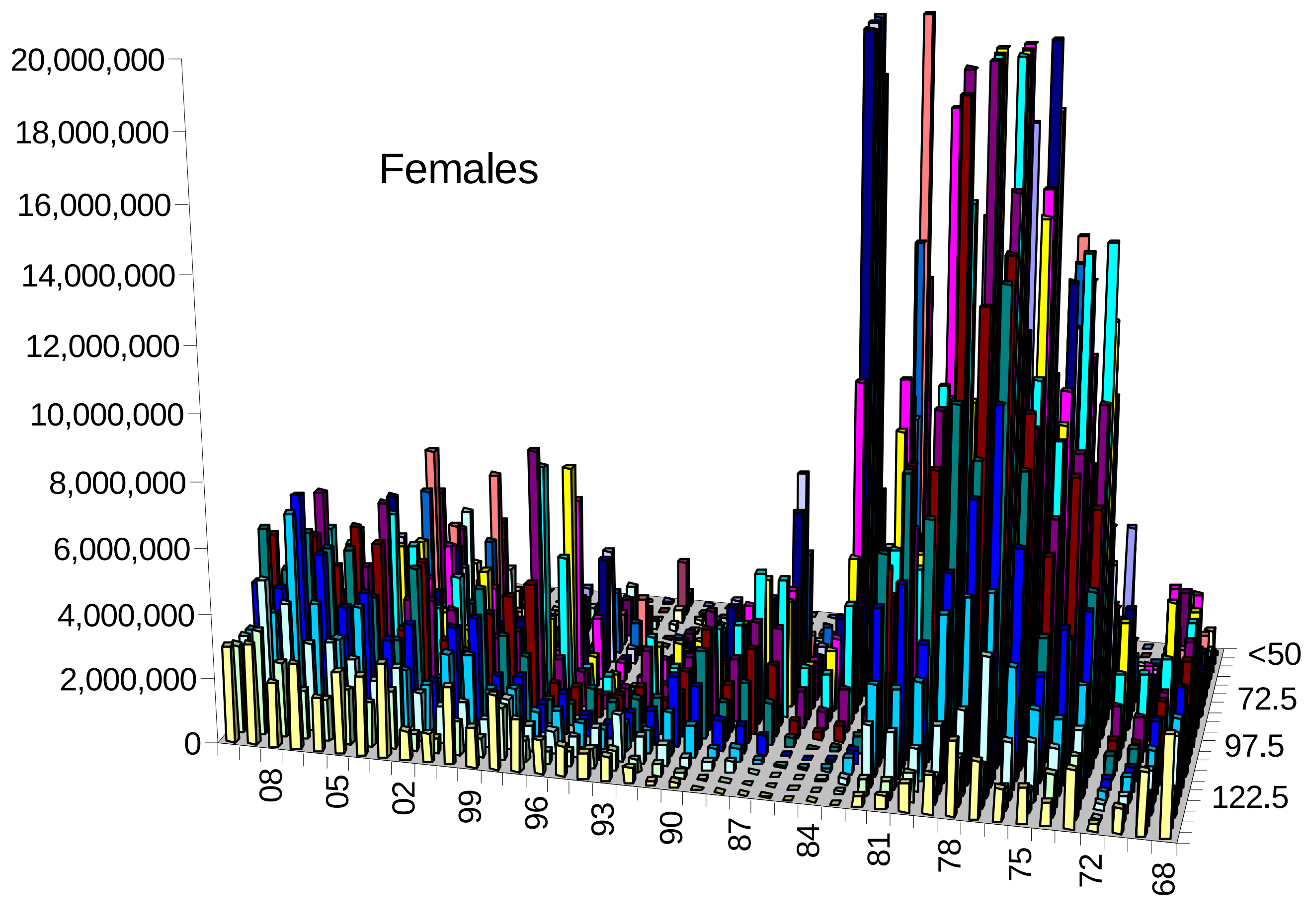


Figure 5. Survey abundances by length for female Bristol Bay red king crabs from 1968 to 2010.

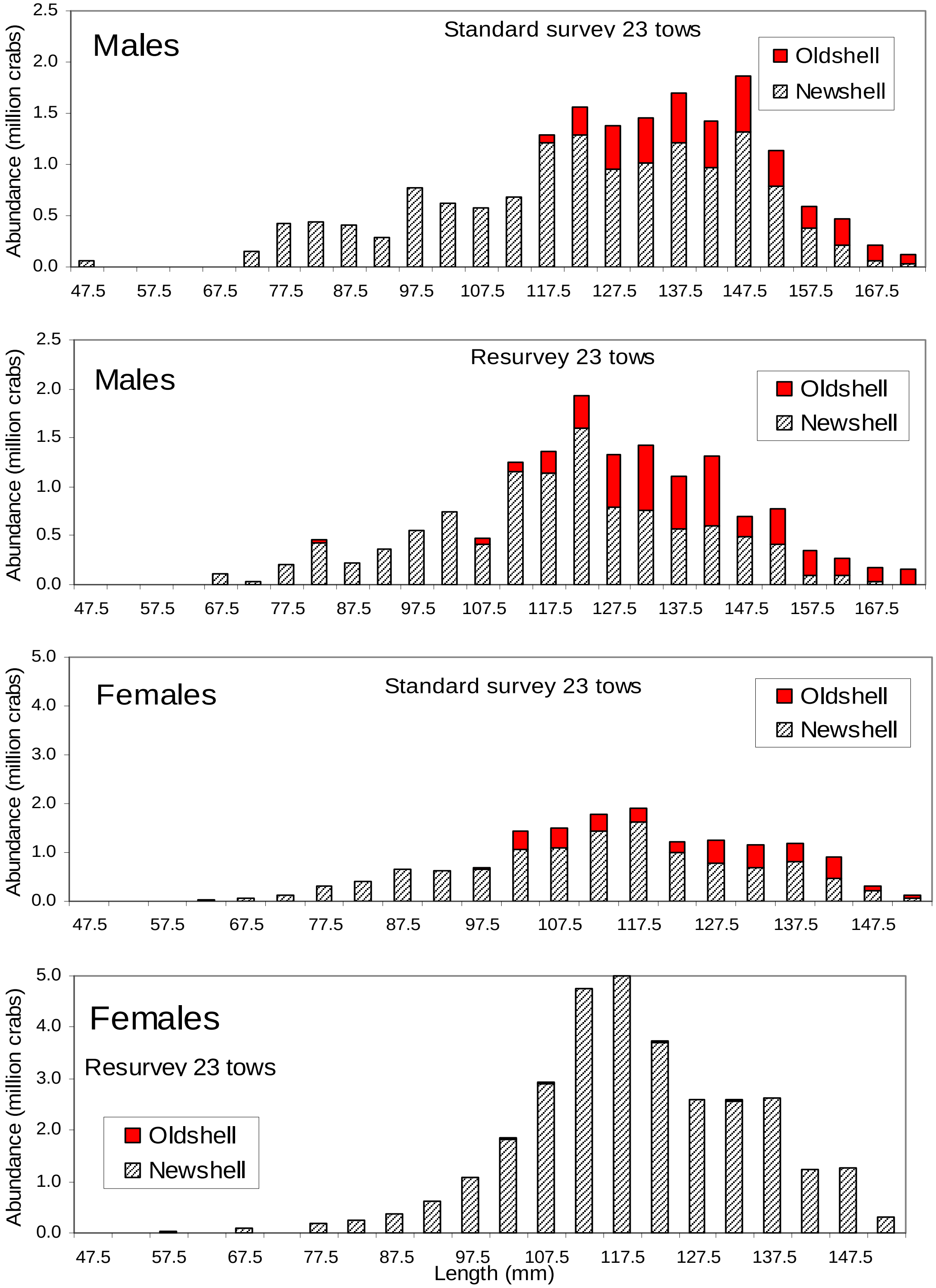
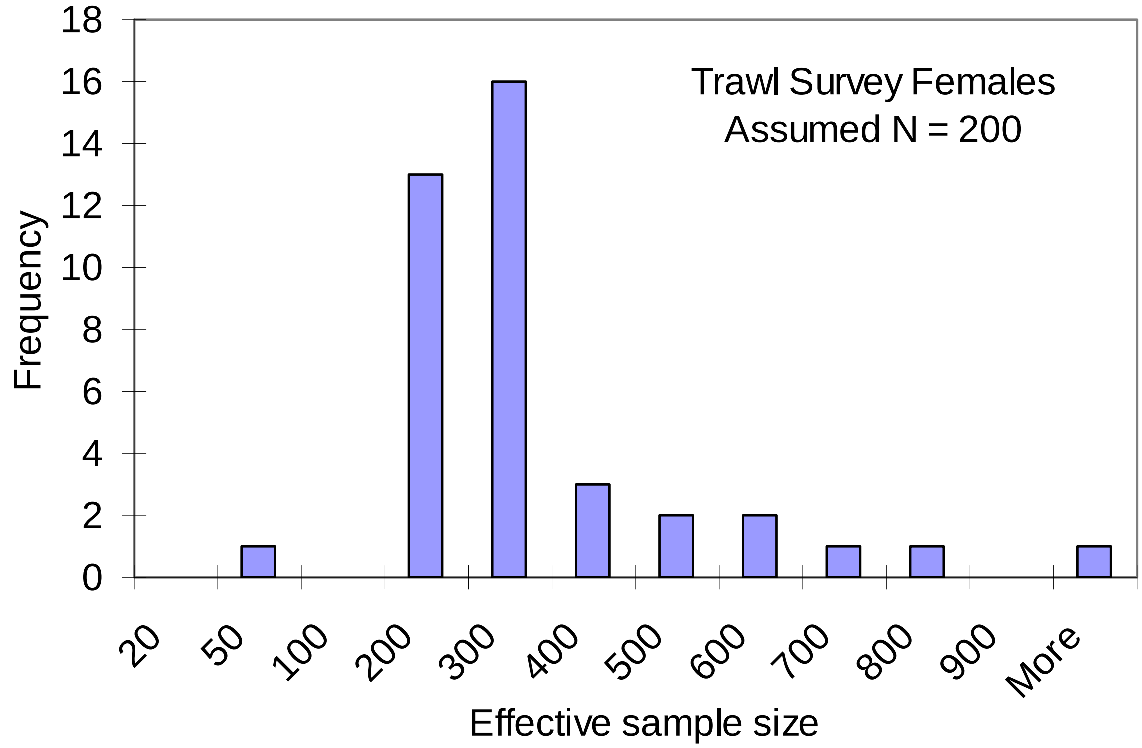


Figure 6. Comparison of area-swept estimates of abundance in 23 stations from the standard trawl survey and resurvey in 2010.



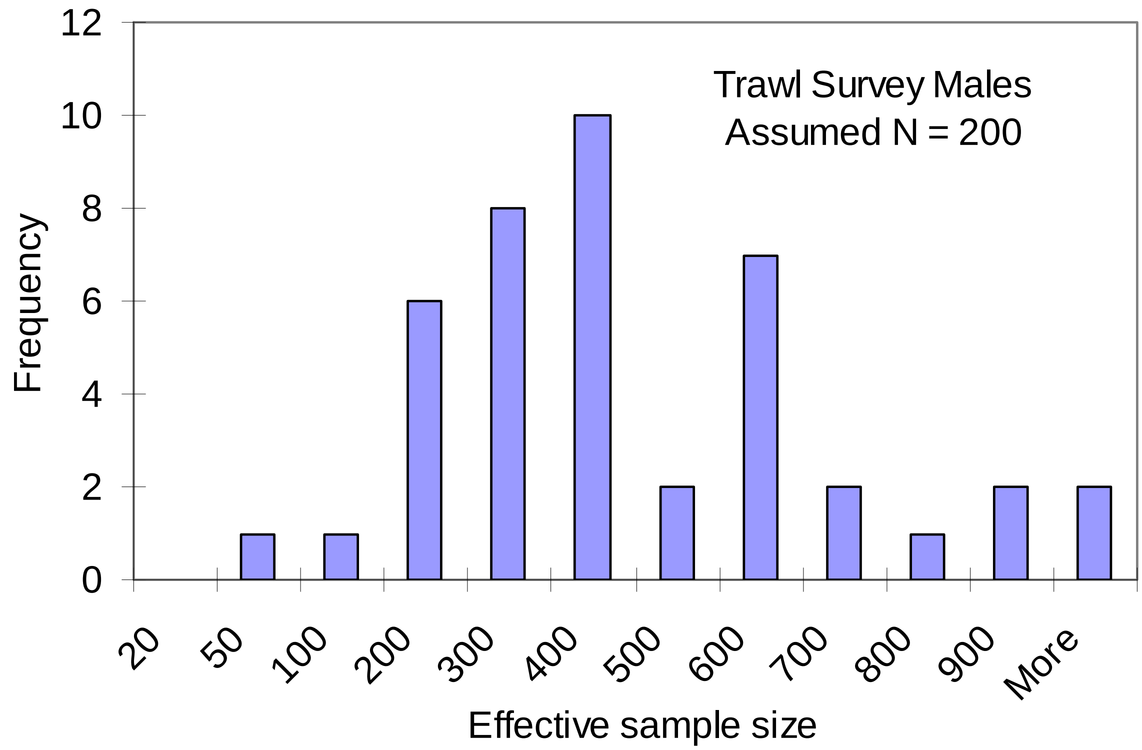


Figure 7a. Estimated effective sample sizes for length/sex composition data: trawl survey data.

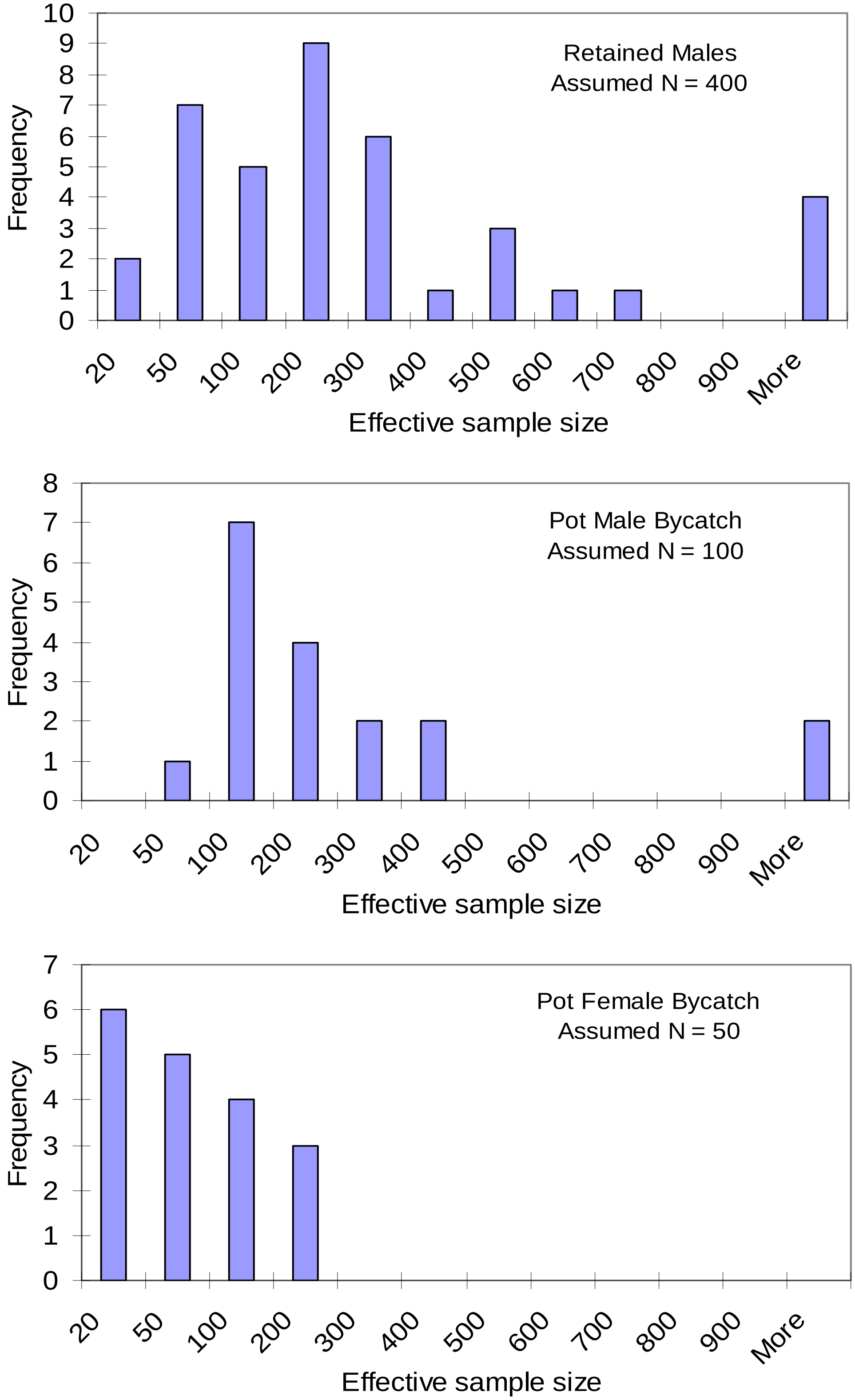
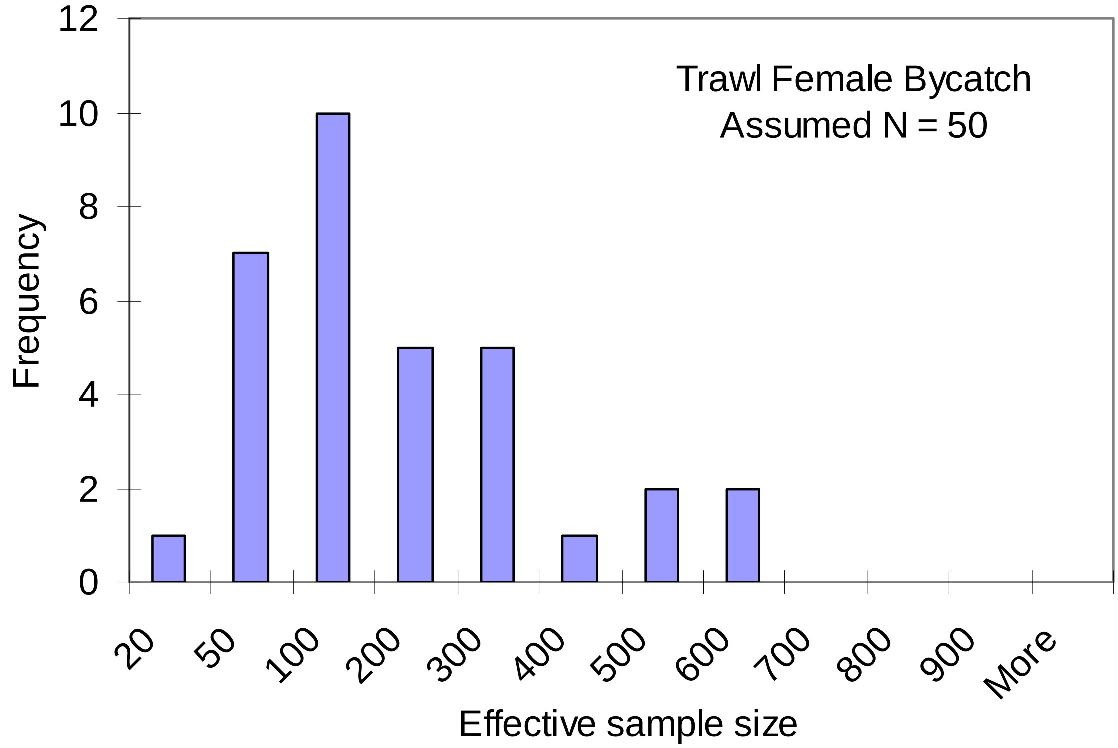


Figure 7b. Estimated effective sample sizes for length/sex composition data: directed pot fishery data



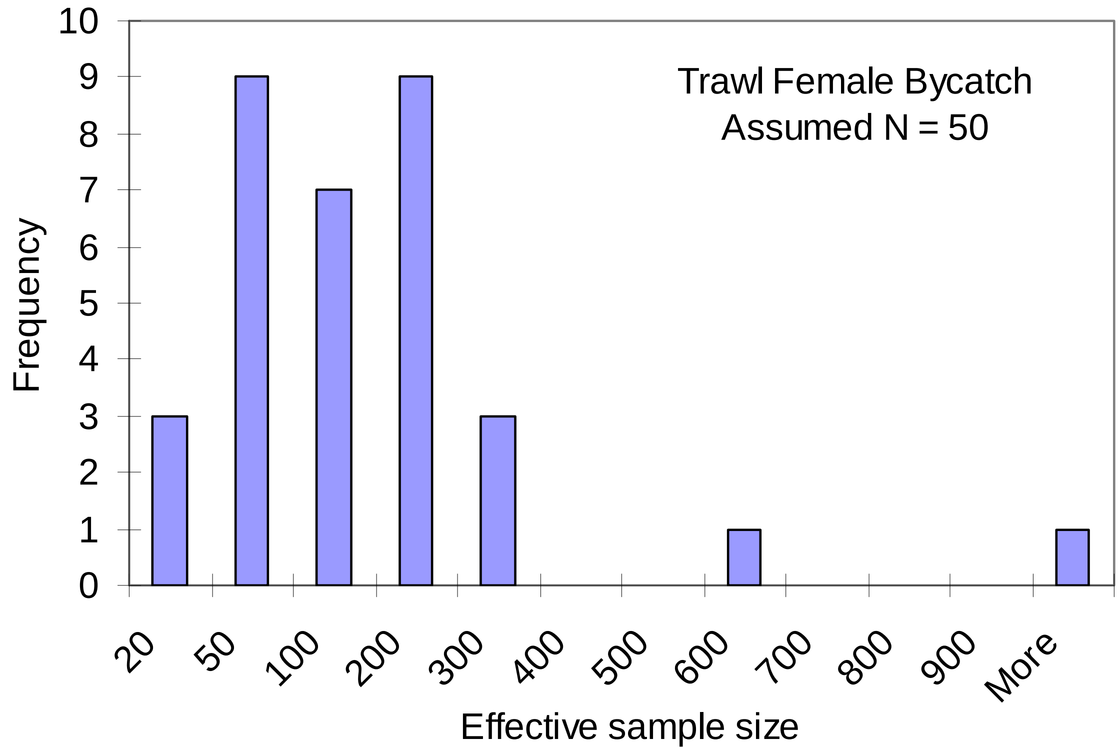


Figure 7c. Estimated effective sample sizes for length/sex composition data: trawl bycatch data.

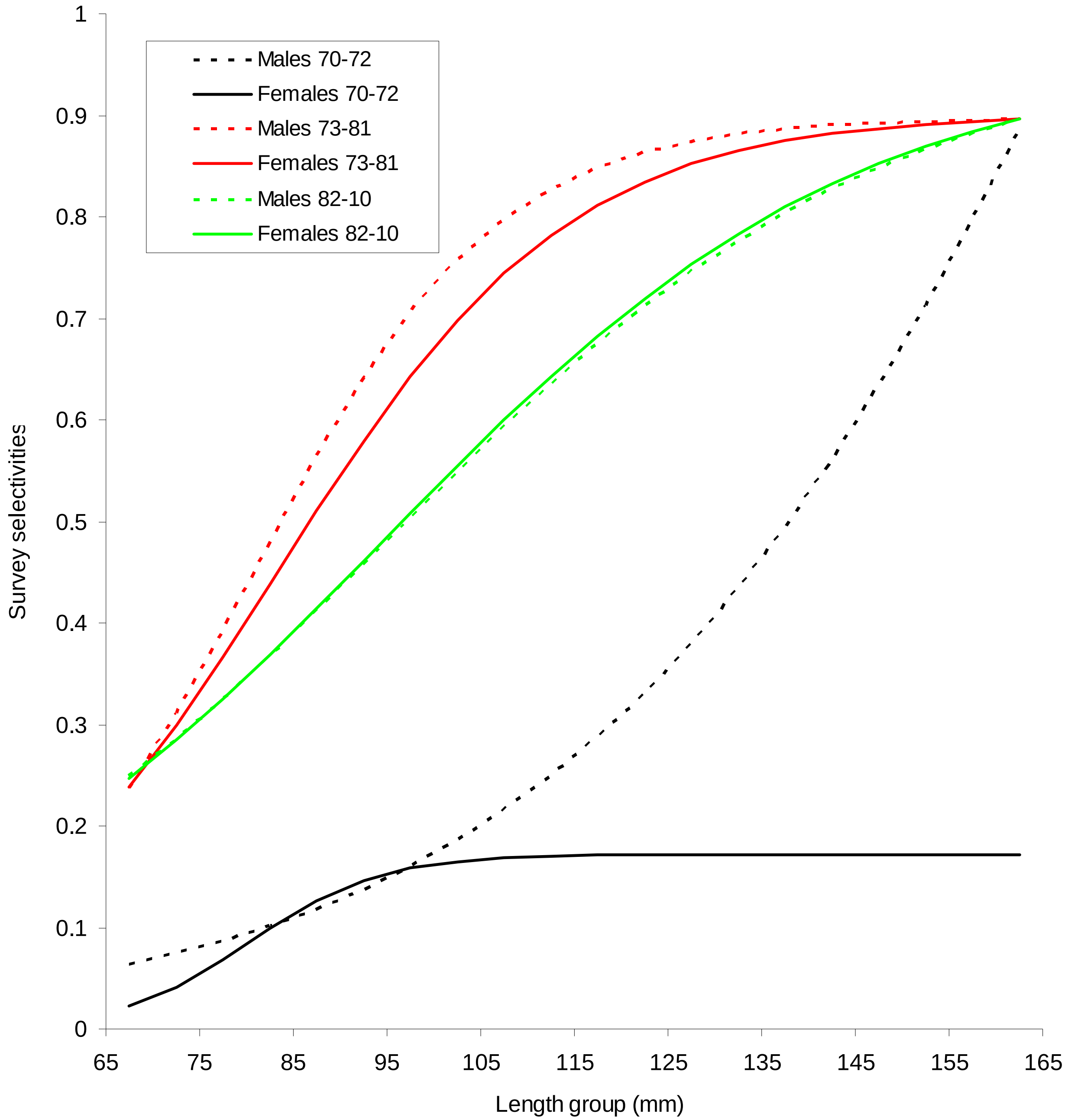


Figure 8a. Estimated trawl survey selectivities. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

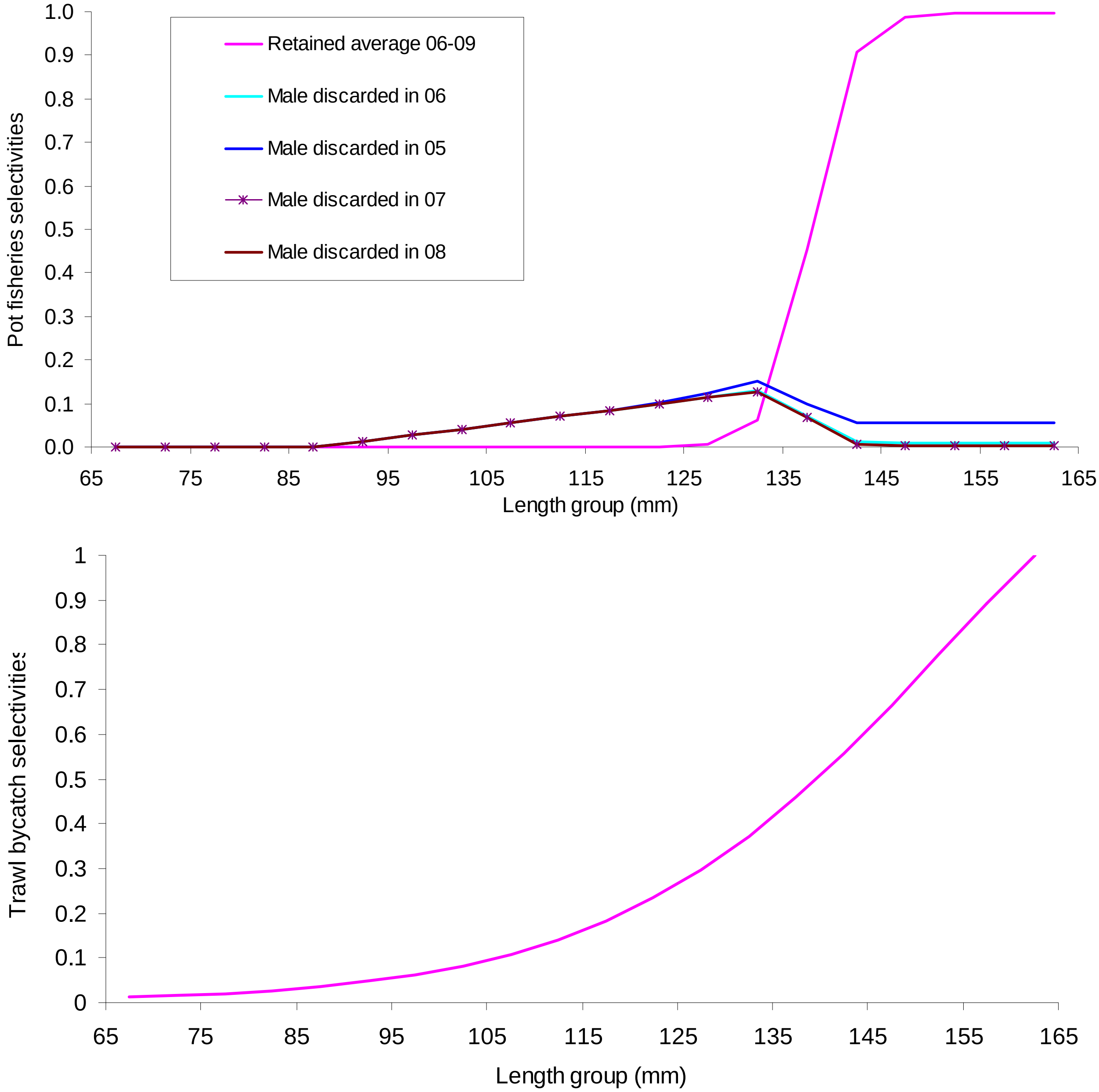


Figure 8b. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

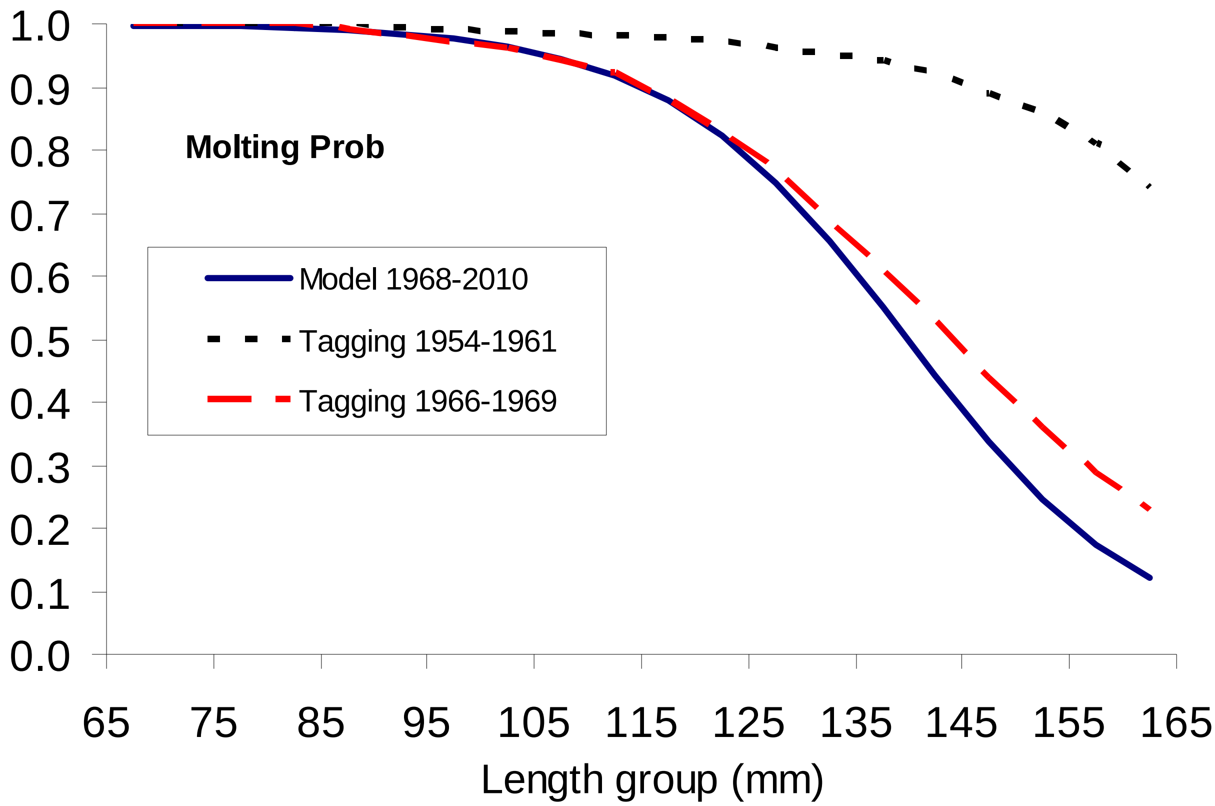


Figure 9. Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1968-2010 were estimated with a length-based model with pot handling mortality rate to be 0.2.

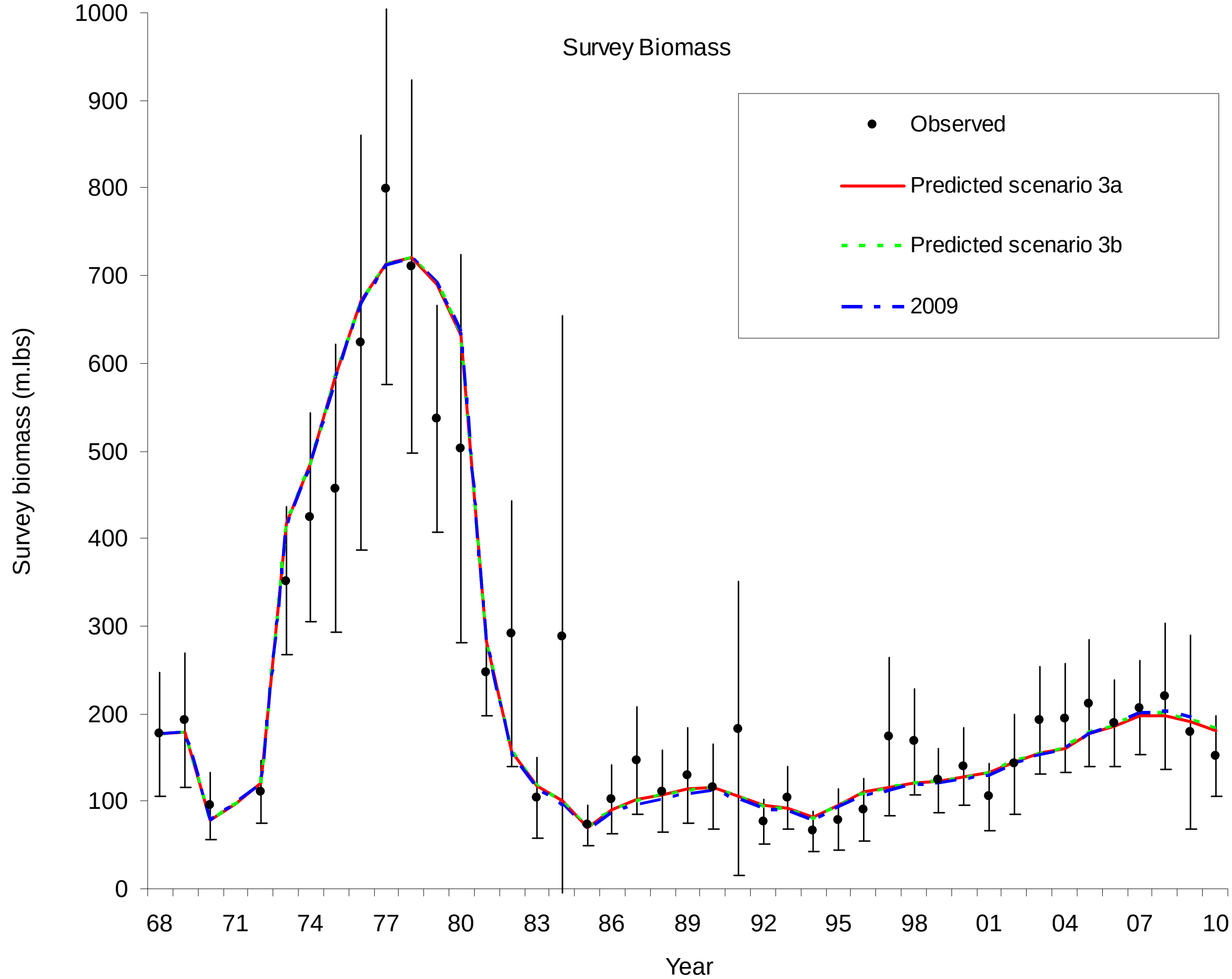


Figure 10a. Comparisons of area-swept estimates of total survey biomass and model prediction for 3 scenarios. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

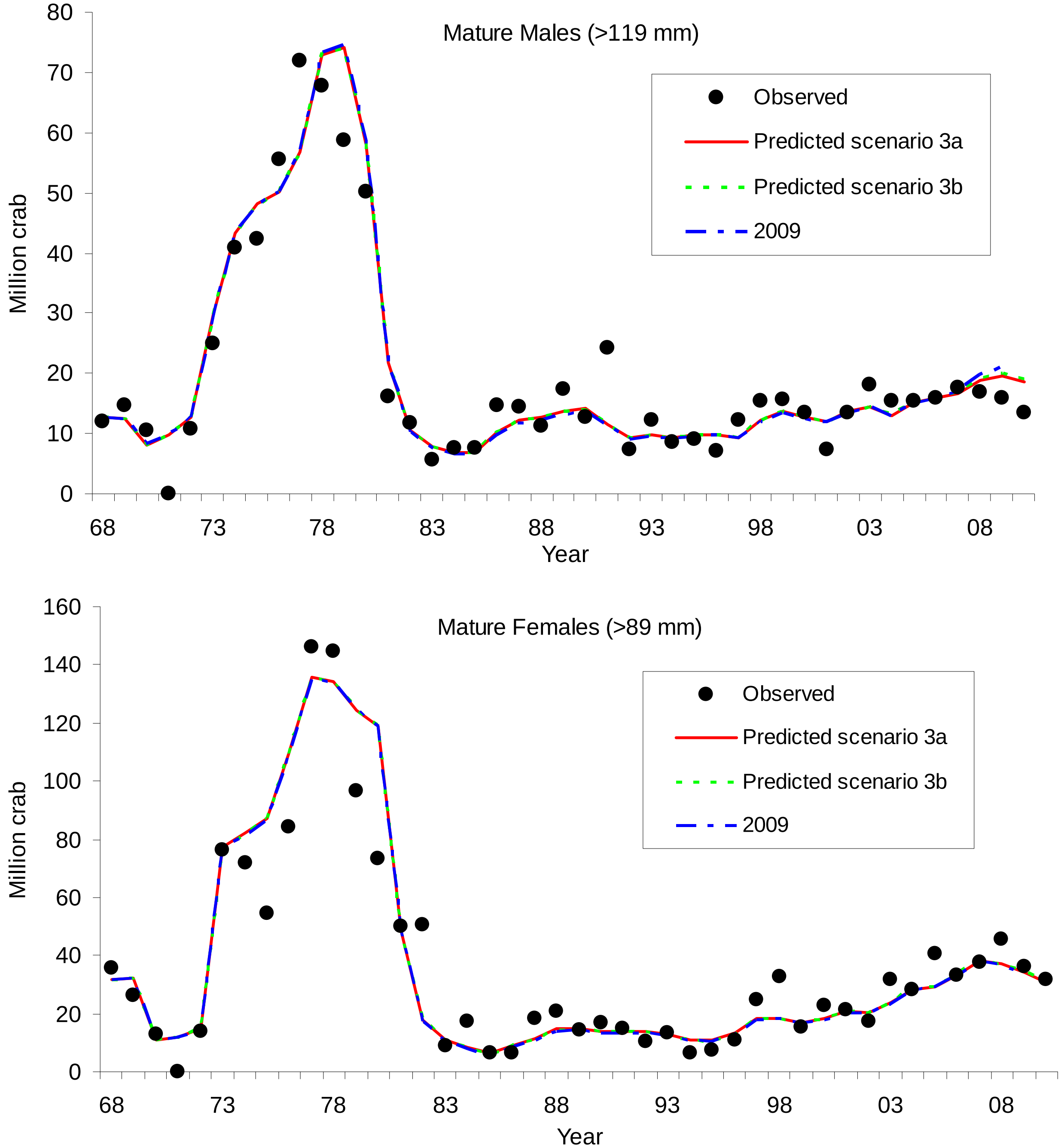


Figure 10b. Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for scenario 3. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

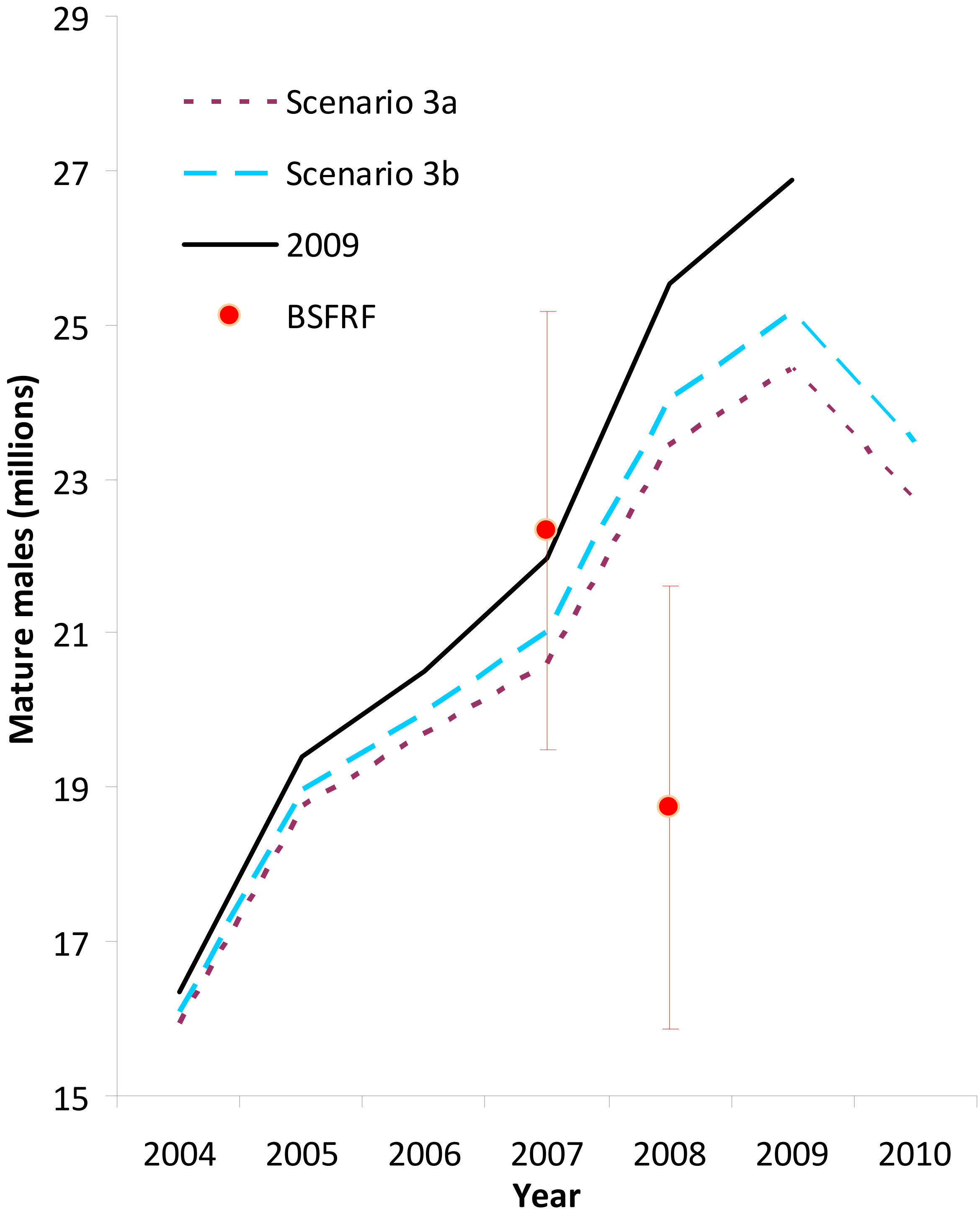


Figure 10c. Comparisons of total mature male abundance estimates by the BSFRF survey and the model for scenario 3. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

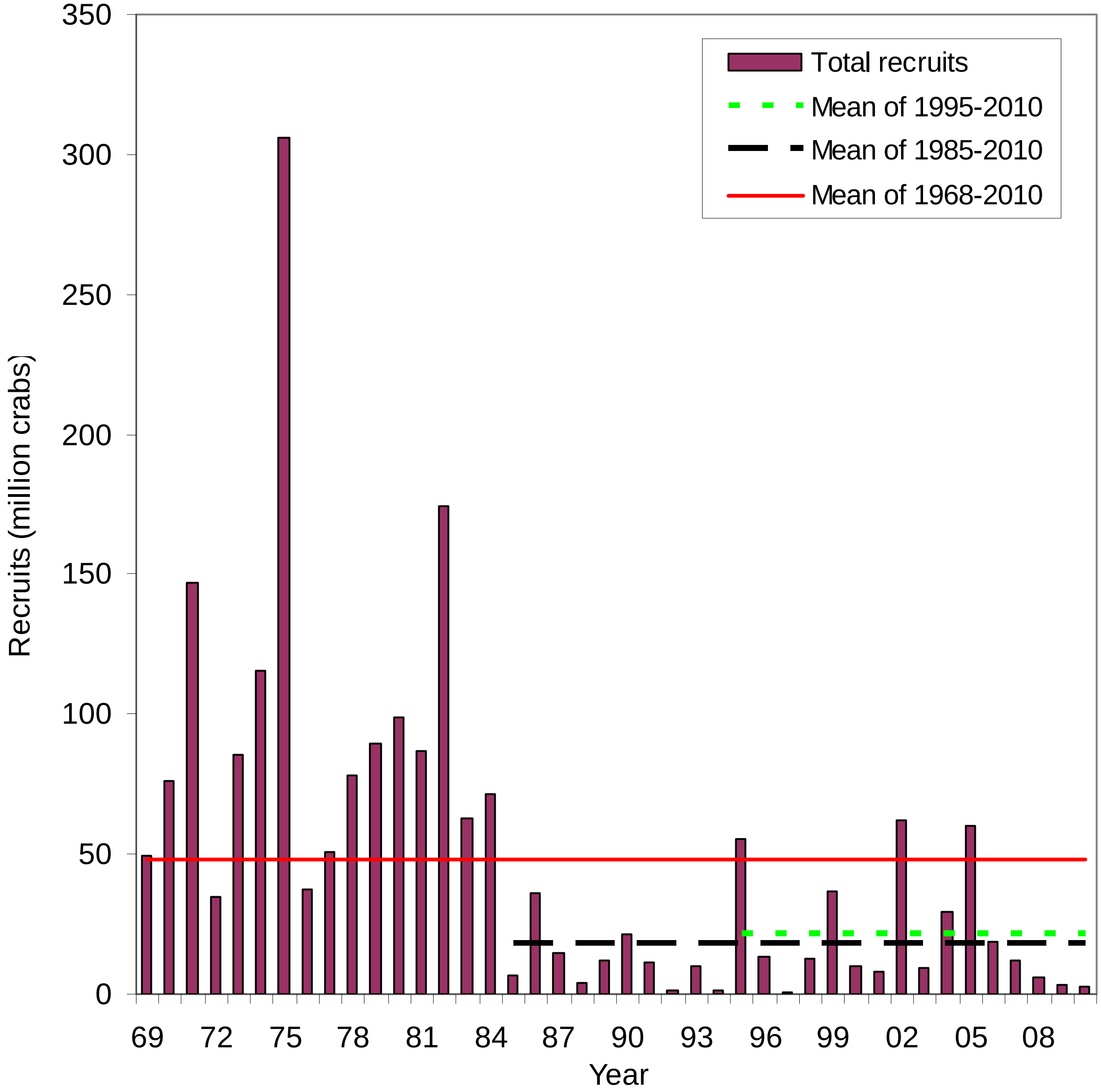


Figure 11. Estimated recruitment time series during 1969-2010 (occurred year) with scenario (3a). Mean male recruits during 1995-2010 was used to estimate $B_{35\%}$.

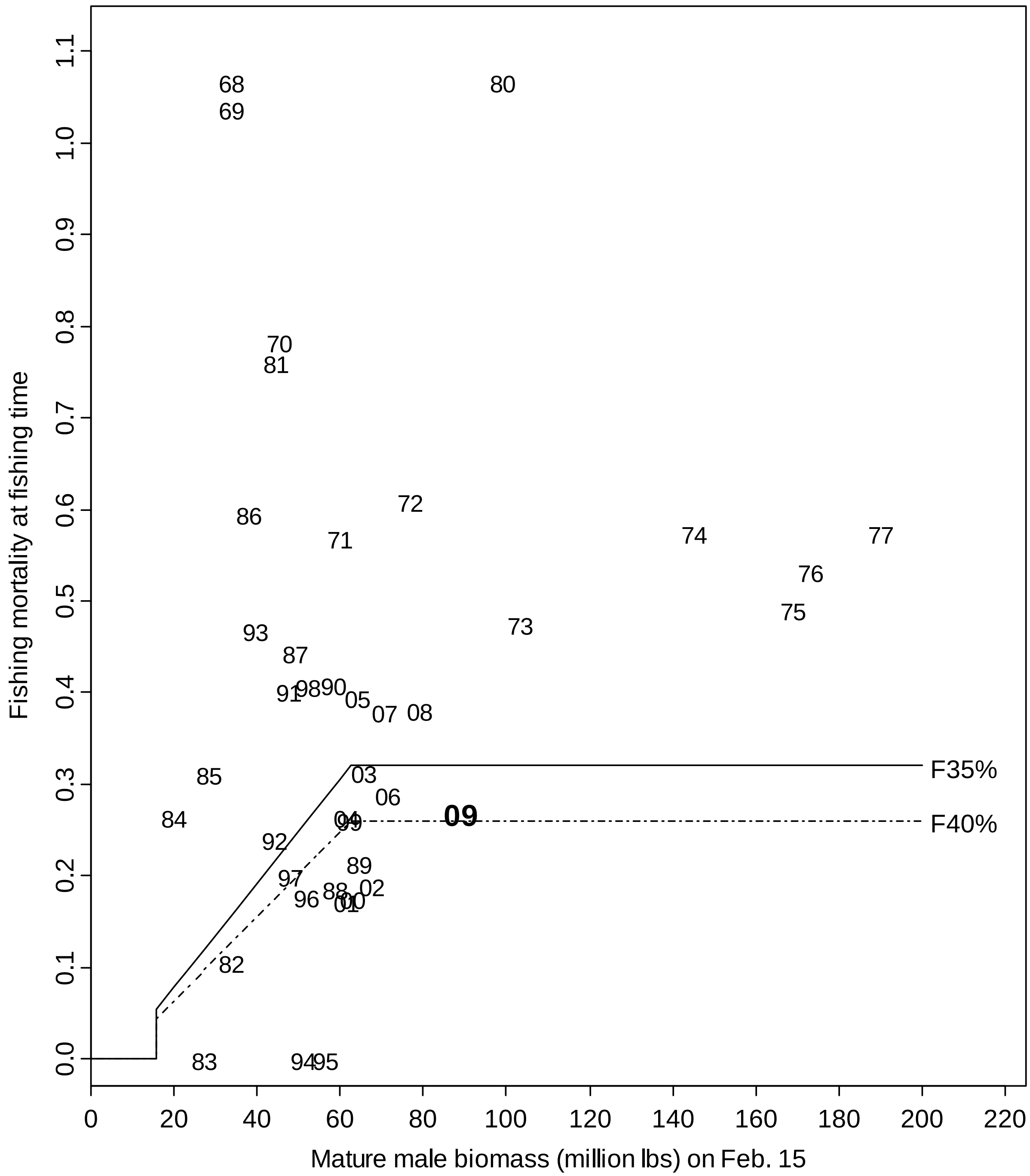


Figure 12. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1968-2009. Average of recruitment from 1995 to 2010 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

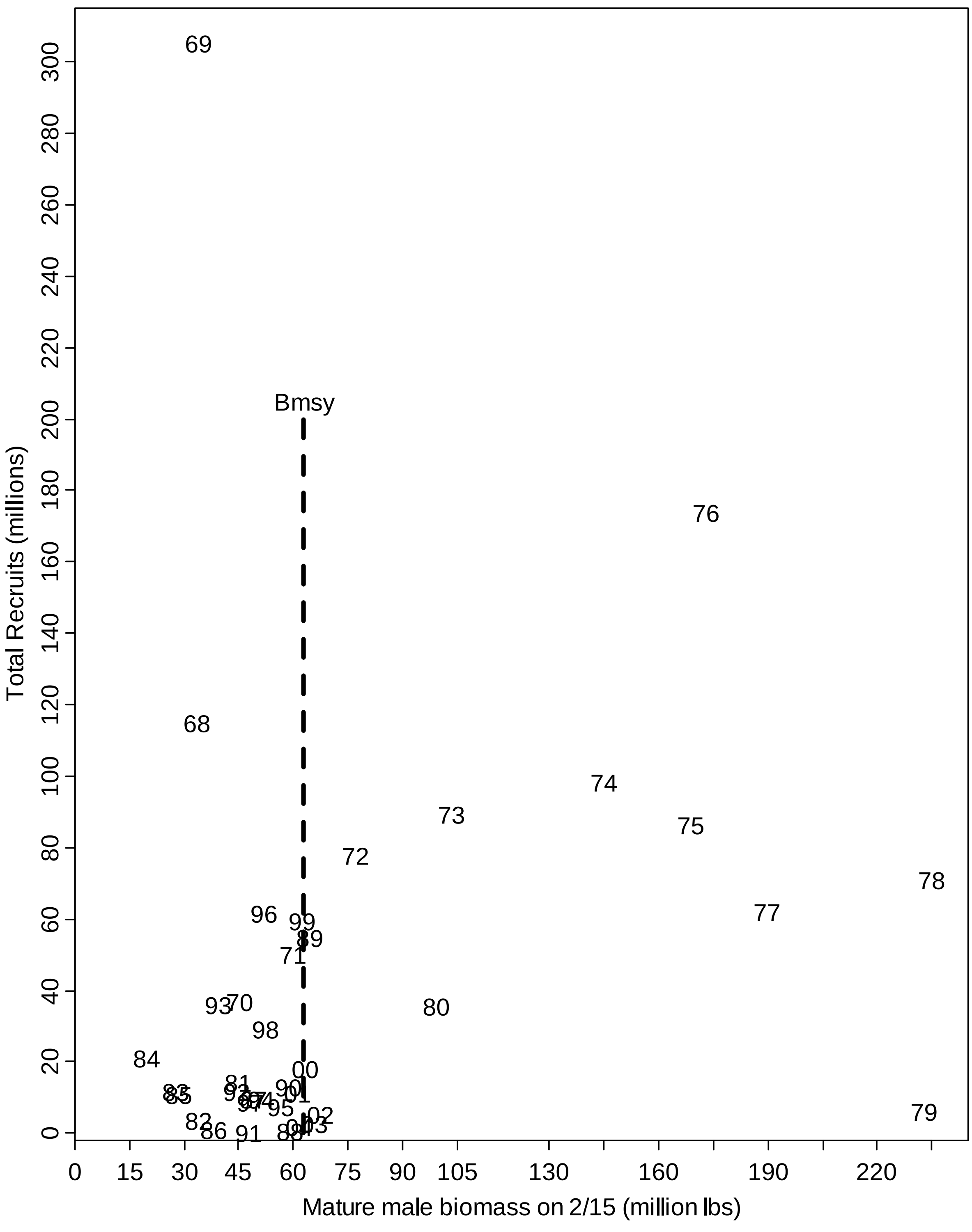


Figure 13a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2. Numerical labels are years of mating, and the vertical dotted lines are the estimated $B_{35\%}$ based on three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

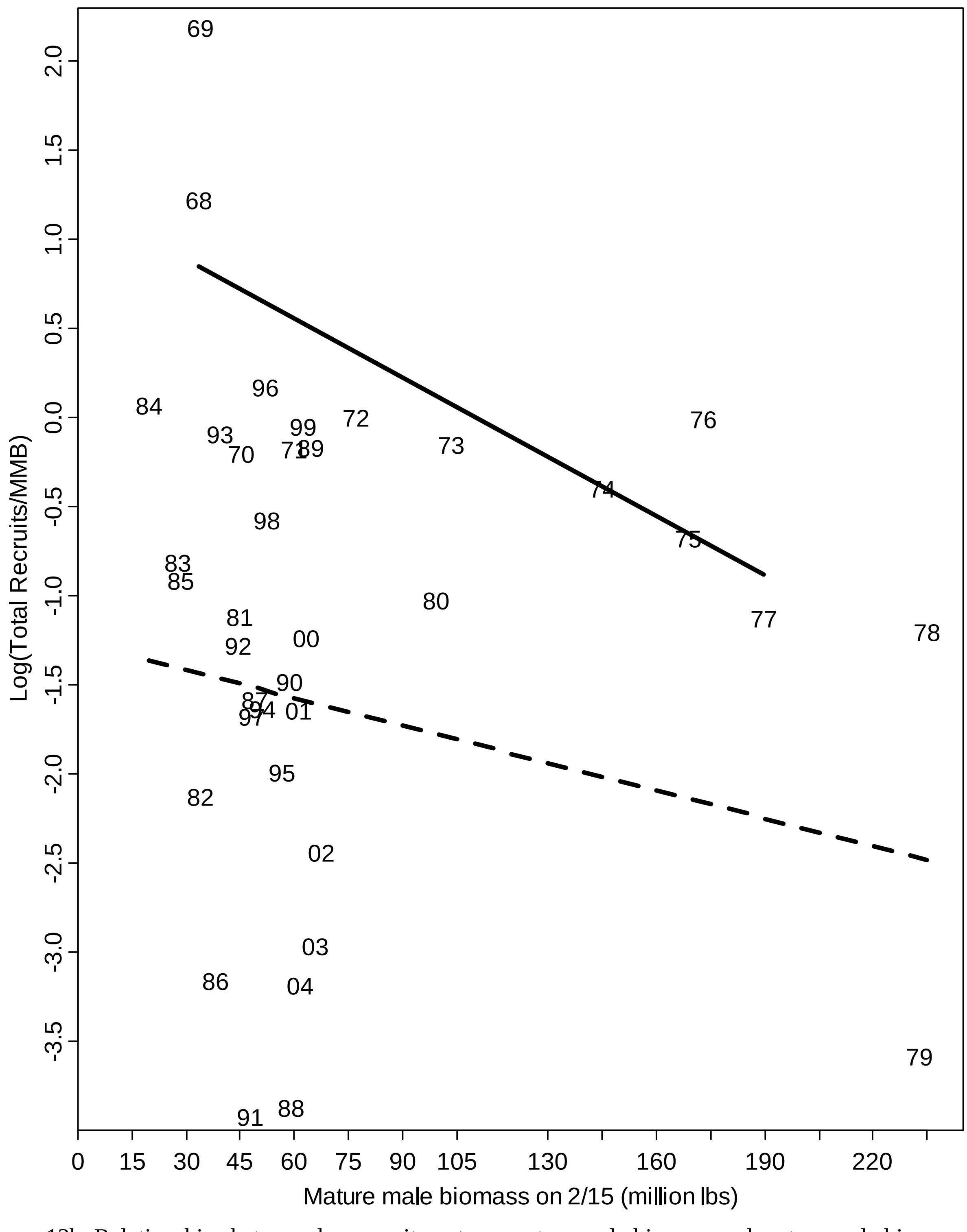


Figure 13b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2. Numerical labels are years of mating, the solid line is the regression line for data of 1968-1977, and the dotted line is the regression line for data of 1978-2004.

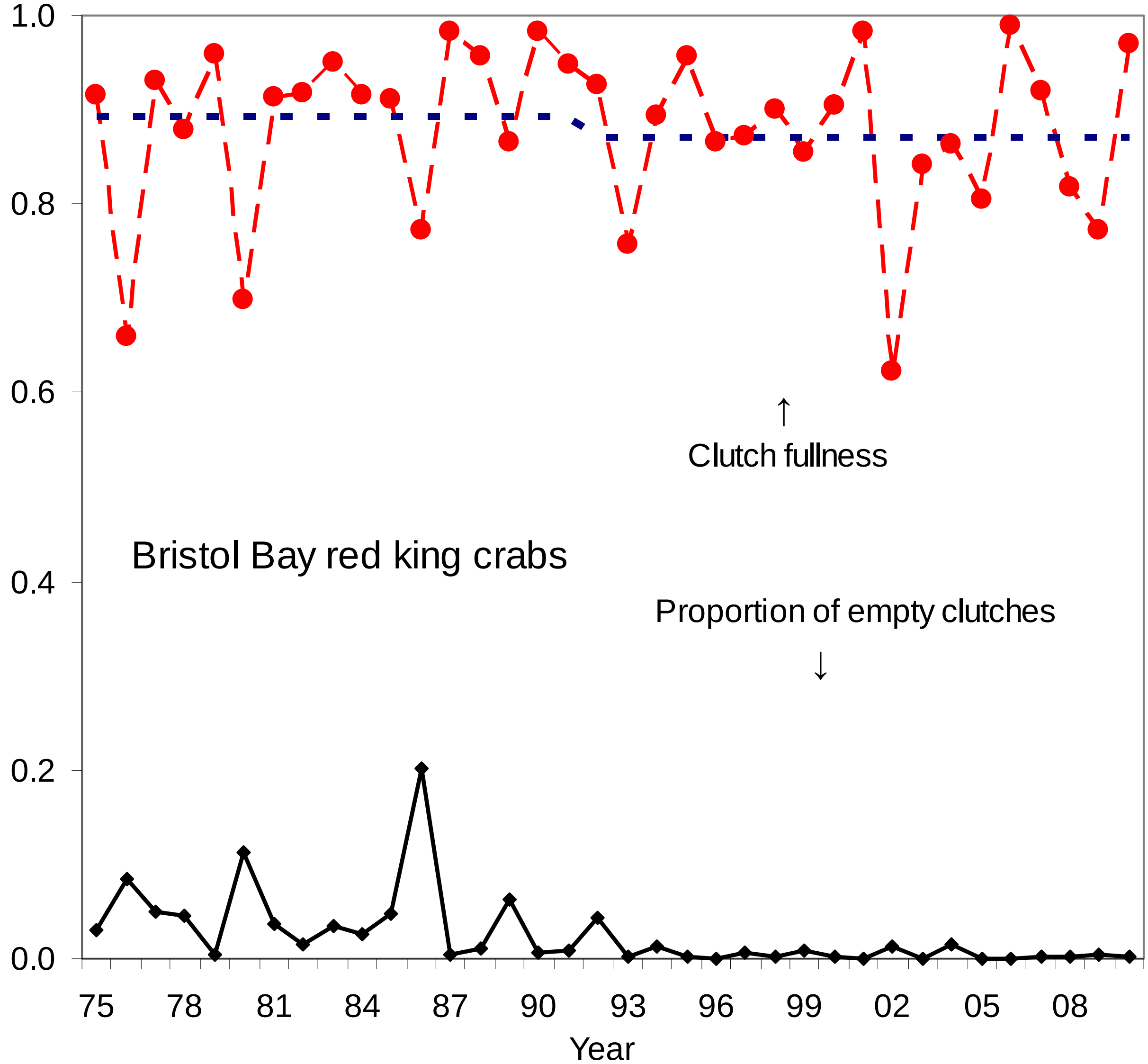


Figure 14. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crabs >89 mm CL from 1975 to 2010 from survey data. Oldshell females were excluded.

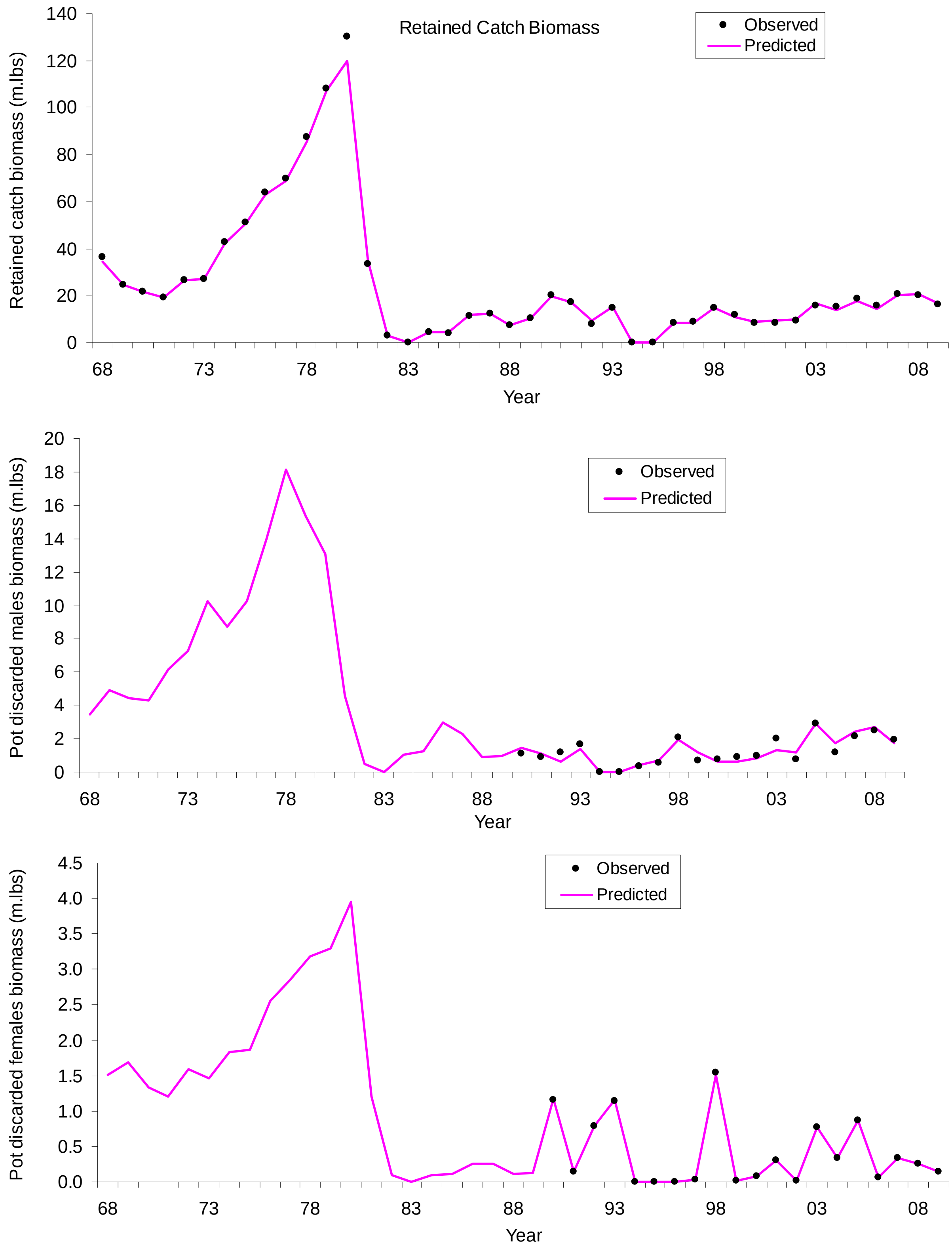
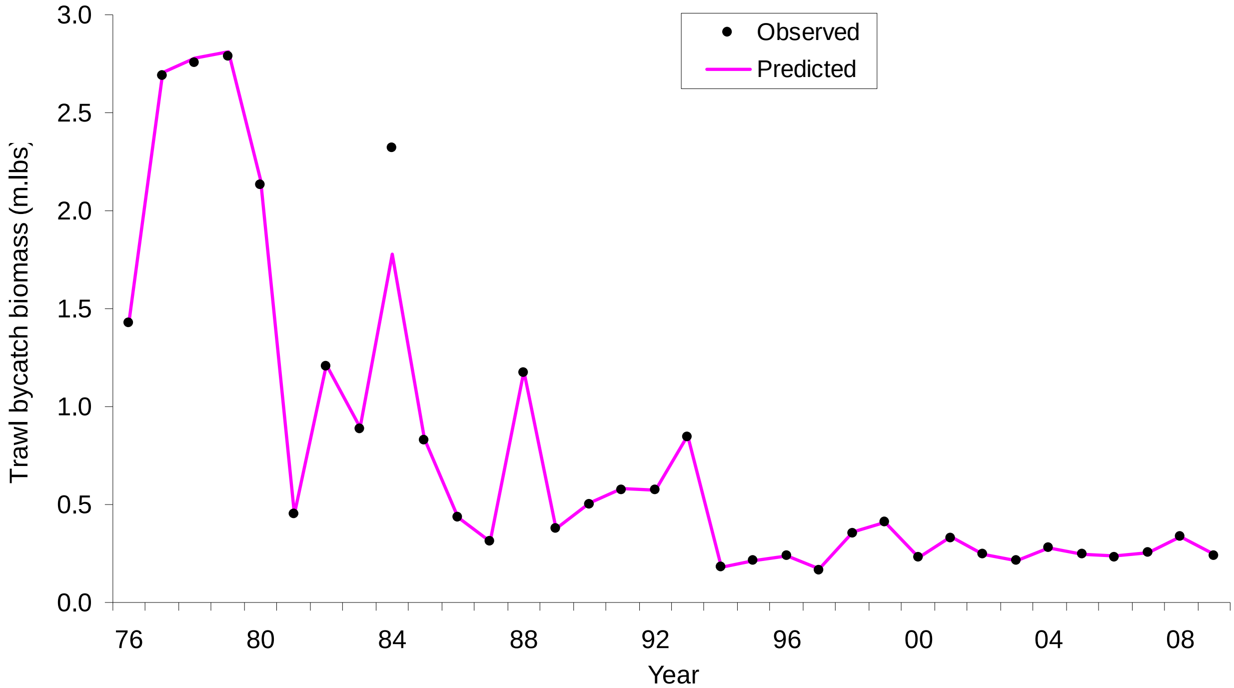


Figure 15a. Observed and predicted catch mortality biomass. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.



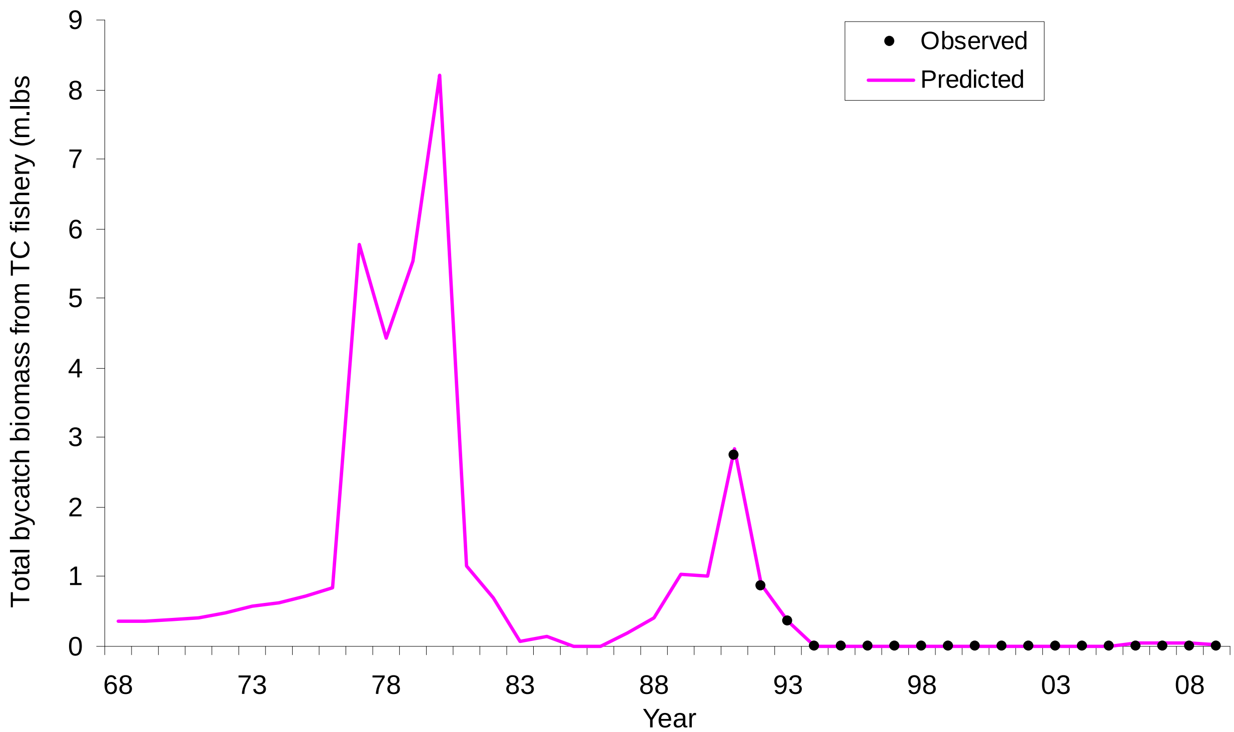


Figure 15b. Observed and predicted catch mortality biomass from trawl fisheries and Tanner crab fishery with scenario (3). Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25.

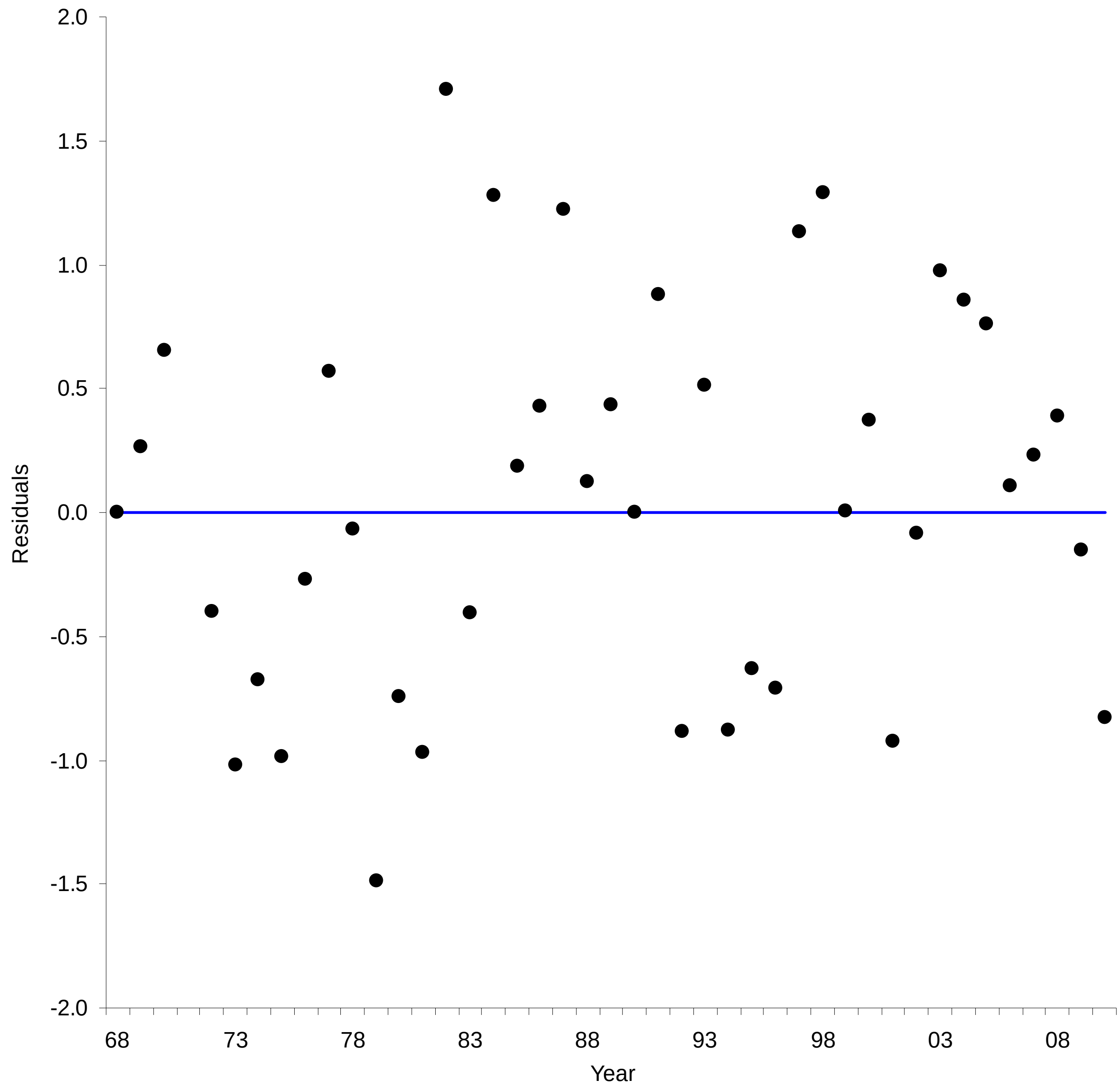


Figure 16. Standardized residuals of total survey biomass. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

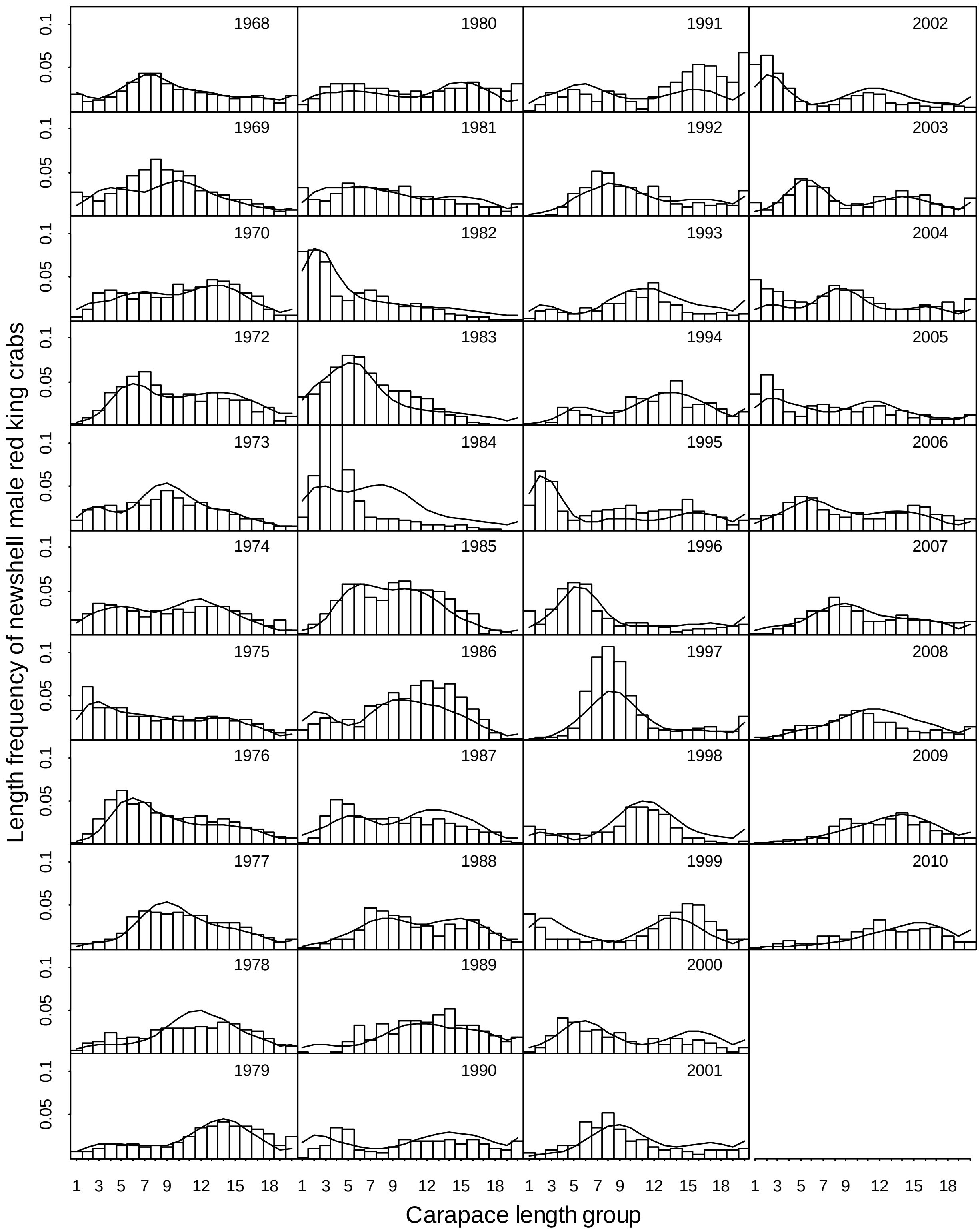


Figure 17. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay all-shell (before 1986) and newshell (1986-2010) male red king crabs by year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, and the first length group is 67.5 mm.

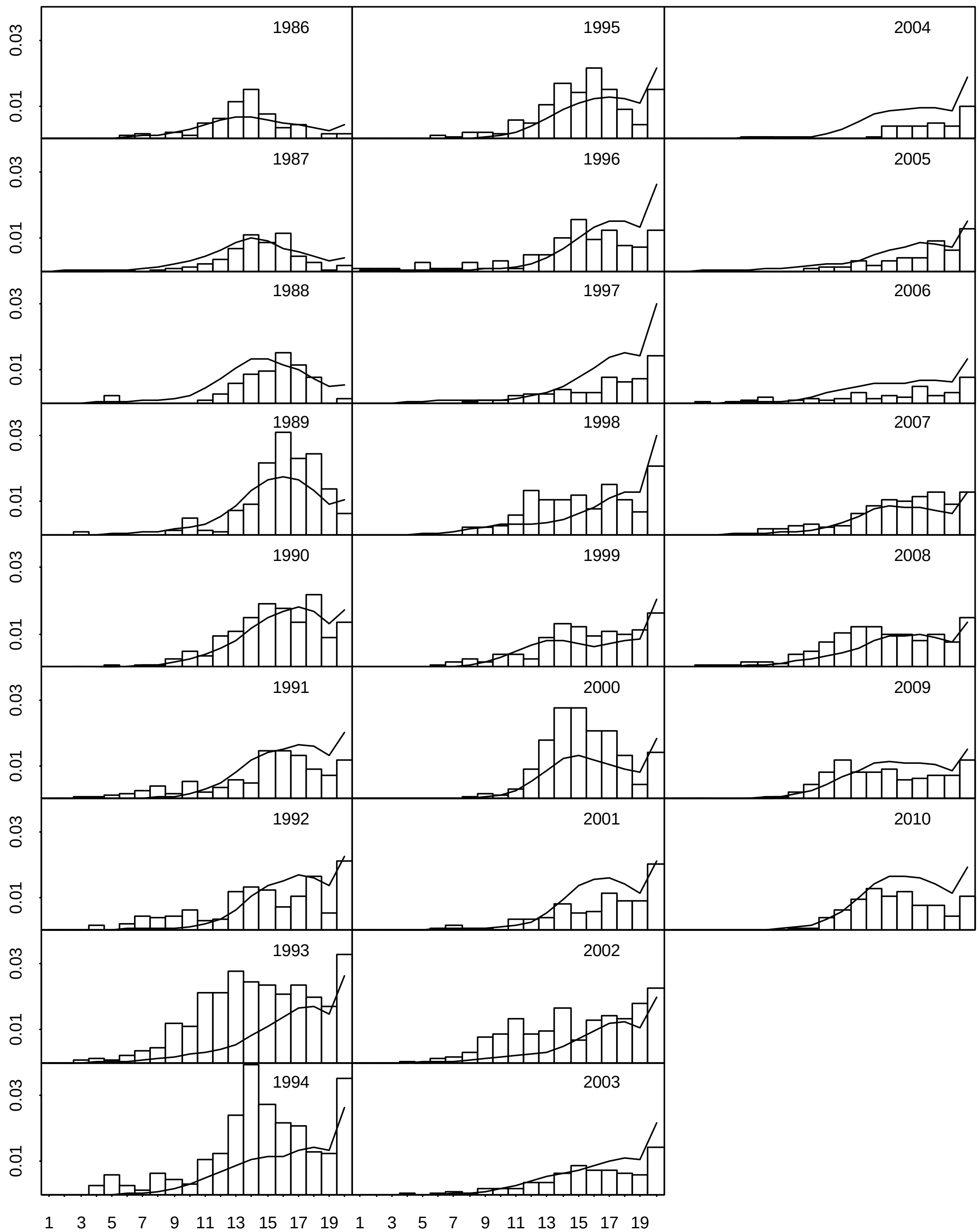


Figure 18. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay oldshell male red king crabs by year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

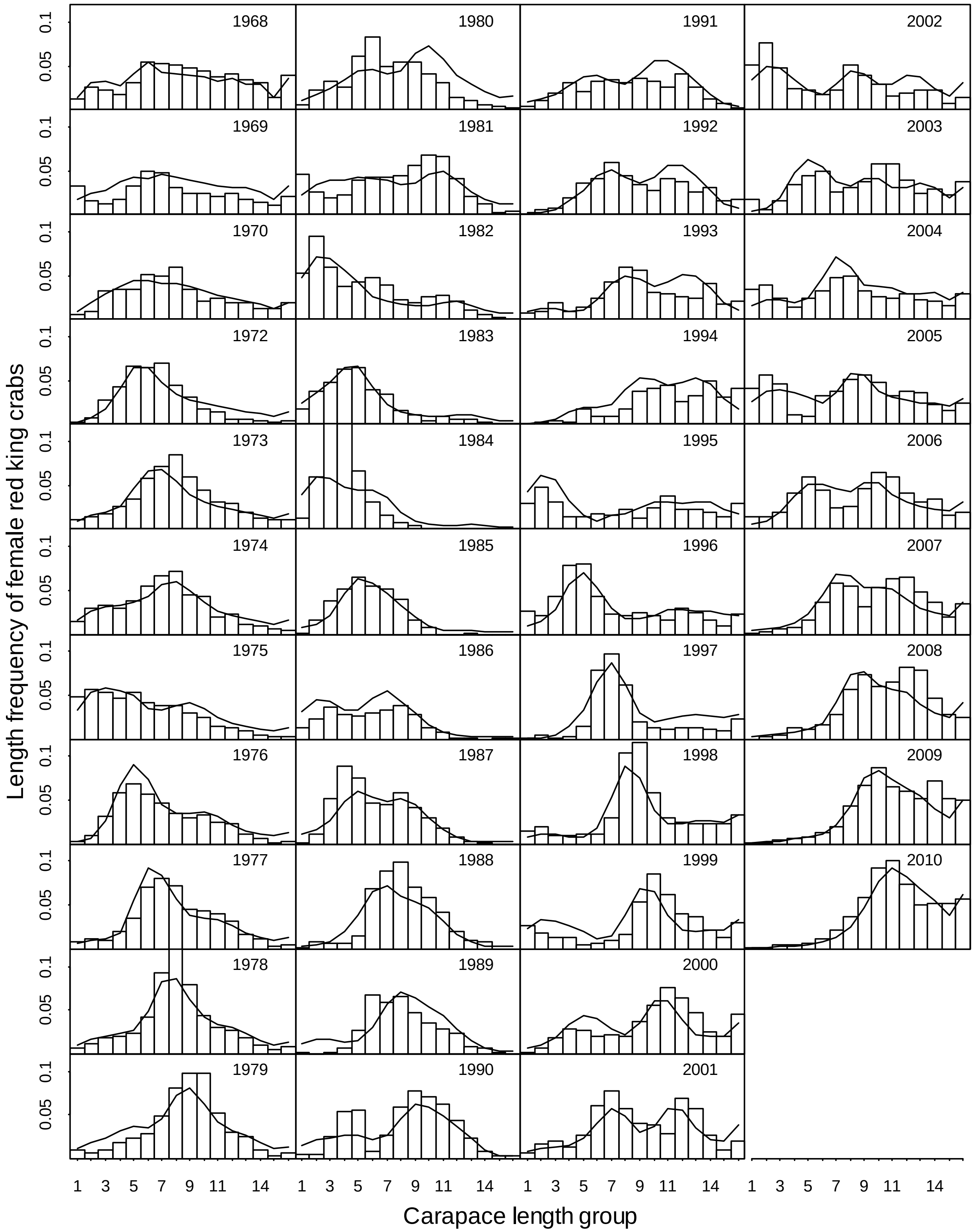


Figure 19. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

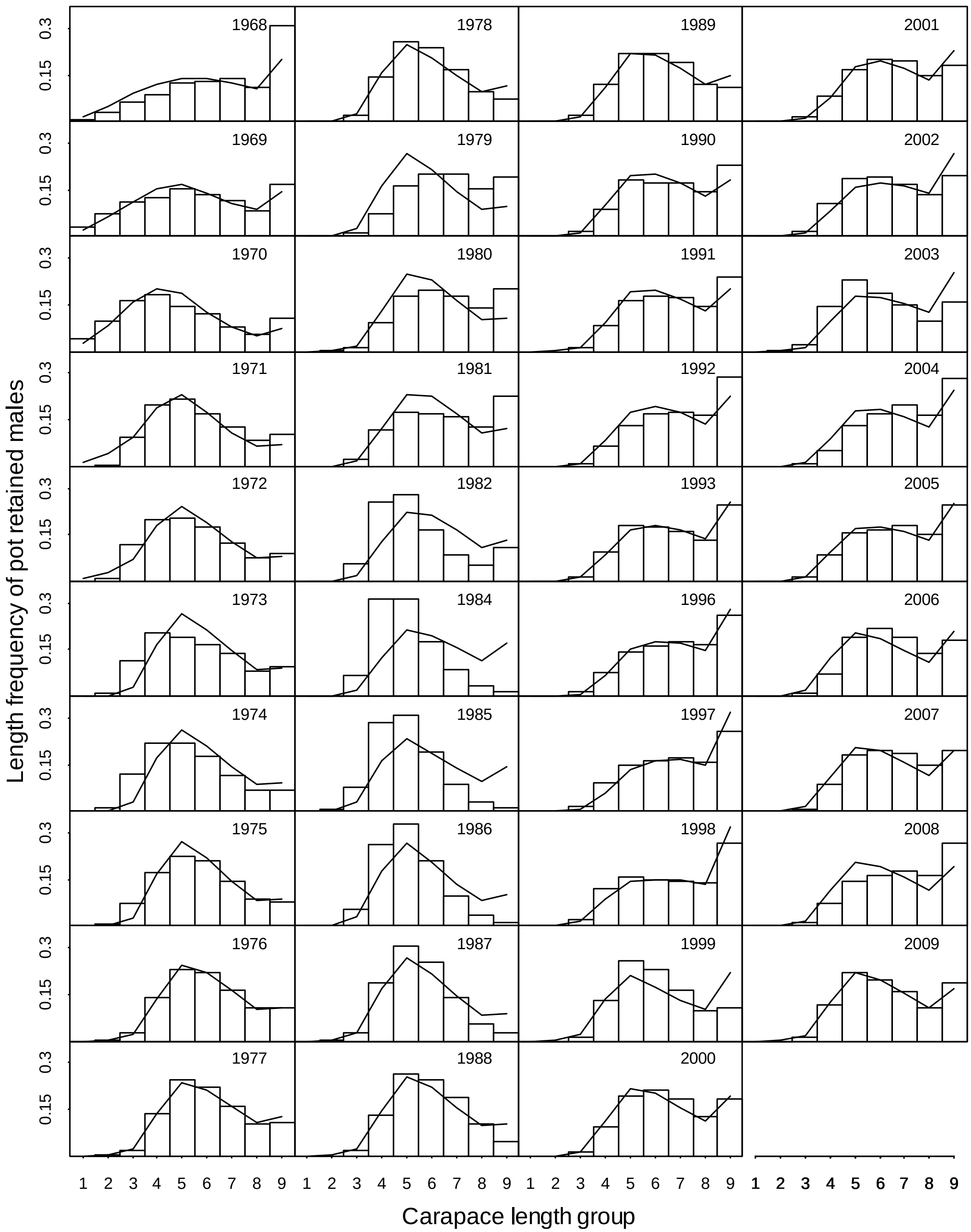


Figure 20. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 122.5 mm.

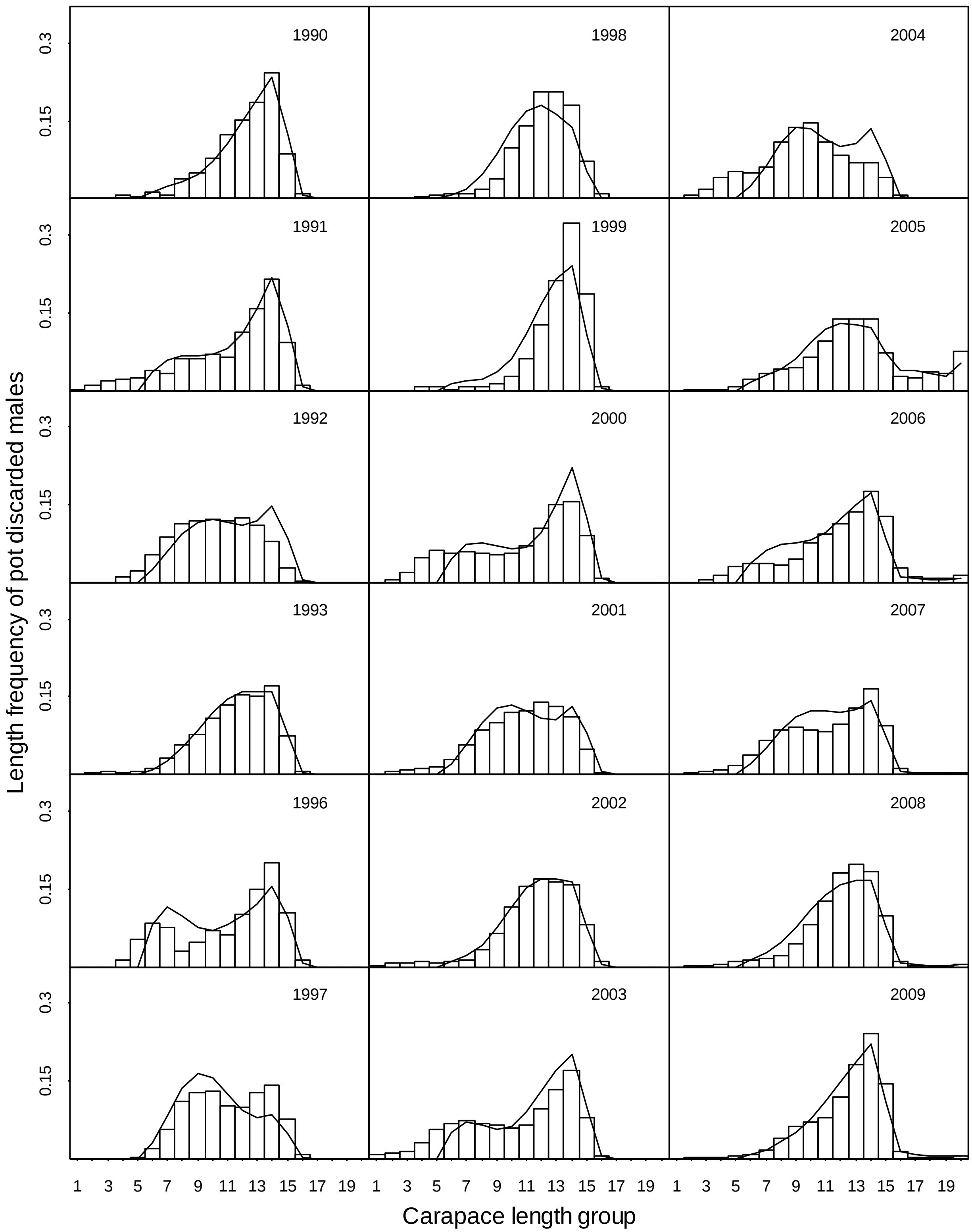


Figure 21. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

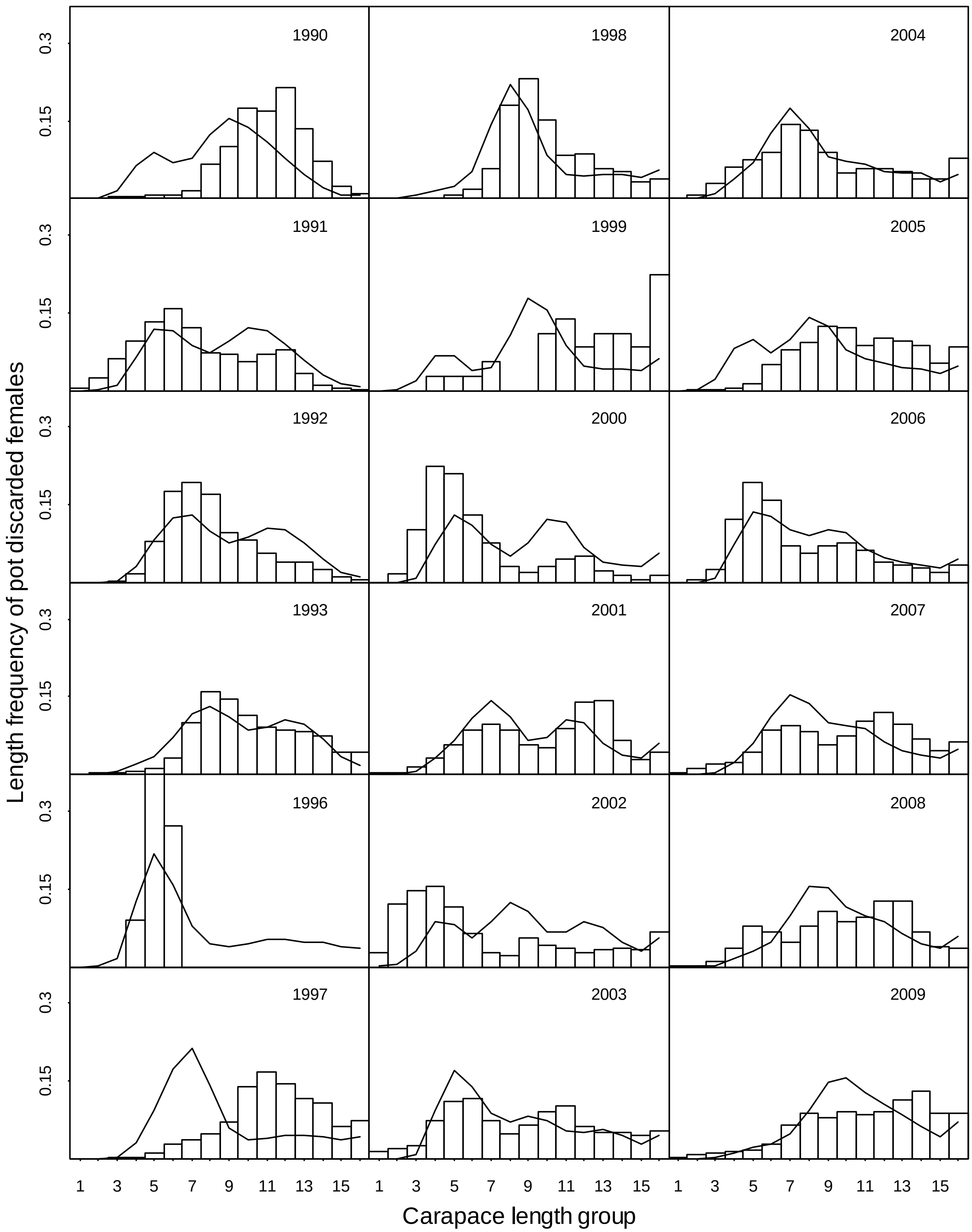


Figure 22. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the first length group is 67.5 mm.

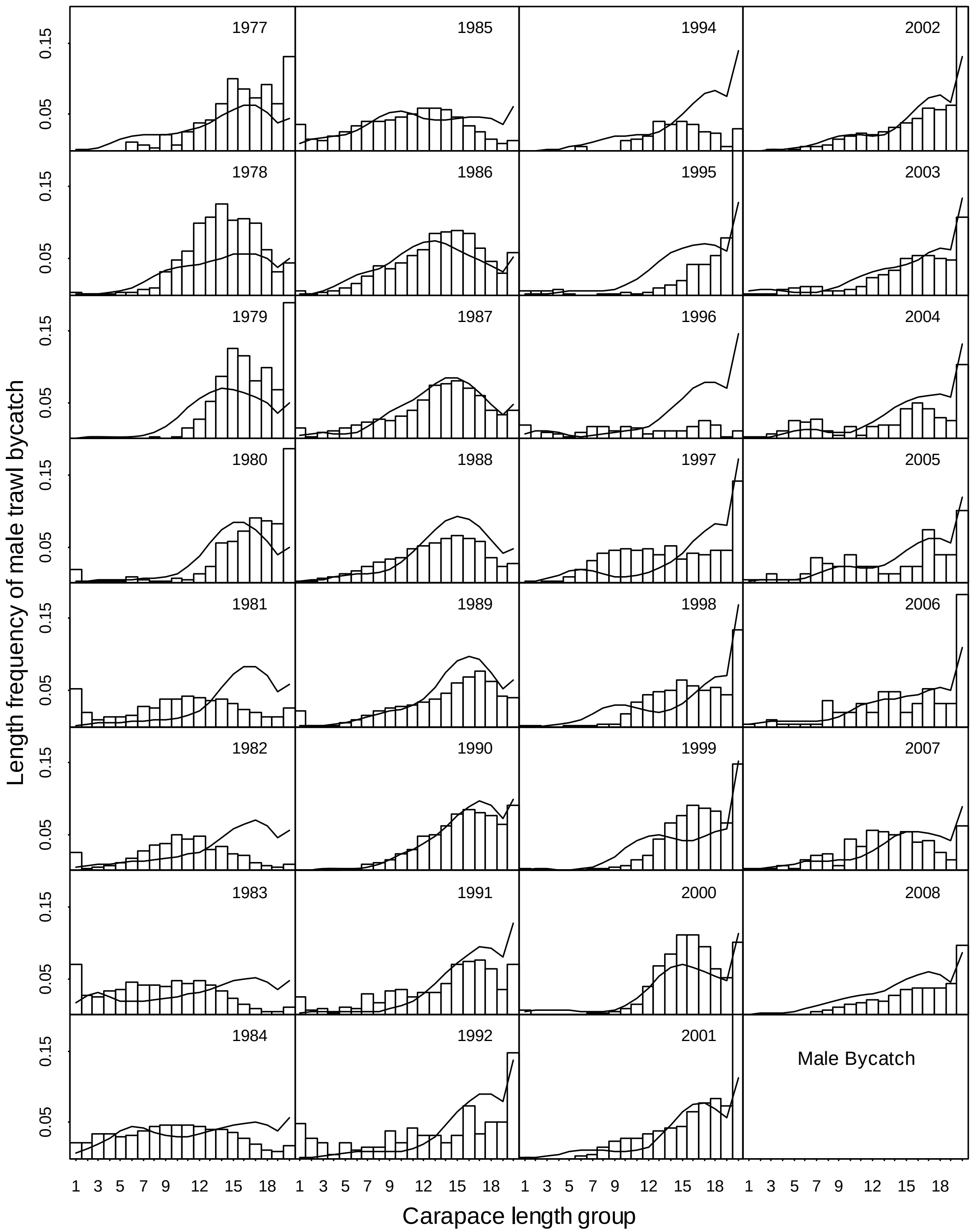


Figure 23. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

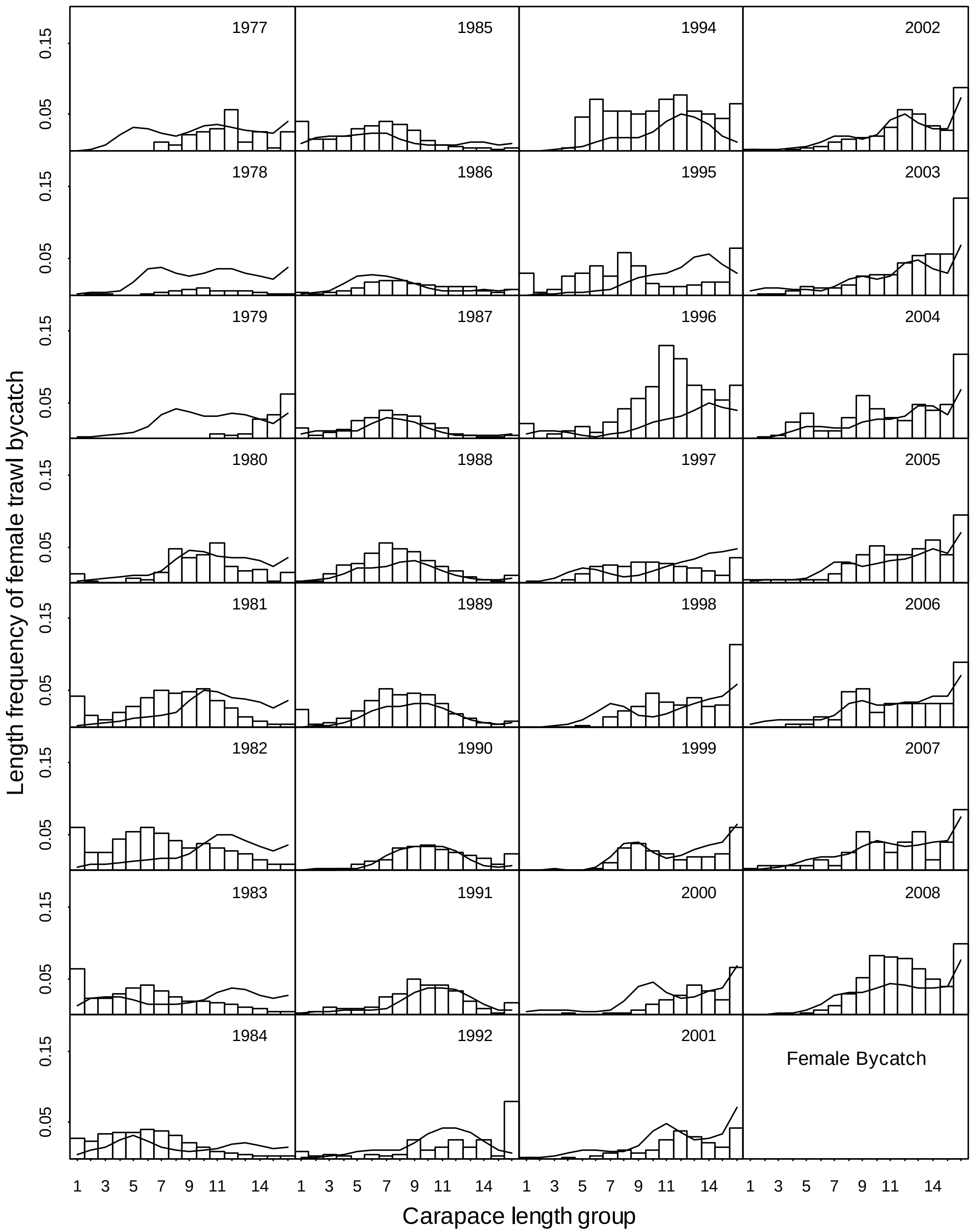


Figure 24. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, trawl bycatch mortality rate is 0.8, and the first length group is 67.5 mm.

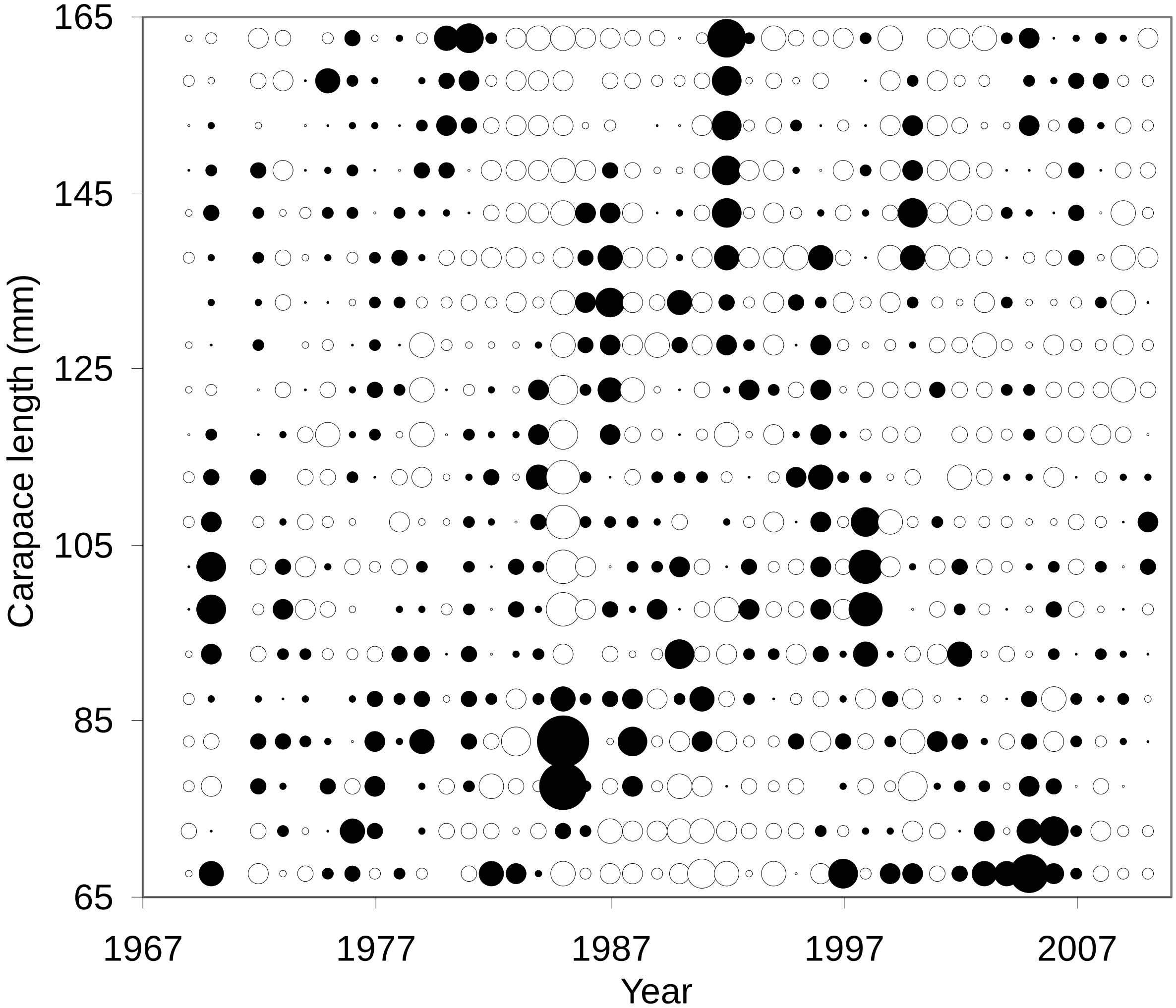


Figure 25. Standardized residuals of proportions of survey all-shell (1968-1985) and newshell (1986-2010) male red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

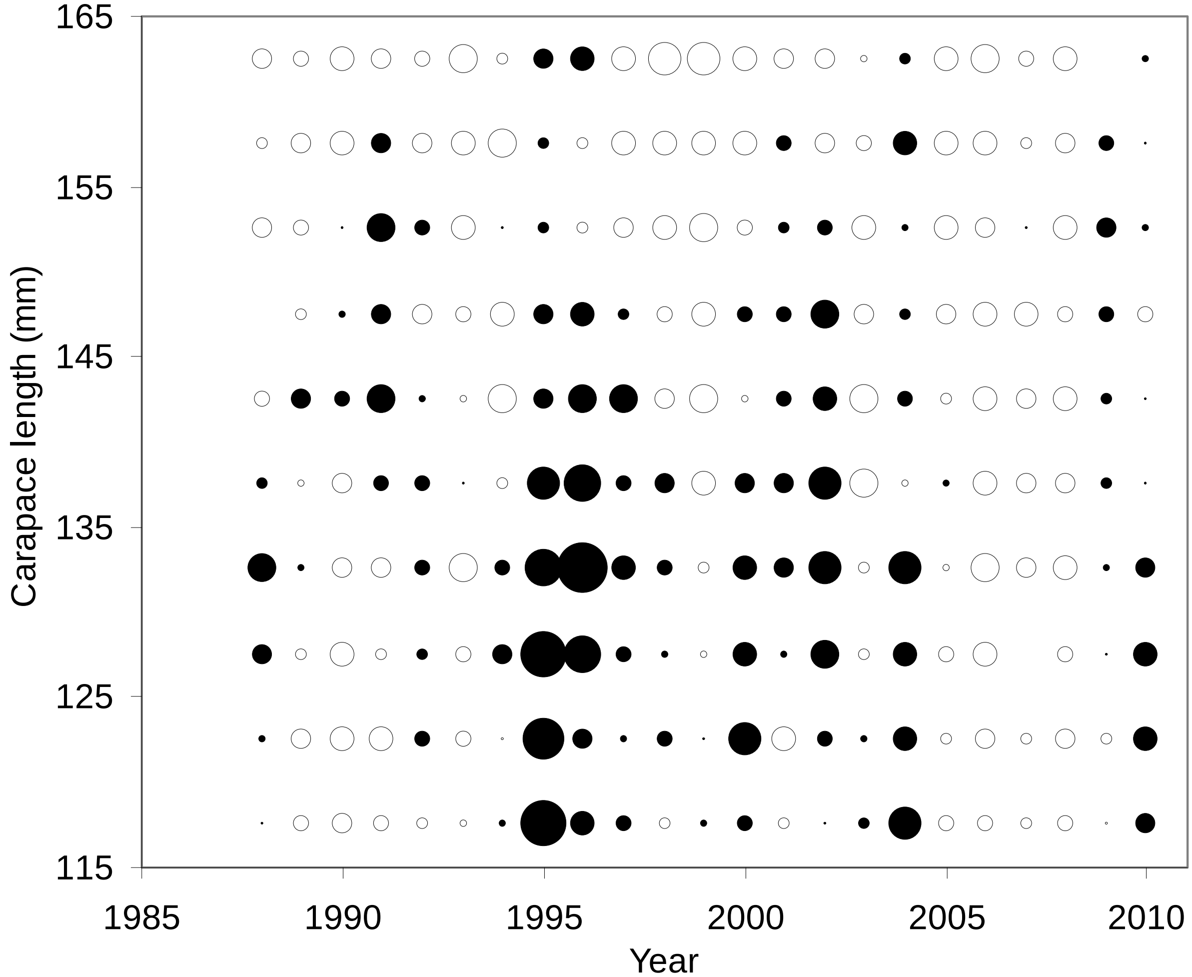


Figure 26. Standardized residuals of proportions of survey oldshell male red king crabs (1986-2010). Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

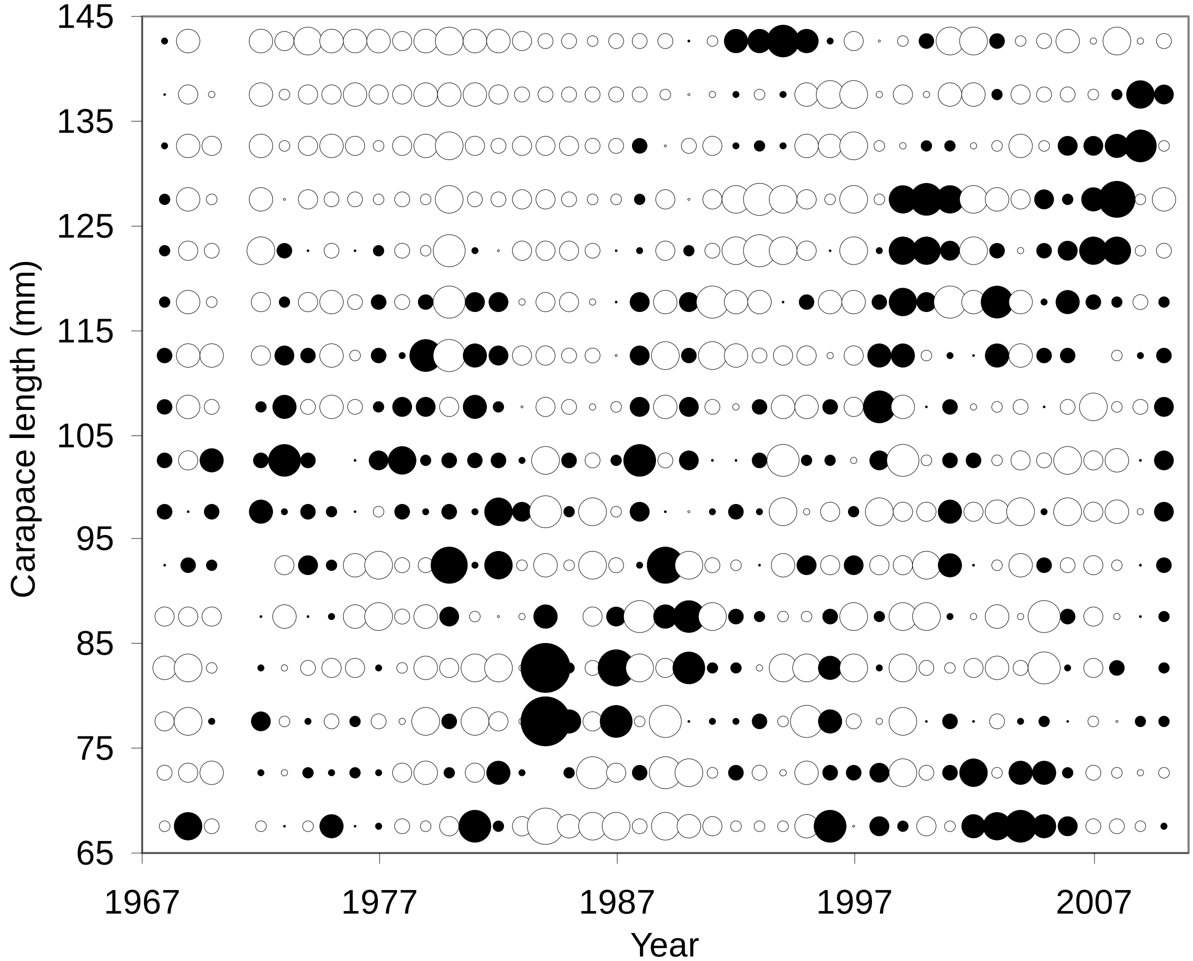
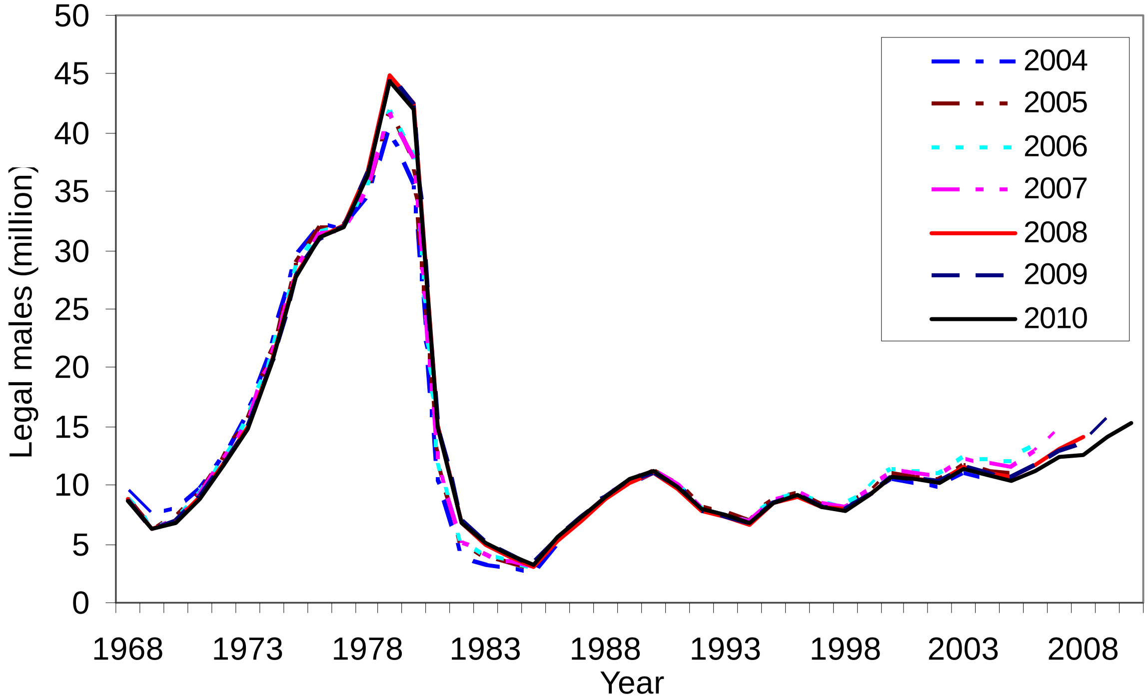


Figure 27. Standardized residuals of proportions of survey female red king crabs (1968-2010). Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



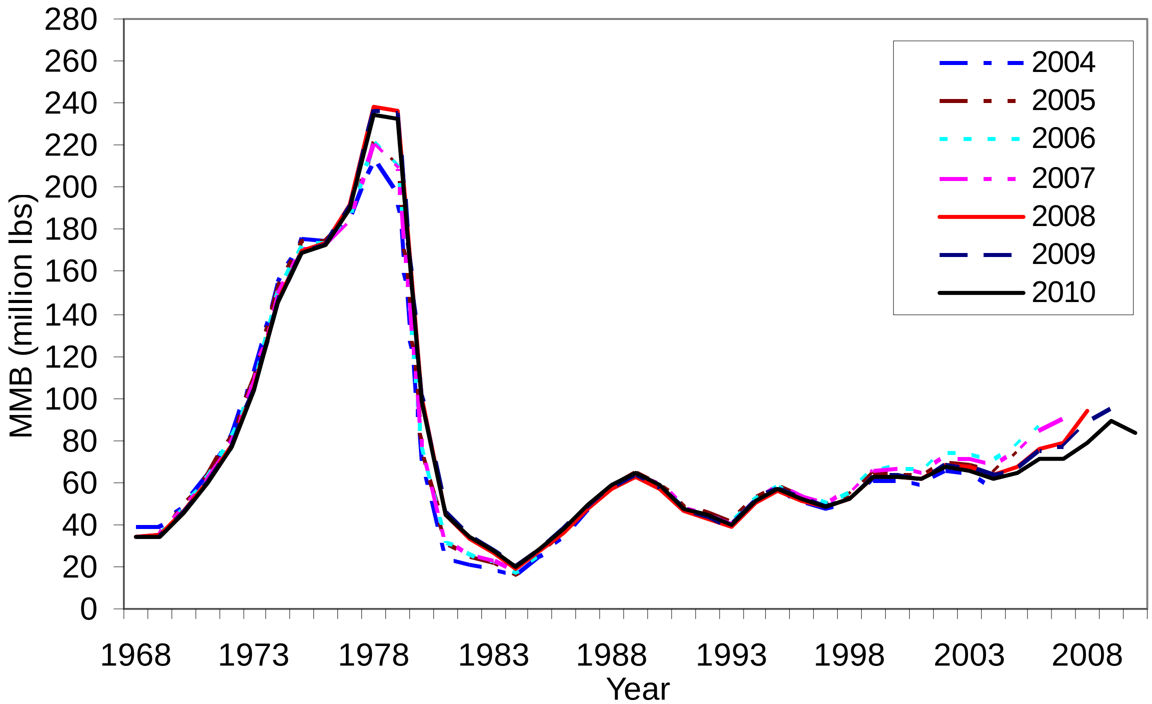


Figure 28. Comparison of estimates of legal male abundance (top) and mature male biomass (bottom) on Feb. 15 of Bristol Bay red king crab from 1968 to 2010 made with terminal years 2004-2010 with scenario (3a). These are results of the 2010 model. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

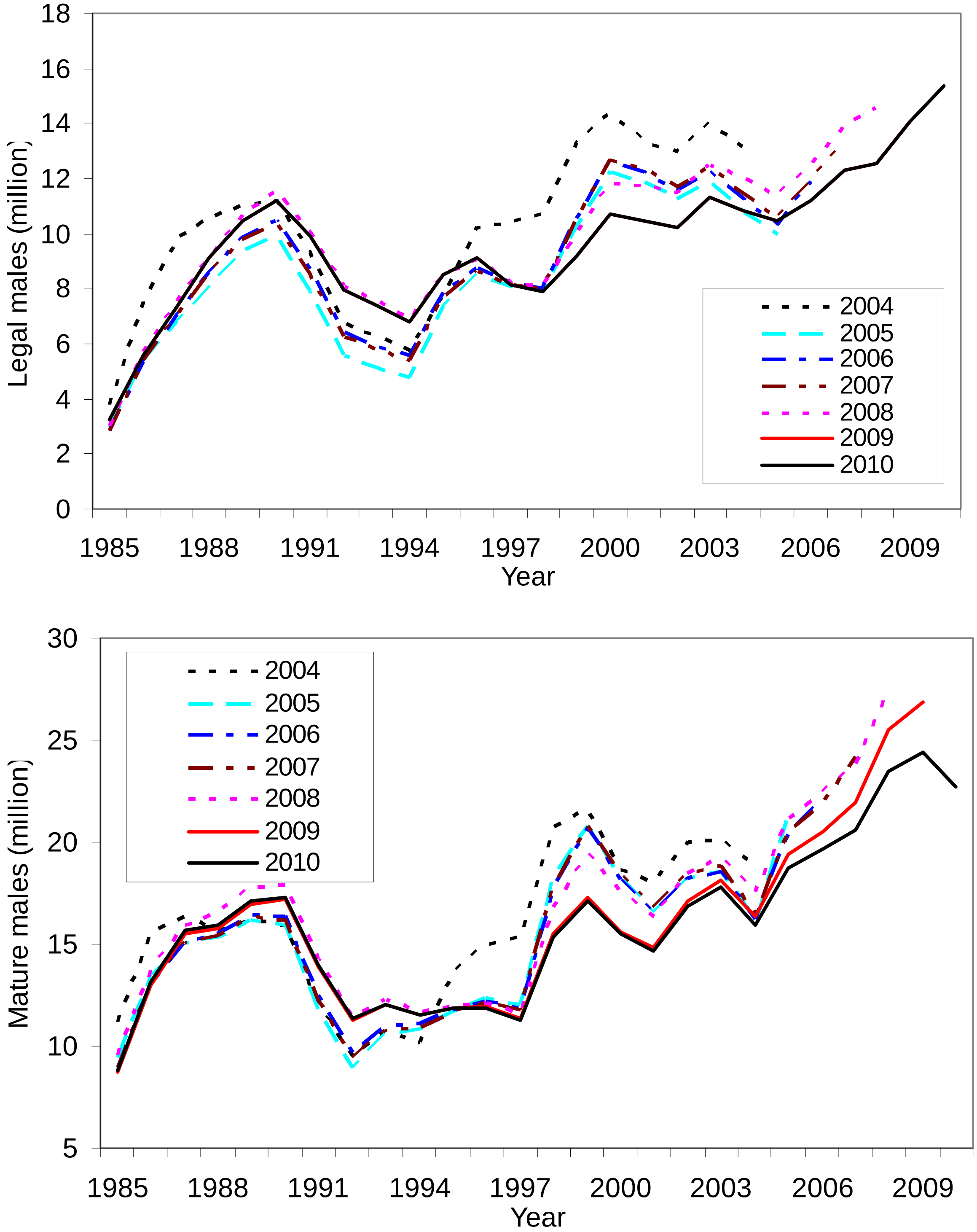
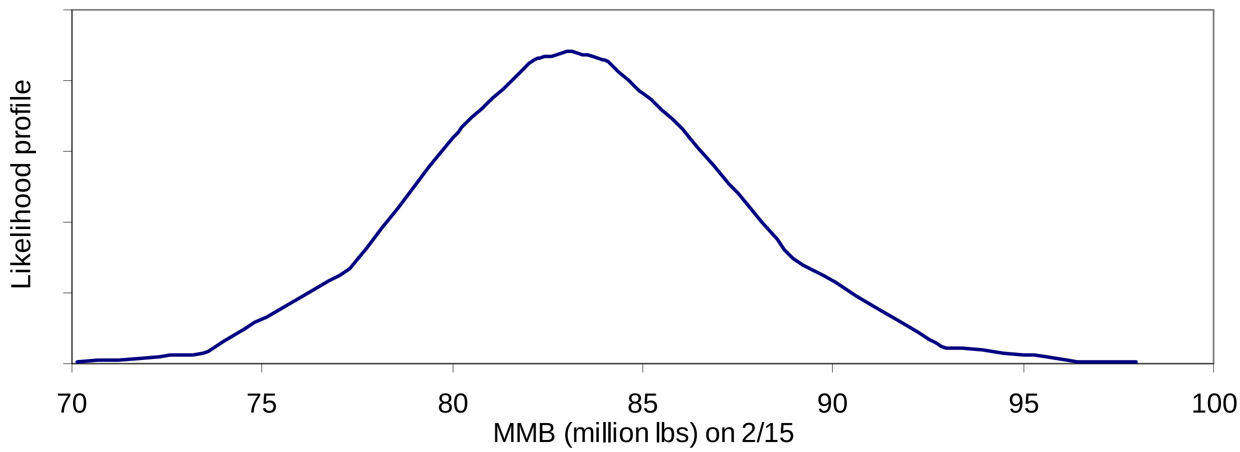
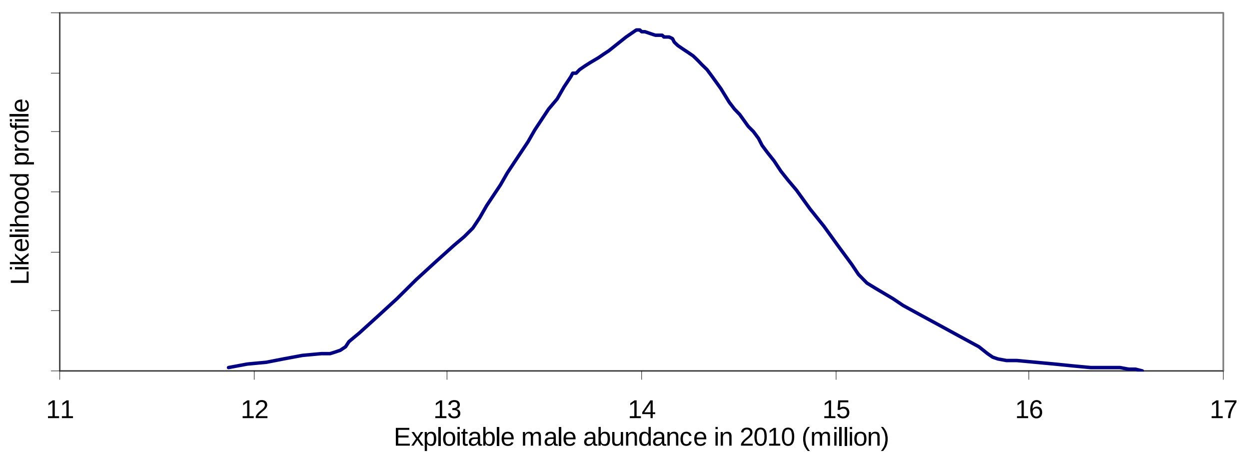


Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1985 to 2010 made with terminal years 2004-2010 with scenario (3a). These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.





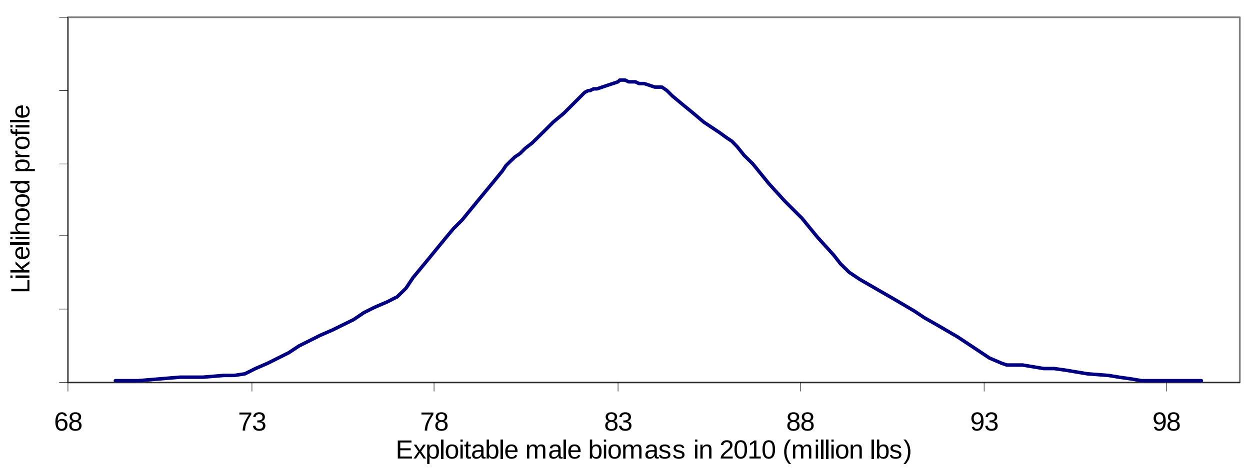


Figure 30. Likelihood profiles for estimated mature male biomass on Feb. 15 and exploitable male abundance and biomass at the fishing time for the 2010 season with $F_{35\%}$. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

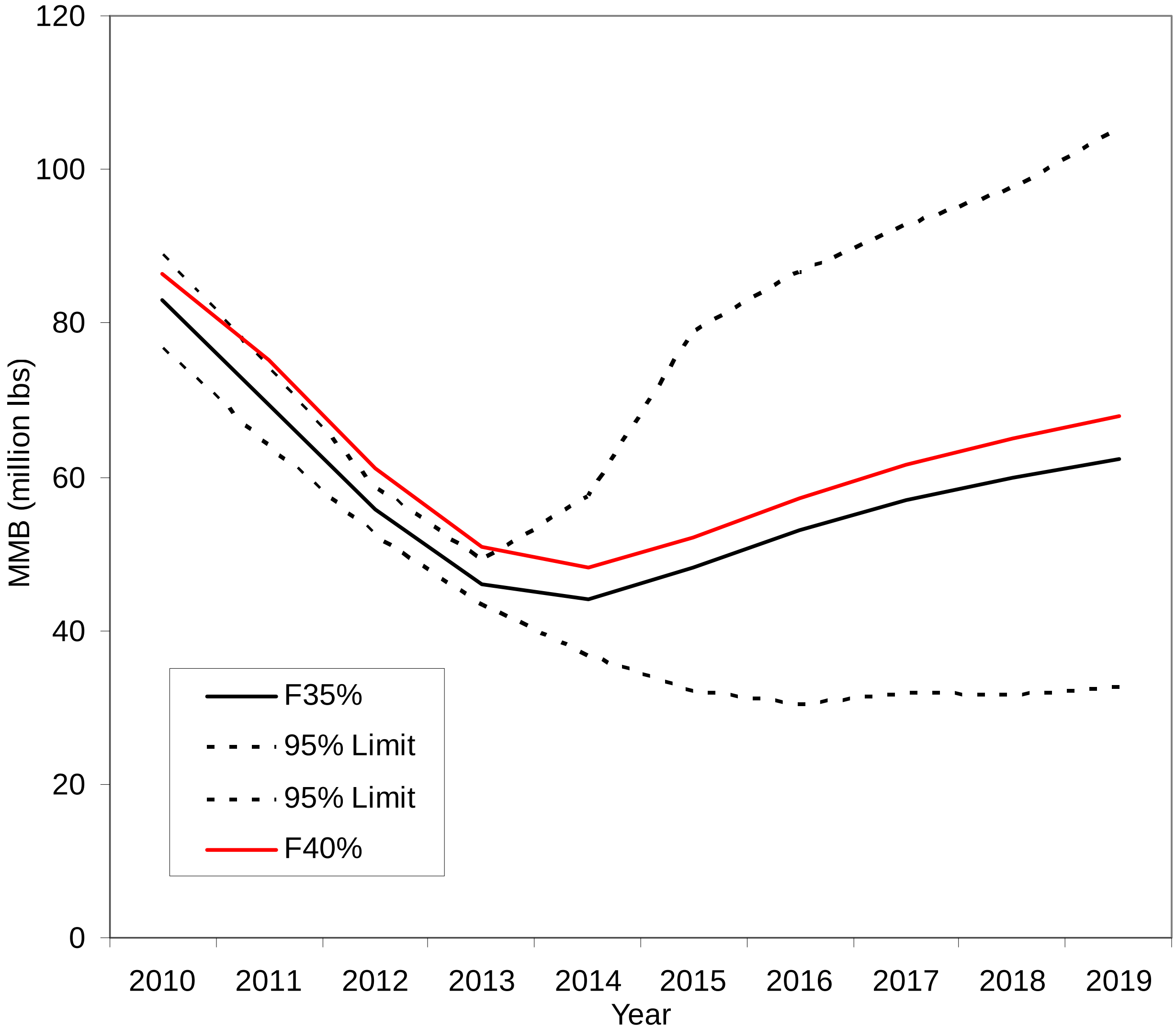


Figure 31. Projected mature male biomass on Feb. 15 with $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2010-2119. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

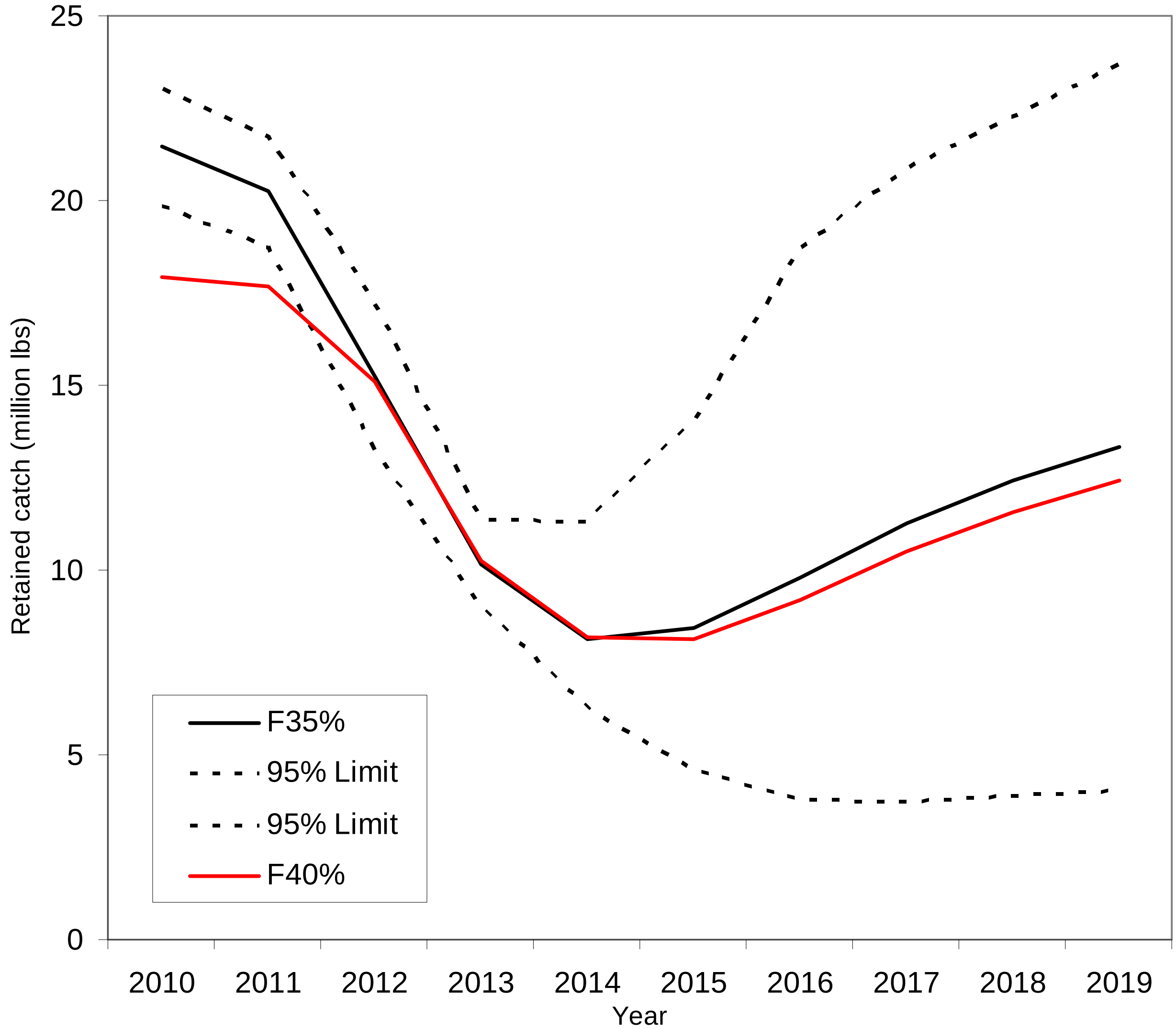


Figure 32. Projected retained catch biomass with $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2010-2119. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

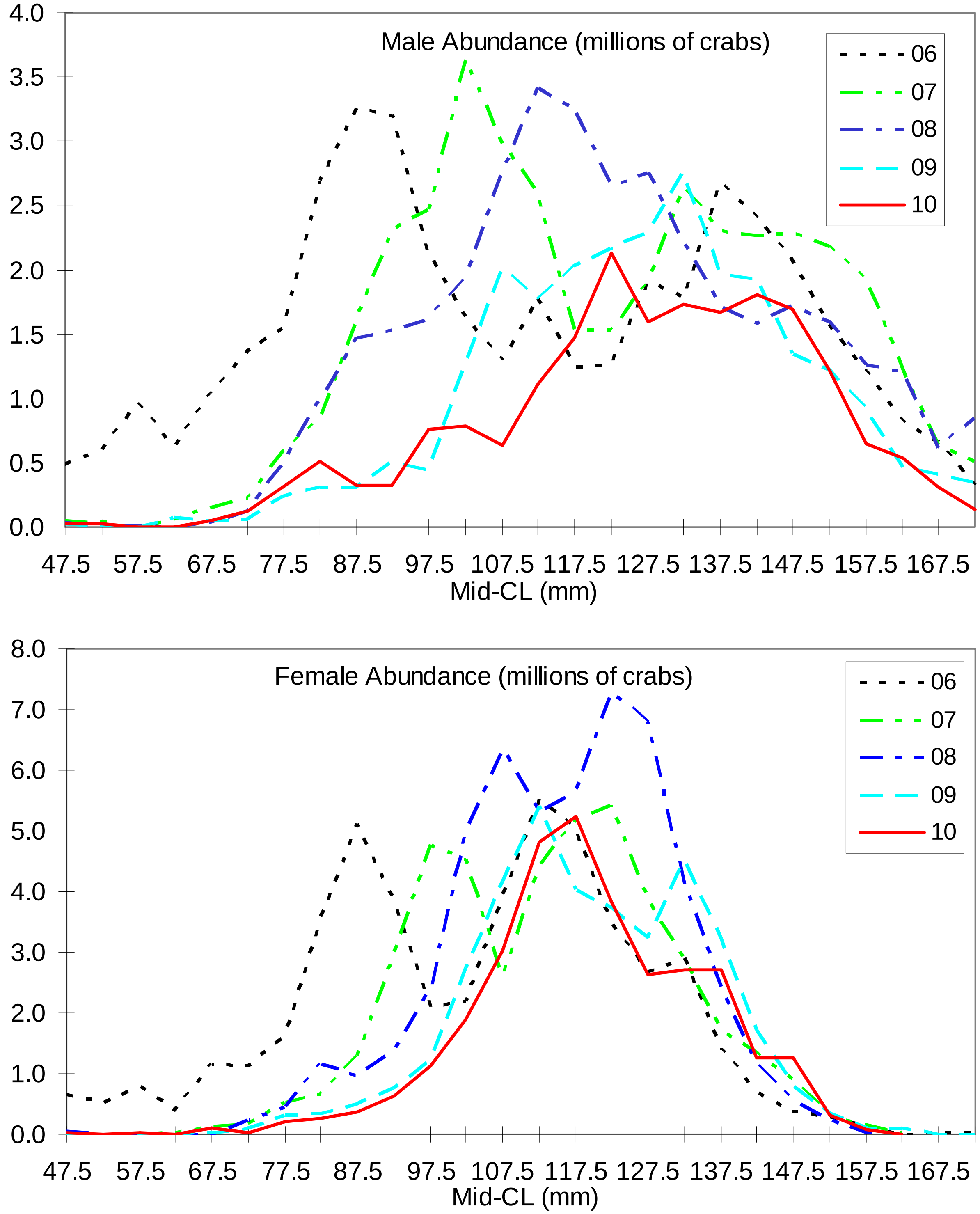


Figure 33. Length frequency distributions of male (top panel) and female (bottom panel) red king crabs in Bristol Bay from NMFS trawl surveys during 2006-2010. For purposes of these graphs, abundance estimates are based on area-swept methods.

Appendix A. Description of the Bristol Bay Red King Crab Model

a. Model Description

i. Population model

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). Male crab abundances by carapace length and shell condition in any one year are modeled to result from abundances in the previous year minus catch and handling and natural mortalities, plus recruitment, and additions to or losses from each length class due to growth:

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

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

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:

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

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

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

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

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

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

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

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

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

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

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

Before 1990, no observed bycatch data were available in the directed pot fishery; the crabs that were discarded and died in those years were estimated as the product of handling mortality rate, legal harvest rates, and mean length-specific selectivities. It is difficult to estimate 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:

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

where

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

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

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

The female crab model is the same as the male crab model except that the retained catch equals zero 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:

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

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

Male pot bycatch selectivity is modeled by two linear functions:

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

Where

φ, κ, γ are parameters.

During 2005-2008, a portion of legal males were also discarded in the pot fishery. The selectivity for this 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 A1). Q was assumed to be constant over time except during 1970-1972 when the survey catchability was small.

Assuming that the BSFRF survey caught all crabs within the area-swept, the ratio between NMFS abundance and BSFRF abundance is a capture probability for the NMFS survey net. The Delta method was used to estimate the variance for the capture probability. A maximum likelihood method was used to estimate parameters for a logistic function as an estimated capture probability curve (Figure A1). For a given size, the estimated capture probability is smaller based on the BSFRF survey than from the trawl experiment, but the Q value is similar between the trawl experiment and the BSFRF surveys (Figure A1). Because many small-sized crabs are in the shallow water areas that are not accessible for the trawl survey, NMFS survey catchability/selectivity consists of capture probability and crab availability.

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

c. Likelihood Components

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

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

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

where

L is the number of length groups,

T is the number of years, and

n is the effective sample size, which was assume ed 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:

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

Where

R_t is the recruitment in year *t*,

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

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

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

Weights λ_j are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, and 10 for recruitment sex ratio. These λ_j values represent prior assumptions about the accuracy of the observed catch biomass data and about the variances of these random variables.

d. Population State in Year 1.

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

e. Parameter estimation framework:

i. Parameters estimated independently

Basic natural mortality, length-weight relationships, and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 72.5 for both males and females. 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.

(1). Natural Mortality

Based on an assumed maximum age of 25 years and the 1% rule (Zheng 2005), basic M was estimated to be 0.18 for both males and females. Natural mortality in a given year, M_t, equals to $M + Mm_t$ (for males) or $M + Mf_t$ (females). One value of Mm_t during 1980-1985 was estimated and two values of Mf_t during 1980-1984 and 1976-79, 1985-93 were estimated in the model.

(2). Length-weight Relationship

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

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

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

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

where

W is weight in grams, and
L is CL in mm.

(3). Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, 1960s and 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967; Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974; McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be only a function of body size in the models. Tagging data were used to estimate mean growth increment per molt as a function of pre-molt length for males (Figure A2). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1968-1993 and 1994-2008, respectively, and the data presented in Gray (1963) were used to estimate those for mature females (Figure A2). To make a smooth transition of growth increment per molt from immature to mature females, weighted growth increment averages of 70% and 30% at 92.5 mm CL pre-molt length and 90% and 10% at 97.5 mm CL were used, respectively, for mature and immature females during 1983-1993. These percentages are roughly close to the composition of maturity. During 1968-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2008, females matured at a slightly higher size, so the growth increment per molt was shifted to high increments for immature crabs (Figure A2). Once mature, the growth increment per molt for male crabs decreases slightly and annual molting probability decreases, whereas the growth increment for female crabs decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

(4). Sizes at Maturity for Females

NMFS collected female reproductive condition data during the summer trawl surveys. Mature females are separated from immature females by a presence of egg clutches or egg cases. Proportions of mature females at 5-mm length intervals were summarized and a logistic curve was fitted to the data each year to estimate sizes at 50% maturity. Sizes at 50% maturity are illustrated in Figure A3 with mean values for three different periods (1975-82, 1983-93 and 1994-08).

(5). Sizes at Maturity for Males

Sizes at functional maturity for Bristol Bay male RKC have been assumed to be 120 mm CL (Schmidt and Pengilly 1990). This is based on mating pair data collected off Kodiak Island (Figure A4). Sizes at maturity for Bristol Bay female RKC are about 90 mm CL, about 15 mm CL less than Kodiak female RKC (Pengilly et al. 2002). The size ratio of mature males to females is 1.3333 at sizes at maturity for Bristol Bay RKC, and since mature males grow at much larger increments than mature females, the mean size ratio of mature males to females is most likely larger than this ratio. Size ratios of the large majority of Kodiak mating pairs were less than 1.3333, and in some bays, only a small proportion of mating pairs had size ratios above 1.3333 (Figure A4).

In the laboratory, male RKC as small as 80 mm CL from Kodiak and SE Alaska can successfully mate with females (Paul and Paul 1990). But few males less than 100 mm CL were observed to mate with females in the wild. Based on the size ratios of males to females in the Kodiak mating pair data, setting 120 mm CL as a minimum size of functional maturity for Bristol Bay male RKC is proper and conservative in terms of managing the fishery.

(6) Potential Reasons for High Mortality during the Early 1980s

Bristol Bay red king crab abundance had declined sharply during the early 1980s. Many factors have been speculated for this decline: (i) completely wiped out by fishing: directed pot fishery, other directed pot fishery (Tanner crab fishery), and bottom trawling; and (ii) high fishing and natural mortality. With the survey abundance, harvest rates in 1980 and 1981 were among the highest, thus the directed fishing definitely had a big impact on the stock decline, especially legal and mature males. However, for the sharp decline during 1980-1884 for males, 3 out of 5 years had low mature harvest rates. During 1981-1984 for females, 3 out of 4 years had low mature harvest rates. Also pot catchability for females and immature males are generally much lower than for legal males, so the directed pot fishing alone cannot explain the sharp decline for all segments of the stock during the early 1980s.

Red king crab bycatch in the eastern Bering Sea Tanner crab fishery is another potential factor. The main overlap between Tanner crab and Bristol Bay red king crab is east of 163^{o} W. No absolute red king crab bycatch estimates are available until 1991. So there are insufficient data to fully evaluate the impact. Retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure A5. The observed red king crab 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 for older crabs, and disease for all crabs. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of 0.18, all directed fishing mortality and non-directed fishing mortality. These three mortality parameters could be attributed to natural mortality as well as undocumented non-directed fishing mortality. The model fit the data much better with these three parameters than without them.

ii. Parameters estimated conditionally

The following model parameters were estimated for male and female crabs: total recruits for each year (year class strength R_t for t = 1969 to 2009), total abundance in the first year (1968), growth parameter β and recruitment parameter β_r for males and females separately. Molting probability parameters β and L_{50} were also estimated for male crabs. Estimated parameters also include β and L_{50} for retained selectivity, β and L_{50} for pot-discarded female selectivity, β and L_{50} for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, β and L_{50} for groundfish trawl discarded selectivity, φ, κ and γ for pot-discarded male selectivity, and β for trawl survey selectivity and L_{50} for trawl survey male and females separately. NMFS survey catchabilities Q for 1968-69 and 1973-2009 and Q_m (for males) and Q_f (for females) for 1970-72 were also estimated. Annual fishing mortalities were also estimated for the directed pot fishery for males (1968-2008), pot-discarded females from the directed fishery (1990-2008), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93), and groundfish trawl discarded males and females (1976-2008). Three additional mortality parameters for Mm_t and Mf_t were also estimated. The total number of parameters to be estimated was 223. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

f. Definition of model outputs.

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

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

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

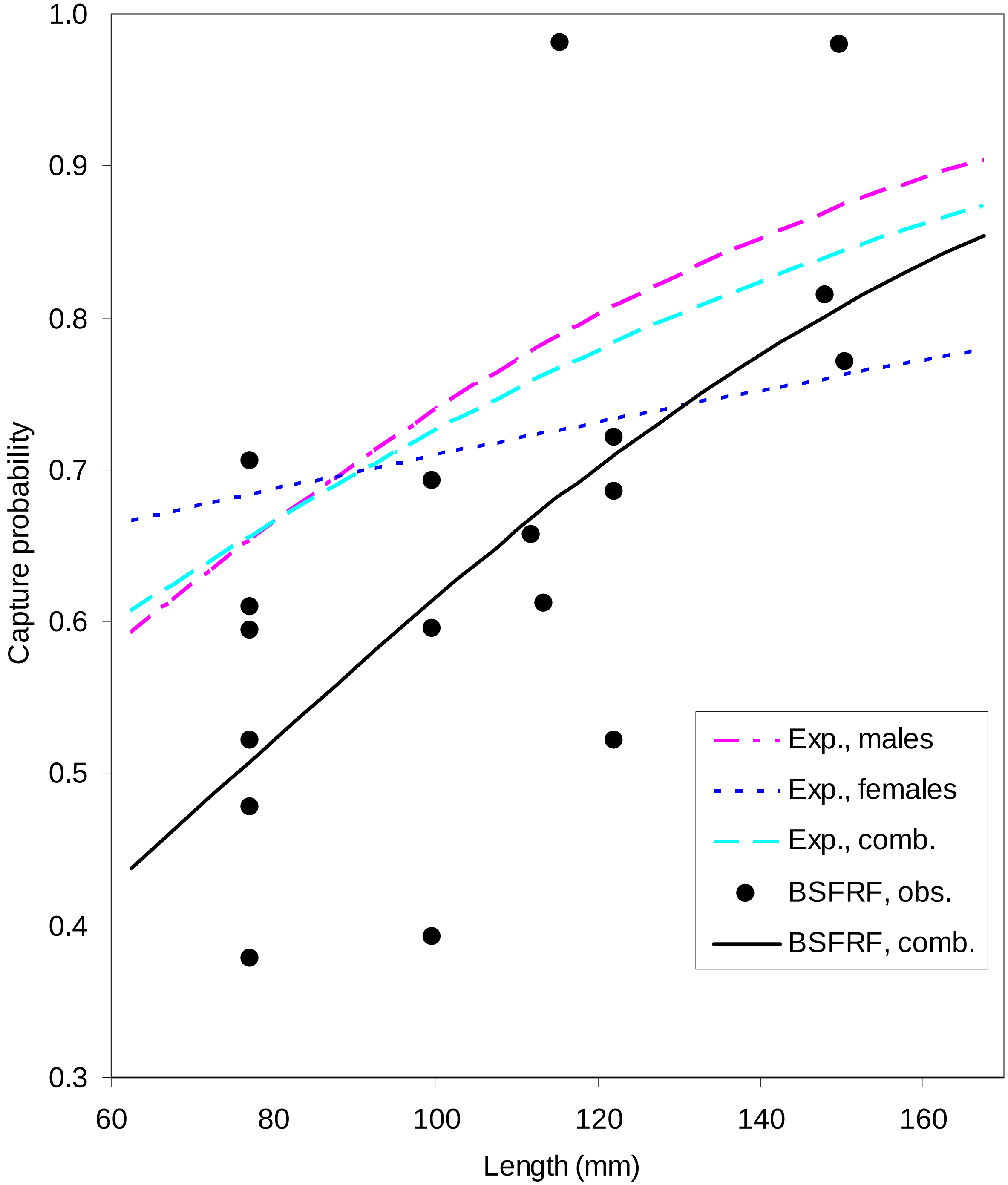
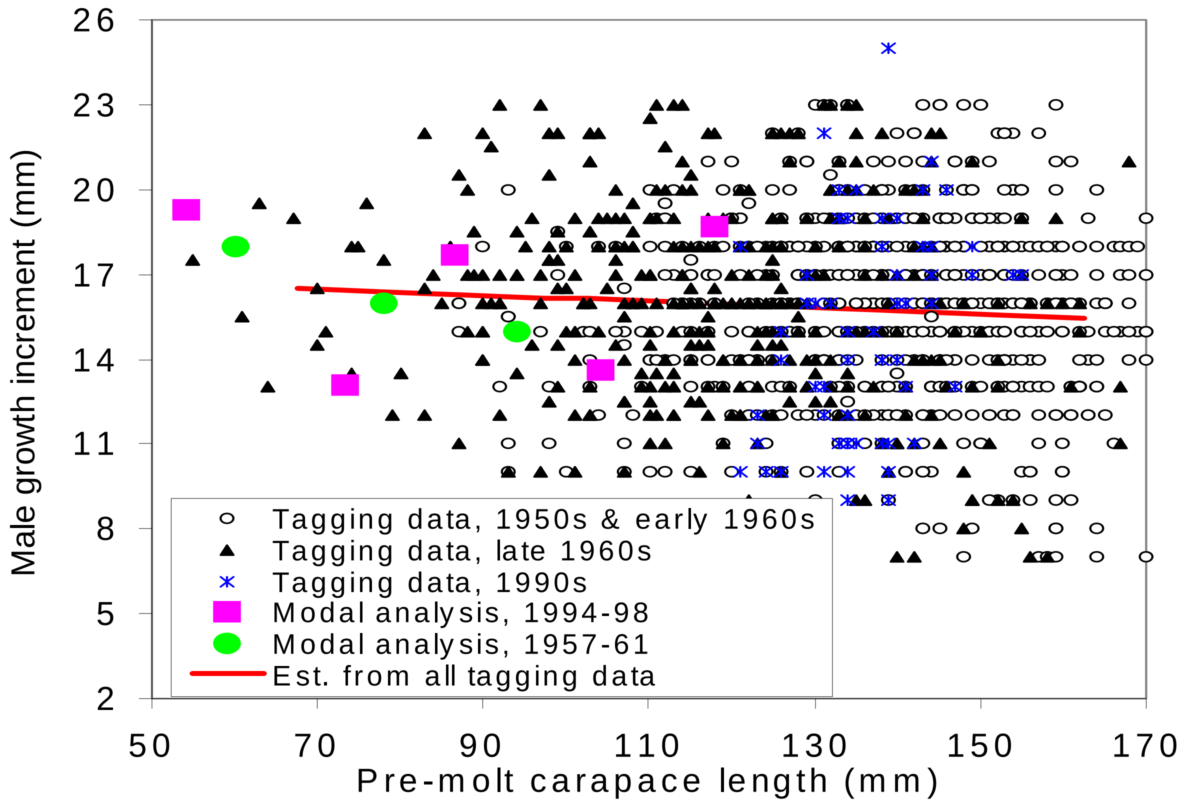


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.



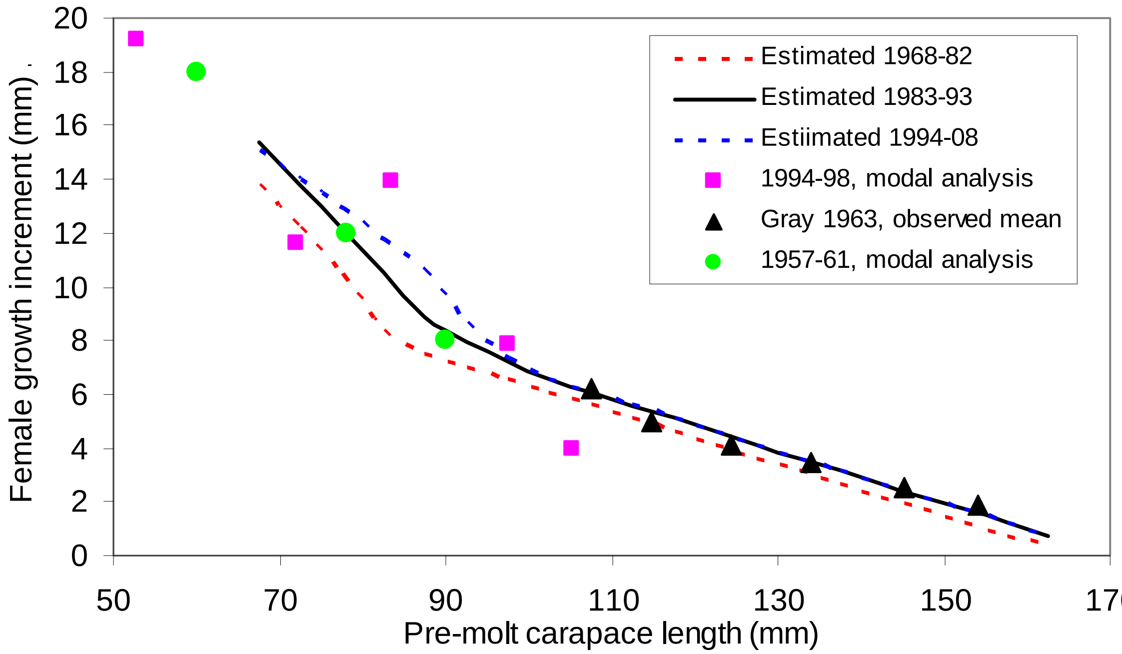


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: “tagging”---based on tagging data; “mode”---based on modal analysis.

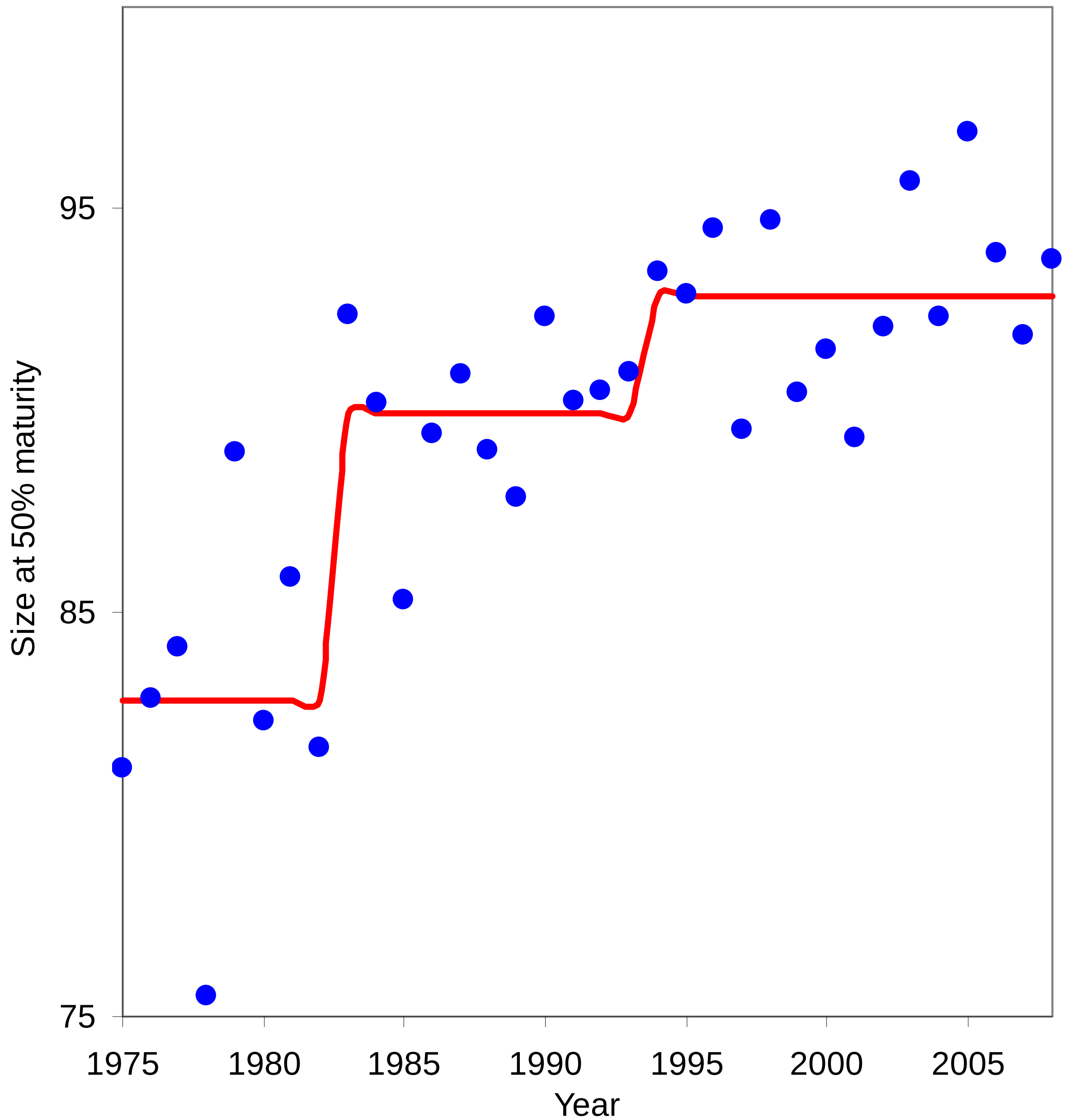


Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

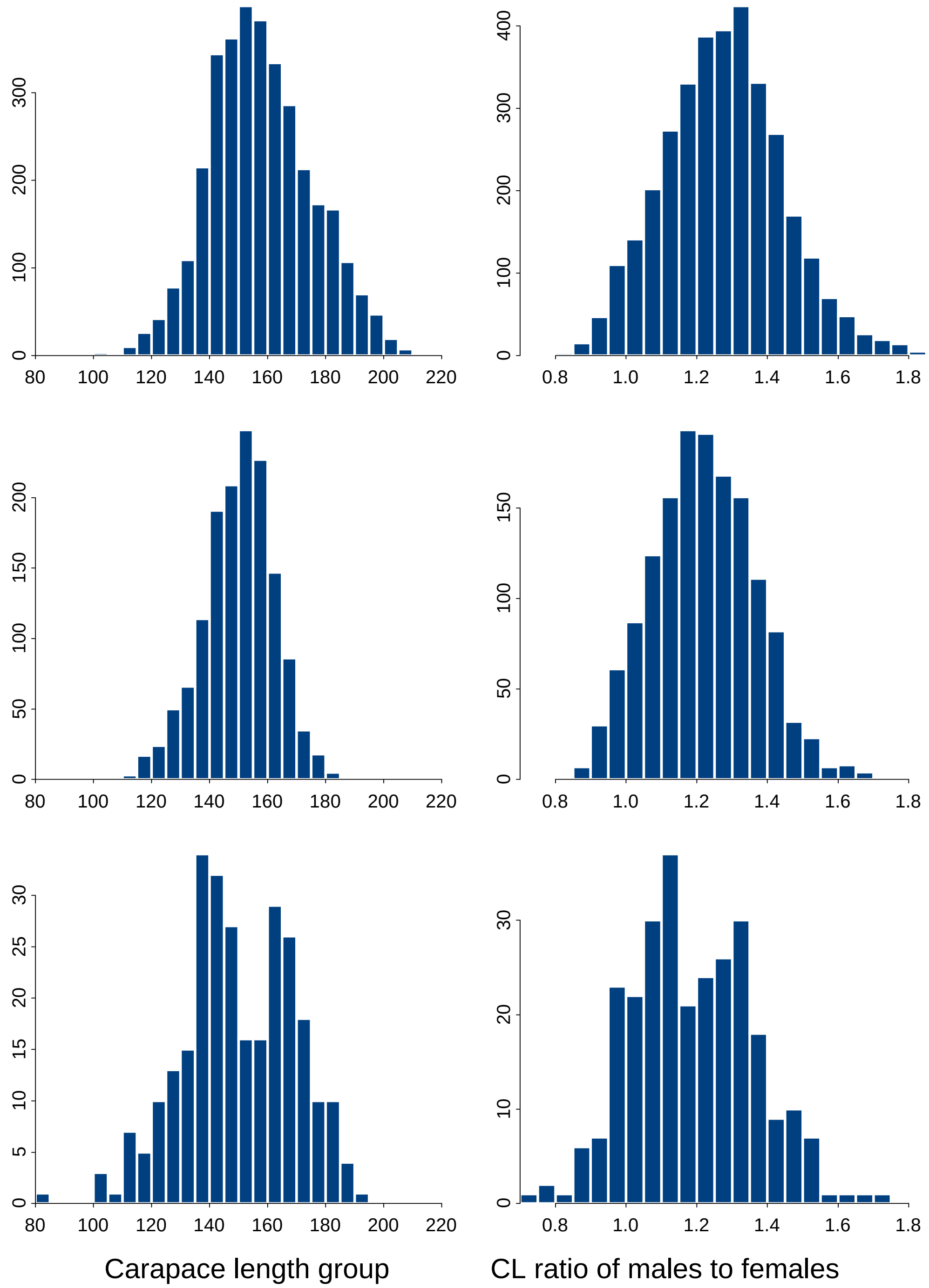
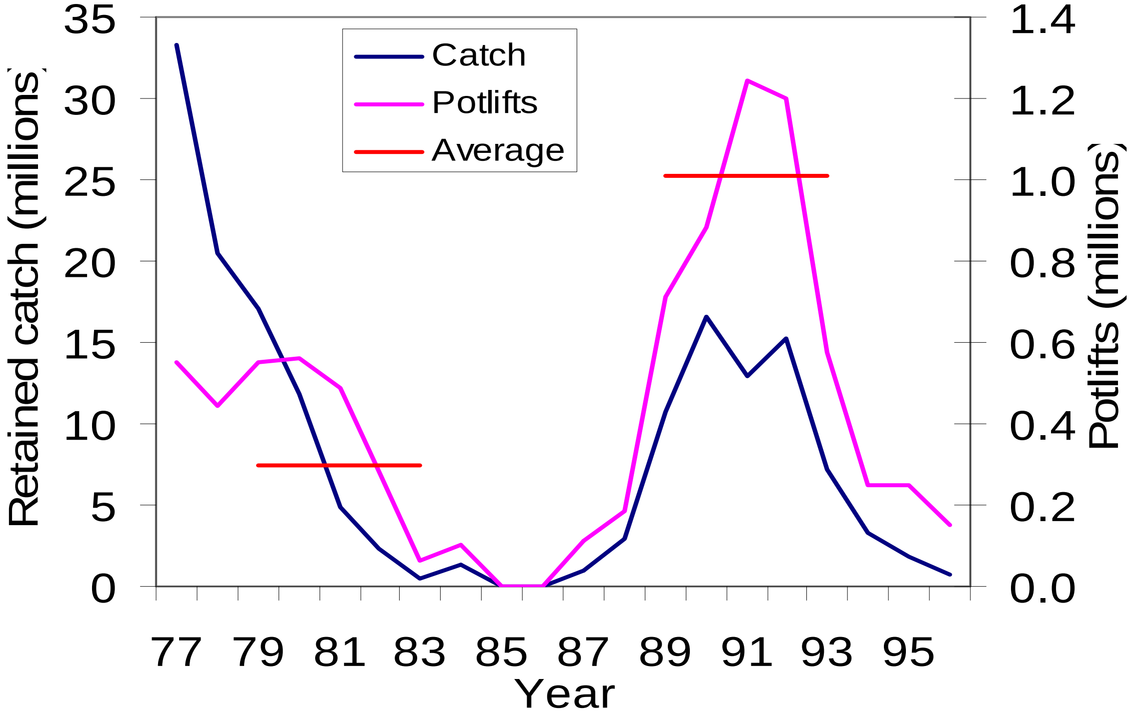


Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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



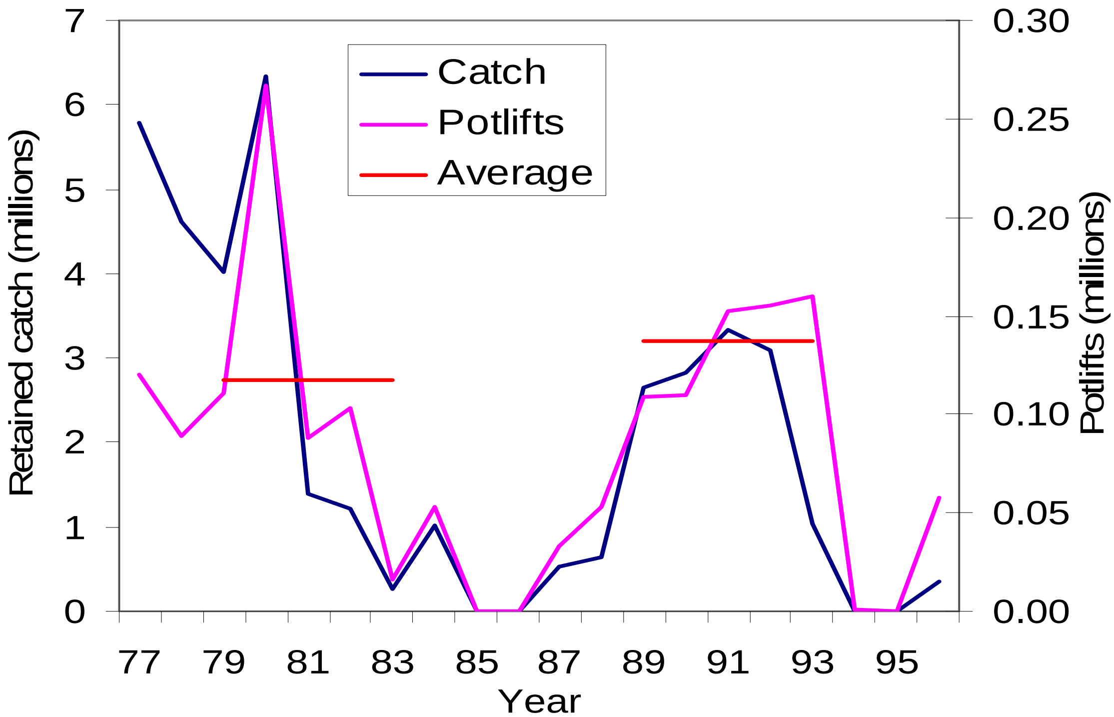
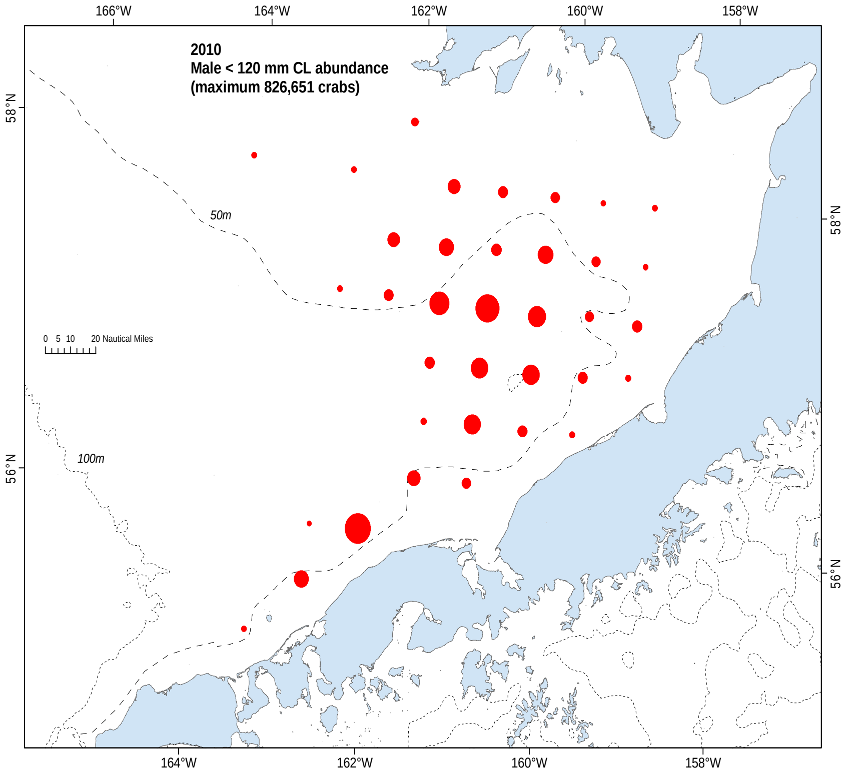
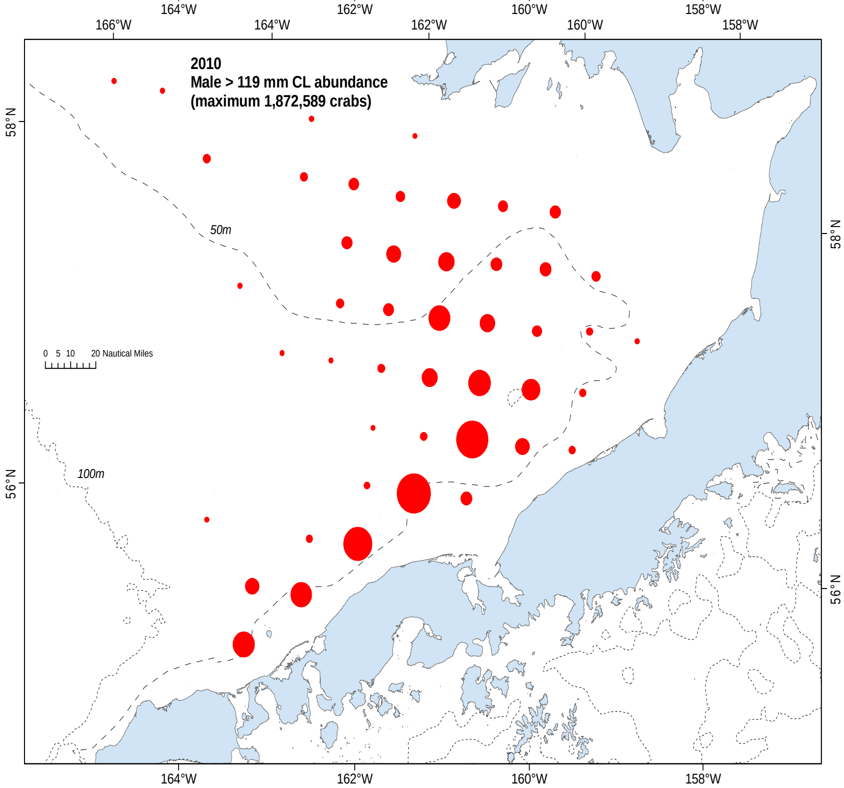
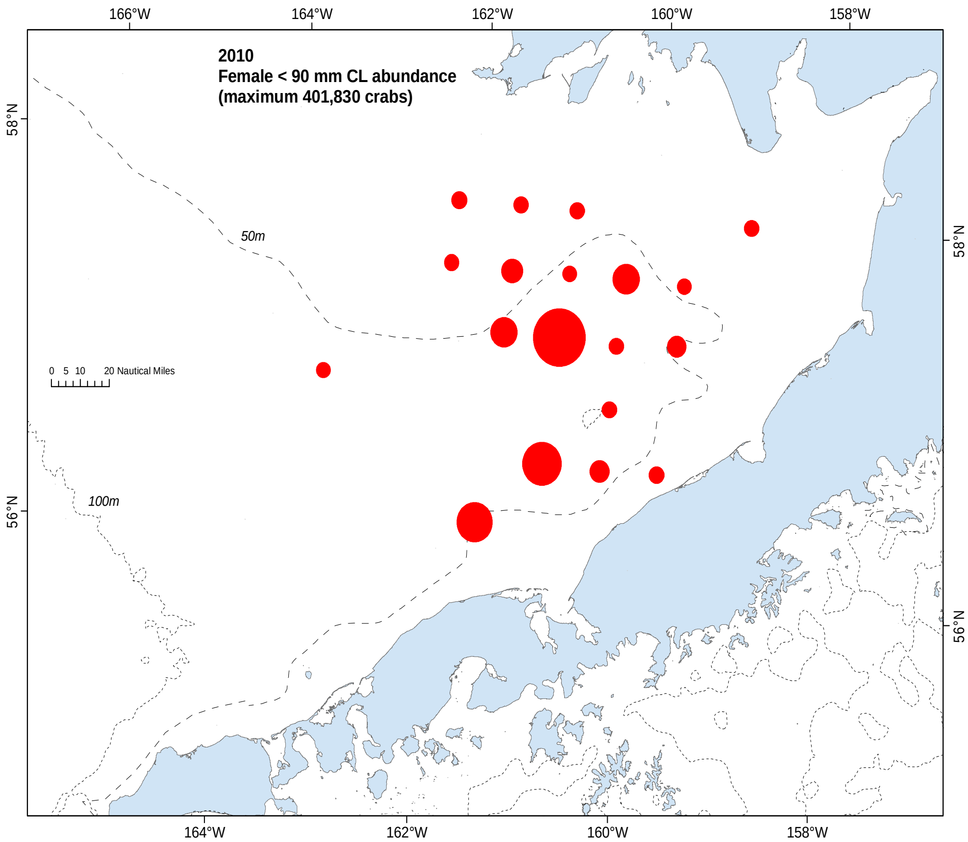


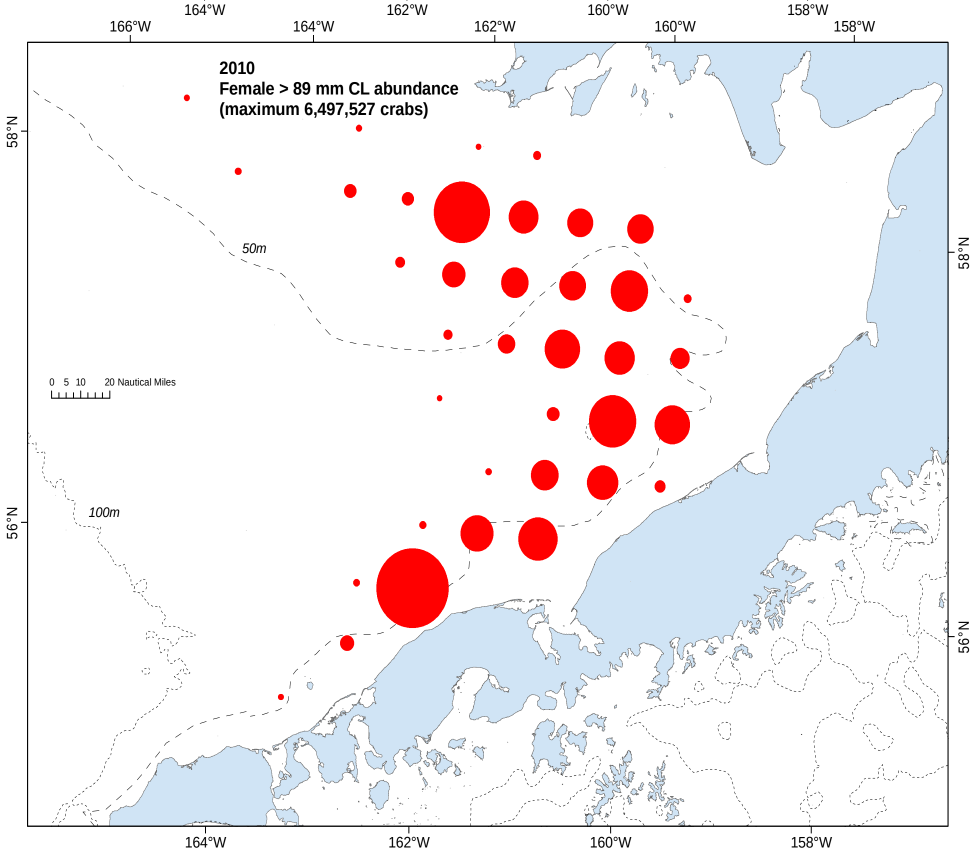
Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

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






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


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

Appendix C. CIE review comments.

August 12 2009

Bristol Bay Red King Crab Stock Assessment Review

Seattle, Washington

29 June – 3 July 2009

Dr Nick Caputi

Department of Fisheries (Western Australia)
Western Australian Fisheries and Marine Research Laboratories
PO Box 20, North Beach, WA 6920, Australia

Representing the Center of Independent Experts

Executive Summary

The Center of Independent Experts (CIE) requested a review of the population dynamics and harvest strategy models for the Bristol Bay red king crab (*Paralithodes camtschaticus*) assessment. The review was also to examine the potential utility of conducting a dedicated crab survey for eastern Bering Sea stocks including Bristol Bay red king crab (BBRKC). The current NMFS survey is a multispecies survey that has issues with respect to survey timing relative to mating, molting and egg extrusion, survey boundaries and movement, and catchability.

Two CIE reviewers conducted the peer review. Two weeks before the peer review, NMFS made available at an FTP site all necessary background information and reports for the peer review. The CIE reviewers participated in a panel review meeting in Seattle, Washington, from 29 June to 3 July, 2009 to conduct a peer review with the authors of the red king crab assessment. The reviewers met with scientists involved in the RKC fishery including those from the Alaska Fisheries Science Center and the Alaska Department of Fish and Game. The scientists presented the key aspects of their research on the first two days. Copies of the presentations were provided to the reviewers. The CIE panel and other scientists present asked questions on issues of the stock assessment and related research that was presented. All presenters answered questions and expanded on some aspects of the stock assessment and research. The panel sought additional analyses from the authors of the stock assessment report and additional information on bycatch estimates in late 1970s and early 1980s, which was also presented.

The review addressed the following Terms of References:

1. A statement of the strengths and weaknesses of the Bristol Bay red king crab stock assessment and stock projection models;
2. Recommendations for alternative model configurations or formulations;
3. Recommendations of alternative model assumptions and estimators.
4. A review of the results of the Bering Sea Fisheries Research Foundation (BSFRF) Bristol Bay red king crab supplemental survey and its potential contribution to the stock assessment.
5. A review of the cost and benefit of diverting research from studies that would reduce uncertainty in key parameters used in the assessment to conduct a dedicated crab survey.
6. Suggested research priorities to improve the stock assessment.

The key strengths of the BBRKC stock assessment include: (a) a multi-species NMFS research trawl survey conducted since the 1968; (b) resurveys of the NMFS surveys undertaken in some recent years to obtain an improved estimate of mature female crab abundance which are required when water temperature is cold and there is a delayed mating period into early June; (c) a BSFRF dedicated RKC survey has been undertaken in 2005, 2007 and 2008; (d) observer bycatch data of the RKC fishery since 1990 and groundfish trawl bycatch estimates of the RKC fishery since 1976; (e) catch length frequencies by sex; (f) catch and effort estimates; (g) research studies relevant for stock assessment, e.g. growth, selectivity, mortality, stock recruitment, environmental factors affecting recruitment; (h) food web assessment; (i) a length-based stock assessment model has been used to integrate the above information; and (j) decision rule framework that has overfishing and overfished definitions.

Some weaknesses of the BBRKC stock assessment include: (a) use of different natural mortality rates for males and females for different time periods provides a better fit to the data but it is not clear what the biological processes may be to justify this assumption; (b) the complex state/federal decision rule framework in the stock assessment process and the step function being used in the Alaskan state decision framework for setting quotas may make it difficult if the biological estimates are close to the threshold levels given there is some uncertainty with estimates; (c) the stock assessment process does not utilize the fishing effort and catch rate (CPUE) information for the trap fishery; (d) potential underestimate of the Tanner and RKC fisheries bycatch of RKCs that may affect the estimate of natural mortality; (e) the occurrence of the hotspots of abundance of RKCs from the annual trawl survey on the boundary of the trawl area near the coast could result in a significant underestimate of the biomass if there is a high abundance in the non-surveyed areas along the coast; and (f) a useful addition to the stock assessment document would be a description of the life cycle that provides an understanding of the key biological processes taking place over time and space.

Recommendations for alternative model configurations and assumptions are: (a) the move to crab rationalization has resulted in improved economic data collection that can be used to set harvest rate targets for improved profitability of the fishery; (b) average recruitment during 1968-2008, 1985-2008, 1995-2008 were considered in setting overfishing limits - the choice of $B_{35\%}$ should take into account the stock-recruitment relationship so that the level of mature biomass is sufficiently high that if good environmental conditions occur then good recruitments will occur; (c) the assessment of the mature male biomass (MMB) contributing to the mating each year should take into account the decline in molting probability with size which means that the larger males may be contributing proportionally more to mating than smaller males that are molting most years; (d) alternative hypotheses for cause of mortality in the early 1980s should be explored e.g. an additional mortality at different time periods, bycatch in the RKC and/or tanner crab fisheries. Information on size structure should be taken into account to obtain improved estimates of bycatch when observer data was not available as well the effectiveness of the escape gaps and bycatch mortality rates at different levels of catch rate; and (e) sensitivity analysis of trawl survey catchability estimates.

The RKC BSFRF survey is a directed survey using a smaller mesh and a smaller vessel than the NMFS survey. The BSFRF survey has enabled the multi-purpose NMFS survey to be ground truthed and most abundance estimates were similar, though the BSFRF survey may provide a better estimate of smaller crabs. The BSFRF survey sampling approach with short trawl durations results in improved precision of abundance estimates. This survey also provided for an improved inshore sampling regime, but there is still a sampling gap in the inshore area near abundance hotspots as parts of this inshore area may be unsuitable of trawling. The inshore habitat may need to be surveyed first to determine areas suitable for trawling before a RKC survey is planned and this should possibly be a focus for any future BSFRF survey. The sampling approach for high abundance samples (‘hotspots’) also needs review and one approach be to undertake additional samples near the hotspots area every year as they typically occur in the same area each year.

If the BSFRF survey is to be undertaken on a regular basis then it probably should be undertaken in late June or early July to ensure migration/mating is complete. This avoids the need for resurveys of the NMFS survey that are required when water temperature is cold and there is a delayed mating period into early June which results in an underestimate of mature females. Consideration should be given to see whether any adjustment for mature female abundance can be undertaken for survey abundance undertaken when temperature was cold at the time of the survey (or the ratio of eyed to uneyed eggs was high) and no resurveying was undertaken. An adjustment should be possible based on the water temperature at the time of survey. The timing of previous surveys should be examined to check whether adjustments to the mature female abundance needs to be undertaken in the model for years when the survey was early.

In general there does not appear to be any significant benefit associated from undertaking a dedicated RKC survey that effectively repeats the multi-species NMFS survey. If the timing of the NMFS cannot be changed to accommodate the timing of the mating and migration, then there appears to be some value in undertaking a dedicated RKC resurvey. Consideration should be given to whether the resurvey can be undertaken as a 5-10 min survey to minimize costs.

Some suggested research priorities to improve the stock assessment include:

1. Catch rate (CPUE) assessment of logbook and monitoring data using generalized linear modeling (GLM) taking into account factors such as year, month, location, fishing boat, soak time, fishing power, environmental conditions which provide estimates of standardized annual abundance.
2. Fishing effort can also be analyzed to: (a) undertake an assessment of effective fishing effort that can be used to compare with fishing mortality estimates from the modeling; and (b) compare the spatial distribution of effort since the introduction of the crab rationalization (individual quotas) to assess whether fishers have changed their fishing practices by fishing closer to port to save costs.
3. A depletion analysis of blocks that are heavily fished during a season such that there is a significant decline in catch rate due to the effects of fishing could provide some valuable insights into fishery dynamics.
4. Assessment of nominal and effective fishing effort required to take the TAC is needed to evaluate the relationship between fishing effort and catch which is required for the assessment of catch and effort that targets maximum economic yield.

5. The introduction of crab rationalization has seen the annual collection of economic data on the cost of fishing and revenues. The economic data can be combined with the catch-effort relationship for an assessment of the MEY.
6. A number of closed areas are in place for different fishing methods. Consideration should be given to whether any research monitoring of these closed areas (with appropriate control areas) should be undertaken to assess the effects of the fishing and other biological parameters.
7. A number of studies have examined different factors that may be associated with the declining abundance of crabs in the early 1980s. However when there is such a large magnitude of change that has affected the recruit and adult abundance as well as the spatial distribution of abundance, it is likely that a combination of factors have contributed to the change. A research project should be considered to review and update these studies and consider the combined effects of these factors on the stock. A conceptual model can be developed to examine the relationship between the factors identified as affecting the RKC stocks including:
    a. environmental factors such as Aleutian low may affect recruitment – this factor has decadal variation as well as an annual variation;
    b. the same or other environmental variables may have also affected groundfish abundance which may have resulted in increased predation on RKC;
    c. increased groundfish trawling may have resulted in increased RKC bycatch;
    d. increased groundfish fishing was concentrated in the southern part of RKC stock where there was a high abundance of mature multiparous females due to an ontogenic migration south;
    e. changes in the spatial distribution of RKC occurred during late 1970s and early 1980s with the centre of abundance moving to the northeast and this coincided with a decrease in the area of the cold pool summer near-bottom temperatures in early 1980s;
    f. the change in distribution may have been affected by the changes to the migration pattern due to the environmental effects; and
    g. the decline in the spawning abundance, particularly in the south may have affected the larval dynamics and negatively affected the recruitment.
8. An experimental approach should be considered to assess the effects of fishing on the southern grounds by closing a research area to trawling to determine whether the crab stocks build up there. The two competing hypotheses on decline of the king crab stocks since the 1980's, i.e. regime shift and the effects of increased crab fishing and increased bycatch, may both be contributing to the decline in recruitment. Many stocks quite often collapse when there is the combined effect of poor environmental conditions at a time when the breeding stock is reduced.
9. While research and management changes on escape gaps have been undertaken, there is still considerable retention of undersize crabs, many of which may die as a result of being captured. This makes it imperative to undertake further research (if necessary) to choose the number and size of the escape gaps that maximizes the escape of undersize male and female crabs even if it means that some of the smaller legal-size males are allowed to escape. Additional research on the handling practices should also be undertaken to assess if there are ways to improve them and hence increase survival of discards.

Background

The Center of Independent Experts (CIE) requested a review of the population dynamics and harvest strategy models for the Bristol Bay red king crab (*Paralithodes camtschaticus*) assessment. While a red king crab stock assessment model was developed in 1995 for use in TAC setting, the model has recently been revised for use in setting overfishing levels and determining reference points. An independent review of this revised model was needed to evaluate its suitability in defining overfishing definitions and reference points. The CIE requested a review of the use of Bering Sea trawl survey data in the assessment, the stock assessment model structure, assumptions, life history data, and harvest control rule. New overfishing definitions for Bering Sea crab stocks require the use of the red king crab stock assessment model to estimate reference points and the status of the stock relative to those reference points. Uncertainty exists in several key parameters including the survey selectivity and catchability, molting probabilities, natural mortality, discard mortality and age.

The CIE also requested a review of the potential utility of conducting a dedicated crab survey for eastern Bering Sea stocks including Bristol Bay red king crab (BBRKC). The current survey is a multispecies survey that has issues with respect to survey timing relative to mating, molting and egg extrusion, survey boundaries and movement, and catchability. The CIE review was asked to comment on the costs and benefits of a crab specific survey relative to other research needed to improve the red king crab stock assessment.

Two CIE reviewers conducted the peer review in accordance with the Terms of Reference (ToRs) in Annex 2 of the Appendix. Two weeks before the peer review, the NMFS made available at an FTP site all necessary background information and reports for the peer review. The CIE reviewers participated in a panel review meeting in Seattle, Washington from 29 June to 3 July 2009 to conduct a peer review of the stock assessment with the authors of the red king crab assessment. The reviewers met with scientists involved in the RKC fishery including those from the Alaska Fisheries Science Center and the Alaska Department of Fish and Game. The meeting was chaired by Dr Anne Hollowed. The scientists presented the key aspects of their research on the first two days according to the agenda in Annex 3 of the Appendix. Copies of the presentations were provided to the reviewers. Throughout the presentations the CIE panel and other scientists present asked questions on issues of the stock assessment and related research that was presented. All presenters answered questions and expanded on some aspects of the stock assessment and research. On the third and fourth day the CIE panel met to determine the key issues in the stock assessment modeling that would require some additional comment. The reviewers sought additional analyses from the authors of the stock assessment report and additional information on bycatch estimates in late 1970s and early 1980s (from Turnock and Rugolo) which was later presented. The reviewers then prepared to write their individual reports.

The report generated by reviewers addressed the following TORs:

1. A statement of the strengths and weaknesses of the Bristol Bay red king crab stock assessment and stock projection models;
2. Recommendations for alternative model configurations or formulations;
3. Recommendations of alternative model assumptions and estimators.
4. A review of the results of the BSFRF Bristol Bay red king crab supplemental survey and its potential contribution to the stock assessment.
5. A review of the cost and benefit of diverting research from studies that would reduce uncertainty in key parameters used in the assessment to conduct a dedicated crab survey.
6. Suggested research priorities to improve the stock assessment.

Summary of Findings

The findings of the review have been presented based according to the terms of reference set of the panel:

1. *A statement of the strengths and weaknesses of the Bristol Bay red king crab stock assessment and stock projection models.*

The strength of the BBRKC stock assessment include:

- A multi-species NMFS research trawl survey has been conducted since the 1968 that provides reliable estimates of abundance which are consistent with fishery catch data.
- Resurveys of the NMFS surveys are sometimes undertaken to obtain an improved estimate of mature female crab abundance. These resurveys have been undertaken in 1999, 2000 and 2006-2008 and appear to be required when water temperature is cold and there is a delayed mating period into early June which affects the migration back into the deepwater area (Dew 2008).
- More recently a Bering Sea Fisheries Research Foundation (BSFRF) dedicated RKC survey has been undertaken in 2005, 2007 and 2008 which have provided a cross check to the multi-purpose NMFS survey.
- Observer bycatch data of the RKC fishery since 1990 and estimates of bycatch before 1990 have been made.
- Groundfish trawl bycatch estimates of the RKC fishery since 1976.
- Catch length frequencies, sex and other biological data.
- Catch estimates from the pot RKC fishery and from other foreign fleets in the 1960s and 1970s
- A number of research studies over the years, e.g. growth, selectivity, mortality, stock recruitment, environmental factors affecting recruitment, that have provided valuable information for the stock assessment.
- A length-based stock assessment model has been used to integrate the above information. It was based on the period since 1968 when survey data was available.
- A number of recent improvements have been made in the stock assessment modeling which are summarized in the Executive Summary of the stock

assessment document (Zheng and Siddeek 2009) including (a) all bycatch mortality; (b) extended time series back to 1968; (c) changes in size of maturity over the years; (d) improved catchability estimates based on experimental data; (e) changes weighting factors being based on CVs;
- Decision rule framework that has overfishing and overfished definitions
- Consideration of other research including environmental effects on spatial distribution, predation, and food webs.

Some weaknesses of the BBRKC stock assessment include:

- The use of different natural mortality rates for different periods appears to be justified to explain the declines in abundance in the early 1980s which may be linked to regime shifts, predation, bycatch or effects of trawling. The changes in the mortality rates for males and females for different time periods provides a better fit to the data but it is not clear what the biological processes may be to justify this assumption.
- The model has been developed for the whole stock which hides some interesting spatial dynamics that is occurring in the fishery such as (a) differential rates of migration between inshore and offshore; and (b) changes in the spatial distribution of the spawning stock that may have affected the recruitment abundance and distribution.
- The complex state/federal decision rule framework is a weakness in the stock assessment process. The step function being used in the Alaskan state decision framework for setting quotas (Fig.1 of Zheng and Siddeek 2009) may make it difficult if the biological estimates are close to the threshold levels given there is some uncertainty associated with these estimates. A slope function between the harvest rate and biomass may provide a better representation for the decision rule.
- The stock assessment process does not utilize the fishing effort and catch rate (CPUE) information for the pot fishery. This may be a valuable data set that may enhance the stock assessment process. Further comments on this analysis are provided below.
- Potential underestimate of the Tanner and RKC fisheries bycatch of RKCs that may affect the estimate of natural mortality. Consideration should be given to the effect that: (a) rate of retention for undersize in traps may be greater during periods of high catch rate as escape gaps may not function as well; and (b) higher bycatch mortality rate may be associated with handling in periods of high catch rate.
- One of the hotspots of abundance of RKCs from the annual trawl survey regularly occurs on the boundary of the trawl area near the coast. This could result in a significant underestimate of the biomass if there is a high abundance in the non-surveyed areas along the coast.
- A useful addition to the stock assessment document would be a description of the life cycle that provides an understanding of the key biological processes taking place over time and space. This should include time and place of primiparous and multiparous mating, hatching, larval period and movement, settlement period and location, growth, time and size at maturity, time to legal size, molt frequency and

timing, migration patterns of males and females. Some of this information is directly relevant to the stock assessment and other information may be supplementary to the stock assessment process. Development of a spatial-temporal conceptual model of the life history of RKC and the fisheries affecting it would be useful.

2. *Recommendations for alternative model configurations or formulations;*

3. *Recommendations of alternative model assumptions and estimators.*

Issues associated with TOR 2 and 3 are dealt with together as follows:

- The move to crab rationalization has resulted in improved economic data collection. This provides an opportunity to set harvest rate targets that take into account cost of fishing and revenues and provide management options for improved profitability of the fishery such as maximum economic yield (MEY). The threshold levels can be maintained at the current maximum sustainable yield (MSY) but a new target level for harvest rate and biomass could be developed based on MEY.
- Average recruitment during 1968-2008, 1985-2008, 1995-2008 were considered in setting overfishing limits. The stock assessment document outlines a number of reasons for selecting 1995-2008 (Zheng and Siddeek 2009) which appear to be reasonable. Another consideration in determining the choice of $B_{35\%}$ is the stock-recruitment relationship of the stock assessment document (Fig. 35 of Zheng and Siddeek 2009). The cause of the reduction in the red king crab stocks since the 1980s is critical in determining what should be the target B_{msy} level. If the reduction is due to a regime shift then basing the B_{msy} on the lower levels of mature biomass since the 1980s is appropriate. There is evidence of the negative effect of the increase in trawling since 1980, particularly in the most productive south spawning grounds. If it is not possible to restrict trawling from the more productive RKC spawning areas then basing the B_{msy} on the lower levels of mature biomass since the 1980s is appropriate as the breeding stock may not return to the levels of the 1970s. However it is important that the level of mature biomass be sufficiently high that if good environmental conditions occur then good recruitments are able to occur. The sustained level of poor recruitment in 1985 to 1994, were often associated with low biomass (Fig. 35 Zheng and Siddeek 2009) and target biomass at this level should be avoided. The biomass level in the range of 60-80 million lbs of mature male biomass (MMB) appears sufficient to achieve good recruitment if the environmental conditions are satisfactory. The other option for MMB_{msy} of about 140 million lbs appears overly conservative from a stock recruitment perspective.
- The assessment of the MMB contributing to the mating each year should also be undertaken. Dew and McConnaughey (2005) indicate that about 50% of the MMB contribute to the mating each year i.e. recently molted males are incapable of mating. However the relationship of male molting probability and size indicates that there is a decline in molting probability with size (Fig. 22 Zheng

and Siddeek 2009). This means that the larger males may be contributing proportionally more to mating than smaller males that are molting most years. As the male size distribution can vary between years then an estimate of the 'effective' MMB should be made. If the larger males are proportionally more important in mating females then this may have implications for level of harvesting being allowed. The monitoring of the proportion of mature females with empty clutches and the level of clutch fullness provides an indication of whether there are sufficient males for mating the mature females.

- Alternative hypotheses for the cause of mortality in the early 1980s should be explored e.g. an unknown mortality, bycatch in the RKC and/or tanner crab fisheries. The stock assessment model currently assumes an additional mortality applied to males and female at different time periods. Preliminary estimates of possible bycatch in late 1970s and early 1980s were presented (Turnock and Rugolo) based on some bycatch monitoring in 1982 by Griffin et al. (1983) and applying these data to earlier years. However it was suggested that some assumptions about bycatch to legal catch from 1982 may not be applicable to earlier years as the size structure would have changed. Information on size structure is available from the earlier period and this could be used to obtain improved estimates of bycatch during this period when observer data was not available. Another issue to consider in making these estimates is the variation in total numbers of crabs per pot lift between years as this can affect the effectiveness of the escape gaps. A higher retention rate of undersize would be expected if there was a higher overall abundance of crabs per pot as access to escape gaps is reduced. This hypothesis may be examined for years when bycatch estimates are available. Also the handling mortality of undersize and female bycatch crabs being returned is likely to be higher in years when crabs per pot lift are higher. Fishers will take more time to physically sort and measure the undersize when there are a large number of crabs to be sorted. This increases the time the bycatch crabs spend onboard the vessels exposed to the elements and hence an increased level of mortality may occur. The air temperature has been identified as one of the key factors affecting mortality of bycatch. Currently a constant pot handling mortality rate of 0.2 is assumed and a sensitivity analysis is required.
- Trawl survey catchabilities were estimated in the LBA model but based on a trawl experiment (Weinberg et al. 2004). A sensitivity analysis of these estimates would be worthwhile. Separate estimates were made for 3 periods, 1970-1972, 1973-1981 and 1982-2008 and for males and females (Fig. 21a Zheng and Siddeek 2009). For the two latter periods the estimates of males and females were similar however for the 1970-1972 period the female catchability was much less that for males for sizes greater than 115 mm and the basis for this is not clear.

4. *A review of the results of the BSFRF Bristol Bay red king crab supplemental survey and its potential contribution to the stock assessment.*

The RKC BSFRF survey is a directed survey using a smaller mesh and a smaller vessel. The following observations are made about the survey that was conducted in 2005, 2007 and 2008:

- The BSFRF survey has enabled the multi-purpose NMFS survey to be ground truthed with a targeted RKC survey. Most abundance estimates were similar, however the BSFRF survey may provide a better estimate of smaller crabs due to its smaller mesh that may provide an improved estimate of recruitment to the model. The sampling survey approach with short trawl durations results in improved precision of abundance estimates.
- This survey also provided for an improved inshore sampling regime but there is still a sampling gap in the inshore area as parts of this inshore area may be unsuitable of trawling. This gap is important as this survey confirms the regular existence of an abundance hotspot on the inshore boundary of sampling. It appears that the inshore habitat may need to be surveyed first to determine areas suitable for trawling before a RKC survey is planned.
- If the BSFRF survey is to be undertaken on a regular basis then it probably should be done late in June or early July to ensure migration/mating is complete. This avoids the need for resurveys of the NMFS survey.

5. *A review of the cost and benefit of diverting research from studies that would reduce uncertainty in key parameters used in the assessment to conduct a dedicated crab survey.*

There are two dedicated crab surveys that are complementary to the longstanding multi-species NMFS survey that can be discussed under this TOR. They are the resurvey of the NMFS survey that is sometimes undertaken to obtain an improved estimate of mature female crab abundance and the BSFRF surveys that has been used to verify the abundances being achieved under the NMFS survey. The following observations are made about these surveys (see also comments under TOR 4):

- These resurveys of the multi-species NMFS surveys appear to be required when water temperature is cold and there is a delayed mating period into early June which results in an underestimate of mature females. As the resurveys are focused on crabs then an alternative cost-effective survey strategy may be to use 5-10 min trawls as these have proved effective in the BSFRF survey.
- When resurveys are undertaken then both surveys are used to assess male abundance in the stock assessment model as there does not appear to be a major difference in male abundance between the surveys. However in some years (e.g. 2008) the percent of old shell males appears to increase in the second survey which may be expected if the old shell males are returning from a mating migration. Using both surveys for the estimate of male abundance in the model is a reasonable approach as it utilizes all the survey data. The use of resurvey data

only for female abundance in the modeling is also reasonable as these provide a better representation of the mature female abundance. However consideration should be given to see whether any adjustment can be undertaken for earlier survey abundance undertaken when temperature was cold at the time of the survey (or the ratio of eyed to uneyed eggs was high) and no resurveying was undertaken. An adjustment may be possible based on the water temperature data at the time of survey.

- Dew (2008) also indicated that the timing of survey may affect estimates of mature females. The timing of previous surveys should be examined to check whether adjustments to the mature female abundance need to be undertaken in the model for years when the survey was early,
- The sampling approach required to treat high abundance samples (‘hotspots’) was discussed. One approach would be to undertake the additional samples near the hotspot so the area of the hotspot is better defined and use a geostatistic approach to estimate the abundance and variance. As the hotspots encountered are typically in the same area when they do occur (about every couple of years), consideration should be given to undertaking multiple samples in these hotspots which is effectively a stratification involving the potential hotspot areas.
- Concern was also raised about whether the samples with zero crabs should be resampled. This is usually unnecessary as it is unlikely that the resample of zero sample will result in a revised abundance estimate that makes a significant change to the overall abundance in the way that a resample of a hotspot abundance can make a difference.

In general there does not appear to be any significant benefit associated from undertaking a dedicated RKC survey that effectively repeats the result in the multi-species NMFS survey. If the timing of the NMFS cannot be changed to accommodate the timing of the mating and migration then there appears to be some value in undertaking a dedicated RKC resurvey. Consideration should be given to whether this can be undertaken as a 5-10 min survey to minimize costs. As discussed above there would be value in exploring the potential of a survey of the currently unsurveyed inshore areas, particularly those areas adjacent to the hotspot abundance areas.

6. *Suggested research priorities to improve the stock assessment.*

Some suggested research priorities to improve the stock assessment include:

1. Catch rate (CPUE) assessment of logbook and monitoring data using generalized linear modeling (GLM) taking into account factors affecting catch rates such as year, month, location of fishing, fishing boat, soak time, fishing power effects, environmental conditions, etc. and providing estimates standardized annual abundance. These analyses may also be used to provide a comparison between the CPUE from the fishery and the abundance in the survey data using a different fishing method (see 1991, Fig. 3 Zheng and Siddeek 2009). A comparison of the spatial distribution of catch and catch rate compared to the survey spatial distribution could also be informative.

2. Fishing effort data can also be analyzed to: (a) undertake an assessment of effective fishing effort that can be used to compare with fishing mortality estimates from the modeling; and (b) compare the spatial distribution of effort since the introduction of the crab rationalization (individual quotas) to assess whether fishers have changed their fishing practices by, for example, fishing closer to port to save costs.
3. A depletion analysis of some blocks that are heavily fished during a season such that there is a significant decline in catch rate due to the effects of fishing could provide some valuable insights into fishery dynamics. A comparison of the daily retained male CPUE in a block (or groups of blocks) and the cumulative legal catch removed from that block(s) over the period that the fishery operates enables an estimate of the residual legal biomass at the end of fishing, the catchability of potting for male crabs and the exploitation rate.
4. An assessment of nominal and effective fishing effort required to take the TAC is required to evaluate the relationship between the level of fishing effort and catch which is required as part of the assessment of catch and effort that targets MEY.
5. The introduction of crab rationalization has seen the annual collection of economic data on the cost of fishing and revenues. The economic data can be combined with the catch-effort relationship for a preliminary assessment of the MEY.
6. A number of closed areas are in place for different fishing methods. Consideration should be given whether any research monitoring of these closed areas (with appropriate control areas) should be undertaken to assess the effects of the fishing and other biological parameters.
7. A number of studies have examined different factors that may be associated with the declining abundance of crabs in the early 1980s (e.g. Dew and McConnaughey 2005, Loher and Armstrong 2005, Zheng and Kruse 2006) and some are referred to in the stock assessment document under ecological considerations. However when there is such a large change in abundance that has affected the recruit and adult abundance as well as the spatial distribution of abundance, it is likely that a combination of events have contributed to the change. A research project should be considered to review and update these studies with additional years of data and consider the combined effects of these factors on the stocks. The factors identified to be affecting the RKC stocks include:

    - environmental factors such as Aleutian low may affect recruitment – this factor has decadal variation as well as an annual variation (Zheng and Kruse 2006);
    - the same or other environmental variables may have also affected groundfish abundance (Zheng and Kruse 2006) which may have resulted in increased predation on RKC;
    - increased groundfish trawling may have resulted in increased RKC bycatch (Dew and McConnaughey 2005);

- increased groundfish fishing was concentrated in the southern part of RKC stock where there was a high abundance of mature multiparous females due to an ontogenic migration south (Dew and McConnaughey 2005);
- changes in the spatial distribution of RKC occurred during late 1970s and early 1980s with the centre of abundance moving to the northeast and this coincided with a decrease in the area of the cold pool summer near-bottom temperatures in early 1980s (Loher and Armstrong 2005);
- the change in distribution may have been affected by the changes to the migration pattern due to the environmental effects;
- the decline in the spawning abundance in the southern area in particular may have affected the larval dynamics which may have negatively affected the recruitment (Loher and Armstrong 2005, Zheng and Kruse 2008).

A starting point for this assessment of factors affecting the RKC stocks may be the development of a conceptual model (see Fig. 1).

8. An experimental approach should be considered to assess the effects of fishing on these productive southern grounds by closing an appropriately-sized research area to trawling to determine whether the crab stocks build up in that area. The two competing hypotheses on decline of the king crab stocks since the 1980's, i.e. regime shift and the effects of increased targeted crab fishing and increased bycatch from trawling, may both be contributing to the decline in recruitment. Many stocks quite often collapse when there is the combined effect of poor environmental conditions at a time when the breeding stock is reduced due to changes in fishing practices.
9. While considerable research on escape gaps and subsequent changes have been undertaken on escape gaps, it appears that there is still considerable retention of undersize crabs, many of which may die as a result of being captured. This makes it imperative to undertake further research (if necessary) to choose the number and size of the escape gaps that maximizes the escape of undersize male and female crabs even if it means that some of the smaller legal-size males are allowed to escape. Additional research on the handling practices should also be undertaken to assess if there are ways to improve them and hence increase survival of discards.

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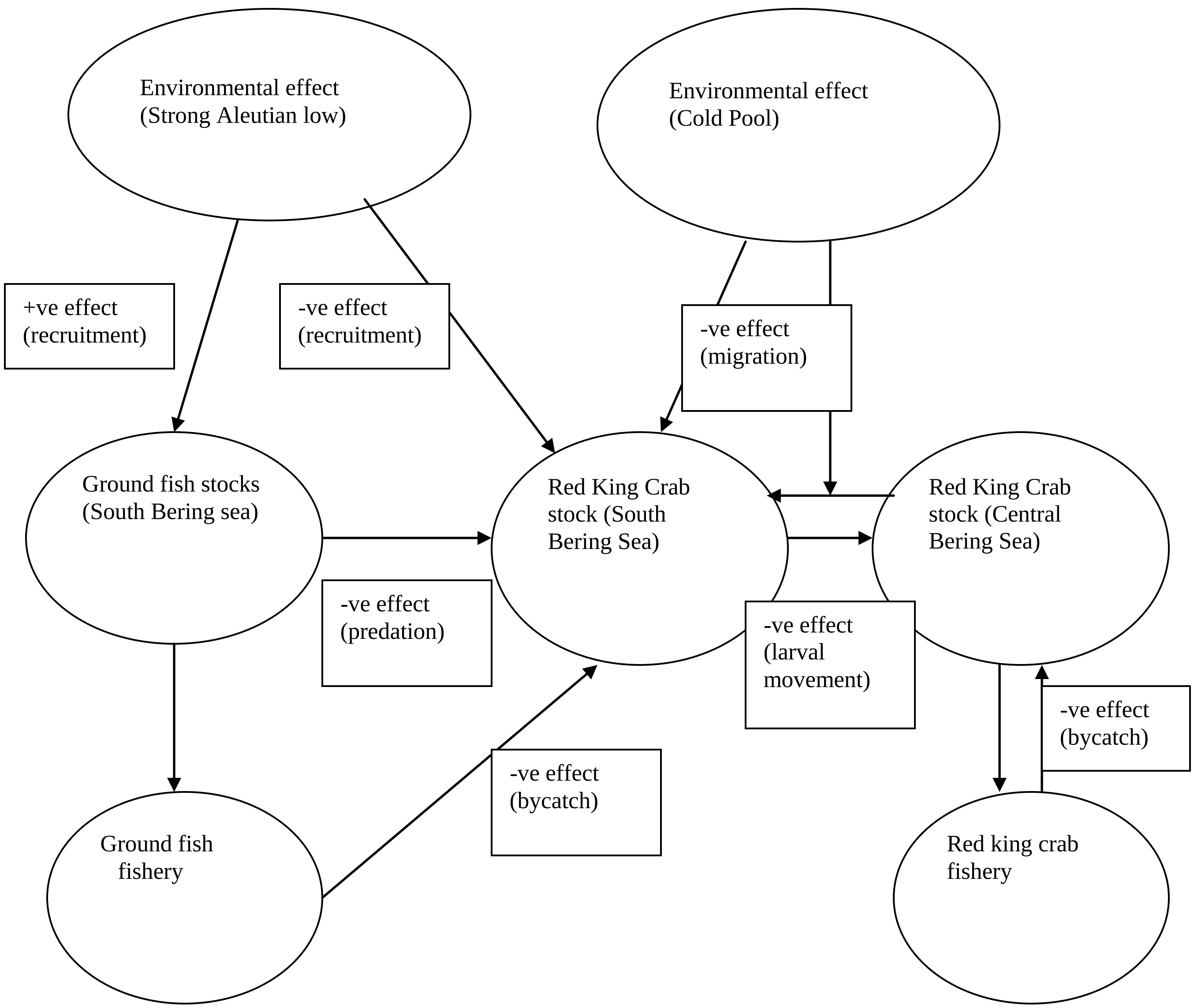

Fig. 1. Example of possible relationships between environmental effects, ground fish stocks and fishery, red king crab stocks and fishery.

Appendix 1: Statement of Work

Statement of Work for Dr. Nick Caputi

External Independent Peer Review by the Center for Independent Experts

Bristol Bay Red King Crab Stock Assessment

Scope of Work and CIE Process: The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract to provide external expertise through the Center for Independent Experts (CIE) to conduct impartial and independent peer reviews of NMFS scientific projects. This Statement of Work (SoW) described herein was established by the NMFS Contracting Officer's Technical Representative (COTR) and CIE based on the peer review requirements submitted by NMFS Project Contact. CIE reviewers are selected by the CIE Coordination Team and Steering Committee to conduct the peer review of NMFS science with project specific Terms of Reference (ToRs). Each CIE reviewer shall produce a CIE independent peer review report with specific format and content requirements (**Annex 1**). This SoW describes the work tasks and deliverables of the CIE reviewers for conducting an independent peer review of the following NMFS project.

Project Description: The CIE requests a review of the population dynamics and harvest strategy models for the Bristol Bay red king crab (*Paralithodes camtschaticus*) assessment. While a red king crab stock assessment model was developed in 1995 for use in TAC setting, the model has recently been revised for use in setting overfishing levels and determining reference points. An independent review of this revised model is needed to evaluate it's suitability in defining overfishing definitions and reference points. The red king crab assessment is a high profile assessment and with the adoption of revisions to the overfishing definitions it is critical that it provides the best available science on the status of this resource. The CIE requests a review of the use of Bering Sea trawl survey data in the assessment, the stock assessment model structure, assumptions, life history data, and harvest control rule. New overfishing definitions for Bering Sea crab stocks require the use of the red king crab stock assessment model to estimate reference points and the status of the stock relative to those reference points. Uncertainty exists in several key parameters including the survey selectivity and catchability, molting probabilities, natural mortality, discard mortality and age. This review will help in the decision process as to which alternative model is most appropriate, given the current state of knowledge of Bristol Bay red king crab.

The CIE also requests a review of the potential utility of conducting a dedicated crab survey for eastern Bering Sea stocks including Bristol Bay red king crab (BBRKC). The current survey is a multispecies survey that has issues with respect to survey timing relative to mating, molting and egg extrusion, survey boundaries and movement, and catchability. The CIE should comment on the costs and benefits of a crab specific survey relative to other research needed to improve the red king crab stock assessment.

The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements for CIE Reviewers: Two CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. Each CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review described herein. CIE reviewers shall have the expertise, background, and experience to complete an independent peer review in accordance with the SoW and ToRs herein. CIE reviewer expertise shall include working experience with stock assessment, estimates of survey catchability and selectivity, population dynamics, length based models, knowledge of crab life history and biology, harvest strategy models for invertebrates, and the AD Model Builder programming language.

Location of Peer Review: The CIE reviewers shall participant during a panel review meeting in Seattle, Washington to conduct a peer review of the stock assessment with the authors of the red king crab assessment in accordance to the Schedule of Milestones and Deliverables herein.

Statement of Tasks: Each CIE reviewers shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

Prior to the Peer Review: Upon completion of the CIE reviewer selection by the CIE Steering committee, the CIE shall provide the CIE reviewer information (name, affiliation, and contact details) to the COTR, who forwards this information to the NMFS Project Contact no later the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, foreign national security clearance, and information concerning other pertinent meeting arrangements. The NMFS Project Contact is also responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COTR prior to the commencement of the peer review.

Foreign National Security Clearance: When CIE reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for CIE reviewers who are non-US citizens. For this reason, the CIE reviewers shall provide requested information (e.g., name, contact information, birth date, passport number, travel dates, and country of origin) to the NMFS Project Clearance for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations (available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/sponsor.html).

Pre-review Background Documents: Two weeks before the peer review, the NMFS Project Contact will send by electronic mail or make available at an FTP site the CIE reviewers all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE on where to send documents. The CIE reviewers shall read all documents in preparation for the peer review including the following:

1. Zheng, J., M.S.M Siddeek. 2008. Bristol Bay Red King Crab Stock Assessment in Fall 2008. **In** the Stock Assessment Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, 605 W. 4th Ave. #306, Anchorage, AK.
2. North Pacific Fishery Management Council (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.
3. The BSAI king and Tanner crab FMP Amendment 24.
4. 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, E.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 Limited Situations. Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, AK.
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8. 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.

This list of pre-review documents may be updated up to two weeks before the peer review. Any delays in submission of pre-review documents for the CIE peer review will result in delays with the CIE peer review process, including a SoW modification to the schedule of milestones and deliverables. Furthermore, the CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein.

Panel Review Meeting: Each CIE reviewers shall conduct the independent peer review in accordance with the SoW and ToRs. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified in the contract SoW. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Other Tasks – Contribution to Summary Report: Each CIE reviewer will assist the Chair of the panel review meeting with contributions to the Summary Report. CIE reviewers are not required to reach a consensus, and should instead provide a brief summary of their views on the summary of findings and conclusions reached by the review panel in accordance with the ToRs.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review;
2) Participate during the panel review meeting at the NMFS Alaska Fisheries Science Center from June 29 – July 3, 2009, as called for in the SoW, and conduct an independent peer review in accordance with the ToRs (Annex 2);
3) No later than July 17, 2009, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Mr. Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and CIE Regional Coordinator, via email to David Die at ddie@rsmas.miami.edu.
4) Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in Annex 2;
5) CIE reviewers shall address changes as required by the CIE review in accordance with the schedule of milestones and deliverables.

Schedule of Milestones and Deliverables: CIE shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

25 May 2009	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
15 June 2009	NMFS Project Contact sends the CIE Reviewers the pre-review documents
29 June - 3 July 2009	Each reviewer participates and conducts an independent peer review during the panel review meeting (June 29-July 3, 2009)
17 July 2009	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
31 July 2009	CIE submits CIE independent peer review reports to the COTR
7 August 2009	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be made through the Contracting Officer's Technical Representative (COTR) who submits the modification for approval to the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the CIE within 10 working days after receipt of all required information of the decision on substitutions. The COTR can approve changes to the milestone dates, list of pre-review documents, and Terms of Reference (ToR) of the SoW as long as the role and ability of the CIE reviewers to complete the SoW deliverable in accordance with the ToRs and deliverable schedule are not adversely impacted. The SoW and ToRs cannot be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COTR for final approval as contract deliverables based on compliance with the SoW. As specified in the Schedule of Milestones and Deliverables, the CIE shall send via e-mail the contract deliverables (the CIE independent peer review reports) to the COTR (William Michaels, via William.Michaels@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COTR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards: (1) each CIE report shall have the format and content in accordance with Annex 1, (2) each CIE report shall address each ToR as specified in Annex 2, (3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon notification of acceptance by the COTR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COTR. The COTR will distribute the approved CIE reports to the NMFS Project Contact and regional Center Director.

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Annex 1: Format and Contents of CIE Independent Peer Review Report

1. The CIE independent report shall be prefaced with an Executive Summary providing a concise summary of the findings and recommendations.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR, and Conclusions and Recommendations in accordance with the ToRs.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including providing a detailed summary of findings, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, and especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the Summary Report that they feel might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The CIE independent report shall be a stand-alone document for others to understand the proceedings and findings of the meeting, regardless of whether or not they read the summary report. The CIE independent report shall be an independent peer review of each ToRs, and shall not simply repeat the contents of the summary report.

3. The reviewer report shall include as separate appendices as follows:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of the CIE Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference for the Peer Review

Review of the Bristol Bay Red King Crab Assessment

. The report generated by the consultant should include:

1. A statement of the strengths and weaknesses of the Bristol Bay red king crab stock assessment and stock projection models;
2. Recommend for alternative model configurations or formulations;
3. Recommendations of alternative model assumptions and estimators.
4. A review of the results of the BSFRF Bristol Bay red king crab supplemental survey and its potential contribution to the stock assessment.
5. A review of the cost and benefit of diverting research from studies that would reduce uncertainty in key parameters used in the assessment to conduct a dedicated crab survey.
6. Suggested research priorities to improve the stock assessment.

Annex 3:

Bristol Bay Red King Crab Stock Assessment Review

NMFS Alaska Fisheries Science Center

7600 Sand Point Way NE, Building 4
Seattle, Washington
Tentative Agenda June 29-July 3, 2009

Day 1
9:00 Welcome and Introductions
9:15 Overview (species, surveys, fishery, catch levels, bycatch)
10:00 Biology (growth, natural mortality, diets, spawning areas, nursery areas, maturity curves, mating, molting frequency)
11:00 Field experiments on escapement, discard mortality, tagging
11:30 Age Determination, shell condition
12:00 Lunch
1:00 Biology continued
2:00 Harvest control rules and overfishing definition
3:00 Ecosystem considerations - Predation, prey
4:00 Summary of on-going research
Egg viability
Migrations and movement
Larval drift
Spatial modeling
Management Strategy Evaluation

Day 2
9:00 Survey methodology and analysis
12:00 Lunch
1:00 Description of Bristol bay red king crab assessment model

Day 3
9:00 Description of projection model and Continued discussion of assessment model
12:00 Lunch

Day 4 and 5 (day 5 must be off campus in hotel)
Reviewer discussions with assessment authors

Julie Pearce will serve as the point of contact for reviewer security & check-in.

Bristol Bay Red King Crab stock assessment review

July, 2009, Seattle

Author

Dr. Billy Ernst

Department of Oceanography

University of Concepción

Chile

Executive summary, findings and recommendations

Summary

The Alaska Fisheries Science Center (AFSC – Seattle) through the Center for Independent Experts (CIE) requested an independent review for the 2009 Bristol Bay red king crab (BBRKC) stock assessment. This review includes a NMFS trawl survey, a stock assessment model and a harvest strategy for the red king crab (*Paralithodes camtschaticus*) of the southeastern Bering Sea. This review was carried out at NOAA-Sand Point in Seattle (Washington) from June 29 to July 3 of 2009. The other CIE member for the review panel was Dr. Nick Caputi.

During the review process, several people from AFSC, NMFS, ADF&G, BSFRF and NPFRC gave presentations on biology, management, stock assessment, IFQs, survey methodology and observer programs. The meeting was well-organized. Participants engaged in fruitful discussions and were responsive to most of our queries.

The stock assessment is based on a complex sex, stage (old-new shell) and size structured model. It was written in ADMB (Otter Research 2001) and allows for simultaneous estimation of over 200 parameters. Parameter uncertainty is readily available from the ADMB statistical environment. The first version of this model was designed in 1995 and has been used ever since for BBRKC assessment. The stock assessment documentation is large and comprehensive, but requires some improvements to accurately describe the model equations implemented in ADMB. A general overview of the entire code does not indicate any major coding problems, but it is strongly recommended that the code also be implemented in a user friendly platform (i.e., EXCEL) to check for bugs and to facilitate the technical interaction between ADF&G and NMFS scientists.

The reviewers asked Dr. Jie Zheng to re-run the BBRKC stock assessment model under different natural mortality and catchability scenarios. These scenarios produced suboptimal fits to the data, indicating that the current model configuration (Scenario 3 from BBRKC stock assessment report) is better supported by the data. From these additional run results it seems that the model is performing numerically well.

We made several recommendations throughout the text, some strictly related to assessment issues and others to future research work to improve the assessment.

Findings and recommendations

ToR 1: A statement of the strengths and weaknesses of the Bristol Bay red king crab stock assessment and stock projection models.

Strengths

- Since 1991, the EBS NMFS survey gear, vessel and instrumentation have remained fairly constant and provide a consistent methodological approach.
- EBS NMFS survey re-tows (about 30 core stations) seem to be a good empirical approach for dealing with environmental uncertainty in the estimation of fertilized females.
- The new industry survey (Bering Sea Fisheries Research Foundation, BSFRF) represents a good cross-check for NMFS survey abundance estimates.
- The sex and length structured stock assessment model was developed in an appropriate statistical environment (ADMB) which allows for point and standard error estimation.
- Retrospective analysis shows temporal consistency in the relevant population statistics.
- Survey data is generally consistent with fishery data (CPUE).
- Despite the need for further sensitivity analysis, the fixed model parameter values in this case (natural mortality and survey catchability) were more likely than those obtained in alternative case studies requested by the reviewers.
- Stock assessment report includes comments on ecological considerations to try to explain temporal changes in parameter values.

Weaknesses

- Some relevant fisheries data were omitted from the stock assessment. The time series of catch-per-unit effort (catch-per-pot) was not used in the stock assessment, and it would have been useful to have a second index of relative abundance.
- There is a potential bias with inter-annual variability in the EBS NMFS trawl survey abundance estimates due to timing of the survey, spatial dynamics and environmental variability.
- Parameter uncertainty in fixed model quantities was not appropriately addressed in the stock assessment document.
- There is a lack of a general conceptual model that integrates life history and spatial dynamics. This would help to interpret the survey data, model configuration and relevant statistics for management.
- There is a lack of theoretical support for variable natural mortality scenarios. These might be replaced by more mechanistic bycatch mortality scenarios.
- The stock assessment document is extensive but incomplete in describing all model equations and formulations.
- The selection of recruitment time series interval for reference points calculations is debatable.

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

- Re-analyze EBS NMFS trawl survey data using an alternative likelihood based geostatistical approach (Roa and Niklitschek 2007). If the same approach is used, the criteria for estimating abundance and its variance across the entire time series should be unified.
- Include new mechanistic scenarios that address more clearly the decline in female and male abundance during the early 1980s (use Griffin et al. 1983 bycatch rates to complete the time series).
- Explore alternative configurations for initial conditions and evaluate their effects on the assessment parameters.
- Improve diagnostics and comparative analyses of different model configuration results (scenarios), including fixed parameter values, effect of likelihood weights, initial conditions.
- More precisely assess the effect of including and excluding the BSFRF survey, with an emphasis on current biomass estimates (males and females) and likelihood value of different pieces of information.
- Use observed proportions as opposed to predicted ones in the variance term of the normal likelihood function.
- Compute implicit sample sizes and variances for each piece of information and compare it to the ones used in the assessment.
- Consider a formal statistical approach to estimate the male size transition matrix externally, using historical tagging data (Punt et al 2009).
- If male molting probabilities are estimated outside of the model (from tagging data), then there should be no need to use old shell and new shell categories in the dynamics of the model. This would simplify model assumptions and the number of parameters to be estimated.
- Assess mature male molting time. If a fraction of mature males are not capable of mating during the survey time (Dew 2009), then the current calculation of mature males available for mating (>120 mm) would be overestimated.
- Because an unknown fraction of the population remains unsampled in the survey and this proportion varies from year to year, it would appropriate to implement a scenario that allows for inter-annual variation in survey availability. Ideally this variation could be modeled based on oceanographic data during the survey, or available year around from ROMs outputs.
- Implement a management strategy evaluation to assess harvest rates under different productivity scenarios.

ToR 4: A review of the results of the BSFRF Bristol Bay red king crab supplemental survey and its potential contribution to the stock assessment.

No technical reports on the BSFRF Bristol Bay red king crab supplemental survey were provided before or during the CIE review. Mr. Steve Hughes, from BSFRF, gave a detailed presentation (“Bering Sea Crab Trawl Surveys 2005-2008”) on the motivation, key methodological differences and results differences with EBS NMFS trawl survey. Two surveys were carried out for red king crab in Bristol Bay area in 2007 and 2008. Both had similar configurations and matched in general the NMFS survey grid.

Main differences between surveys are:

- BSFRF includes some stations that are further inshore, especially the geographical area between the historical sampling grid and the Aleutian Islands.
- Sampling nets are different and the BSFRF net allows for a higher proportion of small crab to be captured.
- BSFRF survey tows are shorter and more frequently spaced (4 times).
- NMFS survey uses traditional systematic sampling estimators for mean, variances and BSFRF geostatistical estimators.

The comparison of both approaches indicates that the BSFRF survey yields larger abundance estimates, this being even greater for smaller crab. Confidence bounds are, in general, narrower for the BSFRF survey (using geostatistical analysis). Differences in abundance for larger males are smaller and they can potentially be reduced if geostatistical estimators are used for the NMFS survey data.

I believe that, despite the great methodological differences, the abundance estimates come close together, especially for stock assessment relevant abundance data (larger males). These results validate the NMFS trawl survey, at least from a methodological approach.

The male and female abundance density plots provided by Mr. Steve Hughes do a good job of highlighting a very important point depicted by Dew and McConnaughey (2005), namely, that an unknown fraction of adult males and/or females probably remain outside of the survey area during May and June of each year. This unsampled area encompasses the zone between the southeastern border of the survey polygon and the Aleutian Islands.

The BSFRF survey is a very flexible research platform (i.e. shorter tows, smaller net, crab oriented sampling) for carrying out an exploratory survey in the uninvestigated zone. The spatial dynamics between the researched and unresearched areas are not clear. Swept area sampling and potentially mark recapture studies (using the fishery to recapture the samples) should provide a great opportunity to learn about connectivity between these two areas and the spatial dynamics of this stock in general. Dew (2008) proposed that a fraction of the mature biomass migrate to shallow waters, out of the survey area. This process is also variable in the inter-annual basis, probably regulated by near bottom temperature (NBT).

ToR 5: A review of the cost and benefit of diverting research from studies that would reduce uncertainty in key parameters used in the assessment to conduct a dedicated crab survey.

The BSFRF survey provides a good methodological contrast to assess the performance of the standard multispecies EBS NMFS trawl survey in evaluating red king crab abundance. Despite several technical differences in the sampling procedure, results were similar for relevant stock statistics. From that point of view a dedicated crab survey in the same time period would not be advantageous. Replacing the BBRKC traditional survey by a dedicated crab survey (with BSFRF characteristics) has the disadvantage of breaking the survey time series.

I foresee three main advantages of a dedicated crab survey:

- The possibility of using a different survey gear and sample a larger amount of smaller crab. This might be advantageous for the stock assessment, but it should be evaluated in a MSE framework.
- Delaying survey time to evaluate potential biases in crab abundance because of late migration of a fraction of the population into the survey area. This could also have an inter-annual component.
- Extending the survey area to the zone between the standard NMFS sampling grid and the Aleutian Islands.

The dedicated crab survey can also provide with a good research platform to develop mark recapture programs, aimed at the study of migration, mortality, growth increments and molting probabilities.

ToR 6: Suggested research priorities to improve the stock assessment

- Re-analyze survey data to obtain a consistent time series of mean and variance abundance estimates, considering tow length corrections in early years, re-tows, hotspots and variable swept area.
- Design a survey to estimate the abundance between the survey grid and the Aleutian Islands (potentially based on BSFRF survey).
- Re-analyze the male growth tagging data using a formal statistical approach (Punt et al. 2009) and parameterize the size transition matrix outside the model.
- Standardize CPUE data to generate a fisheries derived index of relative abundance, using soaking time and fishing power.
- Make better use of spatial information of the NMFS survey data to understand the spatial patterns and dynamics of males and females throughout their life history.
- Analyze the historical data on fishing effort, catch by statistical area and perform local depletion estimates using catch and effort data. This, in combination with catch-effort data, should help to understand the localized effect of the fishery.
- Implement a tagging program to better understand the potential ontegenetic migrations (endless belt model, Dew and McConnaughey 2005) and the seasonal

reproductive movement during survey time (male and female inshore-offshore movement).

- Initiate a tagging program to study male molting probabilities and female growth (size transition matrix).
- Extend the time series analysis of recruitment and environmental factors to explore statistically potential regime shifts assumed throughout the assessment document.

Background

The Alaska Fisheries Science Center (AFSC – Seattle) through the Center for Independent Experts (CIE) requested an independent review for the 2009 Bristol Bay red king crab (BBRKC) stock assessment. This review included the NMFS trawl survey, the stock assessment model and the harvest strategy of red king crab (*Paralithodes camtschaticus*) of southeastern Bering Sea.

The Bristol Bay red king crab stock assessment model was developed in 1995 for use in TAC setting. The model incorporates a sex, stage and size-structured statistical stock assessment approach and uses various sources of information. The model has recently been updated for use in setting over fishing levels and determining reference points. This is the first CIE review for this stock.

Description of review activities

Documentation

Before the staff meeting at the AFSC/NOAA in Sand Point (Seattle), several papers from the official BBRKC CIE review webpage were uploaded:

ftp://ftp.afsc.noaa.gov/afsc/public/crab/CrabWS.htm

Before and during the meeting

1. Dew, B. 2008. Red King Crab Mating Success, Sex Ratio, Spatial Distribution, and Abundance Estimates as Artifacts of Survey Timing in Bristol Bay, Alaska. North American Journal of Fisheries Management 28:1618–1637.
2. Dew, B. and McConnaughey, R. 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? Ecological Applications, 15(3): 919–941.
3. Loher, T. and Armstrong, D. 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. Fish. Oceanogr. 14:4, 292–306.
4. North Pacific Fishery Management Council (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.
5. Otto, R. S. 1986. Management and assessment of eastern Bering Sea king crab stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 92:83–106.
6. The BSAI king and Tanner crab FMP Amendment 24.
7. Weinberg, K., Otto, R. and Somerton, D. 2004. Capture probability of a survey trawl for red king crab (*Paralithodes camtschaticus*). Fish. Bull. 102:740–749.
8. 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, E.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 Limited Situations. Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, AK.
9. 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.
10. 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.
11. 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.
12. 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.
13. Zheng, J., M.S.M Siddeek. 2008. Bristol Bay Red King Crab Stock Assessment in Fall 2008. **In** the Stock Assessment Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, 605 W. 4th Ave. #306, Anchorage, AK.

Review in Seattle

The CIE review was held at NOAA Sand Point in Seattle between June 29 and July 3 of 2009 to consider the 2009 Bristol Bay red king crab stock assessment. The meeting was chaired by Dr. Bob Foy (NMFS, Kodiak) and Dr. Anne Hallowed (AFSC, Seattle).

During the first two days, we had several presentations by people from NMFS, ADF&G, Bering Sea Fisheries Research Foundation and North Pacific Fisheries Management Council, which included topics such as stock assessment, harvest strategies, crab biology, economics and the rationalization of the fishery, observers program, survey methodology, ecosystem considerations, among others. Debate and discussions developed throughout the presentations and the working environment was appropriate.

During Days 3 and 4 we continued with discussions on particular assessment issues, and we asked Dr. Zheng to re-run the model for particular model configurations. These were presented on day four. On the last day both reviewers discussed and shared points of view about the review.

Dr. Nick Caputi from the Department of Fisheries (Western Australia) was the other CIE member on the review panel.

Summary of findings

Conceptual model

The modeling of population dynamics and fishery management of invertebrate stocks can be a difficult task to accomplish, mainly because of a complex life history, spatial dynamics and a lack of age information. The complexity of stock assessment models used for stock status evaluation balances out between a good description of key biological and fishery processes affecting the population dynamics and the amount of available data to estimate key model parameters.

From the stock assessment report and other available documents and papers, it can be inferred that the Bristol Bay red king crab has a complex life history, spatial dynamics and exploitation history. The stock assessment process would greatly benefit from the development of a clear conceptual model that summarizes key life history traits, spatial patterns of abundance and spatial dynamics. This would help to interpret survey and model results, judge several model assumptions and develop auxiliary research work to increase knowledge beyond the scope and structure of the stock assessment model.

Some key components that require special attention are:

- Key life history characteristics (male molting period, female size-at-maturity, etc.)
- Sex specific spatial patterns in the Bristol Bay area and its changes throughout the ontogeny.
- Female lifetime movement from northeast to southwest of Bristol Bay (endless belt hypothesis Dew and McConnaghey 2005).
- Seasonal movement between the survey area and the zone adjacent to the Aleutian Islands and the effect of environmental covariates.
- Timing of multiparous spawning and the effect of environmental factors.

Mark recapture studies and early life history IBMs can help to understand the spatial dynamics of this stock and test hypotheses like the disruption of the pot Sanctuary area by trawlers (Dew and McConnaghey 2005).

EBS NMFS trawl survey

The annual Eastern Bering Sea NMFS trawl survey follows a systematic sampling design, with one station sampled at the center of each 20x20 nm grid. Since 1973, the survey has covered the entire BBRKC stock distribution. The database is being compiled and maintained by NMFS personnel in Alaska; it is currently under review and several improvements have been introduced to account for temporal biases and variance calculations.

In the last forty years, several changes/improvements have been introduced in the sampling procedure. This information will soon be documented in a comprehensive technical survey report. Figure 1 summarizes these changes.

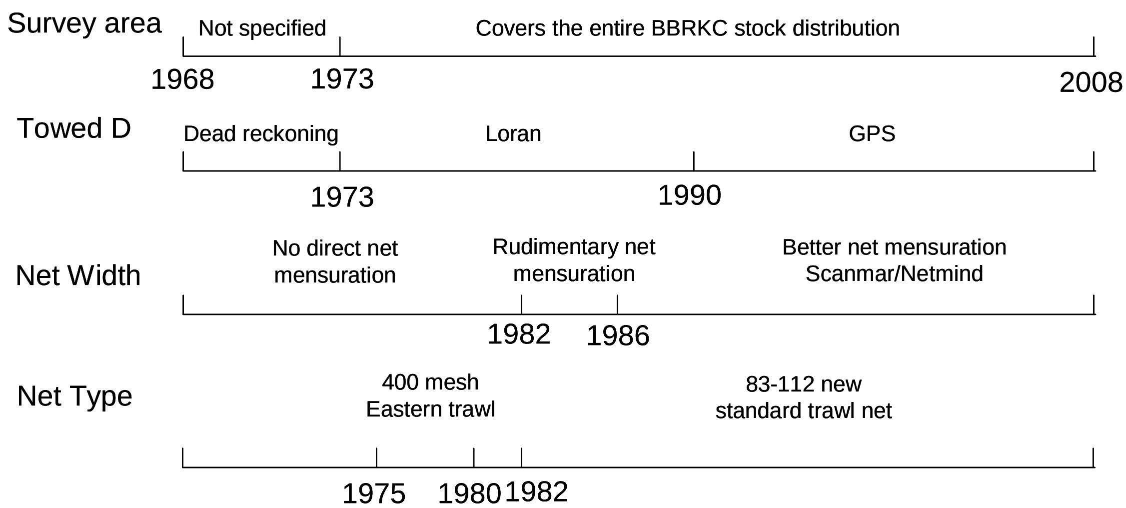


Figure 1: Relevant changes in EBS NMFS trawl survey.

The estimation of density for one particular tow (not accounting for selectivity) would be a function of the following five quantities.

$$\hat{D} = \frac{\alpha\, q\, N}{w\, L}$$

$\hat{D}$: estimated density
α : availability coefficient
q : catchability coefficient
N : number of crab in the gear
w : width of net
L : total distance traveled by the gear

Generally w and L are known quantities (with no measurement error). These quantities have been assessed with accurate instruments since 1986. Net width mensuration was only rudimentary between 1982 and 1986. The early part of the time series did not have a direct net width measurement, towing distance was estimated by dead reckoning and probably the survey did not covered the entire stock distribution. These factors might have induced some biases or at least generate greater uncertainty in abundance estimates. From the information provided in the stock assessment report, the point estimates and their associated uncertainty of survey abundance between 1968 and 1972 were taken at face values from assessment reports. Figure 12a from Zheng and Siddeek (2009) shows very precise abundance estimates, which could be affecting the stock assessment in early years. I recommend to carefully address this issue and consider the possibility of running some scenarios with more uncertainty associated to those abundance estimates.

Different initial conditions and very uncertain abundance estimates for the first five years of the series might create a different recruitment pattern, which might have consequences for reference point calculations.

Several other issues were discussed during the meetings, some of them being re-tows, hot-spot and the possibility of using geostatistics for abundance estimation. I recommended the use of likelihood based geostatistics (Roa and Niklitscheck 2007).

Initial conditions

The initial conditions of statistical stock assessment models can strongly affect the dynamics of early years of the population. These model equations were not found in the stock assessment document and need to be incorporated. Drs. Zheng and Siddeek indicated during the meeting that they based the initial population size structure on a 1968 survey size frequency and an estimated parameter that scaled the proportions to abundance at size.

The size structure from the survey in those early years was probably very unreliable, so we recommend assessing the sensitivity of the model to this assumption using other initial conditions. Of special interest is the effect on the time series of estimated recruitments for early years of the time series.

Growth

Somatic growth is an important component of size-structured models and is represented in Bristol Bay red king crab by a size transition matrix and a molting probability function (males).

Size transition matrix

Sex specific size transition matrices are used in the red king crab stock assessment model. The probability of growing from one size bin to another is modeled by gamma density with a variable mean growth increment at size and an estimated beta parameter for each sex. For males, mean size increments were estimated outside the stock assessment model based on historical tagging data (Figure 2). It is recommended to re-analyze the male tagging data and estimate the full size transition matrix outside of the model using formal statistical procedures (Punt et al 2009). This would reduce the number of estimated parameters within the stock assessment model, probably reducing potential parameter confounding effects.

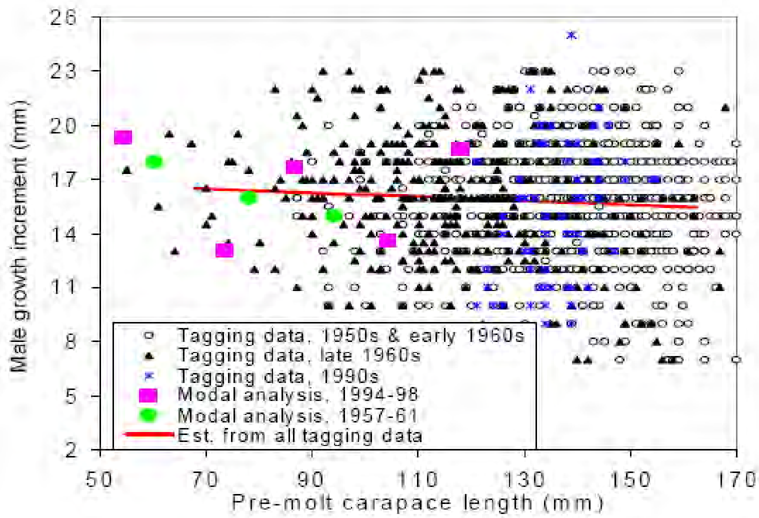


Figure 2: Size increments at size for the male red king crab (from Zheng and Siddeek 2009)

Tagging data is not available for Bristol Bay red king crab female size transition matrix parameterization. The mean size increment was estimated based on modal decomposition analysis. The general pattern is a sharp decline in molt increments at the onset of maturity and a less conspicuous linear decline at sizes greater than 90 mm (Figure 3). The size increment data shows a clear linear trend and not much variability, probably because the data was derived from a von Bertalanffy growth model.

I suggest developing a tagging program, to better characterize red king crab female growth in the Bristol Bay area, and to fully estimate the size transition matrix parameters outside the stock assessment model.

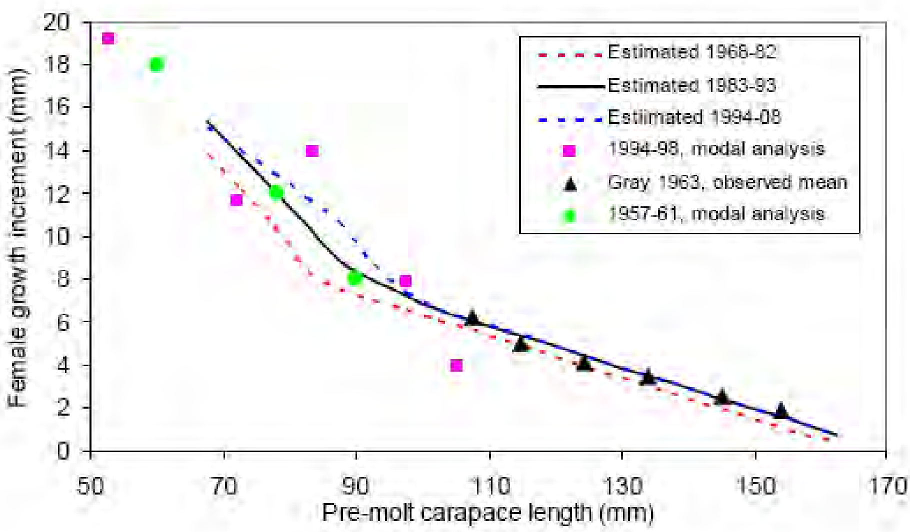


Figure 3: Female growth increments at size for BBRKC females (from Zheng and Siddeek 2009)

Molting probabilities

A molting probability function is only used to model male growth. Females show an annual molting schedule. The molting probability function is probably confounded with mean size increment, because morphometric changes can be explained by molting frequency and size increments at molt.

Male molting probabilities that were estimated internally within the stock assessment model coincide with molting probabilities that were estimated from tagging data. I recommend using tagging data to estimate male molting probabilities outside the stock assessment model.

Natural mortality

Natural mortality was computed based on an estimated maximum age of 25 years and the 1% rule (Zheng 2005). The estimated M=0.18 value should be handled with care, because no good estimate of maximum age is available for red king crab. Zheng (2005) compiled red king crab natural mortality estimates from the scientific literature and values ranged from 0.1 to 1.75, clearly indicating that the natural mortality value for BBRKC is an open question.

In the stock assessment model, natural mortality is allowed to change in some particular years (males and females independently) to deal with some major unexplained mortalities. Some of these mortalities are associated with the high bycatch of trawl and pot fisheries in the early 1980s. More plausible alternative mechanistic bycatch mortality scenarios should be explored before letting difficult to defend abrupt natural mortality changes account for unaccounted mortalities.

Based on additional model runs and under scenario 3 model configuration (Zheng and Siddeek 2009), values of M=0.13 and M=0.26 are less likely (based on the assessment data) than an M value of 0.18 (see additional model runs). Nevertheless these results apply under the model configuration of scenario 3.

It is recommended that a more comprehensive sensitivity analysis be performed considering other model configurations (scenarios) to evaluate M.

Females are only affected by natural and bycatch mortalities (less confounding effect with F); therefore a good tagging project might help to obtain more appropriate natural mortality estimates for females.

Fisheries data

The commercial pot fishery catch rates are included in the stock assessment report, but not in the assessment. Despite the fact of being non-standardized data, it tracks, in general, the abundance survey very well (Figure 4). Major differences arise at the beginning and at the end of the time series. Good observer data should be available from the middle of the time series, so that it might be possible to standardize the catch rates from 1988 through 2008. Prior archival data might be available to standardize the first half of the time series. After the rationalization of the fishery (2005), soaking time seems to be an important factor to have in mind. It is good to have a second source of relative abundance to calibrate the stock assessment model, especially one closely associated to fishery. This statistic would be necessary for implementing a bioeconomical modeling approach and estimating bioeconomical reference points.

A spatial analysis of catch and effort information should provide helpful insights on spatial and temporal patterns of target crab catch and bycatch. This, in conjunction with spatial information provided by the survey, can reveal some unexplained spatial dynamics.

Additionally, analyzing catch and effort data by statistical areas throughout the season (one or 2 weeks) might provide estimates of local harvest rates through Leslie-Delury estimators (Hilborn and Walters 1992).

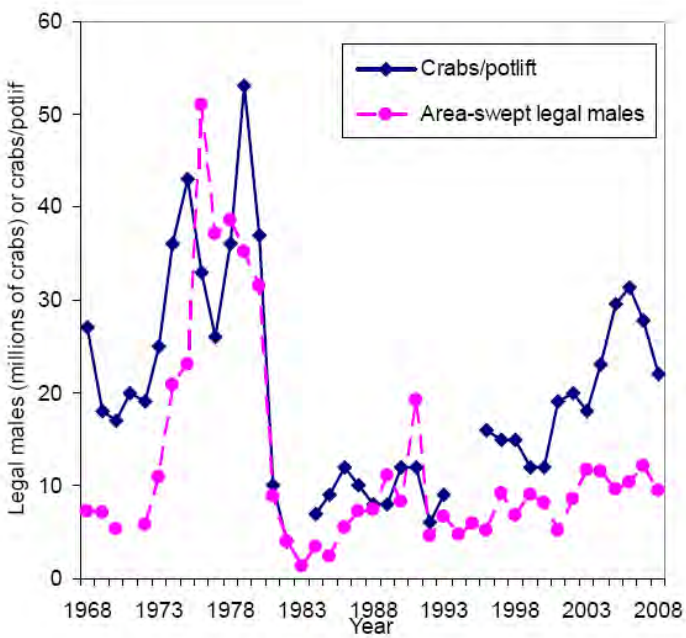


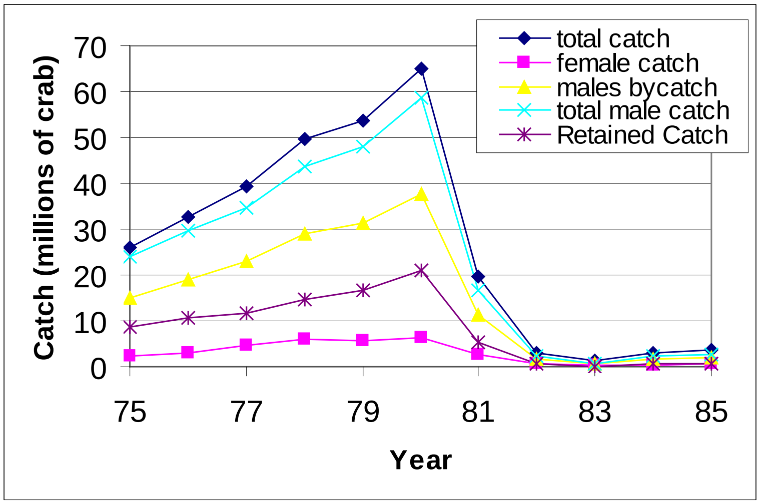
Figure 4: NMFS survey abundance estimates and commercial pot catch rates for BBRKC (source: Zheng and Siddeek 2009)

Historical by-catch data

Dew and McConnaghey (2005) and Dew (2008) indicated that much of the rapid historical BBRKC decline could be explained by massive bycatch mortalities induced by trawl and red king and tanner crab pot fisheries between the mid-1970's and 1980's. Regular bycatch sampling in the BBRKC and tanner crab fishery started only in the 1988/1989 season, so direct estimates are not available for those years.

During the meetings in Seattle, Dr. Lou Rugolo and Jack Turnock pointed out that the Griffin et al, 1983 report provides good bycatch rate estimates of sublegal males and females from the red king crab fishery. Using those discard rates before and after 1983, they were able to reconstruct the female and undersized male crab bycatch time series for those years (Figure 5). Dr Zheng indicated that this calculation would hold only if the population size structure was at equilibrium. His point was well taken, but additional information was provided by Mr. Turnock, indicating that the ratio of males in the 110-134 mm to greater than 110 mm categories had not changed dramatically (Figure 5b).

I recommend that a stock assessment scenario on Tanner and RKC crab bycatch be evaluated on the basis of these numbers or something along these lines. This could potentially explain the great decay in females and smaller males throughout this period and avoid the need to incorporate sudden changes in natural mortality.



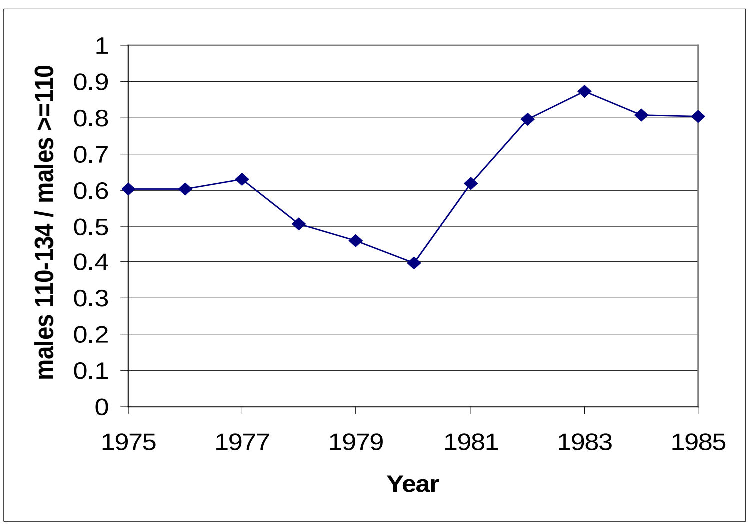


Figure 5: Upper panel: Estimated bycatch of small males and females from the red king crab fisheries. Lower panel: Ratio of males between 110 and 134 mm to males greater than 110 mm.

Stock assessment report

The stock assessment report is comprehensive. Some model equations in the report need improvement to facilitate the reader an accurate interpretation of the stock assessment model. A glossary with all parameters of the model, including weights/variances and sample sizes would definitely facilitate the understanding and interpretation of the model. Of special interest is a clear specification of which parameters are being estimated. The description of the initial conditions was missing in the report.

The current multinormal likelihood function for proportions might be producing biased results. Maunder and Watters (2003) switched predicted for observed proportions in the variance component of the length frequency likelihood. I recommend to check this option or to try a multinomial likelihood.

All the candidate scenarios should be clearly organized in a table, including model configurations. The results of model sensitivity to different assumptions should be better organized, presenting in a table the values for each likelihood component, gradient and number of parameters (see additional model runs).

Implicit variance and effective sample size calculation were missing in the report, these are helpful diagnostics.

Scenarios

The variances and sample sizes can, in some cases, have a large influence on the stock assessment results, therefore a sensitivity analysis should be carried out to determine the influence of the sample sizes and variance components. I recommend including an additional variance component to the initial part of the survey time series, because it should be more uncertain. This might be playing an important role in the early years of the assessment.

Other scenarios should consider alternative initial conditions, M and q values. Based on the BSFRF survey it can be inferred that a fraction of the crab population is not available to the survey between May and June (Figure 6). Dew (2008) proposed some relationship with temperature. I recommend an exploratory scenario, where additional near bottom temperature related availability parameters be incorporated into de model.

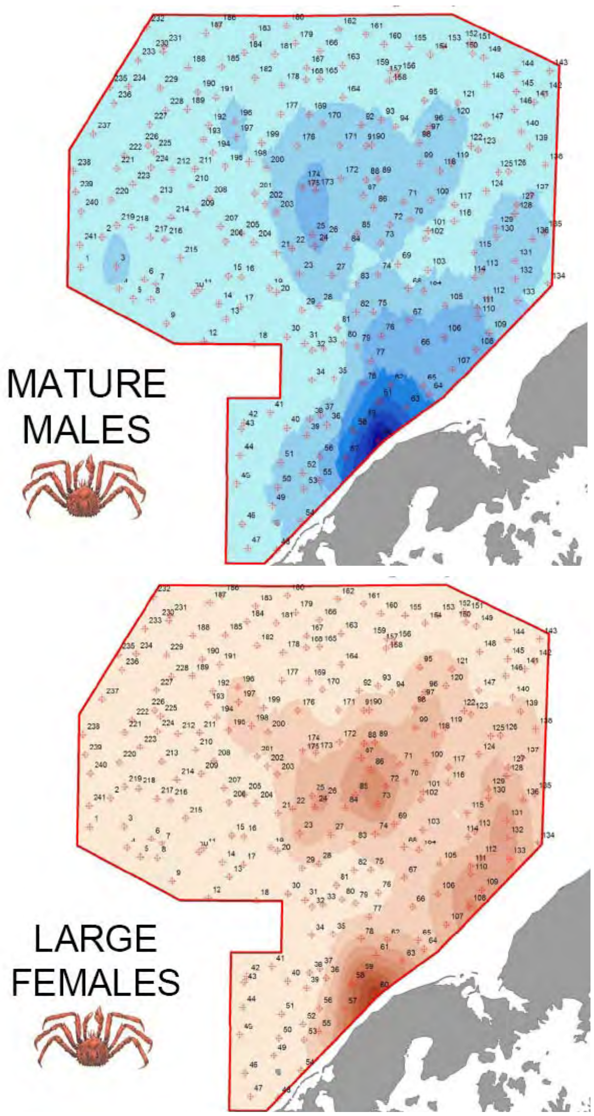


Figure 6: Mature males and large female density plots during 2008 survey (source: Presentation by Mr. Steve Hughes from BSFRF).

Additional model runs

The CIE reviewers asked Dr. Jie Zheng to do some additional model runs to evaluate the sensitivity of the stock assessment model to alternative survey catchability and natural mortality values. In order to keep this exercise simple, we chose scenario 3 (from the stock assessment report) as the base case scenario. This scenario was also chosen by the Crab Plan Team for the 2009 assessment.

The following table summarizes different model run characteristics:

Scenarios	Parameters M	Parameters q	N estimated parameters	Description
3(base)	0.18	Est.	223	Three additional natural mortality parameters are estimated
SC3a	0.18	0.5	222	
SC3b	0.26	0.5	222	
SC3c	0.13	0.5	222	
SC3	0.18	Est.	223	No additional M estimated. Additional bycatch is estimated for Tanner RKC fisheries 1980-1984.
3d	0.26	Est.	223	Same as 3(base) but M=0.26

The results include likelihood values for each piece of information, implied reference points based on mean male recruitment for 1995-2008 and recruitment per mature male biomass.

Table 1: Likelihood components of each piece of information for six different model runs requested by the CIE reviewers (Data provided by Dr. Jie Zheng after the CIE review in Seattle).

	Negative Log Likelihood Components					
	3(base)	**SC3a**	**SC3b**	**SC3c**	**SC3**	**3D**
M	**0.18**	**0.18**	**0.26**	**0.13**	**0.18**	**0.26**
q	**Est.**	**0.5**	**0.5**	**0.5**	**Est.**	**Est.**
Recruitment Variation	148	139	136	148	134	150
Sex Ratio of Recruitment	0.007	0.021	0.006	0.030	0.001	0.017
Length Comp - Retained Catch	-992	-986	-996	-981	-1089	-917
Length Comp -Pot Male Discard	-712	-714	-708	-715	-711	-704
Length Comp - Pot Female Discard	-1865	-1871	-1841	-1875	-1870	-1858
Length Comp Survey	-48885	-48813	-48789	-48830	-48741	-48880
Length Comp Trawl Discard	-1674	-1665	-1670	-1663	-1670	-1682
Pot Discd Male Biomass	132	131	133	130	113	134
Retained Catch Biomass	30	30	29	31	35	29
Survey Biomass	75	86	95	120	106	78
Others	-111	-111	-113	-106	-53	-107
Total Negative Log Likelihood	-53854	-53773	-53724	-53741	-53745	-53757
Maximum Gradient Component	0.960	0.675	0.660	0.992	0.596	0.971

Results indicate that base case scenario 3 is the one mostly supported by the data, with a difference of about 80 and 100 units of likelihood with respect to scenarios 3a and 3D. This implies that under base case Scenario 3, lower catchability values or higher/lower natural mortality rates are less supported by the data. Results of Scenario SC3 indicate that even under a constant mortality rate of M=0.18, including additional sources of bycatch mortality greatly improve the fit to length frequency data of the catch (Table 1).

Only scenarios with different natural mortality values yielded different reference points, as expected smaller with lower M and larger with higher natural mortality.

The model behaved well (converged) under different parameter configurations and the original parameters that are being used are more consistent with the available data.

Table 2: Estimated reference points for six different model runs requested by the CIE reviewers (Data provided by Dr. Jie Zheng after the CIE review in Seattle).

F_{ref} and B_{ref} (mill lbs)

Bref based on mean male R for 1995-2008

	3(Base)	SC3a	SC3b	SC3c	SC3	3d
M	**0.18**	**0.18**	**0.26**	**0.13**	**0.18**	**0.26**
q	**Est.**	**0.5**	**0.5**	**0.5**	**est.**	**Est.**
F_{35}	0.33	0.32	0.51	0.22	0.32	0.53
B_{35}	77.5	48.6	39.1	66.5	73.0	61.2
F_{40}	0.26	0.26	0.41	0.18	0.26	0.42
B_{40}	89.8	55.2	44.5	75.6	83.2	70.0

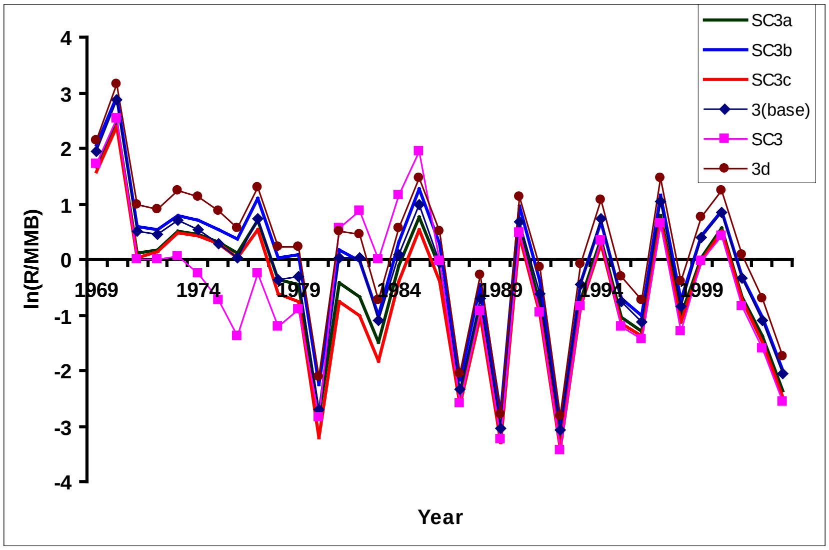


Figure 7: Recruit per spawner (mature male biomass) for six different model runs requested by the CIE reviewers (Figure provided by Dr. Jie Zheng after the CIE review in Seattle).

Recruitment

The estimated recruitment time series for scenario 3 in the stock assessment report (Figure 33b) shows some degree of autocorrelation, some inter-annual variability and three periods of different average recruitment (1969-1984, 1984-1994 and 1995-2008). During the meeting there was substantial debate on possible causes of recruitment changes being finally summarized by the following five points:

1. Environmental conditions (decadal signal) have directly affected red king crab recruitment.

2. Environment has favored the increase in ground fish populations, which have negatively impacted red king crab survival of early life stages.

3. Ground fishery:

a) Induced high RKC female mortality through bycatch during early years
b) Induced a change in habitat

4. The cold pool retracted the spatial distribution of the reproductive potential to the NE.

5. The spatial distribution of the reproductive potential has affected the larval distribution.

Some of these mechanisms imply a change in the underlying stock recruitment relationship (1, 3b and 5). This is relevant at the moment of defining the mean recruitment level used for reference point calculation.

Figure 7 shows a drop in the recruit-per-spawner relationship between 1968-1979. The early part of the time series is affected by different scenarios, so more analysis could show a less abrupt change in productivity. Nevertheless, the very early years of the time series are always going to be the most productive ones, in order to account for a phenomenal increase in biomass from1968 to 1977.

Management Strategies evaluation

As in many other crustacean stocks Bristol Bay red king crab does not have a well defined stock-recruitment relationship. There is a lot of uncertainty in the current productivity level of this stock. Is the stock in a low, medium or high productivity level? To deal with this kind of structural and parameter uncertainty, it is recommended to implement a formal management strategy evaluation to assess harvest strategies under current control rules. They derive from Federal and State regulations.

Different scenarios of recruitment trends and variability can be explored, addressing some of the 5 hypothesis mentioned above.

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Dew, B. and McConnaughey, R. 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? Ecological Applications, 15(3): 919–941.

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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, E.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 Limited Situations. Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, AK.

Zheng, J., M.S.M Siddeek. 2009. Bristol Bay Red King Crab Stock Assessment in Spring 2009. 135 p.

Appendix 1: Statement of Work for Dr. Billy Ernst

External Independent Peer Review by the Center for Independent Experts

Bristol Bay Red King Crab Stock Assessment

Scope of Work and CIE Process: The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract to provide external expertise through the Center for Independent Experts (CIE) to conduct impartial and independent peer reviews of NMFS scientific projects. This Statement of Work (SoW) described herein was established by the NMFS Contracting Officer's Technical Representative (COTR) and CIE based on the peer review requirements submitted by NMFS Project Contact. CIE reviewers are selected by the CIE Coordination Team and Steering Committee to conduct the peer review of NMFS science with project specific Terms of Reference (ToRs). Each CIE reviewer shall produce a CIE independent peer review report with specific format and content requirements (**Annex 1**). This SoW describes the work tasks and deliverables of the CIE reviewers for conducting an independent peer review of the following NMFS project.

Project Description: The CIE requests a review of the population dynamics and harvest strategy models for the Bristol Bay red king crab (*Paralithodes camtschaticus*) assessment. While a red king crab stock assessment model was developed in 1995 for use in TAC setting, the model has recently been revised for use in setting overfishing levels and determining reference points. An independent review of this revised model is needed to evaluate it's suitability in defining overfishing definitions and reference points.

The red king crab assessment is a high profile assessment and with the adoption of revisions to the overfishing definitions it is critical that it provides the best available science on the status of this resource. The CIE requests a review of the use of Bering Sea trawl survey data in the assessment, the stock assessment model structure, assumptions, life history data, and harvest control rule. New overfishing definitions for Bering Sea crab stocks require the use of the red king crab stock assessment model to estimate reference points and the status of the stock relative to those reference points. Uncertainty exists in several key parameters including the survey selectivity and catchability, molting probabilities, natural mortality, discard mortality and age. This review will help in the decision process as to which alternative model is most appropriate, given the current state of knowledge of Bristol Bay red king crab.

The CIE also requests a review of the potential utility of conducting a dedicated crab survey for eastern Bering Sea stocks including Bristol Bay red king crab (BBRKC). The current survey is a multispecies survey that has issues with respect to survey timing relative to mating, molting and egg extrusion, survey boundaries and movement, and catchability. The CIE should comment on the costs and benefits of a crab specific survey relative to other research needed to improve the red king crab stock assessment.

The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements for CIE Reviewers: Two CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. Each CIE reviewer's duties shall not exceed a maximum of 14 days to complete all work tasks of the peer review described herein. CIE reviewers shall have the expertise, background, and experience to complete an independent peer review in accordance with the SoW and ToRs herein. CIE reviewer expertise shall include working experience with stock assessment, estimates of survey catchability and selectivity, population dynamics, length based models, knowledge of crab life history and biology, harvest strategy models for invertebrates, and the AD Model Builder programming language.

Location of Peer Review: The CIE reviewers shall participant during a panel review meeting in Seattle, Washington to conduct a peer review of the stock assessment with the authors of the red king crab assessment in accordance to the Schedule of Milestones and Deliverables herein.

Statement of Tasks: Each CIE reviewers shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

<u>Prior to the Peer Review</u>: Upon completion of the CIE reviewer selection by the CIE Steering committee, the CIE shall provide the CIE reviewer information (name, affiliation, and contact details) to the COTR, who forwards this information to the NMFS Project Contact no later the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, foreign national security clearance, and information concerning other pertinent meeting arrangements. The NMFS Project Contact is also responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COTR prior to the commencement of the peer review.

<u>Foreign National Security Clearance</u>: When CIE reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for CIE reviewers who are non-US citizens. For this reason, the CIE reviewers shall provide requested information (e.g., name, contact information, birth date, passport number, travel dates, and country of origin) to the NMFS Project Clearance for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations

(available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/sponsor.html).

Pre-review Background Documents: Two weeks before the peer review, the NMFS Project Contact will send by electronic mail or make available at an FTP site the CIE reviewers all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE on where to send documents. The CIE reviewers shall read all documents in preparation for the peer review including the following:

1. Zheng, J., M.S.M Siddeek. 2008. Bristol Bay Red King Crab Stock Assessment in Fall 2008. **In** the Stock Assessment Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, 605 W. 4th Ave. #306, Anchorage, AK.
2. North Pacific Fishery Management Council (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.
3. The BSAI king and Tanner crab FMP Amendment 24.
4. 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, E.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 Limited Situations. Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, AK.
5. 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.
6. 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.
7. 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.
8. 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.

This list of pre-review documents may be updated up to two weeks before the peer review. Any delays in submission of pre-review documents for the CIE peer review will result in delays with the CIE peer review process, including a SoW modification to the schedule of milestones and deliverables. Furthermore, the CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein.

Panel Review Meeting: Each CIE reviewers shall conduct the independent peer review in accordance with the SoW and ToRs. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified in the contract SoW. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Contract Deliverables - Independent CIE Peer Review Reports: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Other Tasks – Contribution to Summary Report: Each CIE reviewer will assist the Chair of the panel review meeting with contributions to the Summary Report. CIE reviewers are not required to reach a consensus, and should instead provide a brief summary of their views on the summary of findings and conclusions reached by the review panel in accordance with the ToRs.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review;
2) Participate during the panel review meeting at the NMFS Alaska Fisheries Science Center from June 29 – July 3, 2009, as called for in the SoW, and conduct an independent peer review in accordance with the ToRs (Annex 2);
3) No later than July 17, 2009, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Mr. Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and CIE Regional Coordinator, via email to David Die at ddie@rsmas.miami.edu.
4) Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in Annex 2;
5) CIE reviewers shall address changes as required by the CIE review in accordance with the schedule of milestones and deliverables.

Schedule of Milestones and Deliverables: CIE shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

25 May 2009	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
15 June 2009	NMFS Project Contact sends the CIE Reviewers the pre-review documents
29 June - 3 July 2009	Each reviewer participates and conducts an independent peer review during the panel review meeting (June 29-July 3, 2009)
17 July 2009	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
31 July 2009	CIE submits CIE independent peer review reports to the COTR
7 August 2009	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be made through the Contracting Officer's Technical Representative (COTR) who submits the modification for approval to the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the CIE within 10 working days after receipt of all required information of the decision on substitutions. The COTR can approve changes to the milestone dates, list of pre-review documents, and Terms of Reference (ToR) of the SoW as long as the role and ability of the CIE reviewers to complete the SoW deliverable in accordance with the ToRs and deliverable schedule are not adversely impacted. The SoW and ToRs cannot be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COTR for final approval as contract deliverables based on compliance with the SoW. As specified in the Schedule of Milestones and Deliverables, the CIE shall send via e-mail the contract deliverables (the CIE independent peer review reports) to the COTR (William Michaels, via William.Michaels@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COTR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards: (1) each CIE report shall have the format and content in accordance with Annex 1, (2) each CIE report shall address each ToR as specified in Annex 2, (3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon notification of acceptance by the COTR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COTR. The COTR will distribute the approved CIE reports to the NMFS Project Contact and regional Center Director.

Key Personnel:

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Annex 1: Format and Contents of CIE Independent Peer Review Report

1. The CIE independent report shall be prefaced with an Executive Summary providing a concise summary of the findings and recommendations.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR, and Conclusions and Recommendations in accordance with the ToRs.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including providing a detailed summary of findings, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, and especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the Summary Report that they feel might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The CIE independent report shall be a stand-alone document for others to understand the proceedings and findings of the meeting, regardless of whether or not they read the summary report. The CIE independent report shall be an independent peer review of each ToRs, and shall not simply repeat the contents of the summary report.

3. The reviewer report shall include as separate appendices as follows:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of the CIE Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference for the Peer Review

<u>Review of the Bristol Bay Red King Crab Assessment</u>

. The report generated by the consultant should include:

1. A statement of the strengths and weaknesses of the Bristol Bay red king crab stock assessment and stock projection models;
2. Recommend for alternative model configurations or formulations;
3. Recommendations of alternative model assumptions and estimators.
4. A review of the results of the BSFRF Bristol Bay red king crab supplemental survey and its potential contribution to the stock assessment.
5. A review of the cost and benefit of diverting research from studies that would reduce uncertainty in key parameters used in the assessment to conduct a dedicated crab survey.
6. Suggested research priorities to improve the stock assessment.

APPENDIX 2: Meeting Agenda
Schedule for CIE review of the Bristol Bay Red King Crab stock assessment

June 29-July 3, 2009
Alaska Fisheries Science Center, Seattle, WA

Purpose: To solicit expert advice on the stock assessment for Bristol Bay Red King Crab. We are requesting a review of issues critical to formulating overfishing definitions, biological reference points, input parameters, modeling approaches and methods to deal with uncertainty.

Day 1

9:00 Welcome and Introductions (Foy or Hollowed)
9:15 History of crab management (Stram)
9: 45 Fishery dependent data sources (historical fishery, catch levels, bycatch) (Zheng)
ADF&G Observer program (Doug Pengilly)
10:30 ***Break***
10:50 Biology (growth, natural mortality, diets, spawning areas, nursery areas, maturity curves) (Zheng)
11:30 Field experiments on survey selectivity (Weinberg)
12:00 ***Lunch***
1:00 Biology continued, mating, Age Determination, shell condition (Rugolo or Foy)
2:00 On-going research—reproductive potential of RKC (Kathy Swiney)
3:00 Harvest Control Rules and Overfishing Definitions (Siddeek)
3:30 Survey methodology and analysis (Foy or Rugolo)
4:30 Bering Sea Fisheries Research Foundation survey (Steve Hughes)

Day 2

9:00 Ecosystem considerations - Predation, prey (Aydin)
9:30 Crab rationalization (IFQ) (Garber-Yonts)
10:00 Report on crab data weighting workshop (Kinzey)
11:00 Description of Bristol Bay red king crab assessment model (Zheng)
12:00 ***Lunch***
1:00 Continued description of assessment model and discussions

Day 3

9:00 Examination of the harvest control rules and Continued discussion of assessment model
12:00 ***Lunch***

Day 4

Reviewer discussions with assessment authors

Day 5

Reviewer discussions and preparation of report

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
15 September 2010

Status of the 2009/10 Stock
As reported in Rugolo and Turnock (2009), Tanner crab MMB in 2009/10 declined substantially from previous years and it was below the minimum stock size threshold at survey time (MSST=0.5B_{REF}). Under the current plan, MMB estimated at the time of mating (mid-February) is gauged against the MSST to determine its status relative to the overfished criterion. This accounts for losses due to natural morality from the survey to the time of mating and losses due to directed and non-directed fishing in 2009/10. For the 2009/10 status determination, B_{REF}=83.80 thousand metric tonnes (t) and the overfished status criterion, MSST, was 41.90 thousand t. After accounting for all losses to the stock from natural mortality and the 2009/10 fisheries, the 2009/10 MMB at the time of mating was 28.44 thousand t. This represents a ratio of 0.34 relative to B_{REF} which is below the limit that defines an overfished stock. Thus, the 2009/10 Tanner crab stock is determined to be overfished.

Tanner crab MMB at the time of the 2010 survey declined further relative to 2009. Thus, even under a zero retained catch harvest strategy in 2010/11, there is no change in the 2010/11 stock relative to the overfished determination made in 2010.

Executive Summary
In 2010, Tanner crab MMB at the time of the survey was estimated at 32.08 thousand t representing a 9.1% decrease relative to 2009. Mature male abundance fell 9.4% relative to 2009 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. The total abundance index for legal males increased 13.7% to 8.0 million crabs between 2009 and 2010 owing largely to a high-density station in the area of the Pribilof Islands. Legal males were distributed 56.1% (4.5 million crabs) east and 43.9% (3.5 million crabs) west of 166^{o} west longitude which was comparable to the apportionment in 2009 (Rugolo and Turnock 2009). The 2010 abundance index for pre-recruit male crabs (110-137 mm cw) declined 15.4%, and that for small males (<110 mm cw) increased 13.9% relative to 2009. Total male abundance increased 8.5% between 2009 and 2010 which was largely driven by the increase in small males (<110 mm cw). Comparison of the male size frequency distributions between 2006 and 2010 revealed a decline in male abundance above 70 mm cw between 2009 and 2010 (Figure 10 e), and a relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-e). The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e). The decline in male abundance in 2010 above 70 mm cw coupled with the relatively high percentage of old and very old shell males in the mature stock is an issue of concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab revealed a substantial 49.7% decrease in abundance in 2010 relative to 2009, and mature female biomass was comprised of 79.5% old shell females. Among all female Tanner crab in 2010, 15.5% were collectively old shell and 82.7% new-hard shell. Small females (<85 mm cw) increased by 13.8% relative to 2009. Total 2010 female abundance increased 8.5% which was largely influenced by the increase in small females <85 mm cw. Total survey abundance of males and females combined increased 9.3% over that in 2009 driven by the increase in both small male and small female crabs. The survey length frequency distributions of female Tanner crab from 2006-2010 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11 a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance in 2007 through 2010. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw. A relatively strong recruit mode (35-50 mm cw) is apparent in the 2010 survey data (Figure 11 e).

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 of MMB at the time of mating estimated as the average survey male mature biomass at 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 mortalities) for males and females combined by the directed and all non-directed fisheries.

The value of M for EBS Tanner crab is 0.23. For this analysis, gamma is set to 1.0. The projected 2010/11 estimate of MMB at the time of mating is 26.07 thousand t. Relative to B_{REF}, $MMB_{2010/11}/B_{REF}=0.31$. Under the OFL Control Rule, the 2010/11 $F_{OFL}=0.05$.

For the 2010/11 Tanner crab fishery, we estimated the Total Catch OFL=1,612.1 t for males and females combined. (Note, here we present the catch components are in tonnes for clarity as the values in 1000 t for some components are small at one significant digit). Total losses to MMB in the 2010/11 Total Catch OFL are 1,445.5 t. Directed and non-directed discard losses to MMB in 2010/11 are estimated to be 46.4 t and 1,312.1 t, respectively. The retained part of the catch OFL of legal-sized crabs is 87.0 t. The retained legal catch would comprise 6.4% of the total MMB losses projected in 2010/11. Thus, a significant component of MMB losses 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 166.6 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.03 and 0.05 respectively.

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

Year	MSST	Biomass (MMB)	OFL	TAC [E+W]	Retained Catch	Total Catch
2005/06[1/]		39.28		0.73	0.43	1.61
2006/07[1/]		59.18		1.35	0.96	3.15
2007/08[1/]		68.76		2.55	0.96	3.63
2008/09[1/]	43.04	53.63	7.04	1.95	0.88	2.25
2009/10	41.90	28.44	2.27	0.61	0.60	1.69
2010/11	41.90	26.07[2/]	1.45[3/]	TBD		

Notes:
1/ Biomass and threshold definitions based on survey data derived using fixed 50 ft net width area-swept calculations.
2/ Projected 2010/11 MMB at time of mating after extraction of the estimated total catch OFL.
3/ Total catch OFL for the 2010/11 fishery.

In 2009/10, Tanner crab MMB was below the MSST at the time of the 2009 survey, below MSST at the time of the 2009/10 fishery, and below MSST at the time of mating in mid-February 2010. Overfishing did not occur during the 2009/10 fishing year as total catch losses (1.69 thousand t) did not exceed the total catch OFL (2.27 thousand t). The 2009/10 MMB at the time of mating represented a ratio of 0.34 relative to B_{REF}. The 2009/10 Tanner crab stock is determined to be overfished. In 2010 at the time of the survey, Tanner crab MMB declined further relative to 2009 and, once again, even at that time, was below MSST. Under a zero retained catch harvest strategy in 2010/11, therefore, there is no change in the 2010/11 stock status relative to the overfished determination reached in September 2010.

A. Summary of Major Changes

There are no major changes to assessment methodology in this 2010 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 1976-2010 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) presented the time series of MMB estimated using fixed and measured net widths, and discussed general differences. Secondly, all units of mass are presented in terms of metric tonnes.

B. Responses to SSC and CPT Comments

1. SSC Comments:

June 2010 Meeting:

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

- *Tanner crab abundance has fallen below the MSST which will require a rebuilding plan to be developed. A stock assessment model is under development but not yet ready for review. The plan is to get CPT and SSC review in September / October 2010 for use in the rebuilding plan to be drafted by May 2011. The SSC would like the authors to develop a model capable of handling two different minimum size limits in the eastern and western areas as the BOF may take such action; this might be beneficial for optimal harvesting.*
- *Lacking a stock assessment model, stock status determination continues to be based on the trawl survey. This year the revised survey estimates corrected for survey net width were used for the first time. Final determination will be made after the summer survey.*
- *The SSC concurs with the CPT that the stock is in Tier 4, given the survey series and an estimate of M, and with the use of a default value for gamma of 1 to set OFL. The SSC requests that the authors and CPT reconsider the choice of years to be used in calculating B_{MSY}, currently 1969–*

1980. The issues of data quality and regime shift need to be more fully addressed. The SSC commented that it's possible that the generally warmer Bering Sea is in a new regime, with more groundfish predators (e.g., cod) and competitors (e.g., flatfish), which has caused a change in Tanner crab productivity. Two options might be to extend the time period to the current time or start the time period later, depending on identification of the shift.

- *The CPT recommended that the text for OFL calculation should be revised to represent what was actually done. It might be helpful for the CPT to elaborate on what was incorrect in the SAFE, so that the authors can make the appropriate changes*.

As shown in this assessment, the 2009/10 Tanner crab stock is below the MSST and determined to be overfished. A length-based stock assessment model is in development. The current goal is to complete model development and have it approved by the CPT in May 2011 and by the SSC in June 2011 for application in 2011/12 OFL-setting. The model would be coincidently available for use in developing the rebuilding plan. The timing of the start of the two year time frame for implementing the rebuilding plan by the Council is unclear at the time of this assessment. Neither has it been specified when the draft the rebuilding plan will be required, nor specified the dates of the plan amendment process regarding review, comment and finalization of the rebuilding plan by the Council. The CPT will discuss the requirements of for draft completion at their September 2010 meeting and the authors will have a better understanding of the requirements of model development once the elements of the rebuilding plan are identified and the required benchmark dates identified.

At the May 2010 meeting, the CPT considered genetic evidence presented in support of partitioning the EBS Tanner crab population into two stocks east and west of 166 degrees W longitude. The CPT found this evidence lacking. The authors have found no evidence to support the argument that the eastern Bering Sea shelf is member to two distinct, non-intermixing, non-interbreeding stocks of Tanner crab in which the linked population and fisheries dynamics are bifurcated east and west of 166 degrees W longitude. Nevertheless, the authors will consider approaches to handle different minimum size limits for the Eastern and Western management districts consistent with the total catch OFL that may underlie optimum harvest strategies.

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

The authors agree that Tanner crab is a Tier-4 stock in which the OFL is based on M using a gamma of 1.0. We agree that over the time period 1960s to present, there has been an apparent shift in the eastern Bering sea from a more decapod-dominated regime in the 1960s and 1970s to a more teleost-dominated regime in the 1980s and thereafter. We've found no evidence, however, of a change in Tanner crab productivity over this period, nor evidence of changes in reproductive dynamics or life-history characteristics which indicated temporal changes in recruitment success resulting from the 'generally warmer Bering Sea'. The authors have shown in this and earlier stock assessments (Rugolo and Turnock 2009) that the historical patterns of fishery exploitation on male mature biomass from the late 1960s to the present exceeded rates that we would deem biologically reasonable for this stock. Exploitation rates on MMB rose in the late 1970s and peaked at 0.69, then declined with the collapse in stock biomass through the mid-1980s, then rose again to 0.45 and closely following the build up in the stock in the late1980s to early-1990s. At these rates of exploitation, the Tanner crab stock would not be expected to persist at maximum sustainable levels even in the mid-term, nor moderate around B_{MSY} in the long-term. If there have been effects of 'generally warmer' ambient temperatures on Tanner crab productivity or from increased competition and predation on survival, empirical data are lacking to quantify those effects, nor is the magnitude of those effects, if any, separable from the effects of excessive fishing mortality on the stock. The current range of years (1969-1980) used for estimating B_{REF} includes a five year period (1976-1980) of sharply declining and low male mature biomass. Inclusion of these five years was required by the SSC in 2009. The authors do not believe that these that these five years represent levels of mature male biomass that, if fished at F_{MSY}, would yield MSY to the fishery. Extending the time period to the current time would include time periods where the stock had collapsed and the fishery closed by the SOA because of conservation concerns. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of B_{REF} would be inconsistent with the tenet of selection of a range of years that represent the stock living at B_{MSY}, being fished at rates approximating F_{MSY}, and thereby yielding MSY to the fisheries.

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

<u>October 2009 Meeting</u>:
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 to 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.

<u>June 2009 Meeting</u>:
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.

<u>October 2008 Meeting</u>:
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:
<u>May 2010 Meeting</u>:
In their stock assessment review, the CPT made the following comments concerning the Tanner crab Tier-4 stock assessment:

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

The CPT had the following recommendations for the authors:

- *Include CV's with point estimates in the tables.*
- *Determine whether groundfish discards are based on all groundfish fisheries or only trawl fisheries.*
- *Revise the text for OFL calculation (Eq. 3 and 4) to represent what was actually done.*
- *Remove Appendix A as it came from a prior assessment.*

- *Provide the September meeting with a summary of progress with the new model. The CPT may recommend that additional planning meeting may be necessary depending on progress given the necessity of this model for the rebuilding plan.*

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

March 2010 Meeting:
In their review of the first draft of a Tanner Crab Stock Assessment Model (TCSAM), the CPT made the following observations:

- *The major issue was the lack of fit to the MMB from 2000 to 2009, where the model predicted estimates of FMB are above and MMB are below the corresponding survey estimates. The authors were asked to run different scenarios based on these comments to assess the model performance at the May 2010 CPT meeting.*
- *The CPT recommended that the model may be used for ACL analysis as the basis for long-term projections. The current model will be used for development of initial review EA in June 2010. For this analysis, the current model should be used to estimate the long term impact. The Tier 4 control rule using survey estimates as well as model output should be used to evaluate short-term impacts. Results should not be presented for medium-term predictions to avoid giving the impression that such results are reliable.*
- *The rebuilding plan development will be delayed until it is possible to find a model that better fits the data. The CPT will review a revised model in May 2010 and reassess the timeline and alternatives for rebuilding based on that review. The understanding is that the rebuilding plan analysis must be completed within two years of when the actual determination of overfished is made.*

The CPT makes the following specific requests to the authors for the May 2010 assessment review:

- *Units that were used to fit the data need to be clarified.*
- *Authors should consider the results of the Bechtol et al. 2010 study on minimum size limit. There is genetic research that addresses geographic stock separation and warrants review by the CPT. The SSC convened a workshop on genetic stock separation in 2009. The report from this workshop should be considered by the CPT, discussed at the May CPT meeting.*
- *Consider size distribution of Tanner crab east and west of 166 W longitude.*
- *Add the profile for M.*
- *Fit a gamma distribution to the growth data.*
- *Address lack of model fit to MMB and females:*
    - *Show residual patterns for the model fit to MMB.*
    - *Change M/F ratios at birth to potentially help fit the sexes similarly to the survey.*
    - *Research the probability of maturity at size over time.*
    - *Consider a spatially segregated approach.*
- *Address the survey length versus carapace width fits.*
- *Assess the growth or maturity functions to fix the model specification.*

The authors are continuing development of the TCSAM and will be attentive to requests by the CPT. The authors identified items requiring further development of the TCSAM and presented an update on the status of the model to the SSC at their April 2010 meeting.

The authors clarify the implication in the March CPT report that rebuilding plan development has been “delayed until it is possible to find a model that better fits the data.” Under the process established by the CPT, final recommendation on the status of the 2009/10 Tanner crab stock occurs in September 2010 with the completion of this assessment. In October 2009, the team recommended to the Council init report to the SSC that the stock is approaching an overfished condition. The September 24, 2009 letter from the Alaska Regional Office (ARO) to the NPFMC stated “To comply with section 304(e)(3) of the Magnuson-Stevens Act, the North Pacific Fishery Management Council has two years from this notification to prepare and implement a rebuilding plan for Tanner crab.” As discussed at the March 2010 and May 2010 CPT meetings, the ARO subsequently moderated its position on the start of the two year time frame for implementation of the rebuilding plan. The CPT has not been notified by the ARO that the two year time frame for rebuilding plan implementation has commenced. The CPT has been left with the “understanding [is] that the rebuilding plan analysis must be completed within two years of when the actual determination of overfished is made.” That determination will be made at the upcoming September 2010 meeting. When the two year time frame begins, and when the rebuilding plan must be implemented, and when any or each of the antecedent elements of the rebuilding plan must be completed and reviewed, is yet to be determined or specified.

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.

May 2009 Meeting:
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.

September 2008 Meeting:
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 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.

C. Introduction

1. Scientific Name and General Distribution

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

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

The common name for *C. bairdi* of "Tanner crab" (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" has also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

Tanner crabs are found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a) where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break where water temperatures are generally warmer. The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo

2010). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 58°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

2. Stock structure

Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit. Somerton (1981a) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. Somerton's conclusions are limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor consider stock movement with ontogeny. Thus, biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time are confounded by these omissions.

Despite the custom of setting management controls for this stock east and west of 166° 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 (Chilton et al. 2010). 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 are red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), hair crab (*Erimacrus isenbeckii*), Tanner crab (*Chionoecetes bairdi*) and snow crab *(C. opilio*). The sampling methodology specifies the majority of tows made at the centers of squares defined by a 20 x 20 nmi (37 x 37 km) grid (Figures 1 and 2). Near St. Matthew Island and the Pribilof Islands, additional tows were made at the corners of squares that define high density sampling strata for blue king crab and red king crab.

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

Estimates of Tanner crab stock biomass, population metrics and length frequencies from the trawl survey used in this assessment were based on the actual area-swept calculations using measured net widths spreads for 1976-2010. 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 2010 survey. The highest abundance of males and females occurs from 163 to 170 degrees West longitude with the distinction that males also reveal moderate levels of abundance in the area of the Pribilof Islands. Areas of highest abundance of male and female Tanner crab in 2010 occurred from southwestern Bristol Bay northeastward to 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, Figure 4b). LMB data are currently available for 1980-2010. 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) is also reflected in the pattern of the directed fisheries with peak modes in the mid-1960s through mid-1970s and in the late-1980s to early-1990s (Table 5, Figure 5), and collapsed stock status following those modes. MMB at the survey revealed an all-time high of 283.0 thousand t in 1975, and a second peak of 108.3 thousand t in 1991 (Figure 4). From the late-1990s through 2008, MMB rose at a moderate rate from a low of 10.4 thousand t in 1997 to 73.6 thousand t in 2007 before falling to 32.1 thousand t in 2010. Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the B_{MSY} level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt. Tanner crab MMB at the time of mating in mid-February 2010 fell below the MSST resulting in the 2009/10 EBS stock of Tanner crab declared overfished in September 2010.

In 2010, Tanner crab MMB at the time of the survey was estimated at 32.08 thousand t representing a 9.1% decrease relative to 2009. Mature male abundance fell 9.4% relative to 2009 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. The legal minimum size of 5.5 in cw (spine tip to spine tip) is equivalent to 138 mm cw measured between the spines. 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. Legal males were sparsely and patchily distributed throughout the survey range with an area of moderate abundance in southern Bristol Bay and an area of high density near the Pribilof Islands (Figure 1). The abundance index for legal male Tanner crab in both districts combined increased 13.7% to 8.0 million crabs between 2009 and 2010 owing largely to a high-density station in the area of the Pribilof Islands. Legal-sized males represent only a small portion (3.7%) of total male abundance in 2010. Legal males were distributed 56.1% (4.5 million crabs) east and 43.9% (3.5 million crabs) west of 166° west longitude which compared to 53.3% and 46.7%, respectively in 2009. The abundance index (39.2 million crabs) for pre-recruit male crabs (110-137 mm cw) showed a 15.4% decrease, and the index of 167.3 million small males (< 110 mm cw) increased 13.9% relative to 2009 for all areas combined (Figure 9). Pre-recruit crab in 2010 were widely distributed across the range of the survey from southern Bristol Bay northwest to St. Matthew Island (Figure 1). Regions of highest abundance of pre-recruit males in 2010 were seen in southwestern Bristol Bay and the surrounding area of the Pribilof Islands (Figure 1). Total male abundance increased 8.5% between 2009 and 2010 which was largely driven by the increase in small males (Figure 9).

Comparison of the male size frequency distributions between 2006 and 2010 revealed a decline in male abundance above 70 mm cw between 2009 and 2010, and a relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-e). 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, 2009 and 2010 survey length frequency distributions (Figures 10 c-e and 12a). The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e). Among all male Tanner crab in 2010, 19.3% were old shell in all categories combined, and

80.7% were comprised of molting, new-soft and new-hard shell (78.6%) categories (collectively, new shell males). Among legal-sized males, 42.2% were old shell all categories combined and 49.3% were new-hard shells. The decline in male abundance in 2010 above 70 mm cw coupled with the relatively high percentage of old and very old shell males in the mature stock is an issue of concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab in the combined Eastern and Western Districts revealed a substantial 49.7% decrease in abundance relative to 2009, and these were comprised of 79.5% old shell females (Figure 9). Among all female Tanner crab in 2010, 15.5% were collectively old shell and 84.5% comprised of molting, new-soft and new-hard shell (82.7%) categories (collectively, new shell females). The small female (<85 mm cw) abundance index increased by 13.8% to 150.3 million crabs relative to 2009. Total 2010 female abundance (164.1 million crabs) increased 8.5% which was largely influenced by the increase in small females <85 mm cw, and the total abundance of male and female combined (378.6 million crabs) increased 9.3% over that in 2009 driven by the increase in both small male and small female crabs (Figure 9). Ovigerous females were distributed from southern Bristol Bay at relatively highest abundance northwestward to south of St. Matthew Island with an area of moderate density near the Pribilof Islands (Figure 2). Immature female Tanner crab displayed a similar distribution to mature females although they were slightly more densely distributed relative to matures along the southeast-northwest cline from southwestern Bristol Bay, north of the Pribilof Islands to west and south of St. Matthew Island (Figure 2). The survey length frequency distributions of female Tanner crab from 2006-2010 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance from 2007 through 2010 and revealed consistently declining abundance. The mode of mature females in 2008 at 75 mm cw declined in abundance in 2009 and is comprised of increasing percentages of old and very old shelled females. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw and new shell females dominate the 2010 length frequency distribution below 65 mm cw. A large portion of mature female Tanner crab 75 mm cw and larger in 2010 are comprised of old shell females (Figure 11e). As seen for male Tanner crab, female abundance above 60mm cw declined in 2010 (Figure 11e).

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 0.77 thousand t retained catch between 2005-2009/10 (Table 2). Landings of Tanner crab in the foreign Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 19.95 thousand t in 1969 (Table 2, Figure 5). The Russian tangle net fishery was prosecuted between 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s.

Discard and bycatch losses of Tanner crab originate from the directed pot fishery, non-directed pot fisheries (notably, for snow crab and red king crab), and the groundfish fisheries (Table 3). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). Total Tanner crab discard and bycatch losses by sex are shown in Table 3 for 1965-2009. The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 2). These losses were persistently high during the late-1960s through the late-1970s; male losses peaked in 1970 at 20.17 thousand t (Table 3). A subsequent peak mode of discard/bycatch losses occurred in the late-1980s through the early-1990s which, although briefer in duration, revealed higher losses for males than the earlier mode, peaking at 22.82 thousand t in 1990. From 1965-1975, the groundfish fisheries contributed significantly to total bycatch losses, although the combined crab pot fisheries are the principal source of contemporary non-retained losses to the stock (Table 3). Total Tanner crab retained catch plus non-directed losses of males and females (Table 4, Figure 4a) reflect the performance patterns in the directed and non-directed fisheries. Total male catch rose sharply with fishery development in the early-1960s and reveals a bimodal distribution between 1965 and 1980 with peaks of 47.48 thousand t in 1969 and 52.30 thousand t in 1977 (Table 4, Figure 4a). Total male catch rose sharply after the directed domestic fishery reopened in 1987 and reached a peak of 41.01 thousand t in 1990. Total male and female catch fell sharply thereafter with the collapse of the stock and the fishery closure in 1997.

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

Exploitation Rates

The historical patterns of fishery exploitation on LMB and MMB were derived (Table 6, Figures 7a and 7b). The exploitation rate on LMB was estimated as the proportion of retained catch to LMB at the time of the fishery, while that on MMB as the proportion of total male catch to MMB at the time of the fishery. Estimates of LMB are currently available only for 1976-2009. 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 1976-2009, exploitation rate (μ) on LMB was highest in 1979 at 0.94 and second highest in 1981 at 0.54; thereafter, it fell with stock condition through the mid-1980s. LMB exploitation rate revealed a second prominent mode during 1989-1993, peaking at 0.46 in 1991 and averaging 0.44 during those five years (Table 6, Figure 7b). At these rates of exploitation on LMB, the Tanner crab was not expected to persist at maximum sustainable levels even in the mid-term, nor equilibrate around B_{MSY} in the long-term. The pattern of μ on MMB from 1969-2008 reveals two analogous 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. 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 were limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor did he consider the pattern of ontogenous stock movement. Thus, maturity estimated based on comparisons of the proportions of mature individuals at length in any area, or on changes in the proportion of mature individuals at length over time are confounded by these omissions. Nonetheless, we report that for the 5 survey years from 1975 to 1979, east of 167° 15' W longitude, Somerton (1981a) estimated that the mean size of mature females ranged from 92.0 to 93.6 mm cw. West of that longitude, the size of 50% female maturity ranged from 78.0 to 82.0 mm cw. For male Tanner crab during the same survey years, he estimated size at 50% maturity was 117.0 mm cw and 108.9 mm cw east and west of 167° 15' W longitude, respectively.

Mortality

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

We examined empirical evidence for 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 98.5th percentile of the distribution of ages in an unexploited population, M is estimated to be 0.23 (Hoenig 1983). If 20 years is assumed to represent the 95% percentile of the distribution of ages in an unexploited stock, M is estimated to be 0.15. The natural mortality rate (M) of EBS Tanner crab is set at 0.23 for assessing stock status and OFL-setting based on the current expectation of longevity of at least 15 y. This rate of M=0.23 is consistent with that used in Amendment 24 and its associated EA that established new overfishing definitions for crab stocks under the plan.

Growth and Age

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

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

Weight at Length

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

E. The Analytic Approach

1. History of Modeling Approaches

Tier-4 OFL Control Rule

Old Survey Data:

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

New Survey Data:

Beginning with this 2010 stock assessment, all stock metrics, as well as overfishing definitions are based on survey estimates derived using the actual measured net width area-swept calculations. This results in coincident changes in the historical time series biomass data as well as present and future biomass estimates. Using the revised survey data, the B_{MSY} proxy B_{REF}= 83.80 thousand t and MSST=41.90 thousand t. After accounting for all losses to the stock from natural mortality and the 2009/10 fisheries, the 2009/10 MMB at the time of mating was 28.44 thousand t. This represents a ratio of 0.34 relative to B_{REF} which is below the limit that defines an overfished stock. Tanner crab MMB at the time of the 2010 survey declined 9.1% relative to 2009 and even at that time it was below the MSST. Thus, even under a zero retained catch harvest strategy, there is no change in the 2010/11 stock relative to the overfished determination made in 2010. The projected 2010/11 estimate of MMB at the time of mating is 26.07 thousand t. Relative to B_{REF}, projected $MMB_{2010/11}/B_{REF}$=0.31.

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) belongs to stock status levels a, b or c in the algorithm below. The stock biomass level beta (β) represents a minimum threshold below which directed fishing mortality is set to zero. The F_{OFL} Control Rule sets β=0.25. The parameter alpha moderates the slope of the non-constant portion of the control rule. For biomass levels where $\beta < B \leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B/B_{MSY}. The value of M is 0.23 for eastern Bering Sea Tanner crab. In the analysis of Tier-3 for snow crab, *C. opilio,* and red king crab, *P. camtschaticus*, a B_{MSY} proxy reference value (B_{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.	$B/B_{REF} > 1.0$	$F_{OFL} = \gamma M$
b.	$\beta < B/B_{REF} \leq 1.0$	$F_{OFL} = \gamma M\ [(B/B_{REF} - \alpha)/(1 - \alpha)]$
c.	$B/B_{REF} \leq \beta$	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.

A. Definition of Terms:

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

Let:

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

B. OFL-Setting:

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

1. Finding F_{OFL}:

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

$$F_{OFL} = \gamma M\,[(B_3/B_{REF} - \alpha)/(1 - \alpha)] \qquad (1)$$

2. Finding the TC_{OFL}:

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

$$TC_{OFL} = (B_1 S_2 U_{OFL}) \qquad (2)$$

$$= (B_1 S_2 (1\text{-}e^{-\,FOFL})) \qquad (3)$$

3. Finding B_3:

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

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

$$B_3 = (B_1 S_2) - TC_{OFL} \qquad (4)$$

$$= (B_1 S_2) – (B_1 S_2 U_{OFL}) \qquad (5)$$

$$= (B_1 S_2) – B_1 S_2 (1\text{-}e^{-\,FOFL}) \qquad (6)$$

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

$$F_{OFL} = \gamma M\,[[[(B_1 S_2) – B_1 S_2 (1\text{-}e^{-\,FOFL})]/B_{REF}] – \alpha]/(1 - \alpha)] \qquad (7)$$

Since there are unknowns on either side of the equality in equation (7), there is no analytical solution and it must be solved iteratively. This is because the F_{OFL} rate depends on the level of mature male biomass at mating (B_3) which, in turn, depends on the extracted $TC_{OFL.}$ Thus, we can’t know the F_{OFL} until we extract the total catch OFL using the F_{OFL} control rule, and we can’t estimate the TC_{OFL} until we have know the F_{OFL}. An iterative flow to solve for the F_{OFL} and TC_{OFL} is shown:

i. Initial guess at the $F_{OFL\text{-}1}$ using B_1 in the F_{OFL} control rule. If B_1 is on the sloping part of the control rule, $F_{OFL\text{-}1}$ will be too large by definition since B_1>B_3.

ii. Estimate TC_{OFL} using this F_{OFL-1}.
iii. Estimate B_3 using equation (4).
iv. Re-estimate the F_{OFL-2} using B_3 in the F_{OFL} control rule.
v. Test if F_{OFL-1}-F_{OFL-2} =0. If yes, set the final F_{OFL}=F_{OFL-2}. If no, depreciate F_{OFL-2} by a small increment resulting in F_{OFL-3}.
vi. Repeat using F_{OFL-3} in step ii to estimate the TC_{OFL} using F_{OFL-3} and end the iteration when the test in step v. is yes.

At the termination of the iteration, the final F_{OFL} for the OFL-setting will be known. Given that F_{OFL}, estimate the TC_{OFL} using equation (3) and the B_3 using equation (4).

4. Find Discard Catches in Non-Directed Fisheries:
Discard losses of male mature biomass are attributed to losses from the non-directed EBS crab pot fisheries and the groundfish fisheries. In practice, the discard catch components are estimated from past performance in the respective fisheries considered to be most representative of current conditions.

a. Non-Directed Pot Fishery Discard Mortalities:
Non-directed pot fishery discard losses to male mature biomass are principally attributed to the snow crab fishery and to the Bristol Bay red king crab fishery to a lesser extent. For example, the 2009/10 Tanner crab discards by the snow crab fishery comprised 94.8% of all pot discards from the snow crab and red king crab fisheries combined. In this analysis, we used data from the previous three fishing seasons (2007, 2008 and 2009) to estimate of the 3-year average ratio of Tanner crab mature male biomass discards in the snow crab fishery to snow crab retained catch (R_2) (Table 7b). Discard mortality of MMB by the non-directed snow crab fishery (D_2) in the 2010/11 TC_{OFL} is derived as the product of R_2 and the projected 2010/11 snow crab retained catch OFL (CO_{RET}) (Turnock and Rugolo 2010) given by:

$$D_2 = R_2\, CO_{RET}\, HM_1 \tag{8}$$

b. Groundfish Fisheries Discard Mortalities:
Discard losses to male mature biomass resulting from bycatch in the groundfish fisheries (D_3) was estimated using the average groundfish bycatch of Tanner crab over 2007-09 (R_3) (Table 7c) supplied by the Alaska Regional Office, 08/26/10. We assumed that this average bycatch of Tanner crab would occur in the 2010/11 fishery. Reported bycatch are for males and females combined. The sex distribution of this bycatch is unavailable for this analysis. The proportion of males in the groundfish fisheries bycatch (P_M) was estimated assuming a sex ratio of 1:1 in the bycatch and apportioning the catch based on the ratio of mean weights of 120 mm cw male crab to 87.5 mm cw female crab resulting in a 60.2% v. 39.8% male to female split.

For all groundfish fishery discards, a post-release handling mortality rate of 0.80 was used (HM_2). Discard mortality of MMB by the groundfish fisheries (D_3) in the 2010/11 TC_{OFL} is given by:

$$D_3 = R_3\, P_M\, HM_2 \tag{9}$$

5. Partial TC_{OFL} Available to Directed Tanner Crab Fishery:
Through this stage in the analysis, we've computed the total catch OFL (TC_{OFL}) for the 2010/11 fisheries which represents the threshold level of MMB catch beyond which constitutes overfishing. We have also computed the expected discard mortalities of MMB in the TC_{OFL} from the non-directed crab pot fisheries and the groundfish fisheries. These latter losses to male mature biomass can be considered fixed costs to MMB. They would occur whether or not a directed fishery is allowed, and are independent to an extent of the status of the Tanner crab stock (B_3) in 2010/11. They depend on the expected performance of the respective non-directed

fisheries whose mean performance in terms of discards is not expected to change markedly in the 2010/11 fishing season. Projected discard mortalities depend on the relationship between Tanner male mature biomass and average discards being representative of current conditions – that, neither Tanner MMB nor the operations of the non-directed fisheries will change substantially so as make the relationships between recent 3-year performance and discards invalid.

6. Find Directed Tanner Crab Fishery Discard Mortalities:
The residual part (TC_{PART}) of the TC_{OFL} available to the directed fishery is estimated by extraction of the projected discard mortalities in the non-directed pot (D_2) and groundfish (D_3) fisheries by:

$$TC_{PART} = TC_{OFL} - (D_2 + D_3) \qquad (10)$$

However, since the directed Tanner fishery also contributes to discard mortalities of male mature biomass, the residual part of the total catch OFL (TC_{OFL}) available to the directed fishery must be partitioned to allow for retained catch biomass (C_R) and discard mortalities of male mature biomass (D_1). After accounting for discard losses by the directed fishery, the retained catch component of the OFL is by:

$$C_{RET} = TC_{PART} - D_1 \qquad (11)$$

Discard losses of mature male biomass by the directed 2010/11 fishery (D_1) was estimated using data from the most recent three Tanner crab fisheries supplied by D. Pengilly, ADF&G (08/24/09) and B.Gaeuman (ADF&G, 07/02/10) (Table 7a). The average ratios of legal and sublegal male and female discards to the average retained catch in the 2007, 2008 and 2009 fisheries are used to project discard losses in the 2010/11 fishery. Here, R_1 is the 3-year average rate of discarded mature male biomass per retained catch biomass in the 2007-09 directed Tanner fisheries. For all pot discards, a post-release mortality rate of 0.50 was used (HM_1=0.50). Directed fishery discard losses (D_1) to male mature biomass is given by:

$$D_1 = C_{RET} R_1 HM_1 \qquad (12)$$

Substituting for D_1 in equation (11) with equation (12), gives:

$$C_{RET} = TC_{PART} - C_{RET} R_1 HM_1 \qquad (13)$$

At this stage in the analysis, TC_{PART} is known from equation (10). Also, known are R_1 and HM_1. However, C_{RET} is unknown and D_1 depends on C_{RET}. As with equation (7), there are unknowns on either side of the equality; there's no analytical solution and equation (13) which must be solved iteratively. This is readily accomplished by substitution of C_{RET} in equation (12) to estimate D_1 until the sum of $C_{RET} + D_1 = TC_{PART}$ which is known.

C. Exploitation Rates:

Exploitation rates on legal male biomass (μ_L) and mature male biomass (μ_M) at the time of the fishery are calculated as the ratio of total directed plus non-directed losses to legal male biomass (M_L) and mature male biomass (M_M) to the respective legal and mature male biomass at the time of the fishery (L_2 and M_2, respectively).

$$\mu_L = M_L/L_2 \qquad (14)$$

$$\mu_M = M_M/M_2 \qquad (15)$$

3. Model Selection

In May 2008, the CPT requested that the authors examine the feasibility of estimating $F_{35\%}$ for the Tanner crab stock using fishery selectivity. The SSC had recommended using fishery selectivity and maturity to estimate $F_{35\%}$ as the proxy F_{OFL}, and to estimate gamma as the ratio of $F_{35\%}$ to M. Results of that study are presented in Rugolo and Turnock (2009). In summary, fishery selectivity for Tanner crab used in the EA analysis were estimated on historical fishery performance data prior to the 1997 closure. We estimated selectivity for the contemporary fishery following its reopening in 2005 and found that the current selectivity for the directed and non-directed pot fisheries differed from those used in the EA. While it's desirable for Tier-4 stocks to employ the $F_{35\%}$ proxy for F_{MSY} where reliable data on fishery performance exist, the authors and SSC considered it premature to employ this approach for the Tier-4 Tanner assessment given these changes in performance observed in 2005-2007 versus those of the pre-1997 closure. Since the EA selectivity patterns no longer applied, their use in estimating $F_{35\%}$ and a factor in estimating gamma, may provide misleading and incorrect results in terms of management controls. The SSC concurred with the author's findings and recommended the $F_{35\%}$ not be used in OFL-setting since it could provide misleading results, and to set gamma=1.0.

In this assessment, gamma is set to 1.0, and discard mortalities from the directed and non-directed pot fisheries and the groundfish fisheries are included in OFL-setting. Even if pot fishery selectivities did not change after the reopening in 2005 relative to pre-1997, the EA simulations which suggest that $F_{35\%}$ may be a suitable F_{MSY} proxy for snow crab and Bristol Bay red king crab did not account for non-retained stock losses. Thus, it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. A further consideration in the estimation of gamma as the ratio of the EA $F_{35\%}$ to M is the fact that the MMB metric used in this assessment employs a maturity schedule, whereas the EA simulations employed knife-edge maturity at size. Thus, currency differences in the measure of reproductive biomass are potentially confounding.

The EA guidance prescribes that gamma should not be set to a level that would provide for more risk-prone overfishing definitions without defensible evidence that the stock could support levels in excess of M. Examination of the historical performance of the fishery (Figure 4a) and stock biomass (Figure 6) reveals that the Tanner crab stock has not been maintained in dynamic equilibrium over any sustained period, nor persisted in the face of exploitation rates (Table 6, Figures 7and 7b) that exceed levels we would consider biologically meaningful for this stock. The difference between fishery selectivity and maturity in EBS crab stocks has been suggested as a reason to allow gamma to exceed unity. Notwithstanding the technical challenges noted in estimating current fishery selectivity, this relies on theoretical population dynamic considerations in mature male biomass which are violated given the unique reproductive dynamic features of this stock (e.g., male-female size dependencies for successful copulation, male guarding and competition). Since a fundamental precept of precautionary fishery management is that the stock should not be exploited at a rate in excess of the F_{OFL}, we find no evidence that would justify a gamma in excess of 1.0 or fishing at an F_{OFL} rate greater than M on this stock.

4. Results

In this assessment for OFL-setting for the 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 validity of including the latter 5 years (1976-80) in which stock biomass fell precipitously which ultimately resulted in the SOA closing the fishery in 1985 due to conservation concerns. We note that the use of the average 1969-1980 MMB at mating as a proxy for B_{MSY} is affected 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. 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 in 1999. During this period, the stock experienced exploitation rates in excess of current F_{MSY} estimates – at approximately 3M in the late-1970s, and 2M in the late-1980s preceding the collapses. During 1980-2009, the stock has not maintained itself at a level that could be reasonably construed as in dynamic equilibrium or at a level indicative of B_{MSY} capable of providing maximum sustainable yield to the fisheries. The authors will revisit the choice of a proxy B_{MSY} once the retrospective analysis of the historical trawl survey is completed and with the development of the Tanner crab stock assessment model.

F. Calculation of the 2010/11 OFL

The instantaneous rate of natural mortality, M, for Tanner crab is 0.23. Gamma is set=1.0. B_{REF}=83.80 thousand t, and MSST=41.90 thousand t.

For the 2010/11 Tanner crab fishery, we estimated the Total Catch OFL=1,612.1 t for males and females combined (Table 8). (Note, here we present the catch components in tonnes for clarity as the values in 1000 t for some components are small at one significant digit). Total losses to MMB in the 2010/11 Total Catch OFL are 1,445.5 t. Directed and non-directed discard losses to MMB in 2010/11 are estimated to be 46.4 t and 1,312.1 t, respectively. The retained part of the catch OFL of legal-sized crab is 87.0 t. The retained legal catch would comprise 6.4% of the total MMB losses. Thus, a significant component of MMB losses 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 166.6 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.03 and 0.05 respectively.

The projected 2010 estimate of MMB at the time of mating is 26.07 thousand t after accounting for all retained and non-retained losses to MMB in 2010/11. Relative to B_{REF}, $MMB_{2010/11}/B_{REF}$=0.31. Under the OFL Control Rule, the 2010/11 F_{OFL}=0.05.

G. 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. For this stock, the early years (1969-1975) in the survey time series are critical to deriving biological reference points and threshold stock definitions. This is being accomplished through the work of the Shellfish Assessment Program who is performing a retrospective examination of the historical time series data and re-estimating biomass and abundance for all targeted EBS crab stocks. An essential requirement to successful TCSAM development is a consistent time series of survey population metrics, life-history parameters and biological schedules. The ultimate goal is to promote the Tanner crab stock to a Tier-3 management status and to formulate OFLs based on the TCSAM.

Antecedent analysis of survey data are being preformed to derive model inputs, parameters and schedules. For both males and females, these include the estimation of growth, maturity, survey selectivity, and fishing power. Also required is the reformulation of length-weight relationships, molting probability schedules and growth transition matrices. This analysis commenced in the Fall 2009. It’s the authors’ goal to present a workable TCSAM to the CPT in May 2011 and SSC in June 2011, obtain the approvals of the CPT and SSC for implementation of the model in the 2011/12 OFL-setting process.

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Table 1. Age (months), mean size (mm cw) and instar number for male Tanner crab in Kodiak and the eastern Bering Sea.

	Kodiak		EBS
Instar Number	Mean Size (mm cw)	Mean Age (months)	Mean Size (mm cw)
1	3.4	1.8	-
2	4.5	4.5	-
3	6.0	3.5	-
4	7.9	4.9	-
5	10.4	6.6	-
6	13.7	8.9	-
7	18.1	11.9	17.2
8	23.9	15.9	24.4
9	31.6	21.1	33.5
10	41.7	28.1	45.9
11	53.6	37.3	60.7
12	67.8	47.2	79.3
13	84.6	59.0	98.5
14	106.3	73.1	112.5
15	129.5	85.3	126.8
16	154.3	106.2	141.8
17	180.8	124.5	157.2

Table 2. Eastern Bering Sea *C. bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965-2009.

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	12.00	13.59	3.96	18.00
1969	0.46	29.00	19.95	7.08	27.49
1970	0.08	8.00	18.93	6.49	25.49
1971	0.05	10.00	15.90	4.77	20.71
1972	0.10	6.00	16.80		16.90
1973	2.29	115.00	10.74		13.03
1974	3.30	72.00	12.06		15.24
1975	10.12	63.00	7.54		17.65
1976	23.36	68.00	6.66		30.02
1977	30.21	51.00	5.32		35.52
1978	19.28	42.00	1.81		21.09
1979	16.60	30.00	2.40		19.01
1980	13.47	21.00			13.43
1981	4.99	10.00			4.99
1982	2.39	8.00			2.39
1983	0.55	8.00			0.55
1984	1.43	12.00			1.43
1985	0	0			0
1986	0	0			0
1987	1.00	8.00			1.00
1988	3.15	16.00			3.18
1989	11.11	15.00			11.11
1990	18.19	19.00			18.19
1991	14.42	10.00			14.42
1992	15.92	13.00			15.92
1993	7.67	13.00			7.67
1994	3.54	13.00			3.54
1995	1.92	8.00			1.92
1996	0.82	5.00			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			0.43
2006	0.96	13.77			0.96
2007	0.96	17.00			0.96
2008	0.88	12.60			0.88
2009	0.60	11.57			0.60

Table 3. Eastern Bering Sea *C. bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish fisheries, 1965-2009.

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
2009	0.82	0.01	0.15	0.10	0.97	0.11

Table 4. Eastern Bering Sea *C. bairdi* total catch in the directed (retained) and non-directed fisheries, 1965-2009.

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
2009	1.58	0.11	1.69

Table 5. Eastern Bering Sea *C. bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1965-2009/10.

	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	93.80	83.61	50.45
1977	129.63	115.54	58.90	77.66	69.22	31.09
1978	79.18	70.58	34.86	41.92	37.37	14.87
1979	48.14	42.91	11.71	22.69	20.22	0.46
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	28.44	7.03	6.26	5.43
2010	32.08	28.59		8.22	7.33	

Table 6. Eastern Bering Sea *C. bairdi* fishery exploitation rate on male mature biomass (MMB) and legal mature biomass (LMB), 1965-2009. 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	0.36
1977	0.45	0.51
1978	0.47	0.56
1979	0.69	0.94
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
2009	0.05	0.10

Table 7. Data used to estimate discard and bycatch losses in the terminal 2010/11 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) 2007-09 Tanner crab bycatch in the EBS groundfish fisheries.

(a)

Average Observer Fishery Data
EBS Tanner Crab Directed Fishery
[2007/08, 2008/09, 2009/10]

		1000T	Ratio:
Discard:			
	S.Legal ♂:	0.85	1.05
	Legal ♂:	0.02	0.02
	All ♀:	0.04	0.05
Retained:		0.81	1.0
	Total:	1.72	

(b)

Tanner Crab Non-Directed Pot Fishery Discards
(Combined Opilio + RKC Pot Fisheries)

Year	Opilio Retained (1000T)		Bairdi Discard (1000T)	Ratio
2007/08	28.59		1.93	0.07
2008/09	26.56		1.39	0.05
2009/10	21.78		1.57	0.07
2010/11	33.30	*		
			Average:	0.06
			Projected Bairdi Discard (1000T):	2.13

* Projected retained catch OFL for 2009/10 @ 0.75F35%.

(c)

Groundfish Fishery Tanner Crab Bycatch
(Male + Female Combined)

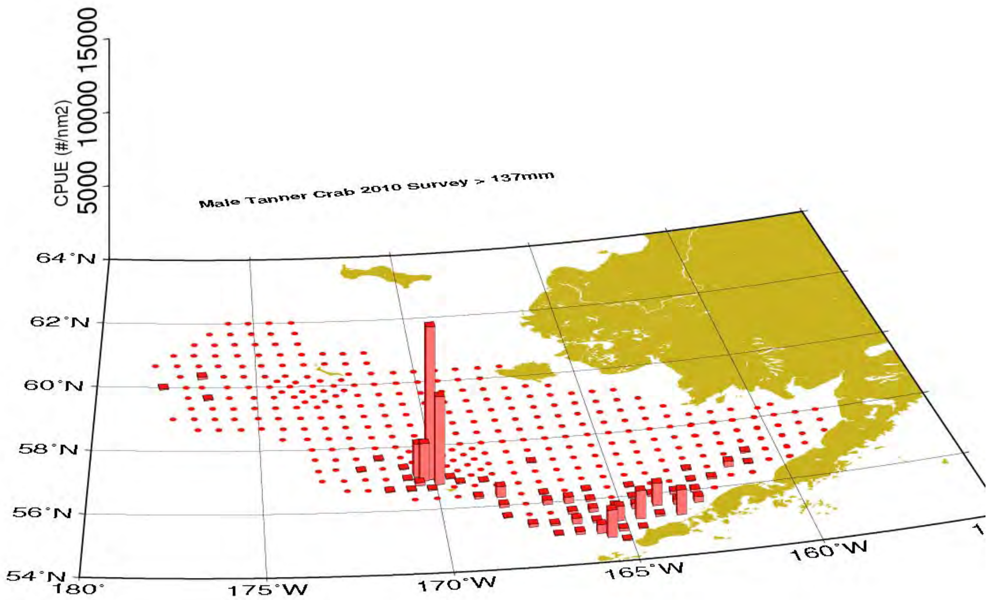
Year		Bycatch (1000T)
2007		0.69
2008		0.53
2009		0.32
	Average:	0.52

Table 8. Catch overfishing limits, stock and fishery metrics for the 2010/11 Eastern Bering Sea *C. bairdi* fishery. (B_{REF}=mean 1969-1980 MMB at the time of mating; 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:	26.07
B/B_{REF}:	0.31
F_{OFL}:	0.05
Catch Components (1000T):	
Total ♂ Catch OFL:	1.45
Directed Discard Losses MMB:	0.05
Non-Directed Discard Losses MMB:	1.31
Retained Part of Total ♂ Catch OFL:	0.09
Discard + Bycatch Losses ♀:	0.17
Total ♂ Catch OFL + ♀ Losses:	1.61
Rates:	
µ on MMB @ Fishery:	0.051

B_{REF}=mean 1969-80 MMB @ mating as proxy for B_{MSY}.



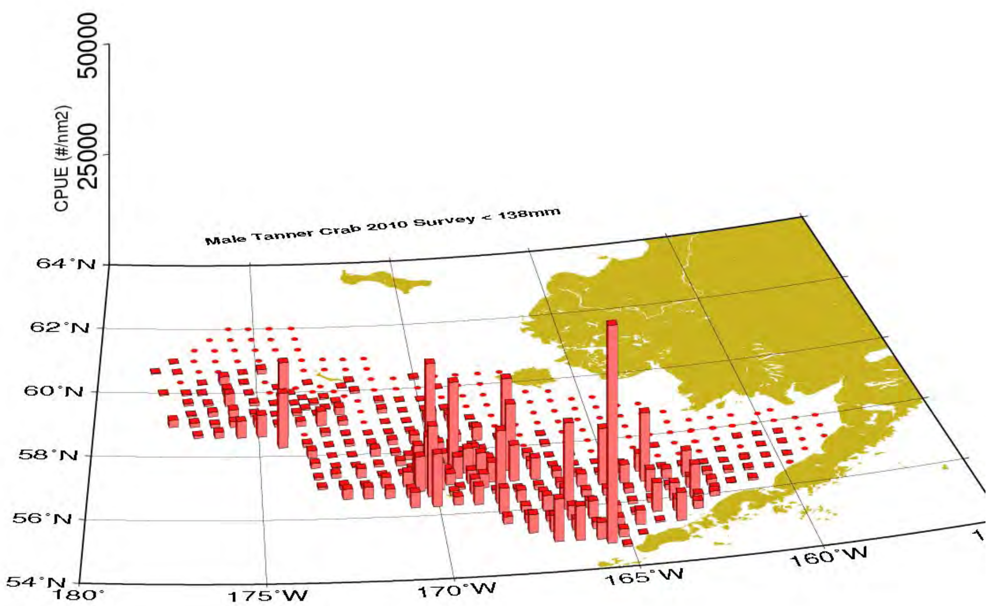


Figure 1. Distribution and abundance of legal (>= 138 mm cw) (top) and sublegal (< 138 mm cw) (bottom) male Tanner crab in the summer 2010 NMFS bottom trawl survey.

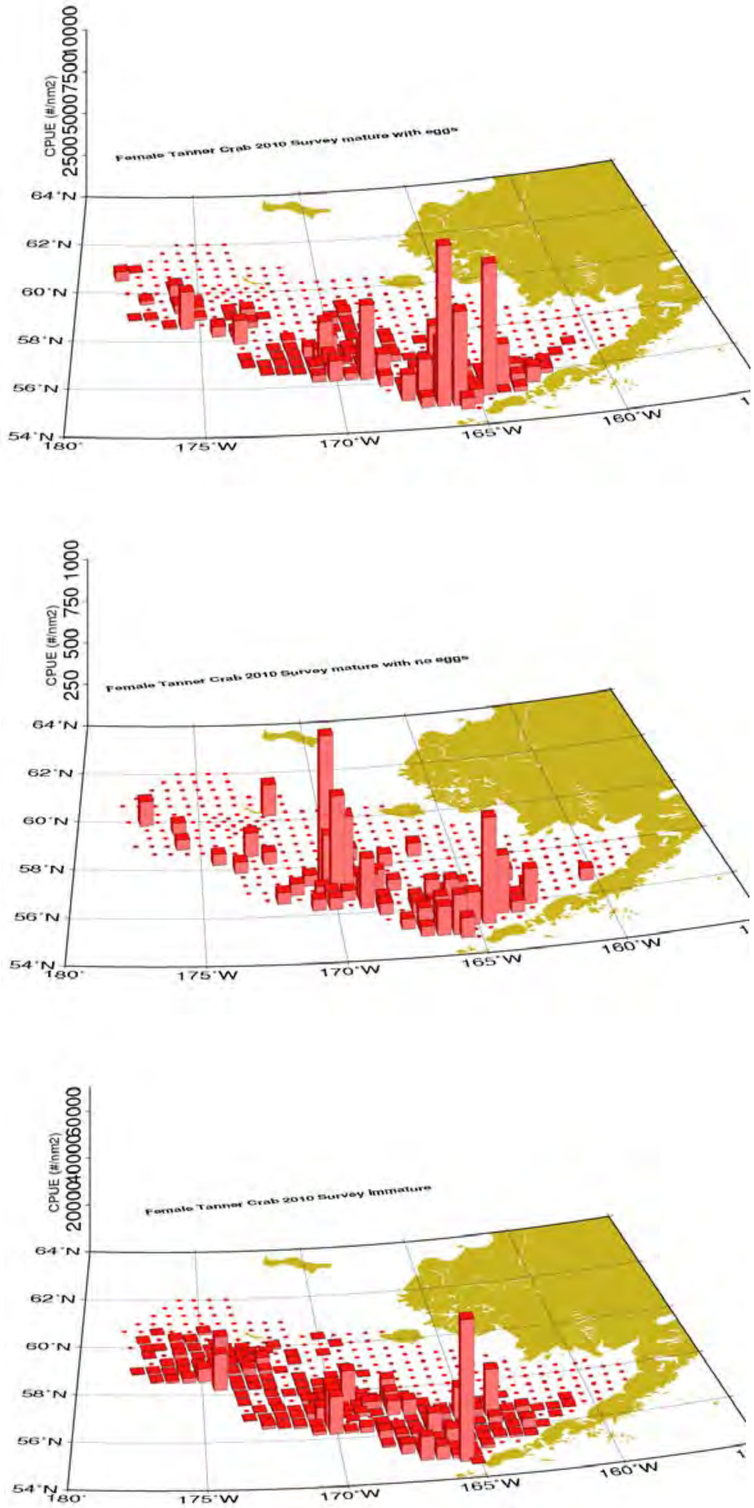


Figure 2. Distribution and abundance of ovigerous (top), barren mature (middle), and immature (bottom) female Tanner crab in the summer 2010 NMFS bottom trawl survey.

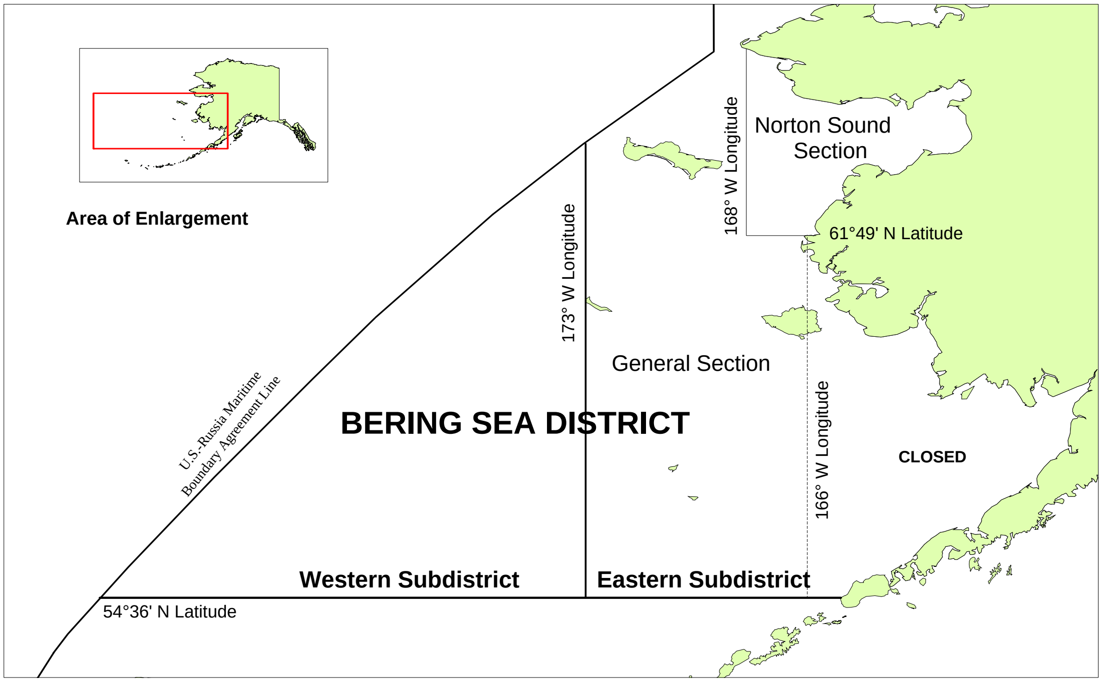
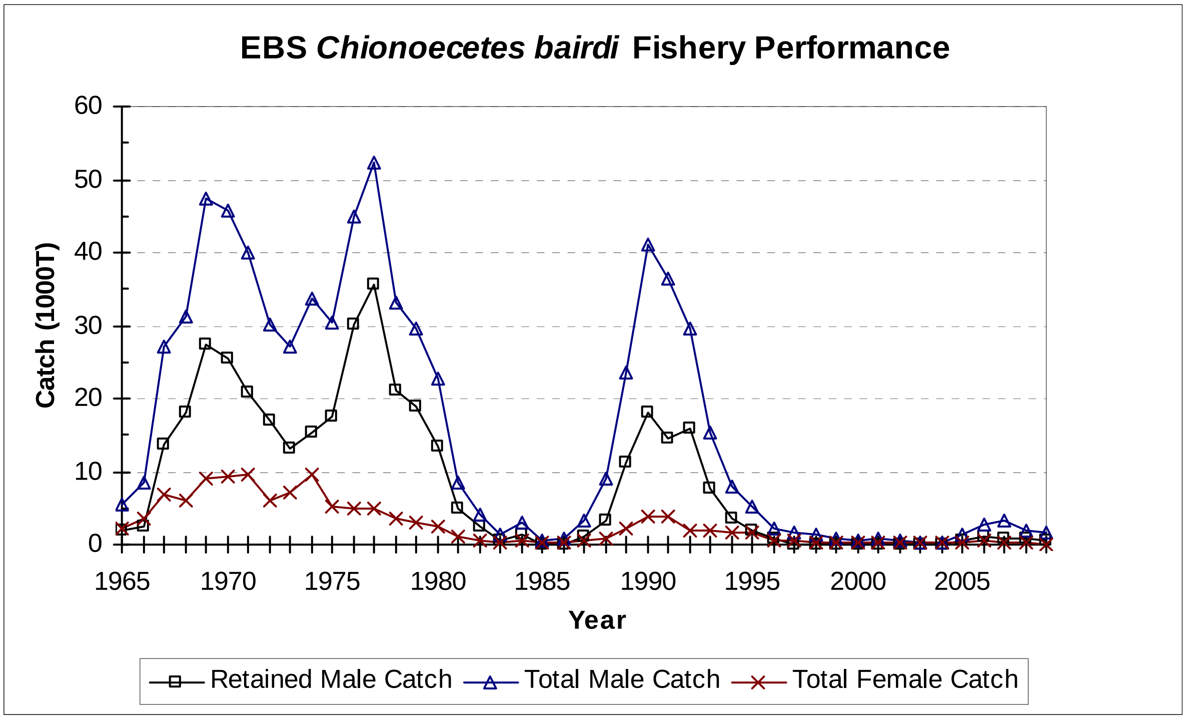


Figure 3. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)



(b)

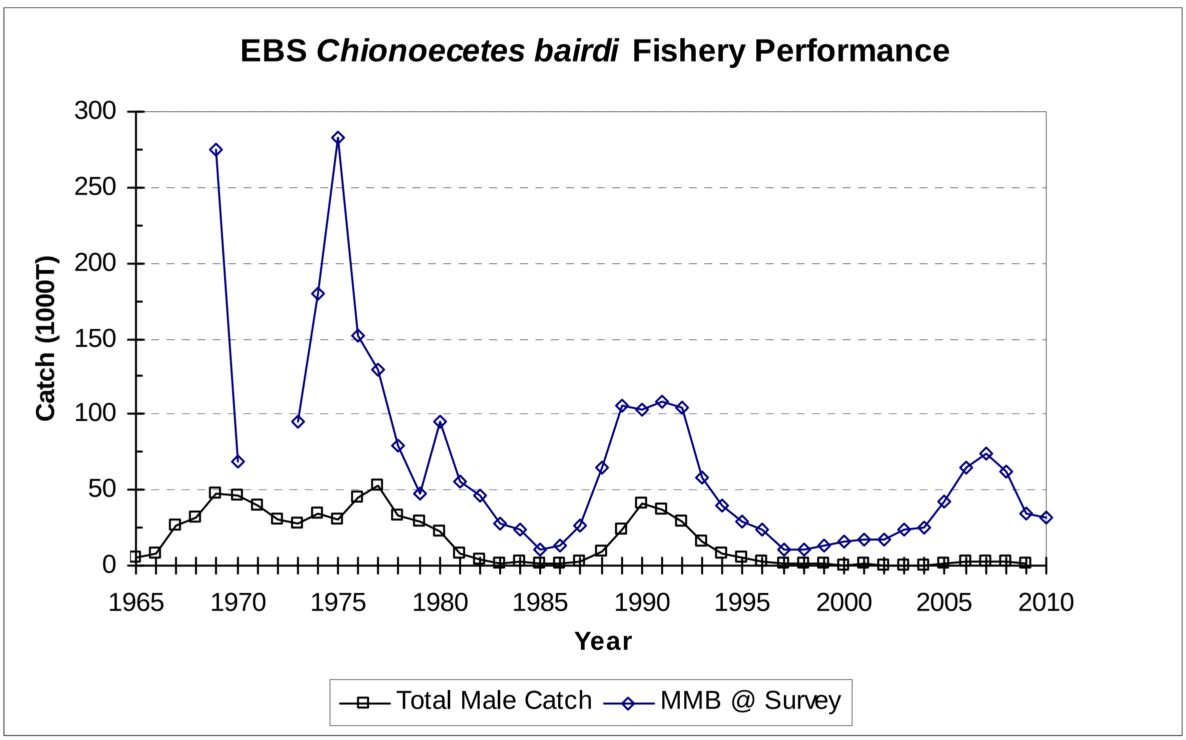


Figure 4. Eastern Bering Sea *C. bairdi* retained male catch, total (retained + bycatch) male catch and total female catch (a), and total male catch v. male mature biomass at the time of the survey (b), 1965-2010.

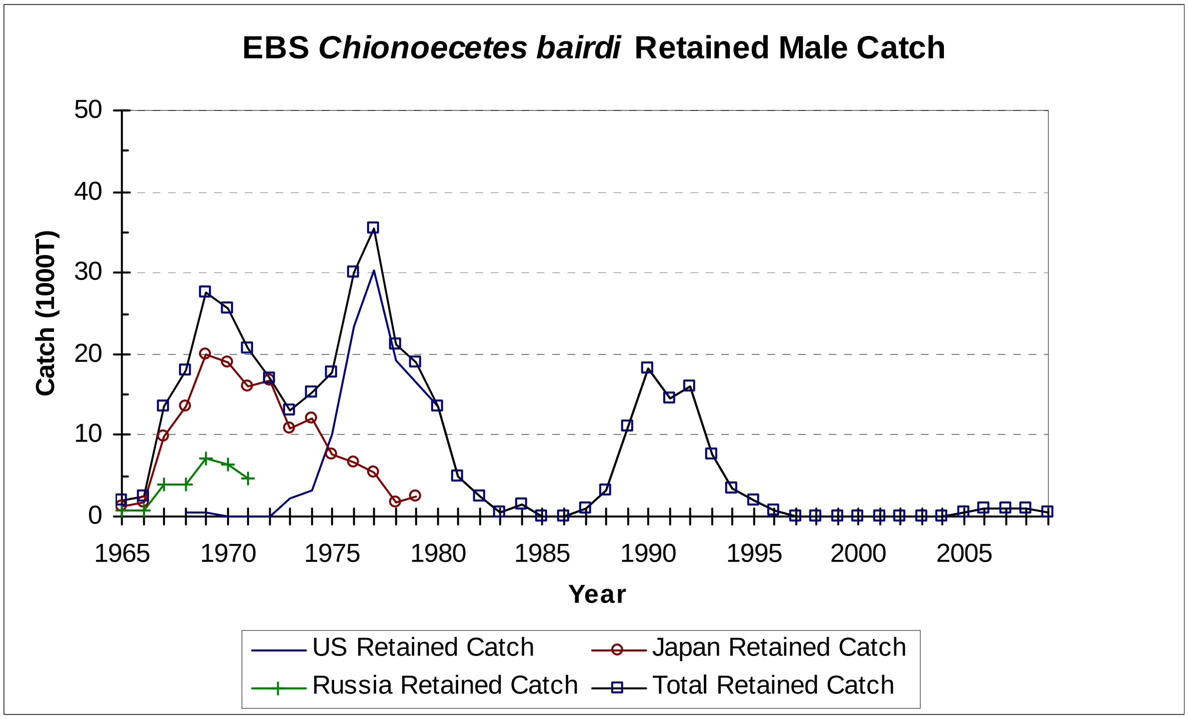


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965-2010.

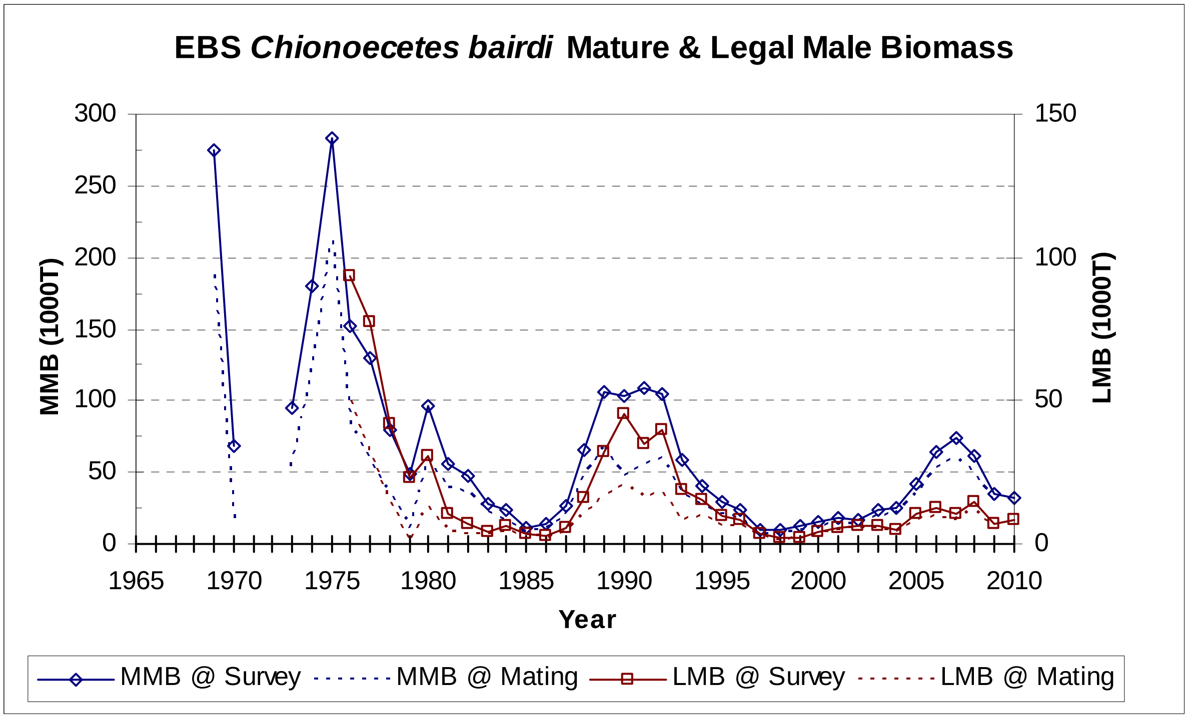
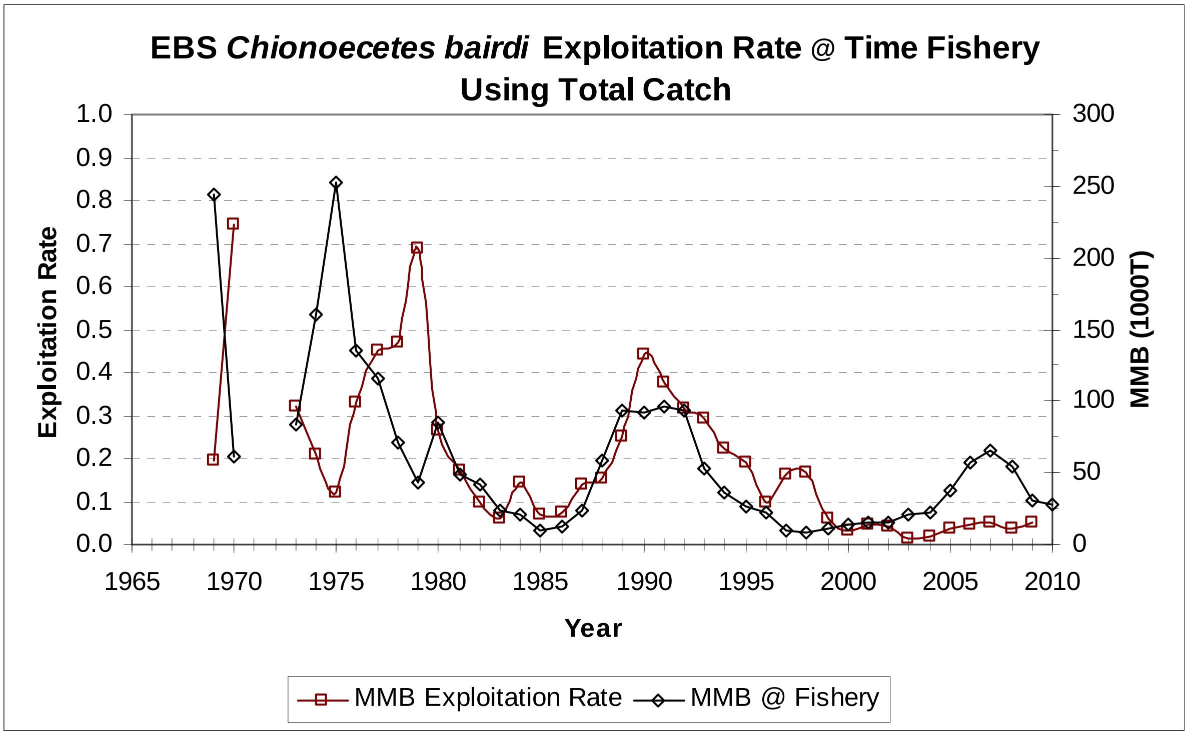


Figure 6. Eastern Bering Sea *C. bairdi* mature and legal male biomass at time of the survey and mating, 1965-2010. (2010/11 MMB and LMB at time of mating not estimable absent 2010/11 catch data).

(a)



(b)

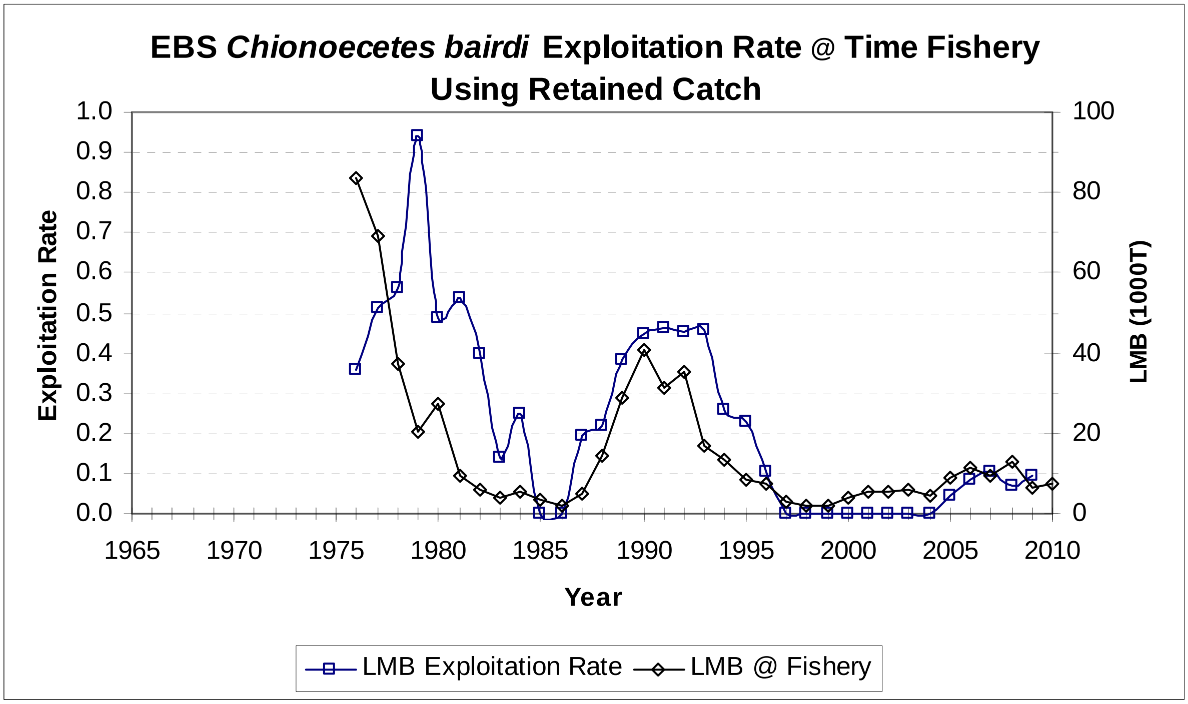


Figure 7. Eastern Bering Sea *C. bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1965-2010.

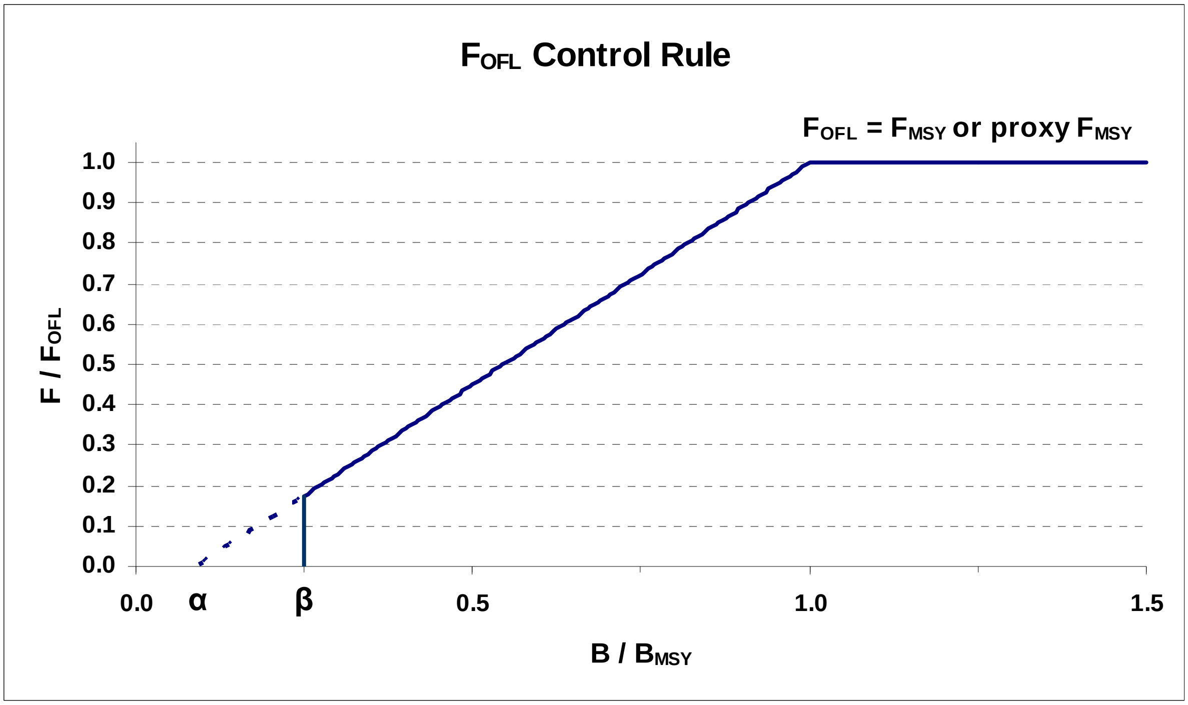


Figure 8. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

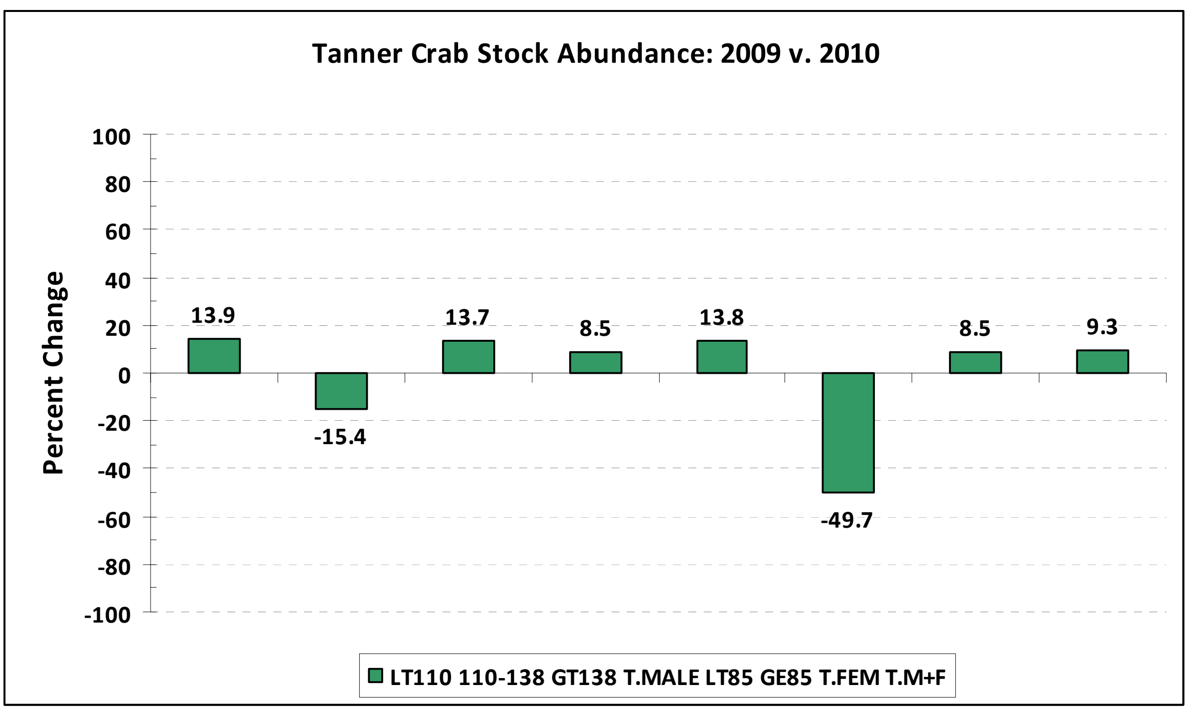
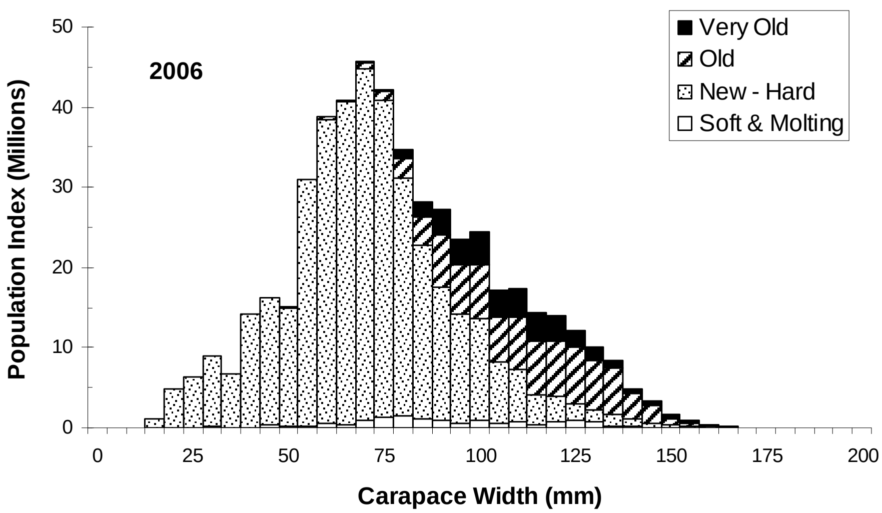


Figure 9. Percent change in Tanner crab stock abundance between 2008 and 2009 for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.

(a)



(b)

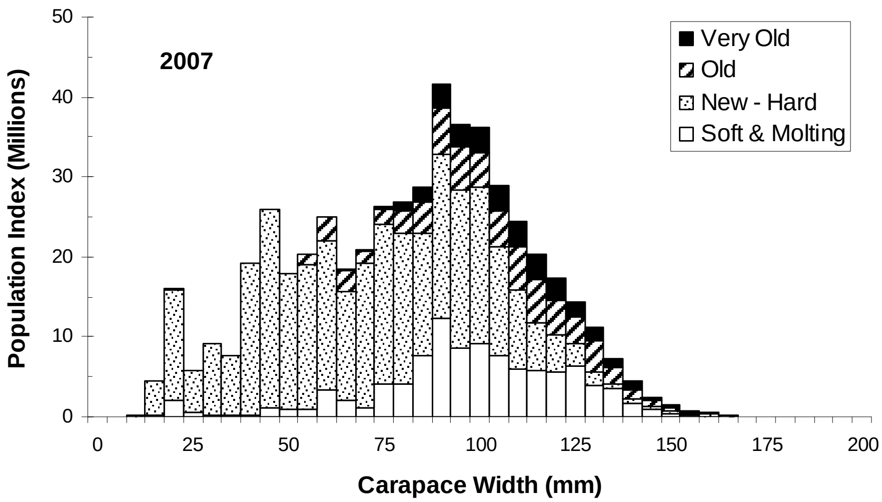
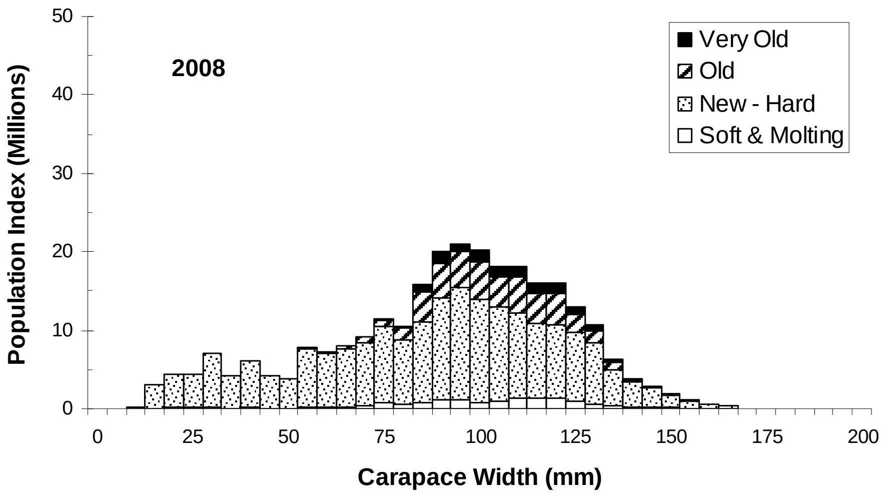


Figure 10 (a-b). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2007.

(a)



(b)

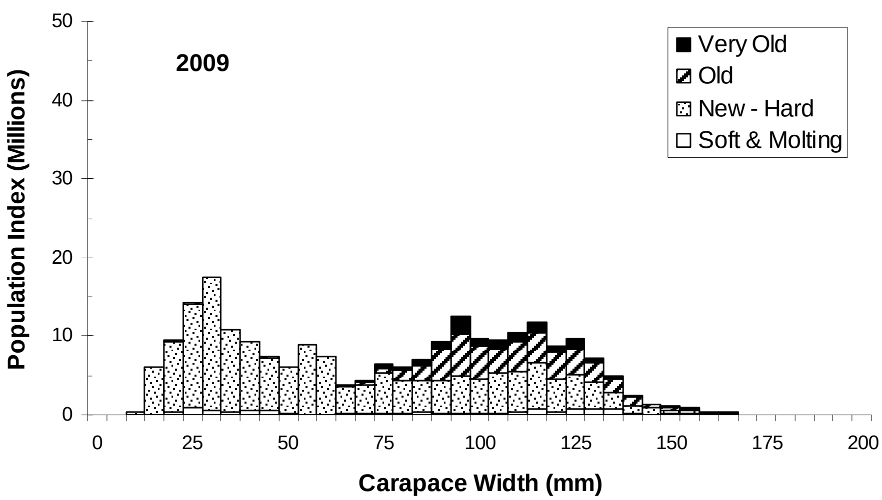


Figure 10 (c-d). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008-2009.

(e)

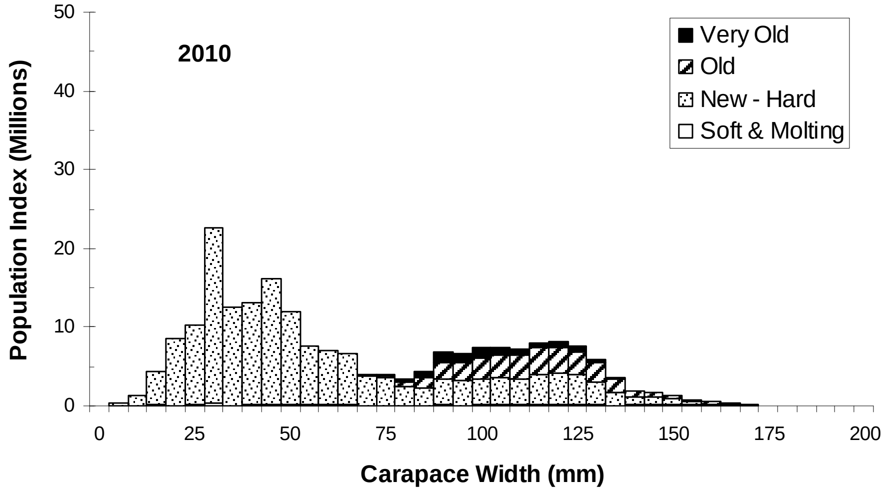
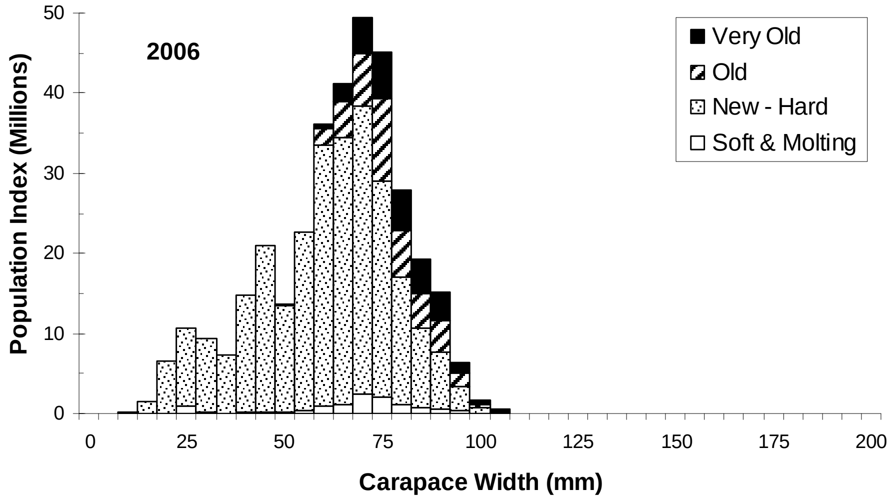


Figure 10 e. Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010.

(a)



(b)

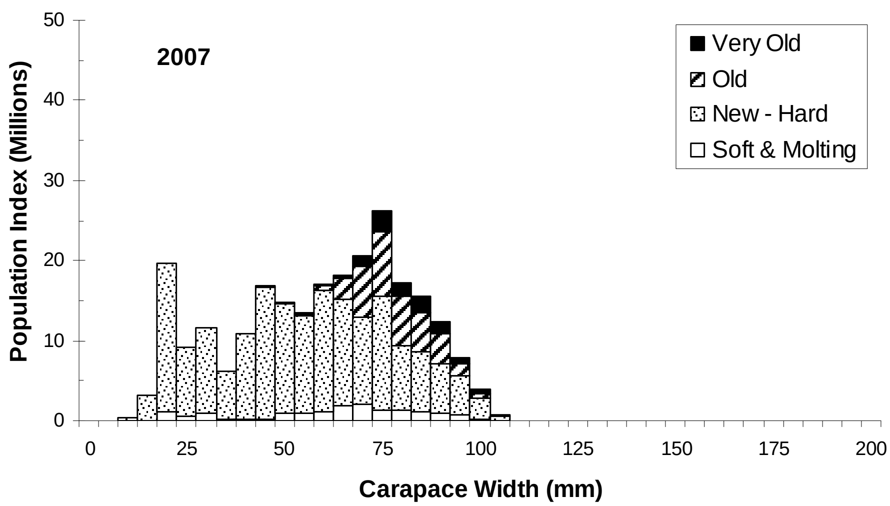
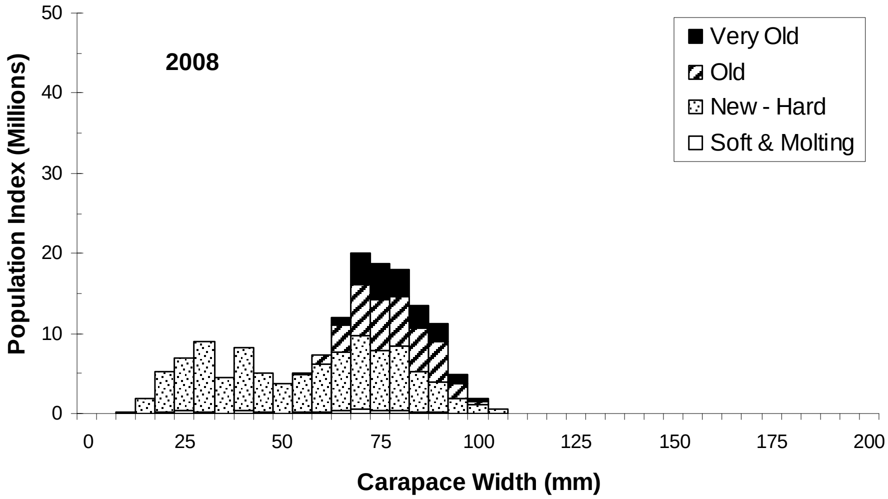


Figure 11 (a-b). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2007.

(a)



(b)

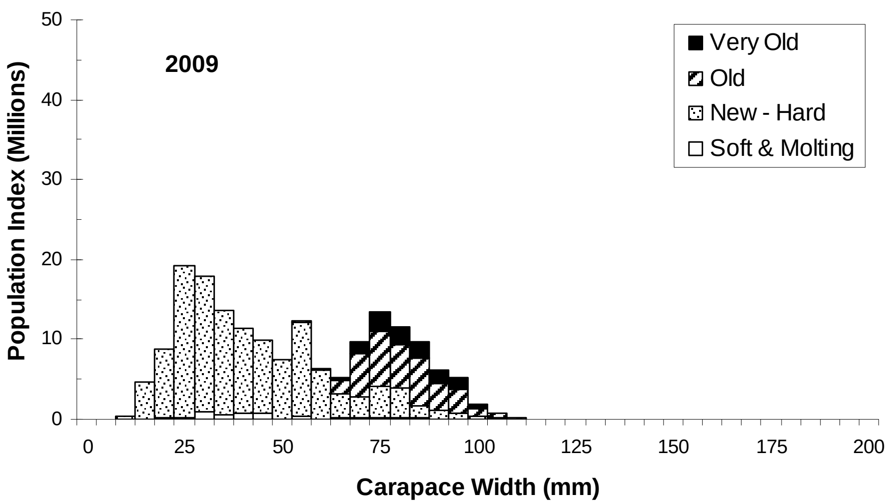


Figure 11 (c-d). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008-2009.

(e)

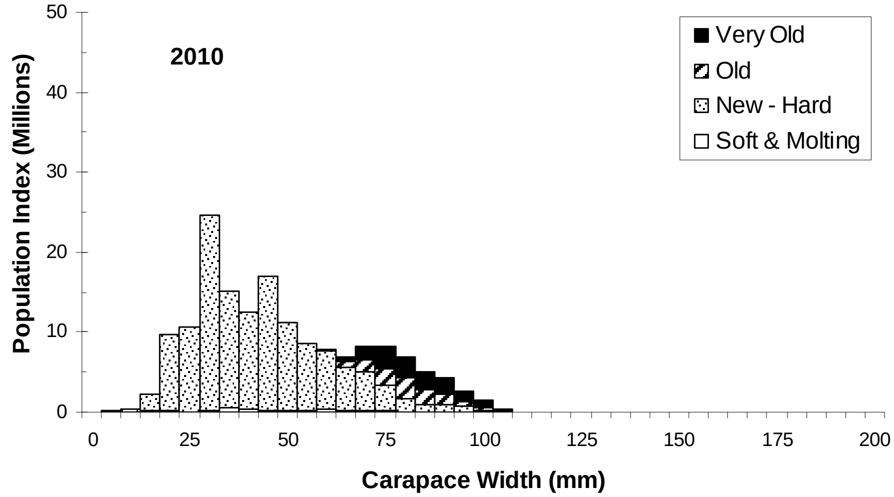


Figure 11 e. Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010.

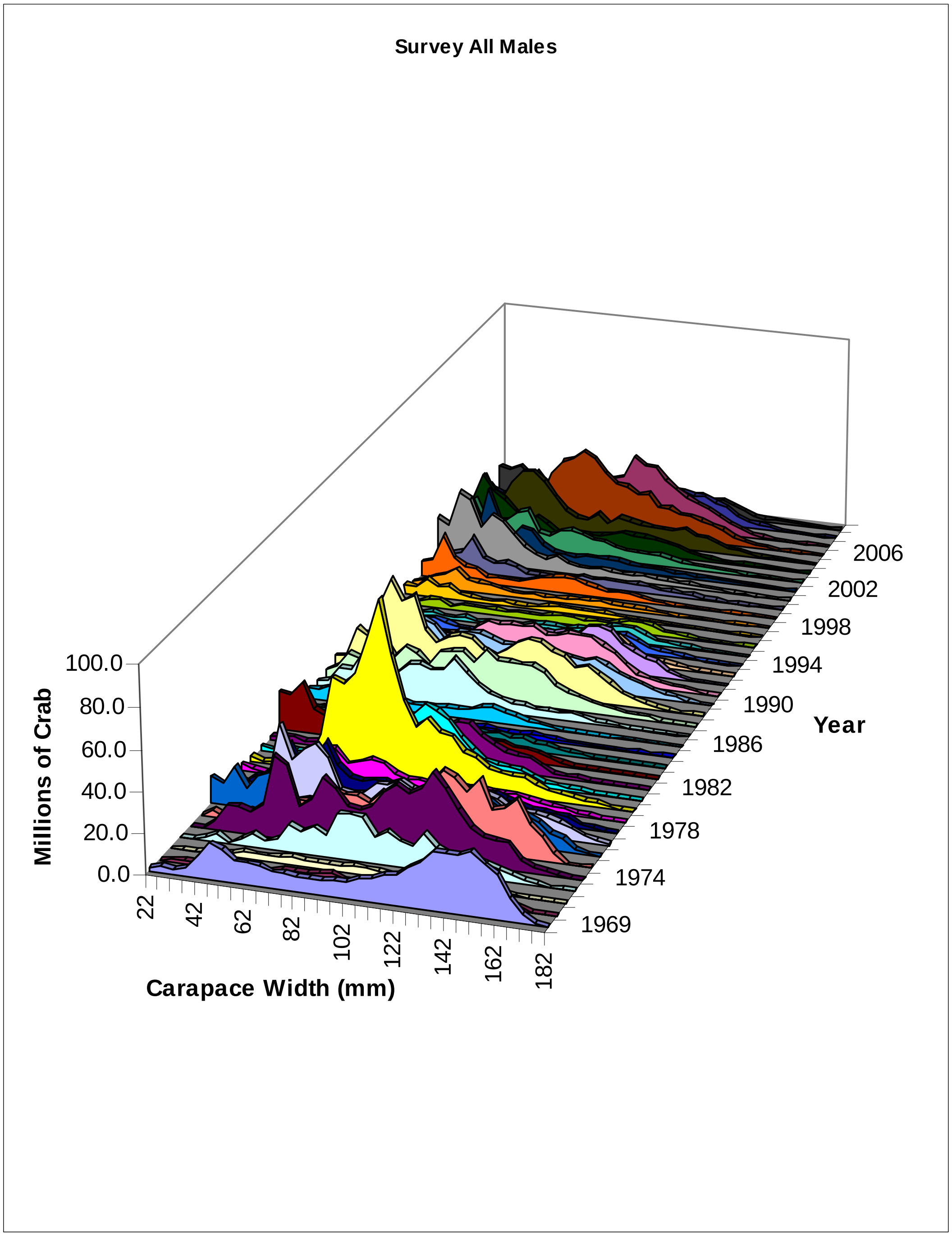


Figure 13. Observed survey numbers (millions of crab) by carapace width and year for male Tanner crab.

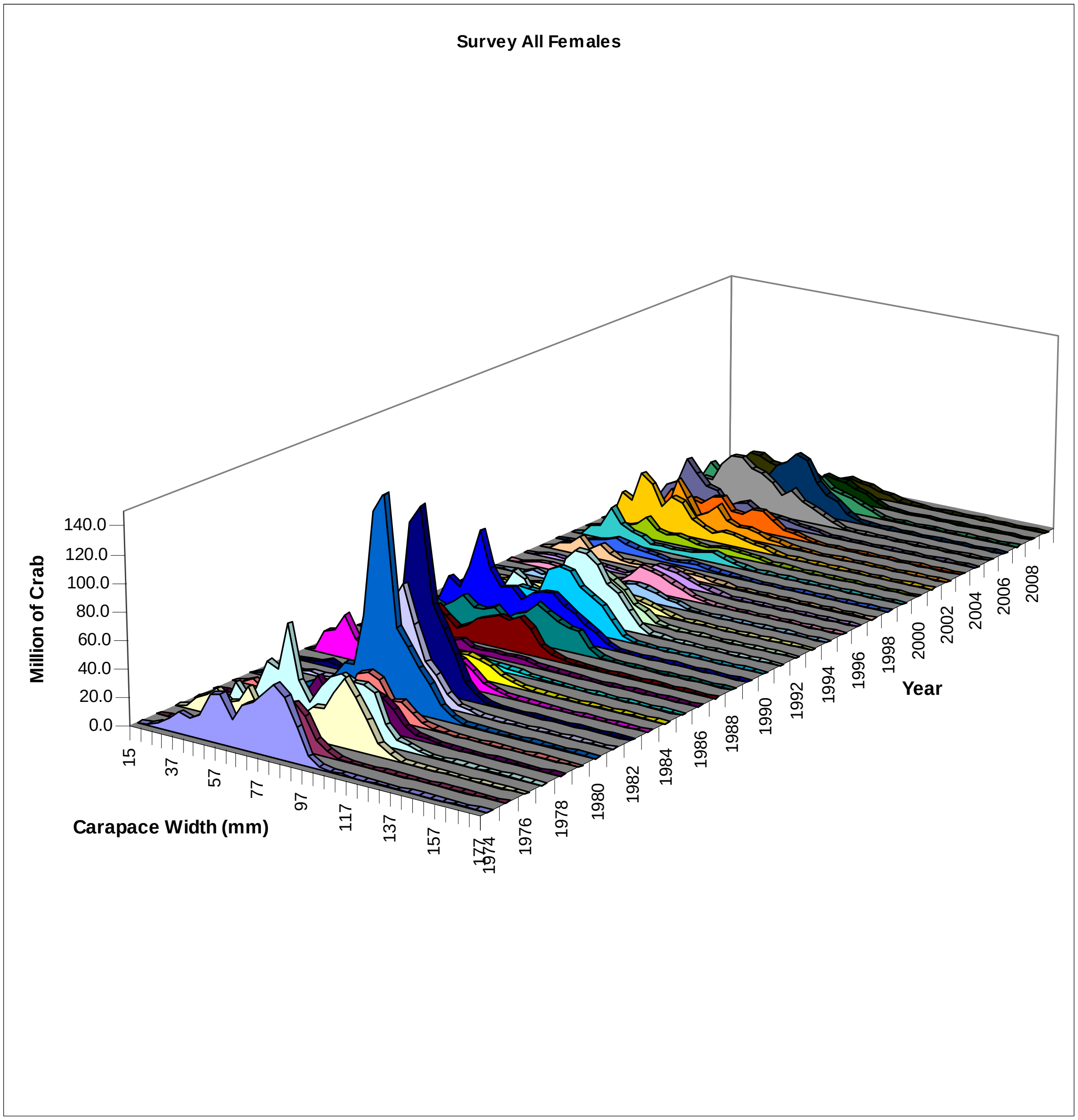


Figure 14. Observed survey numbers (millions of crab) by carapace width and year for female Tanner crab.

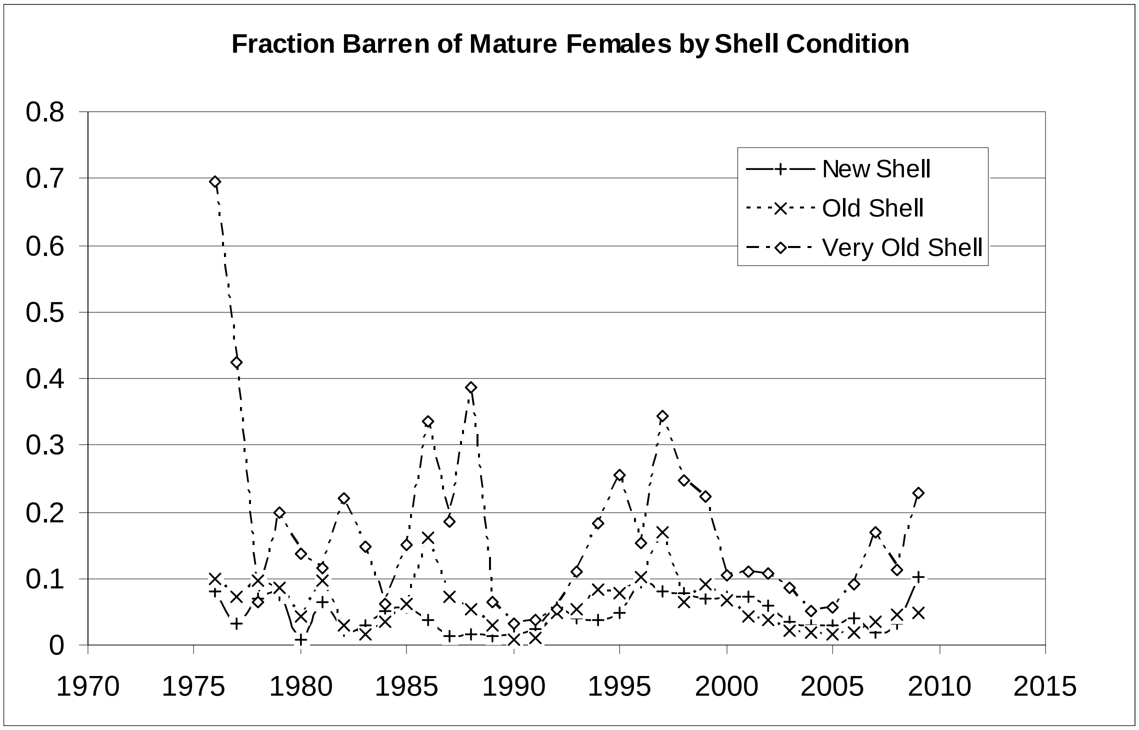


Figure 15. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976 to 2009.

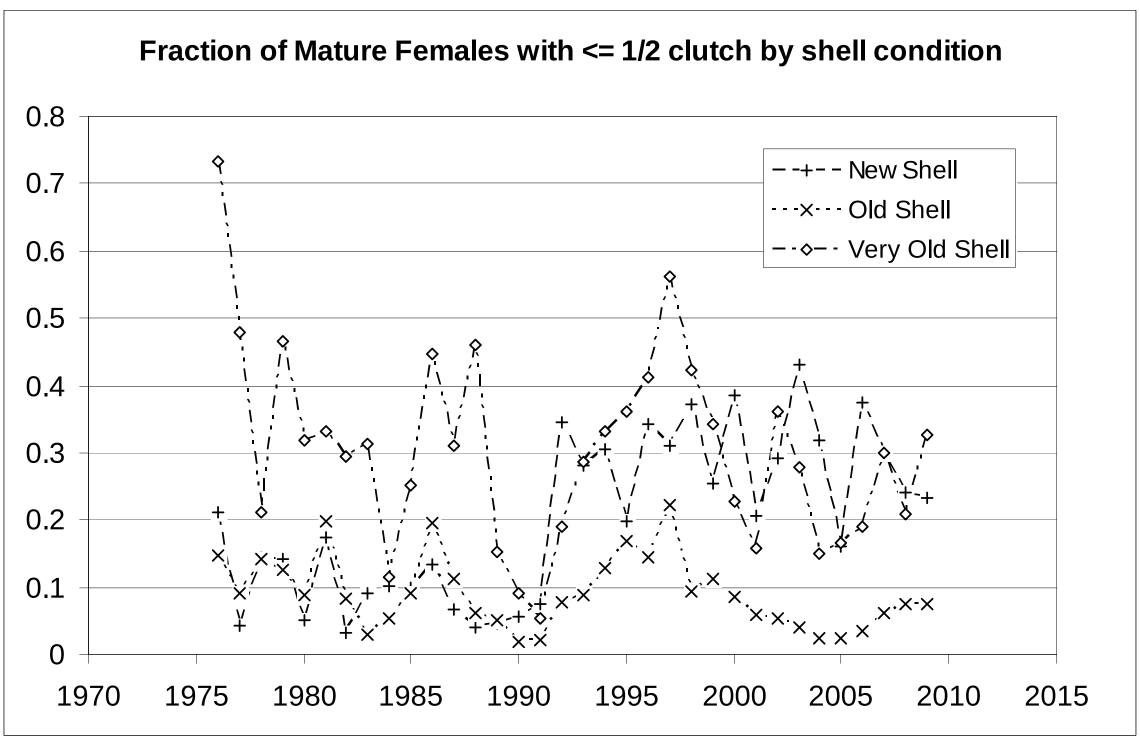


Figure 16. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976 to 2009.

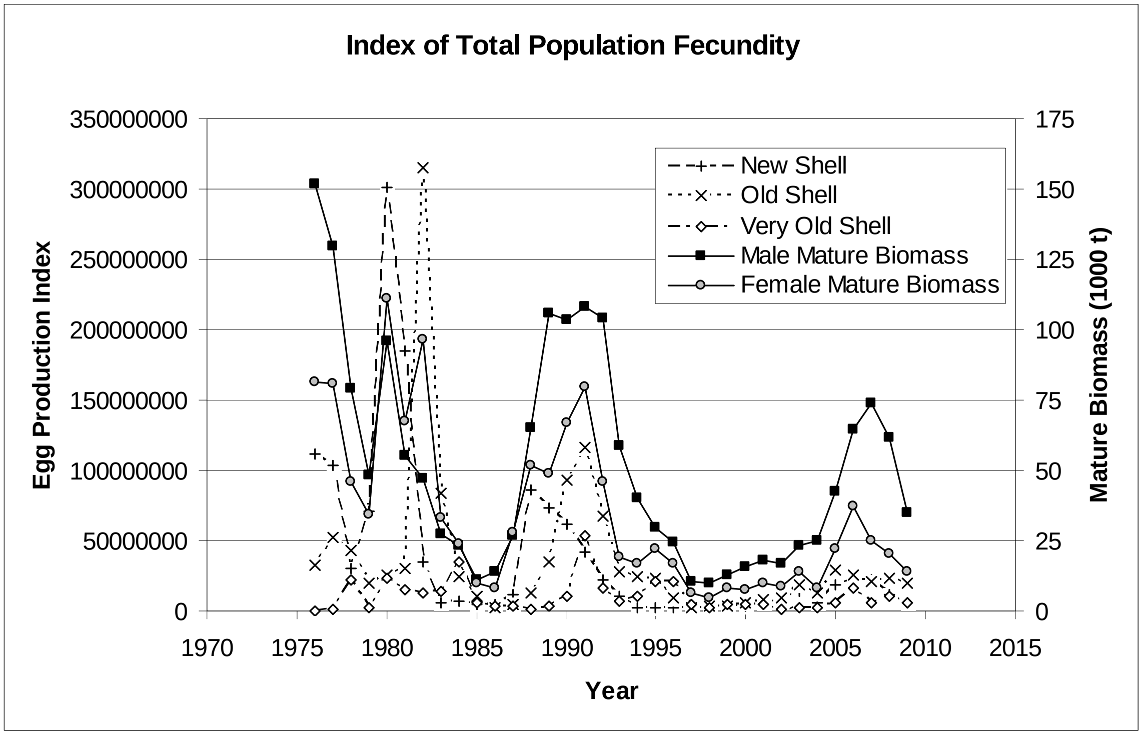


Figure 17. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976 to 2009.

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

1. Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years to current levels with no bycatch.
3. Stock biomass: Stock biomass in recent years has decreased from 2007 to 2009 and increased slightly in all size classes in 2010.
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	4.33	14.69[A]	0	0	0.015	
2008/09	4.39	11.06[B]	0	0	0.021	3.32
2009/10	4.22	4.46[C]	0	0	0.006	0.50
2010/11		5.44[D]				0.77

All units are in million lbs of crabs and the OFL is a total catch OFL for each year. 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 – 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} 10^6 lbs	Current MMB_{mating} 10^6 lbs	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}
2009/10	4b	8.44	5.44	0.64	1.0	1991/1992-2009/2010	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.

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 increased in this assessment. Total catch in 2009/2010 was 0.006 million lbs.

Responses to SSC and CPT Comments

<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>SSC comments June 2010:</u>

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The SSC agrees with the CPT recommendations for continued management of Pribilof Islands red king crab under Tier 4, setting $\gamma=1$, with $M=0.18$, and using the 1991 through current time series for estimating the proxy for B_{MSY}. In regards to stock structure (SAFE page 314) the SSC suggests consulting Seeb and Smith (2005) as described on SAFE page 554 (Adak red king crab chapter) which describes stock structure of red king crab in waters off Alaska. As stated in SSC minutes from June of 2009, the SSC looks forward to the presentation of a catch-survey analysis for this stock in October 2010.

Responses to CPT Comments: The CSA model is in development and will be ready for review during the winter 2011. Stock structure text added.

<u>CPT comments September 2009:</u>

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 added to graphs.

<u>CPT comments May 2010:</u>
General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

- *The 'Total Crab @ survey' column in Table 4 is incorrect and needs to be recalculated.*
- *Equation 3 is the same as equation 1 and needs to be corrected for females.*
- *Reorganize the chapter so that it is in standard format of text, tables, and figures.*
- *All tables on page 1 should be updated for final assessment in September 2010.*

Responses to CPT Comments: All points addressed.

Introduction

1. **Red king crabs, *Paralithodes camtschaticus*** (Tilesius, 1815)

2. **Distribution** - Red king crabs are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58° 39' N lat.), west of 168° W long., east of the United States – Russian convention line of 1867 as amended in 1991, north of 54° 36' N lat. between 168° 00' N and 171° 00' W. long and north of 55° 30'N lat. between 171° 00' W. long and the U.S.-Russian boundary (Figure 2).

3. **Stock structure –** The only available stock structure of red king crabs in the North Pacific is based on 1,800 microsatellite DNA samples from red king crabs originating from the Sea of Okhotsk to Southeast Alaska (Seeb and Smith 2005). In the Bering Sea Aleutian Island region, samples from Bristol Bay, Port Moller, and the Pribilof Islands were divergent from the Aleutian Islands and Norton Sound.

4. **Life History** - Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Unlike brachyurans, red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts and copulation occurs within hours. During copulation, the male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female's gonopores. After copulation, eggs are fertilized as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger

than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).
Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006) and estimates vary. Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data range from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males range from 0.54 to 0.70, however the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, with higher mortality for crabs <125 mm CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24.

The reproductive cycle of Pribilof Islands red king crabs has not been established, however in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous Bristol Bay red king crab females (brooding their first egg clutch) extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990) resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for eastern Bering Sea red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age, during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment is on average 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

5. **Management history** - Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the Sate of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crabs *Paralithodes platypus* being targeted (Figure 3). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof red and blue king crab fisheries which was implemented in 1998. From 1999 to 2008/2009 the Pribilof fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof blue king crab was declared overfished in September of 2002 and is still considered overfished. (see Bowers et al. 2008 for complete management history).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

Pribilof red king crabs occur as bycatch in the eastern Bering Sea snow crab (*Chionocetes opilio*), eastern Bering Sea Tanner crab (*Chionocetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof blue king crab fisheries. Many of these fisheries have been closed or recently re-opened so the opportunity to catch Pribilof red king crab is limited. Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries.

Data

1. The standard survey time series data updated through 2010 and the standard groundfish discards time series data updated through 2010 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2009/2010 data.

2. a. Total catch:
   Crab pot fisheries
   Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (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.

   b. Bycatch and discards:
   Crab pot fisheries
   Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight (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=0.0102, B=2.38849), 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 2009/2010, there were no legal males incidentally caught in the crab fisheries (Table 3).

   Groundfish pot, trawl, and hook and line fisheries
   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, 0.008 million lbs of male and female red king crab were caught in groundfish fisheries which is less than half the estimate of non-retained crab catch in 2008/2009 pot, trawl, and hook and line groundfish fisheries. The catch was mostly in non-pelagic trawls (82%) followed by longline (9%), and pot (8%) fisheries. The targeted species in these fisheries were Pacific cod (30%), pelagic pollock (21%), flathead sole (12%), yellowfin sole (12%), bottom pollock (12%) rock sole (3%), and Greenland turbot (3%).

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.

$$\text{Proportion mature male} = 1/(1 + (5.842 * 10^{14}) * e^{((CL(mm)+2.5) * -0.288)}$$
$$\text{Proportion mature female} = 1/(1 + (1.416 * 10^{13}) * e^{((CL(mm)+2.5) * -0.297)} \quad (3)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 4, Figure 6).

Red king crab were caught at 13 of the 41 stations in the Pribilof District high-density sampling area in 2010 (Chilton et al. in press, Figure 7). The density of legal-sized males caught at a station ranged from 66 to 1,854 crab/nmi^2. Legal-sized male red king crab were caught at 11 stations in the Pribilof District high-density sampling area representing 92% of the total male abundance but below the average from the previous 20 years (Figure 8). The majority of the legal-sized males were distributed south and west of St. Paul Island at stations G-21 and GH-2122. Mature males were encountered at 11 of the 41 stations. Mature males were distributed ubiquitously around St. Paul Island in the nearshore shallow water stations. The 2010 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 2008 shell conditions but an increase when compared to 2009. In 2010, one legal-sized male was in softshell condition and caught east of St. Paul Island at depths less than 50 m while 54% of the legal-sized males were evaluated as new hardshell crabs and distributed north and south of St. Paul Island. Forty-five percent of the legal-sized males were in oldshell and very oldshell condition and primarily distributed east of St. Paul Island. The 2010 biomass estimate of mature-sized red king crab females was 1.03 ± 0.84 million lbs, representing 100% of the total female biomass as no immature females were caught on the 2010 survey. None of the mature females were carrying eyed embryos with 85% of the mature females brooding uneyed embryos and 15% were barren or had empty egg cases. The majority of mature females with uneyed embryos were in the130 mm CL to 140 mm CL size class.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and 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.

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}.

Stock Status Level:	F_{OFL}:	
a. $B/B_{MSY}^{prox} > 1.0$	$F_{OFL} = \boldsymbol{\gamma} \cdot M$	(4)
b. $\beta < B/B_{MSY}^{prox} \leq 1.0$	$F_{OFL} = \boldsymbol{\gamma} \cdot M\ [(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(5)
c. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$	(6)

B_{MSY}^{prox} for the 2010 assessment was calculated as the average MMB_{mating} from 1991 to current based on the observation that red king crab were relatively uncommon in the area prior to 1991.

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	4.33	14.69[A]	0	0	0.015	
2008/09	4.39	11.06[B]	0	0	0.021	3.32
2009/10	4.22	4.46[C]	0	0	0.006	0.50
2010/11		5.44[D]				0.77

All units are in tons of crabs and the OFL is a total catch OFL for each year. 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 – 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 2010/2011 B_{MSY}^{prox}=8.44 million lbs of MMB_{mating} derived as the mean of 1991/1992 to 2009/2010 and is recommended by the authors, CPT and SSC. The stock demonstrated highly variable levels of MMB_{mating} during these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

   Male mature biomass at the time of mating for 2010/2011 is estimated at 5.44 million lbs for B_{MSY}^{prox}. The B/B_{MSY}^{prox} =0.64 and F_{OFL}=0.11. The biomass reference option B/B_{MSY}^{prox} is < 1, therefore the stock status level is b (equation 5). For the 2009/2010 fishery, total catch OFL was estimated at 0.77 million lbs of crab and legal male catch OFL was estimated at 0.62 million lbs of crab. The projected exploitation rates based on full retained catches up to the OFL for LMB and $MMB_{fishery}$ are 0.12 and 0.11 respectively.

   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.

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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 (10^6)	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	2.608	11
1994/1995	167,520	1.339	6
1995/1996	110,834	0.898	3
1996/1997	25,383	0.200	<1
1997/1998	90,641	0.757	3
1998/1999	68,129	0.544	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			

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 (10^6 lbs)	Sublegal male (10^6 lbs)	Female (10^6 lbs)	All fixed (10^6 lbs)	All trawl (10^6 lbs)
1991/1992				0.001	0.101
1992/1993				0.036	0.388
1993/1994				0.001	0.291
1994/1995				0.001	0.034
1995/1996				0.011	0.014
1996/1997				0.004	0.005
1997/1998				0.010	0.017
1998/1999		0.002	0.025	0.023	0.015
1999/2000	0.003		0.018	0.027	0.007
2000/2001				0.005	0.010
2001/2002		0.000007		0.006	0.015
2002/2003				0.001	0.020
2003/2004				0.002	0.022
2004/2005				0.007	0.008
2005/2006		0.0004	0.004	0.010	0.054
2006/2007	0.003	0.0003	0.002	0.015	0.047
2007/2008	0.002	0.0001	0.0002	0.004	0.006
2008/2009	0.0002			0.004	0.015
2009/2010	0	0	0	0.001	0.005

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 10^6 LB	Mature males @ mating 10^6 LB	Legal Males @ survey 10^6 LB	Total males @ survey 10^6 LB	Total females @ survey 10^6 LB
1980/1981	5.82	3.89	5.82		
1981/1982	5.82	4.69	5.82		
1982/1983	2.98	2.59	2.98		
1983/1984	0.77	0.68	0.70		
1984/1985	0.81	0.72	0.67		
1985/1986	0.22	0.19	0.22		
1986/1987	0.27	0.24	0.27		
1987/1988	0.09	0.08	0.09		
1988/1989	0.28	0.25	0.08		
1989/1990	3.11	2.76	1.77		
1990/1991	2.40	2.13	0.13		
1991/1992	8.11	7.14	2.45		
1992/1993	6.81	5.82	5.22		
1993/1994	16.84	12.18	15.72		
1994/1995	16.34	13.13	14.46		
1995/1996	8.51	6.63	7.65		
1996/1997	4.43	3.72	4.37		
1997/1998	11.60	9.51	10.76		
1998/1999	5.07	3.93	3.79		
1999/2000	0.02	0.00	0.02		
2000/2001	8.73	7.73	7.76		
2001/2002	17.44	15.45	11.51		
2002/2003	14.88	13.19	14.84		
2003/2004	11.05	9.78	10.85		
2004/2005	8.55	7.58	8.55		
2005/2006	2.98	2.60	2.95		
2006/2007	15.65	13.84	14.97		
2007/2008	16.58	14.69	15.98	17.01	5.99
2008/2009	12.49	11.06	11.64	13.76	7.61
2009/2010	5.43	4.46	4.66	5.56	1.22
2010/2011	6.85	5.44	6.35	6.92	1.03

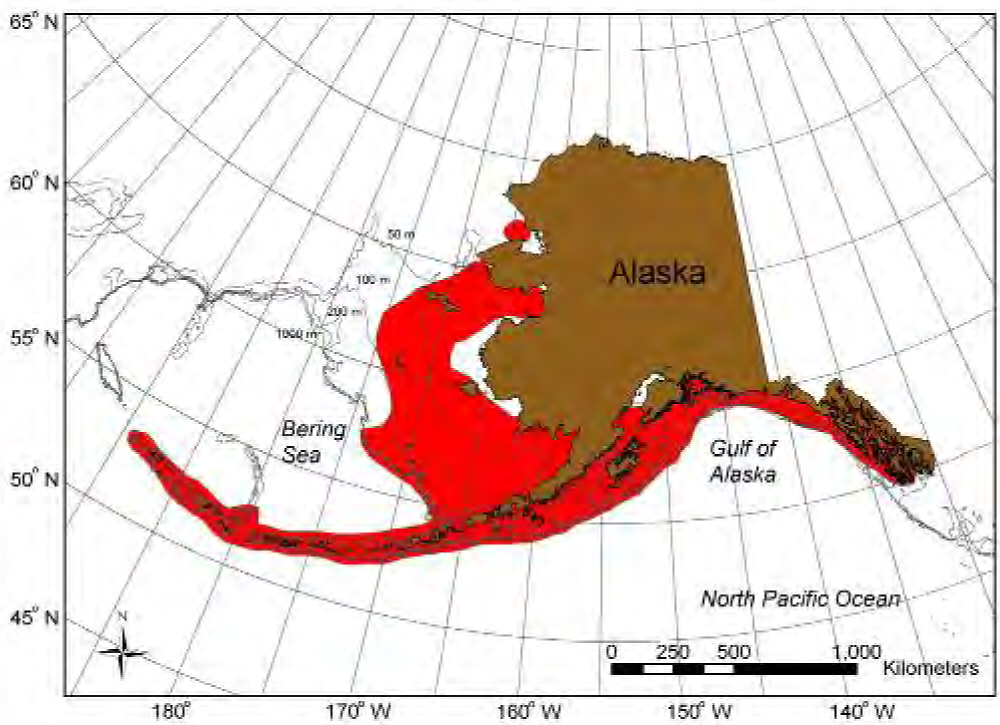

Figure 1. Red king crab distribution.

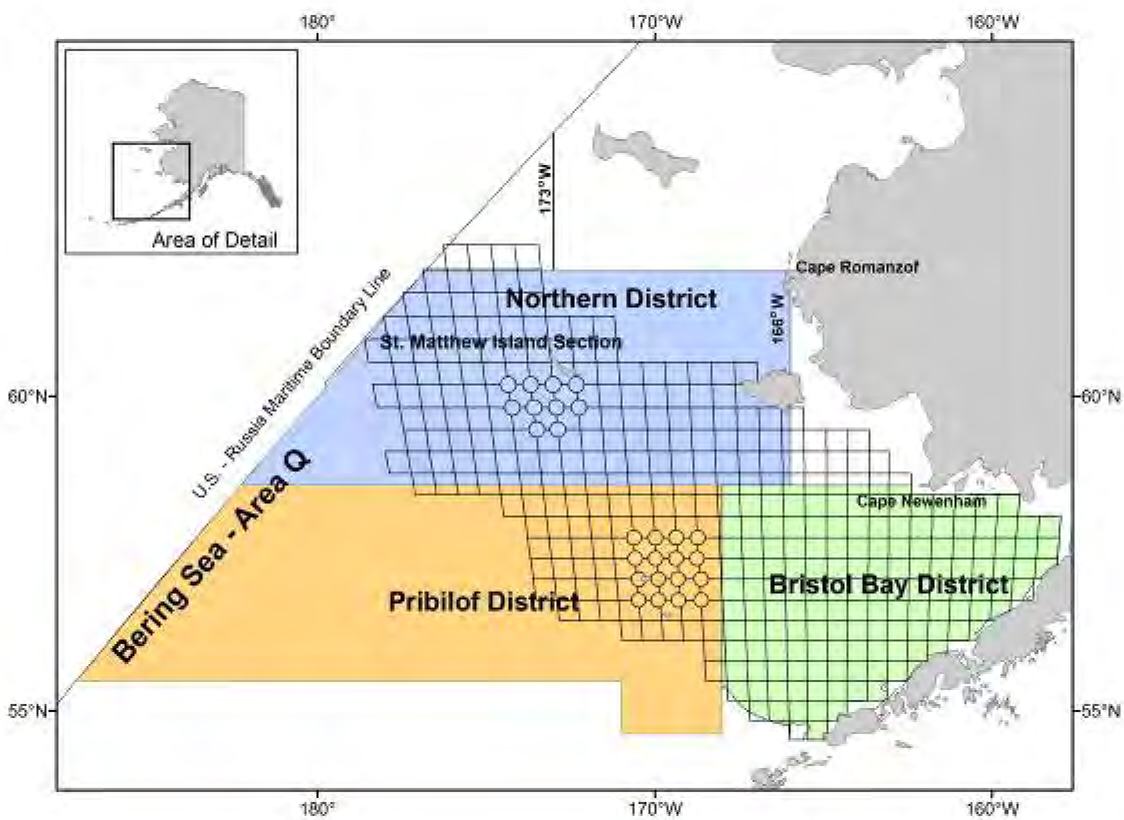

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

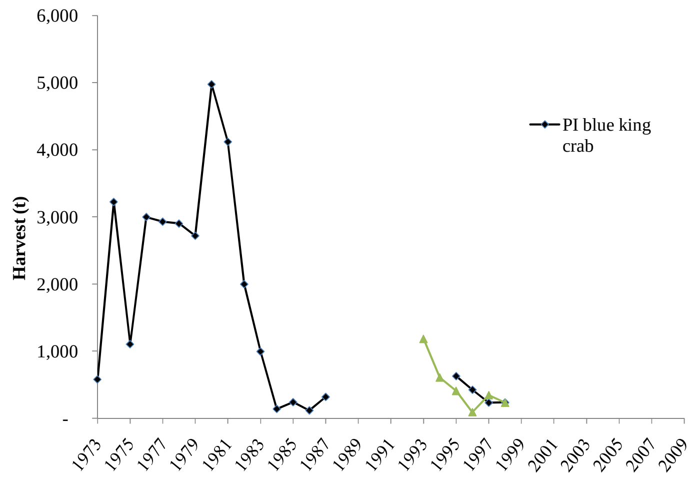

Figure 3. Historical harvests and GHLs for Pribilof Island red king crab (Bowers et al. 2007).

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area

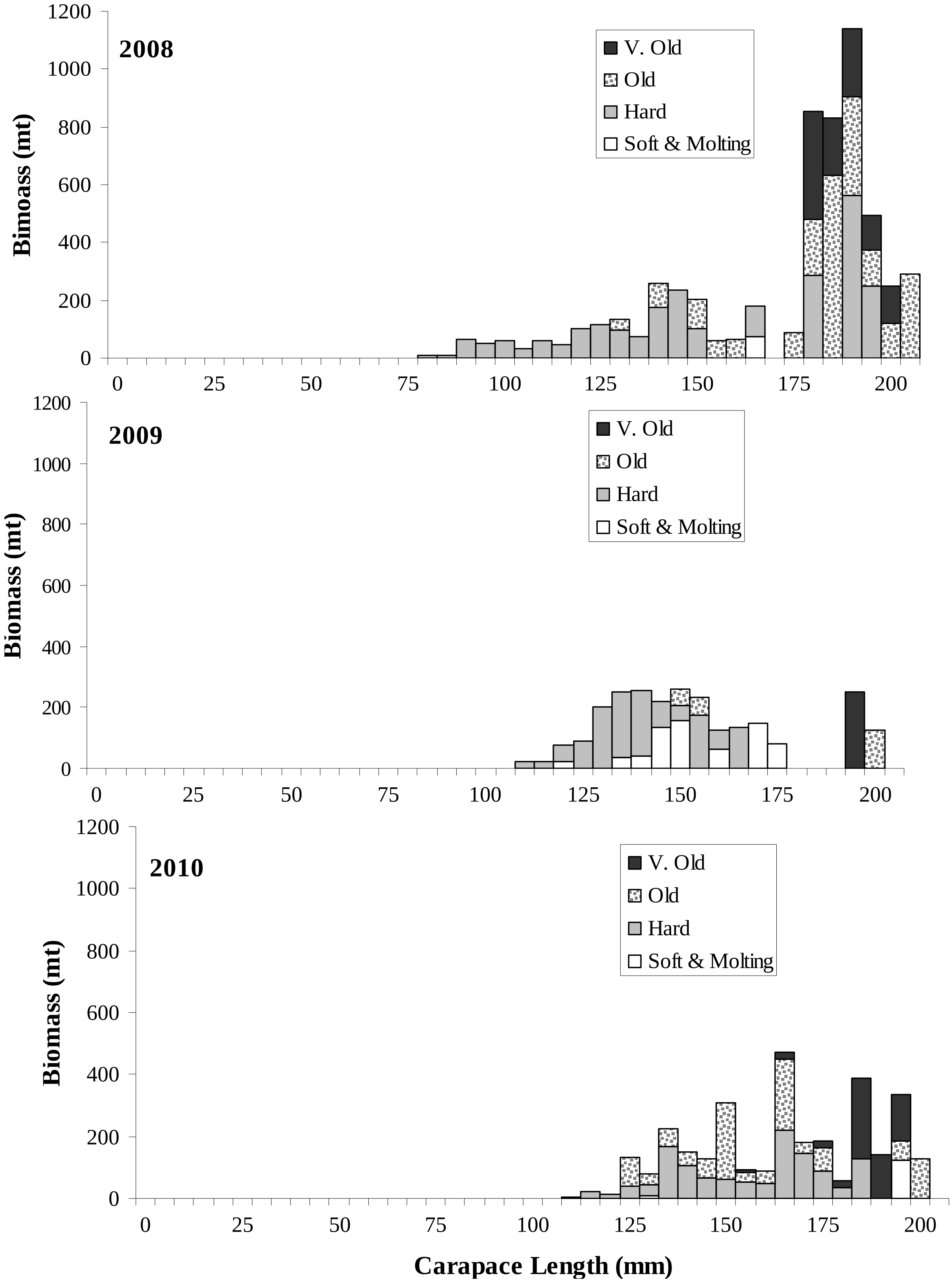

Figure 5. Distribution of Pribilof Island red king crab in 5 mm length bins by shell condition for the last 3 surveys.

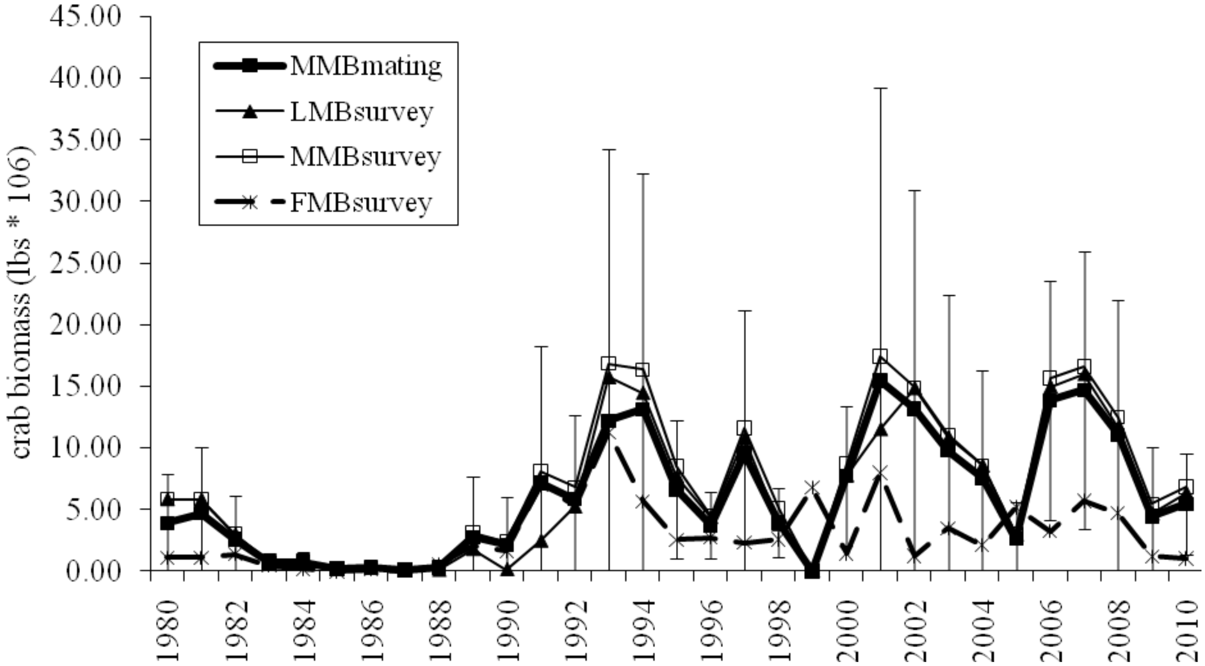

Figure 6. Historical trends of Pribilof Island red king crab mature male biomass (95% C.I.), mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

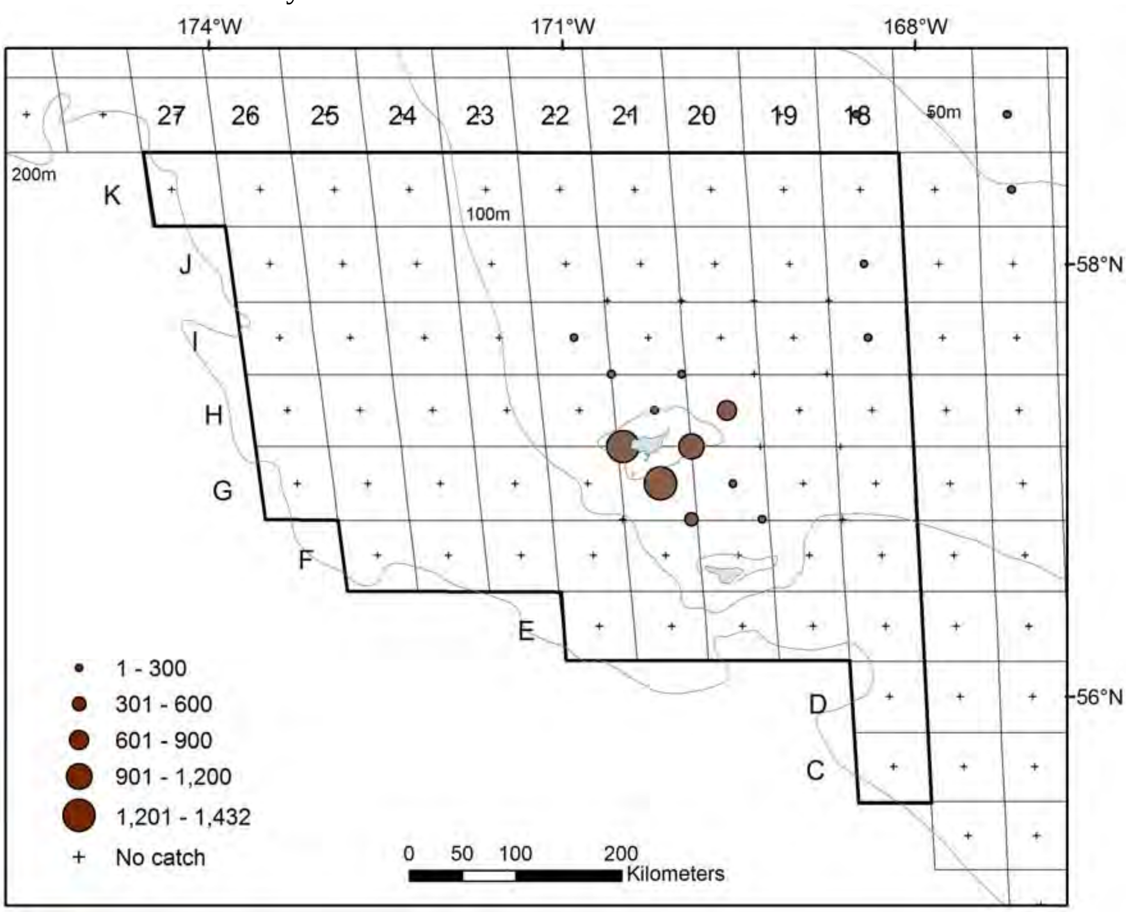

Figure 7. Total density (number/nm^2) of red king crab in the Pribilof District in the 2010 EBS bottom trawl survey.

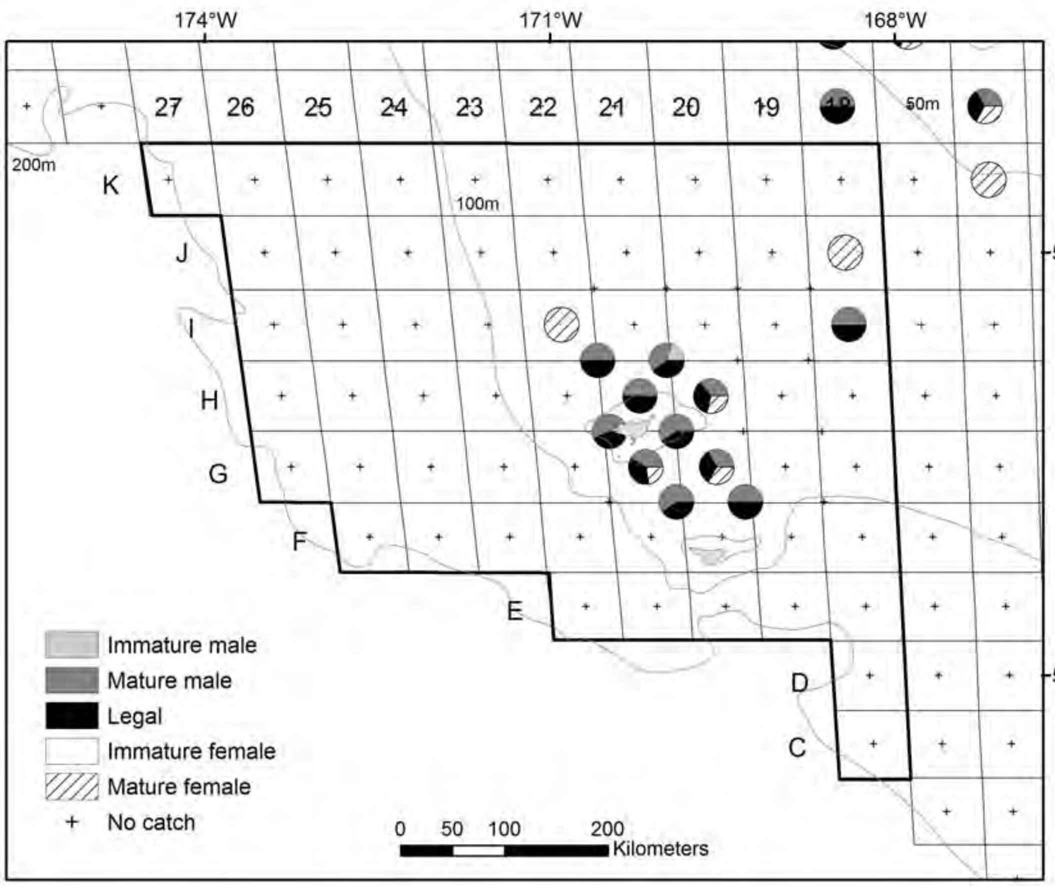

Figure 8. 2010 EBS bottom trawl survey size class distribution of red king crab in the Pribilof District.

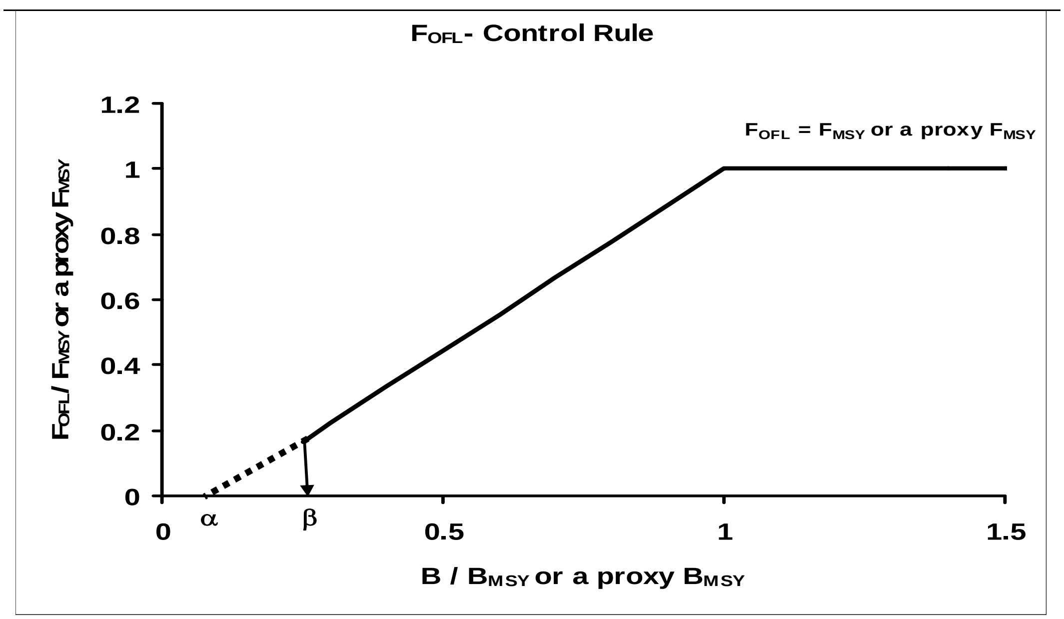

Figure 9. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

2010 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Alaska Fisheries Science Center
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Executive Summary

1. Stock: Pribilof Islands blue king crab, *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years to current levels near 0.001 million lbs.
3. Stock biomass: Stock biomass in recent years was decreasing between the 1995 and 2008 survey, and after a slight increase in 2009, there was a decrease in most size classes in 2010.
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	4.64	0.67[A]	0	0	0.005	
2008/09	4.64	0.25[B]	0	0	0.001	0.004
2009/10	4.64	1.13[C]	0	0	0.001	0.004
2010/11		0.63 [D]				0.004

All units are tons of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2009/10 and is hence overfished. Overfishing did not occur during the 2009/10 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} 10^6 lbs	Current MMB_{mating} 10^6 lbs	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}
20010/11	4c	9.28	0.63	0.07	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:

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 decreased in this assessment and remained below the MSST. Therefore, the OFL remained low with no directed fishery. Total catch in 2009/2010 was 0.001 million lbs.

Responses to SSC and CPT Comments

SSC comments October 2009:

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.

SSC comments June 2010:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The SSC agrees with the CPT recommendation for management of Pribilof Islands blue king crab under Tier 4, where γ=1, M=0.18, and using the 1980 through 1984 and 1990 through 1997 time periods to determine the average MMB as a proxy for B_{MSY}. The SSC reiterates our request from June 2009 that an analysis be included in the revised rebuilding plan to examine information on stock separation from the St. Matthew Island blue king crab stock. The SSC continues to look forward to the implementation of a catch-survey analysis for this stock.

Responses to CPT Comments: Stock separation discussed. CSA model in development.

CPT comments September 2009:

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. This information was included and presented to the CPT.

CPT comments May 2010:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

- *The 'Total Crab @ survey' column in Table 4 is incorrect and needs to be recalculated.*
- *Equation 3 is the same as equation 1 and needs to be corrected for females.*
- *Reorganize the chapter so that it is in standard format of text, tables, and figures.*
- *All tables on page 1 should be updated for final assessment in September 2010.*

Responses to CPT Comments: Each pint addressed.

Introduction

1. **Blue king crabs,** *Paralithodes platypus*

2. **Distribution** - Blue king crab are anomurans in the family Lithodidae which also includes the red king crab (*Paralithodes camtschaticus*) and golden or brown king crab (*Lithodes aequispinus*) in Alaska. Blue king crabs occur off Hokkaido in Japan, with disjunct populations occurring in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are known from the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and the outer parts of Norton Sound. In the remainder of the Bering Sea, they are found in the waters off St. Matthew Island and the Pribilof Islands. In more southerly areas as far as southeastern Alaska in the Gulf of Alaska, blue king crabs are found in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). This disjunct, insular distribution of blue king crab relative to the similar but more broadly distributed red king crab is likely the result of post-glacial period increases in water temperature that have limited the distribution of this cold-water adapted species (Somerton 1985). Factors that may be directly responsible for limiting the distribution include the physiological requirements for reproduction, competition with the more warm-water adapted red king crab, exclusion by warm-water predators, or habitat requirements for settlement of larvae (Somerton 1985; Armstrong et al 1985, 1987).

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab were managed under the Bering Sea king crab Registration Area Q Pribilof District, which has as its southern boundary a line from 54° 36' N lat., 168° W long., to 54° 36' N lat., 171° W long., to 55° 30' N lat., 171° W. long., to 55° 30' N lat., 173° 30' E long., as its northern boundary the latitude of Cape Newenham (58° 39' N lat.), as its eastern boundary a line from 54° 36' N lat., 168° W long., to 58° 39' N lat., 168° W long., to Cape Newenham (58° 39’ N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

3. **Stock structure** - Stock structure of blue king crabs in the North Pacific is largely unknown. However, samples were collected in 2009/2010 to support a M.S. project at the University of Alaska. To assess the potential relationship between blue king crab in the Pribilof Islands and St. Matthew, the author consulted the AFSC report entitled “Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans” by Spencer et al. (In Prep). Per this document, aspects of blue king crab harvest and abundance trends, phenotypic characteristics, behavior, movement, and genetics will be considered. Is was also, noted that ~200 samples have been collected to support a genetic study on blue king crab population structure by a graduate student at the University of Alaska.

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 1.3 million lbs by eight vessels (Figure 3). Landings increased during the 1970s and peaked at a harvest of 11.0 million lbs in the 1980/81 season with an associated increase in effort to 110 vessels (ADF&G 2008). Following 1995, declines in the stock resulted in a closure from 1999 to present. The Pribilof blue king crab stock was declared overfished in September of 2002 and the Alaska Department of Fish and Game developed a rebuilding harvest strategy as part of the North Pacific Fishery Management Council's (NPFMC) comprehensive rebuilding plan for the stock. The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990, ADF&G 2008). The fishery was male only, and legal size was >16.5 cm carapace width (NOAA 1995). Guideline harvest level (GHL) was 10 percent of the abundance of mature male or 20 percent of the number of legal males (ADF&G 2006).

   Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 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.

   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 (*Chionoecetes bairdi*), the Bering Sea hair crab (*Erimacrus isenbeckii*), and the Pribilof red and blue king crab. In addition blue king crab are bycatch in flatfish and Pacific cod fisheries.

Data

1. The standard survey time series data updated through 2010 and the standard groundfish discards time series data updated through 2010 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2009/2010 data.

2. a. Total catch:
   Crab pot fisheries
   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

   b. Bycatch and discards:
   Crab pot fisheries
   Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight (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).

   $$\text{Weight (g)} = A * \text{CL(mm)}^B \qquad (1)$$

   $$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \qquad (2)$$

   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 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 2009/2010, Pribilof blue king crab were not incidentally caught in any crab fishery (Table 2).

   Groundfish pot, trawl, and hook and line fisheries
   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, 0.002 million lbs of male and female blue king crab were caught in groundfish fisheries. The catch was in non-pelagic trawls (61%), longline (22%), and pot (18%) fisheries. The targeted species in these fisheries were yellowfin sole (51%), Pacific cod (39%), and flathead sole (10%).

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 (million lbs).

$$\text{Proportion mature male} = 1/(1 + (3.726 * 10^{15}) * e^{((CL(mm)+2.5) * -0.332)}$$
$$\text{Proportion mature female} = 1/(1 + (8.495 * 10^{13}) * e^{((CL(mm)+2.5) * -0.332)} \quad (3)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 3).

In 2010, Pribilof Island District blue king crab were observed in 8 of the 41 stations in the Pribilof District, all of which were in the high-density sampling area (Chilt0n et al. in press, Figure 7). Legal-sized males were caught at three stations east of St. Paul Island and one station north of St. George, with a density ranging from 62 to 71 crab/nmi^2 . The 2010 abundance estimate of legal-sized males was 0.45 ± 0.42 million lbs, representing 48% of the total male biomass and below the average of 3.67 ± 3.50 metric tons for the previous 20 years (Figure 8). Blue king crab mature males were caught at five stations in the Pribilof District high-density sampling representing 77% of the total male abundance. Immature male blue king crab were caught at two stations representing the remaining 33% of the total male biomass in the Pribilof District (Figs. 15 and 16). Mature female blue king crab were caught at five stations in the Pribilof District high-density sampling area with a biomass estimate of 0.78 ± 0.94 metric tons representing 81% of the total female biomass. Sixteen of the 28 female blue king crab sampled during the survey were brooding uneyed or eyed embryos. While eight of the females were immature and in softshell condition, 50% of the mature females were new hardshell crab all with newly extruded embryos while 50% were oldshell females of which 60% were brooding eyed embryos and 40% had empty egg cases.

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.

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 2010 assessment was calculated as the average MMB_{mating} from 1980 to 1984 and 1990 to 1997 to avoid time periods of low abundance possibly caused by high fishing pressure.

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	4.64	0.67[A]	0	0	0.005	
2008/09	4.64	0.25[B]	0	0	0.001	0.004
2009/10	4.64	1.13[C]	0	0	0.001	0.004
2010/11		0.63 [D]				0.004

All units are tons of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2009/10 and is hence overfished. Overfishing did not occur during the 2009/10 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:
5. For 2009/2010, B_{MSY}^{prox}=9.28 million lbs 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. 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 2010/2011 is estimated at 0.63 million lbs for B_{MSY}^{prox}. The B/B_{MSY}^{prox} ratio and F_{OFL} corresponding to the biomass reference option is 0.07 and F_{OFL}=0.00. B/B_{MSY}^{prox} is < β, therefore the stock status level is c, $F_{directed} = 0$, and $F_{OFL} \leq F_{MSY}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008). The preferred alternative was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/2006 which was 0.004 million lbs. 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.

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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 (10^6 lbs)	Avg CPUE (legal crab count/pot)
1973/1974	174,420	1.28	26
1974/1975	908,072	7.11	20
1975/1976	314,931	2.43	19
1976/1977	855,505	6.61	12
1977/1978	807,092	6.46	8
1978/1979	797,364	6.40	8
1979/1980	815,557	6.00	10
1980/1981	1,497,101	10.97	9
1981/1982	1,202,499	9.08	7
1982/1983	587,908	4.41	5
1983/1984	276,364	2.19	3
1984/1985	40,427	0.31	3
1985/1986	76,945	0.53	3
1986/1987	36,988	0.26	2
1987/1988	95,130	0.70	2
1988/1989	0	0.00	0
1989/1990	0	0.00	0
1990/1991	0	0.00	0
1991/1992	0	0.00	0
1992/1993	0	0.00	0
1993/1994	0	0.00	0
1994/1995	0	0.00	0
1995/1996	190,951	1.38	5
1996/1997	127,712	0.94	4
1997/1998	68,603	0.51	3
1998/1999	68,419	0.52	3
1999/2000	0	0.00	0
2000/2001	0	0.00	0
2001/2002	0	0.00	0
2002/2003	0	0.00	0
2003/2004	0	0.00	0
2004/2005	0	0.00	0
2005/2006	0	0.00	0
2006/2007	0	0.00	0
2007/2008	0	0.00	0
2008/2009	0	0.00	0
2009/2010	0	0.00	0

Table 2. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District blue king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2008; D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (10^6 lbs)	Sublegal male (10^6 lbs)	Female (10^6 lbs)	All fixed (10^6 lbs)	All Trawl (10^6 lbs)
1991/1992	0	0	0	0.0001	0.0109
1992/1993	0	0	0	0.0010	0.1072
1993/1994	0	0	0	<0.0001	0.0604
1994/1995	0	0	0	<0.0001	0.0121
1995/1996	0	0	0	0.0001	0.0023
1996/1997	0	0.001	0	<0.0001	0.0001
1997/1998	0	0	0	0.0016	0.0002
1998/1999	0.003	0.001	0.004	0.0218	0.0001
1999/2000	0.004	0.005	0.002	0.0009	<0.0001
2000/2001	0	0	0	0.0001	<0.0001
2001/2002	0	0	0	0.0009	0.0001
2002/2003	0	0	0	0.0001	0.0005
2003/2004	0	0	0	0.0004	0.0004
2004/2005	0	0	0	0.0009	<0.0001
2005/2006	0	0	0.0001	0.0004	0.0024
2006/2007	0	0	0.0001	0.0002	0.0001
2007/2008	0	0	0.0001	0.0044	0.0002
2008/2009	0	0	0	0.0002	0.0008
2009/2010	0	0	0	0.0004	0.0009

Table 3. Pribilof Islands District blue king crab abundance, mature biomass, and legal male biomass (million lbs), and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature males @ survey 10^6 lbs	Mature males @ mating 10^6 lbs	Legal Males @ survey 10^6 lbs	Total males @ survey 10^6 lbs	Total females @ survey 10^6 lbs
1980/1981	32.63	17.97	28.00		
1981/1982	32.19	19.47	27.56		
1982/1983	16.95	10.63	14.57		
1983/1984	11.51	8.01	8.66		
1984/1985	4.92	4.05	3.97		
1985/1986	2.51	1.70	1.93		
1986/1987	2.84	2.26	2.80		
1987/1988	5.27	3.97	4.96		
1988/1989	1.40	1.24	1.39		
1989/1990	2.02	1.79	1.59		
1990/1991	6.17	5.47	2.29		
1991/1992	8.80	7.74	5.53		
1992/1993	9.17	8.05	5.51		
1993/1994	8.73	7.71	5.78		
1994/1995	6.24	5.53	4.63		
1995/1996	16.49	13.24	12.74		
1996/1997	9.94	7.88	7.63		
1997/1998	6.11	4.89	4.96		
1998/1999	6.75	5.46	5.45		
1999/2000	3.73	3.30	2.93		
2000/2001	4.14	3.67	3.37		
2001/2002	3.17	2.81	2.78		
2002/2003	1.36	1.20	1.29		
2003/2004	1.34	1.19	1.28		
2004/2005	0.29	0.26	0.11		
2005/2006	0.76	0.68	0.76		
2006/2007	0.39	0.34	0.28		
2007/2008	0.76	0.67	0.41	1.02	0.65
2008/2009	0.29	0.25	0.10	0.57	1.74
2009/2010	1.28	1.13	0.37	1.51	1.40
2010/2011	0.71	0.63	0.45	0.93	0.95

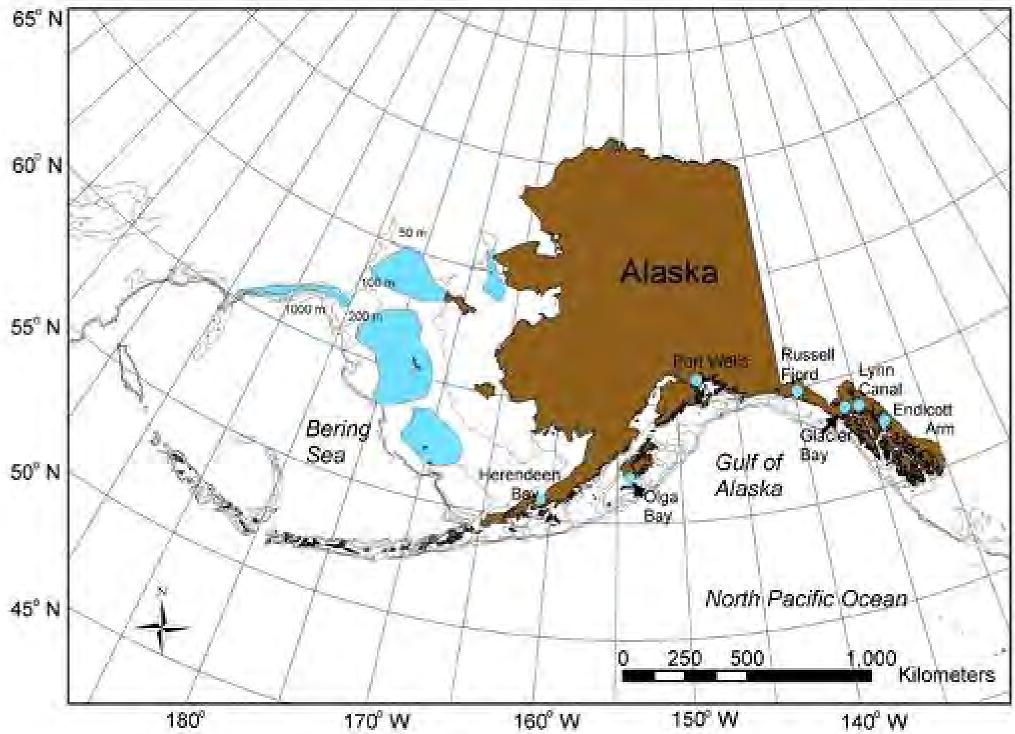

Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

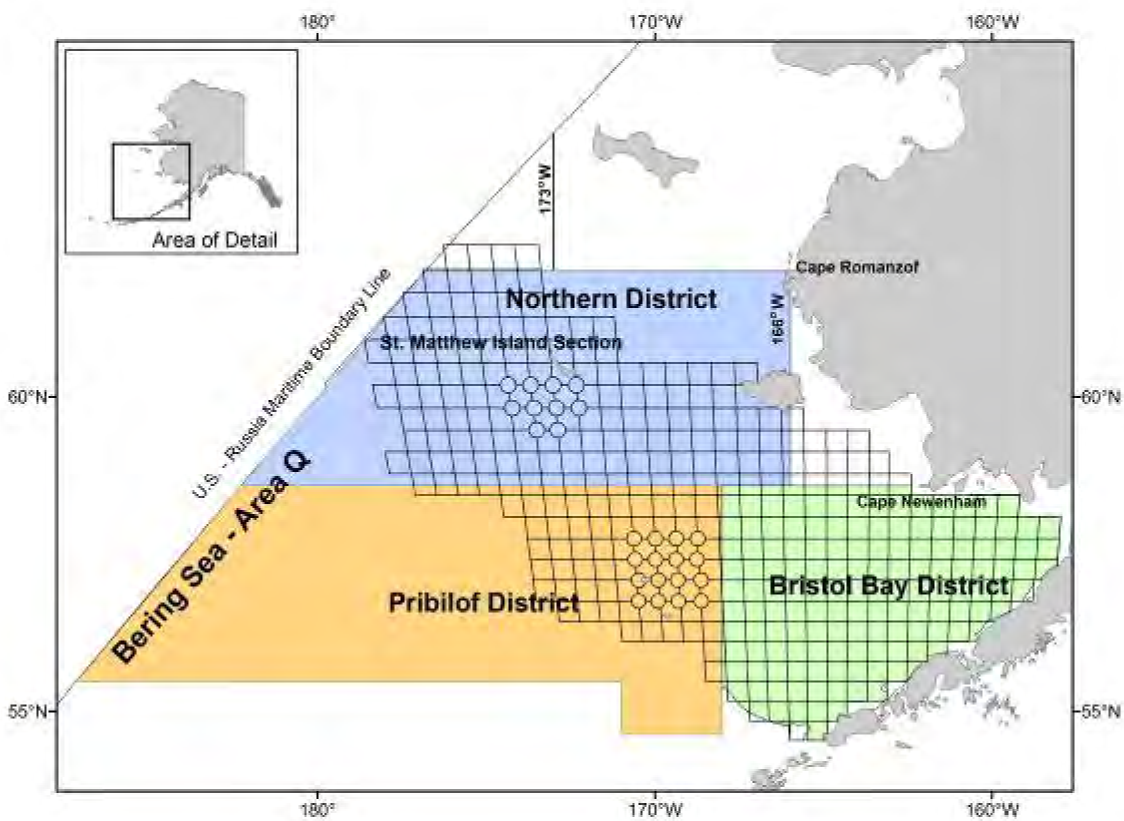

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

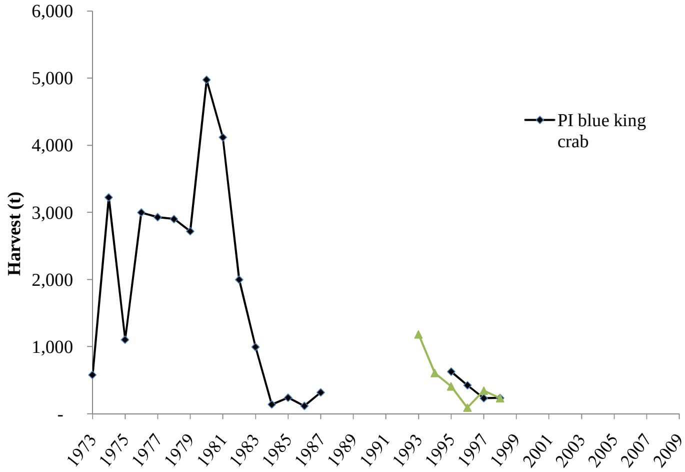

Figure 3. Historical harvests (million lbs) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2007).

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area. Trawl fishing is prohibited year-round in this zone.

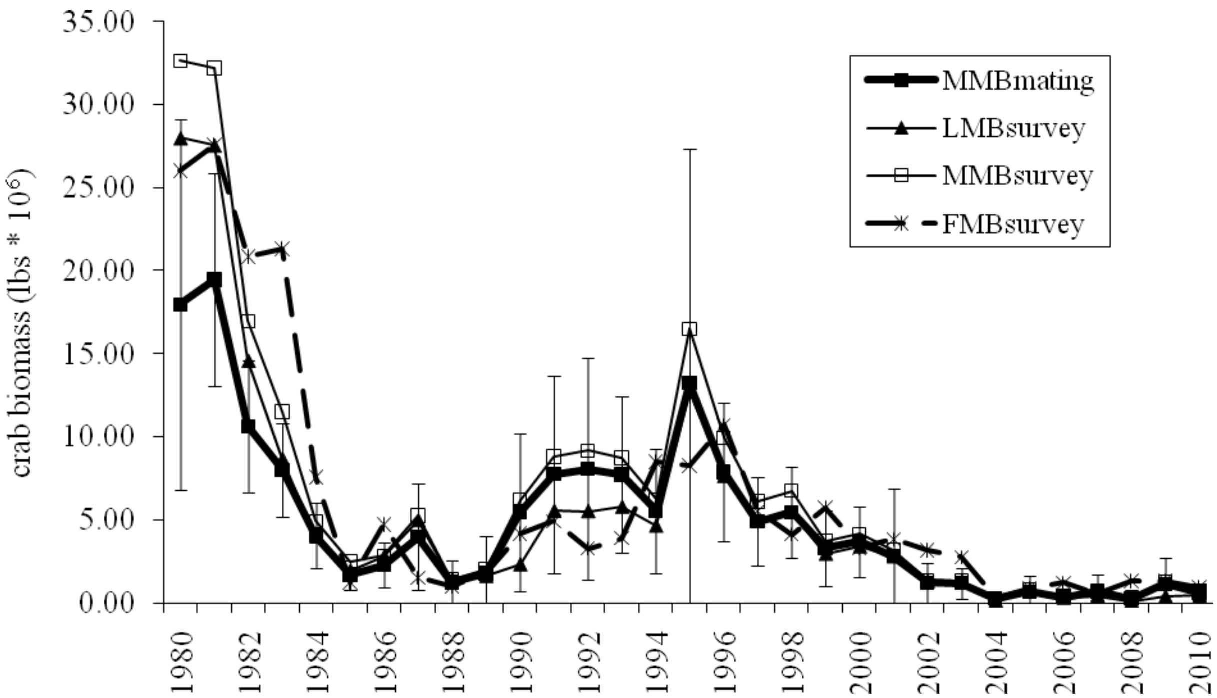

Figure 5. Historical trends of Pribilof Island blue king crab mature male biomass (95% C.I.), mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

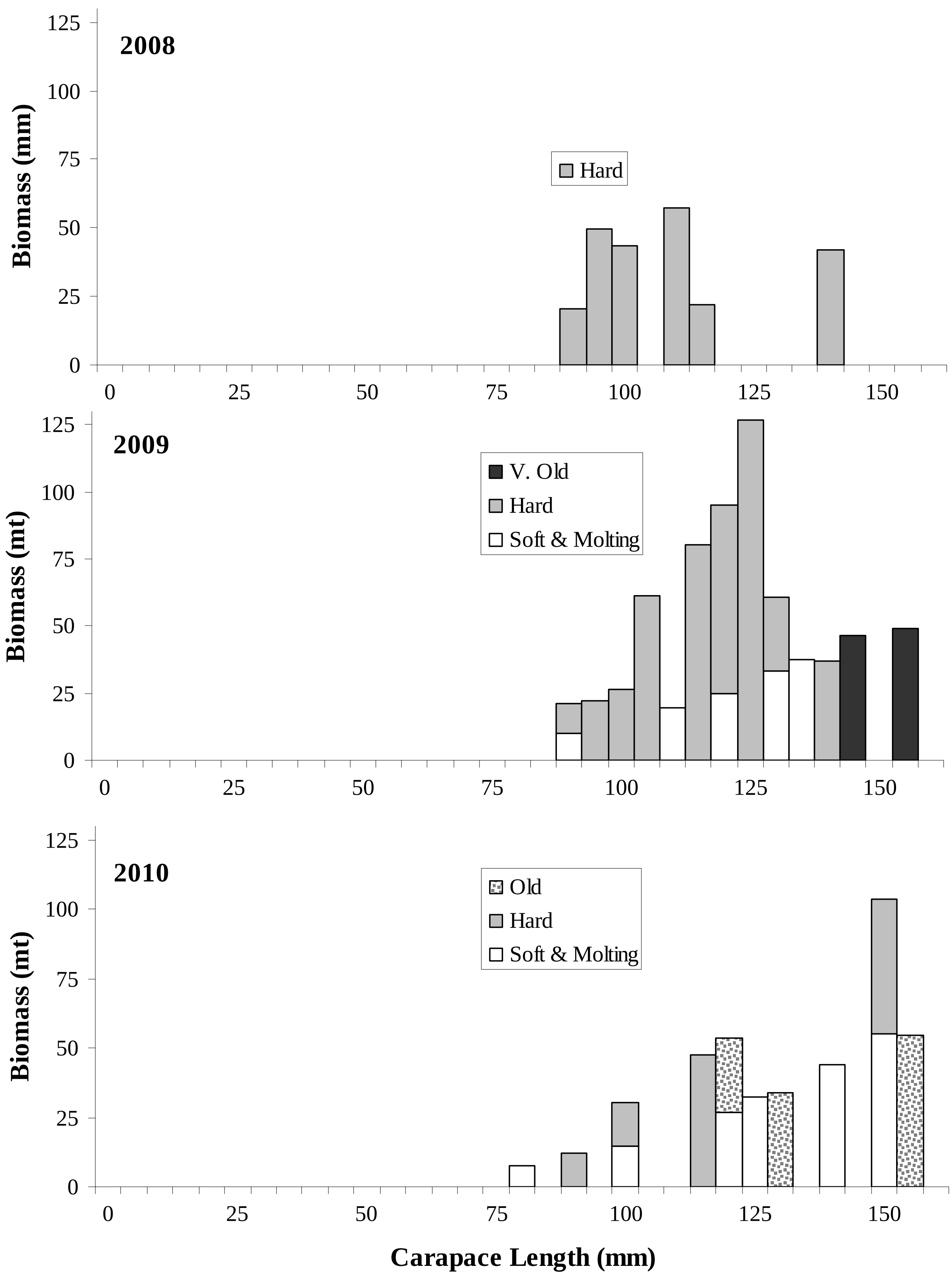

Figure 6. Distribution of Pribilof Island blue king crab in 5 mm length bins by shell condition for the last 3 surveys.

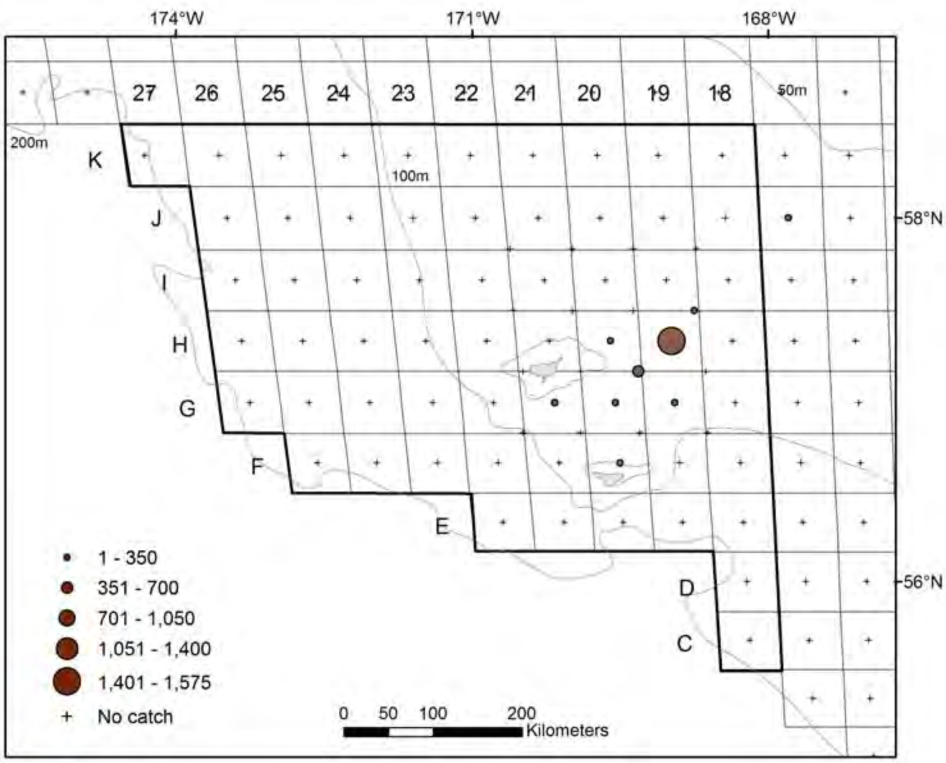

Figure 7. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2010 EBS bottom trawl survey.

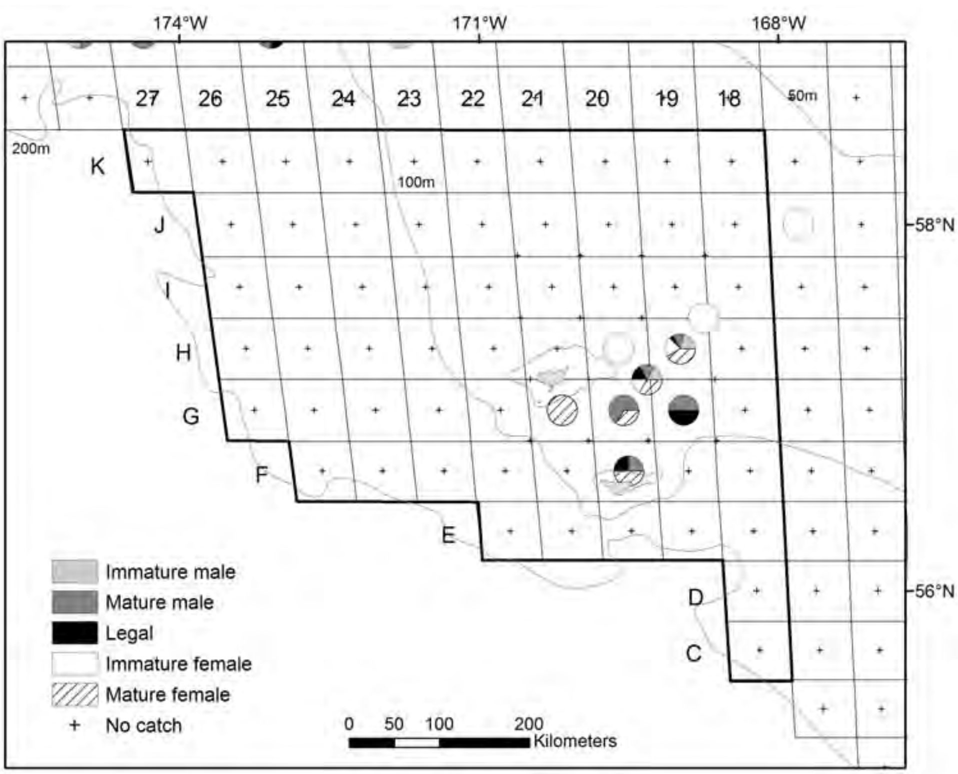

Figure 8. 2010 EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

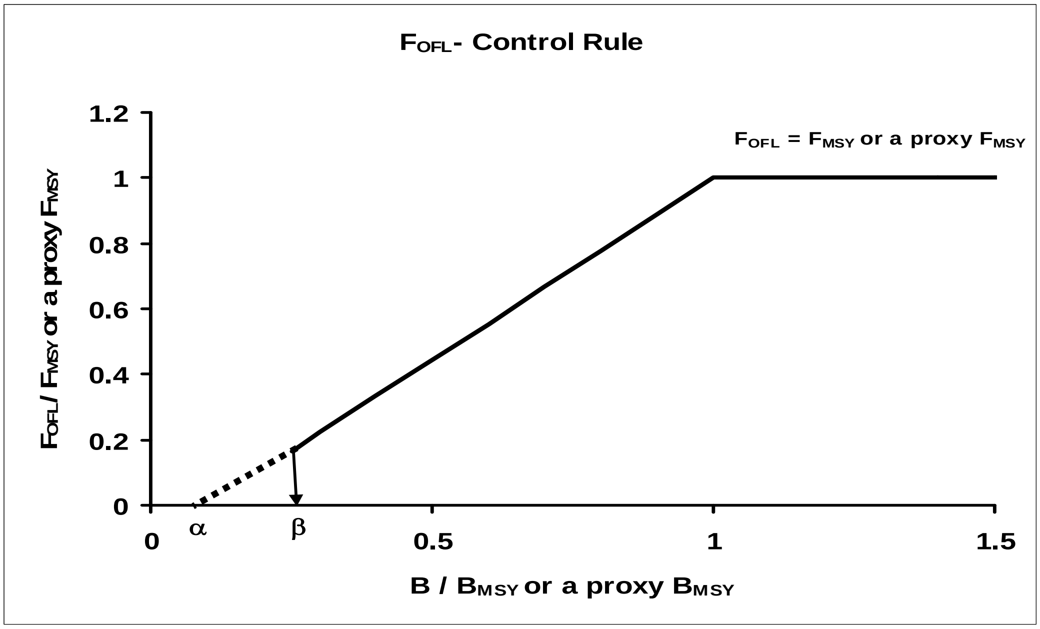

Figure 9. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

St. Matthew Island Blue King Crab
2010 SAFE Chapter

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Executive Summary

1. <u>Stock</u>: Blue king crab, *Paralithodes platypus*, St. Matthew Island, Alaska.

2. <u>Catches</u>: The directed fishery was closed from 1999 to 2008 and reopened during 2009/10 with a TAC of 1.17 million pounds. Fishery reported retained catch was 0.461 million pounds (209 t). Discard mortality in the directed pot fishery was estimated from ADF&G observer data to be 0.048 million pounds (22 t), assuming a 20% handling mortality. Groundfish fishery bycatch has fluctuated over time; 2009/10 bycatch mortality in the groundfish fisheries was estimated at 0.021 million pounds (10 t) under the assumption of handling mortalities of 50 and 80%, respectively, in the fixed-gear and trawl fisheries.

3. <u>Stock biomass</u>: Estimated stock biomass displays an upward trend in recent years. Estimated 2009/10 Feb 15 MMB was 12.762 million pounds (5,789 t). Model predicted 2010/2011 Feb 15 MMB assuming F = F_{MSY} proxy (0.18yr^{-1}) was 15.292 million pounds (6,936 t).

4. <u>Recruitment</u>: Like stock biomass, estimated recruitment is generally strong in recent years, with estimated 2010/11 recruitment to the model markedly higher than that for any other year. This is consistent with the unusually high 2010 trawl-survey abundance estimate of crabs in the model's smallest length class.

5. <u>Management performance</u>: Estimated 2009/10 Feb 15 MMB is above the MSST of 3.431 million pounds (1,556 t); hence the stock is not overfished. As total male catch did not exceed the OFL, overfishing did not occur in 2009/10. Model projections suggest it is unlikely the stock is nearing overfished status in the coming year. See table below. (All biomass measures in millions of pounds.)

Year	MSST	Biomass[a] (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06	-	5.3	Fishery Closed		0.47	-
2006/07	-	7.1	Fishery Closed		0.66	-
2007/08	-	9.7	Fishery Closed		0.35	-
2008/09	4.0	10.74	Fishery Closed		0.20	1.63[b]
2009/10	3.4	12.76	1.167	0.461[c]	0.53	1.72[d]
2010/11	TBD	15.29[e]	--------------TBD-------------			2.29[d,e]

[a] From post-fishery fall assessment.
[b] Retained catch OFL.
[c] Fishery reported value.
[d] Total male catch OFL.
[e] Model projection assuming F = F_{MSY} proxy.

6. Basis for the OFL: Feb 15 MMB is used as the measure of biomass for this Tier 4 stock. The current B_{MSY} proxy is average estimated 1989/99 – 2009/10 Feb 15 MMB, estimated at 6.861 million pounds (3,112 t) using the 2010 model. The F_{MSY} proxy is the assumed $0.18yr^{-1}$ instantaneous natural mortality. See table below. (All biomass measures in millions of pounds.)

Year	Tier	B_{MSY}	B (MMB)	B/B_{MSY}	F_{OFL}	Basis for 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	$0.18yr^{-1}$
2010/11	4a	6.861	15.292*	2.229	$0.18yr^{-1}$	1989/90 - 2009/10	$0.18yr^{-1}$

* Model projection assuming 2010/11 total male catch equals the OFL.

7. A summary of the results of any rebuilding analyses: The stock was declared rebuilt in 2009.

A. Summary of Major Changes in 2010

1. Changes to the management of the fishery: None.

2. Changes to the input data:
- Groundfish trawl and fixed-gear bycatch data were included.
- Trawl survey data were updated to reflect the 2009 revision in NMFS area-swept estimation methodology.
- Survey composition data were adjusted to account for an assumed shell-condition classification error.

3. Changes to the assessment methodology:
- Biomass and composition data were separately incorporated into the likelihood.
- Survey CVs for survey biomass estimates were used in weighting the components of the likelihood.

4. Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:
- Results include comparison of model output and groundfish bycatch data that has been added into the analysis.
- The various components of the OFL (total male catch), including estimates of groundfish trawl and fixed-gear bycatch, are separately provided.

B. Responses to Last Two Sets of CPT and SSC Comments

1. CPT and SSC comments on assessments in general:
- CPT, May 2010
  Comments: *Each stock assessment author should remove the ecosystem section of their chapter and provide it to Liz Chilton for incorporation into the ecosystem consideration chapter.*
  Response: The ecosystem section of the report has been removed and provided to Liz Chilton.

- SSC, June 2010
  Comments: *In order to have greater consistency between assessments, the SSC recommends that catch statistics reported in the executive summary section contain both metric tons and pounds (millions).*

  It would be useful to consider presenting results from the newly developed projection models for stocks during the next assessment cycle. For example, the SSC notes that the projection model for Pribilof red king crab could be interpreted as an indication that the stock is approaching an *overfished condition. This information should be provided in the SAFE when the assessments are finalized in the fall, even though OFL determinations will be based on Tier 4 considerations.*

Response: Recent catches reported in the executive summary section were given in both millions of pounds and metric tons. The projection model for this stock is still in development.

2. CPT and SSC comments specific to this assessment:

- CPT, September 2009
  Comments: *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.*

  Response: Efforts will continue in trying to make the model more sophisticated. Groundfish bycatch data were incorporated into the model for the 2010 assessment. Due to the spatial distribution of this stock, the trawl survey provides little information about the female population. However, future work may allow inclusion of females in the total catch OFL.

- SSC, October 2009
  Comments: *(1) [T]owards 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}.*

  Response: "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." (From May 2010 Report)

- CPT, May 2010
  Comments: *The CPT recommends that the stock be in Tier 4 with gamma =1 used for calculating FOFL. 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.*

  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. [In addition] …the author should: (5) justify weights used in log likelihood computation (e.g., lambda = 100 for retained catch); (6) report CVs in table on pot survey data; and (7) 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).

Response: The stock was considered Tier 4 with $\gamma = 1$ for OFL calculations. The assessment was based on the described scenario and updated survey and bycatch data. All enumerated items except (5) have been explicitly addressed in this report. A rigorous justification of the loglikelihood weighting scheme remains to be given. ADF&G is in the process of reviewing the pot-survey data (Doug Pengilly, ADF&G/Kodiak, pers. comm.).

- SSC, June 2010
  Comments: *The SSC supports all of the CPT recommendations. With respect to the issue that the model cannot duplicate the large proportion of recruits seen in the pot surveys, the SSC recommends to the authors to attempt to identify the potential source(s) of this bias: 1) errors in the database, 2) mis-classification of shell age by the biologists on the surveys, and 3) different carapace wear/biofouling rates for this particular stock. Seemingly some of these issues can be addressed by a mark and recapture study, cross-training of staff, or other approaches. Finally, on Figure 15 (p. 410), the year axis should be re-labeled with actual years.*

  Response: ADF&G is examining the pot-survey data with regard to the recruit issue. All figures have been adjusted accordingly.

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 (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska. Adult blue king crabs 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 Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area 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.).

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional population differences between blue king crabs 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 crabs 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.

A four-stage catch-survey analysis (CSA) is used to assess abundance and prescribe fishery quotas for the St. Matthew Island blue king crab (SMBKC) fishery. The four-stage CSA is similar to a full length-based analysis (Zheng et al. 1995, 1997), the major difference being coarser length groups. The larger size categories are particularly useful for a small stock with consistently low survey catches.

Only male crab abundance is modeled in this approach. To be of legal size, male crabs must be at least 5.5 in carapace width, which corresponds to a carapace length (CL) measurement of 120 mm or more. The average growth increment per molt is about 14 mm CL for adult male blue king crabs (Otto and Cummiskey 1990). We thus categorized SMBKC into four stages: prerecruit-2s (90-104 mm CL), prerecruit-1s (105-119 mm CL), recruits (newshell 120-133 mm CL), and postrecruits (oldshell ≥120 mm CL and newshell ≥134 mm CL). In what follows, these four stages are respectively denoted P2, P1, R, and P, and "legal" refers to all crabs in either the recruit or postrecruit stages, which is not immediately representative of "legal" in the sense of fishery regulations.

D. Catch History

Fisheries

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (Table 1). The fishing seasons were generally short, lasting less than a month. From 1986 to 1990 the fishery was fairly stable, harvesting a mean of 1.252 million pounds. The mean catch increased to 3.297 million pounds during 1991-1998. After 1992, the St. Matthew and Pribilof Islands blue king crab fisheries were opened concurrently, dividing vessel effort between the two fisheries. 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 less than or greater than 38.1 m in length, respectively. Those limits reduced by a third the number of pots registered from 1992 to 1993; however, the number of pot lifts 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 pot lifts increased 54% from 1992 (Bowers et al. 2010).

The 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). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998 commercial fishery and in the 1999 ADF&G near-shore pot survey, as well as the low numbers across all male crab size groups caught in the eastern Bering Sea NMFS annual trawl survey from 1999 to 2005. Watson (2005) has found similar trends in abundance indices for St. Matthew blue king crabs based on the 1995-2004 ADF&G triennial St. Matthew Island district pot survey.

In November of 2000, Amendment 15 to the FMP for the Bering Sea/Aleutian Islands King and Tanner crabs was approved to implement a rebuilding plan for the SMBKC stock. 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. Commercial crab fisheries near St. Matthew Island were scheduled in the fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crabs.

NMFS declared the SMBKC stock rebuilt on Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC (Total Allowable Catch) of 1.17 million pounds, closing again by regulation on Feb 1, 2010. Seven participating vessels landed a catch of just 460,859 pounds (103,376 crabs), with a reported effort of 10,484 pot lifts and an estimated CPUE of 9.9 retained crabs per pot lift (ADF&G/Dutch Harbor, pers. comm.). Based on pot-lift sampling by ADF&G onboard observers, it is estimated that another 17,364 female, 115,154 sublegal, and 3,901 legal male blue king crabs were captured and discarded at sea.

Though historical observer data are limited, bycatch of female and sublegal male crabs from the directed blue king crab fishery off St. Matthew Island was relatively high in past years, with estimated total bycatch in terms of number of crabs captured sometimes twice as high or higher than total catch of legal crabs (Moore et al. 2000). In addition to bycatch in the directed fishery, some limited bycatch of non-retained SMBKC has historically been observed in the eastern Bering Sea snow crab fishery, although ADF&G onboard observers recorded no blue king crabs in 1,646 sampled pot lifts during the

2009/10 season. The St. Matthew Island golden king crab fishery, the third commercial crab fishery in that area, typically occurs in areas with depths exceeding blue king crab distribution. Some SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries.

Harvest Strategy

Subject to the federal overfishing limits, the current SMBKC 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: 1) a threshold of 2.9-million pounds of mature male biomass; 2) an exploitation rate on mature male abundance that is a function of mature male biomass; and 3) a 40% cap on the harvest of legal males.

Mature male biomass (MMB) is defined for the harvest strategy as the biomass of males with a carapace length (CL) of 105 mm or greater 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 at least 105 mm in CL, is determined as a function of MMB. The exploitation rate increases linearly from 10% when MMB equals 2.9-million pounds to 20% when MMB equals 11.6-million pounds. For MMB exceeding 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), with 120 mm CL used as a proxy in stock-assessment computations. To protect from excessive harvest of the legal component of the mature male stock, the targeted number of legal males for commercial harvest is capped at 40% of the estimated legal-sized male abundance.

E. Data

Results reported here are based on SMBKC commercial fishery, survey, and groundfish bycatch data from the 1978/79 through the 2009/10 crab year and including the 2010 NMFS trawl-survey results. (The crab year begins on July 1 and will typically be the time frame referenced by the word "year" in all description of the model, model data, and model results.) Prior to its closure in 1999, ADF&G crab observer coverage in the SMBKC directed fishery was limited at best, with only 1-3 out of 90-131 vessels observed from 1995 to 1998 (Moore et al. 2000). During the 2009/10 fishery, on the other hand, all seven participating vessels carried onboard observers, who sampled approximately 9% of the fishery reported 10,484 pot lifts (ADF&G/Dutch Harbor, pers. comm.). Although those data played no role in this analysis, should the fishery continue to be prosecuted, it can be expected that observer data in the directed fishery will provide a valuable source of information for future stock modeling efforts.

Fishery Catch Data

Basic statistics for the historical directed SMBKC fishery from 1977/78 through 2009/10 are provided in Table 1. For the fall 2010 assessment, both annual reported retained catch weight (including deadloss) and the fishery reported mean retained crab weight were used in the analysis. These data were obtained from ADF&G/Dutch Harbor.

NMFS Trawl Survey Data

As part of its annual Eastern Bering Sea trawl survey, NMFS has conducted summer SMBKC surveys since 1978. Trawl survey stations located within the St. Matthew Island Section of the ADF&G Northern District are used to assess the SMBKC stock. 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. After 1982, distinct low- and high-station-density strata were identified. The low-density stratum consists of 28 stations within an 11,228 nm^2 area, and the high density stratum consists of 29 stations in a 7,619 nm^2 area. Total area calculations assume 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. Further details concerning survey design, gear specifications, and estimation methods are available in Lauth and Acuna (2009) and Stauffer (2004).

Crab density (number/nm^2) was estimated at each station for each of the four crab stages of the catch-survey analysis using recently revised estimates of area swept (Robert Foy, NMFS/AFSC/Kodiak Lab, pers. comm.). Stage abundance within each survey stratum was then estimated by averaging crab densities among all stations within the stratum and multiplying by the total area of the stratum. An estimate of total stage abundance within the St. Matthew Island Section management unit was obtained by adding the stratum estimates (Table 2).

The stage-specific abundance estimates enter directly into the catch-survey analysis in the form of composition data (i.e. proportions). In addition, an estimate of total survey biomass contributed by the four stages, as well as an estimate of its coefficient of variation, was also used in the modeling process. See Table 2. The 2010 trawl survey data were supplied by Robert Foy, NMFS/AFSC/Kodiak Lab.

ADF&G Pot Survey Data

ADF&G performed a triennial SMBKC pot survey in 1995, 1998, 2001, 2004, 2007, and 2010. This survey is designed to sample from areas of important habitat for blue king crabs, particularly female crabs, that are inaccessible to the NMFS trawl survey. The pot surveys were usually conducted during late July and August with a chartered commercial crab pot vessel. Watson (2008) describes survey design and sampling protocols, gives results for the 2007 survey, and compares them with those of the earlier surveys. Complete results from the 2010 survey were not available for the fall 2010 stock assessment.

The 2007 survey station grid encompasses the 2,850 nmi^2 area between 59º30' - 60º30' N. latitude and 172º00' - 174º00' W. longitude and contains 141 primary stations and 24 secondary stations. Ninety-six stations were fished in common to each of the five surveys prior to 2010 (Figure 3), and these stations were again included in 2010. Both crab-stage proportions and mean pot biomass estimates generated from historical (1995-2007) survey CPUE indices from these 96 stations, along with an estimated coefficient of variation for the latter, (Table 3) were used in the catch-survey analysis. These data were supplied by Doug Pengilly, ADF&G/Kodiak.

Groundfish Bycatch Data

Additional data used in this analysis consist of estimated SMBKC crab-stage proportions for selected years in both the trawl (Table 4) and fixed-gear (Table 5) fisheries and a measure of total SMBKC bycatch biomass in each of these fisheries for the years 1992/93 through 2009/10 (Table 6). These data are based on NMFS groundfish observer data, which present some difficulties with respect to their appropriate use in modeling the SMBKC stock because of geographical incongruities between groundfish observer reporting areas and the SMBKC stock management area and because the reported biomass measures apply to all captured crabs, irrespective of CL (Robert Foy, NMFS/AFSC/Kodiak Lab, pers. comm.). For the 2010 fall assessment no composition data were available. SMBKC total biomass estimates were obtained by summing blue king crab biomass numbers from reporting areas 524 and 521 according to gear type.

F. Analytical Approach

Model Description

The CSA model links crab abundances in the four stages in year *t+1* to abundances in the previous year *t* subject to fishing, natural mortality, molting, and growth, while allowing for new crabs entering the model in each year. Given survival to the end of the year, molting crabs within each stage "grow" into different stages according to a growth matrix (Table 7), whereas non-molting crabs remain in the same stage or, if currently in stage R (recruits), move into stage P (postrecruits). For purposes of the analysis, it is assumed that the directed pot fishery occurs in the first half of the crab year, with other relevant fisheries taking place at the start of the second half of the year. Thus with $P2_t^b$ and $P1_t^b$ denoting P2 (prerecruit-2) and P1 (prerecruit-1) abundances after handling mortality and prior to molting and growth in year *t*, model stage dynamics are conveniently described by the set of equations

$$P2_t^b = (P2_t e^{-0.5M_t} - hc2_t e^{-(0.5-y_t)M_t})\, e^{-0.5M_t - st_2 Ft_t - sf_2 Ff_t} (1 - sp_2 Ho_t h),$$
$$P1_t^b = (P1_t e^{-0.5M_t} - hc1_t e^{-(0.5-y_t)M_t})\, e^{-0.5M_t - st_1 Ft_t - sf_1 Ff_t} (1 - sp_1 Ho_t h),$$
$$P2_{t+1} = P2_t^b[(1-m2_t) + m2_t\, G_{P2,P2}] + N_{t+1},$$
$$P1_{t+1} = P1_t^b[(1-m1_t) + m1_t\, G_{P1,P1}] + P2_t^b\, m2_t\, G_{P2,P1},$$
$$R_{t+1} = P2_t^b\, m2_t\, G_{P2,R} + P1_t^b\, m1_t\, G_{P1,R},$$
$$P_{t+1} = [(P_t + R_t)e^{-0.5M_t} - rc_t e^{-(0.5-y_t)M_t}]e^{-0.5M_t - Ft_t - Ff_t} (1 - Ho_t h),$$

where M_t is instantaneous natural mortality in year *t*; y_t is the time lag from the start of the crab year to the mid-point of the fishery in year *t*; $hc2_t$ and $hc1_t$ are year *t* directed fishery bycatches for P2 and P1 crab; st_2, st_1, sf_2, sf_1, sp_2, and sp_1 are P2 and P1 selectivities in the groundfish trawl, groundfish fixed-gear, and crab pot fisheries; Ft_t and Ff_t are year *t* groundfish trawl and fixed-gear instantaneous fishing mortalities; Ho_t is the bycatch rate in all other crab pot fisheries in year *t*; *h* is the general crab pot fishery handling mortality rate; $m2_t$ and $m1_t$ are molting probabilities for P2s and P1s in year *t*; $G_{i,j}$ is the proportion of molting crabs growing from stage *i* to stage *j*; N_t is the number of new P2 crabs entering the model in year *t*; and rc_t is the estimated year *t* retained catch in the directed fishery.

This last quantity, the directed SMBKC pot fishery retained catch, is estimated in the model by $rc_t = (P_t + R_t)hr$, where $hr = 1.0 - e^{-F_t}$ is the estimated year *t* harvest rate on legal males defined with respect to the time of the survey, with associated directed fishing mortality F_t. P2 and P1 bycatch numbers in the directed fishery are then estimated by $hc2_t = sp_2\, hr\, P2_t\, h$ and $hc1_t = sp_1 hr\, P1_t\, h$, where *h* denotes the handling mortality rate, and bycatch numbers in the groundfish fisheries by

$$tc2_t = (P2_t\, e^{-0.5M_t} - hc2_t e^{-(0.5-y_t)M_t})(1 - e^{-st_2\, Ft_t}),$$
$$tc1_t = (P1_t\, e^{-0.5M_t} - hc1_t e^{-(0.5-y_t)M_t})(1 - e^{-st_1\, Ft_t}),$$
$$tc_t = [(P_t + R_t)e^{-0.5M_t} - rc_t e^{-(0.5-y_t)M_t}](1 - e^{-Ft_t}),$$
$$fc2_t = (P2_t\, e^{-0.5M_t} - hc2_t e^{-(0.5-y_t)M_t})(1 - e^{-sf_2\, Ff_2}),$$
$$fc1_t = (P1_t\, e^{-0.5M_t} - hc1_t e^{-(0.5-y_t)M_t})(1 - e^{-sf_1\, Ff_1}),$$
$$fc_t = [(P_t + R_t)e^{-0.5M_t} - rc_t e^{-(0.5-y_t)M_t}](1 - e^{-Ff_t}),$$

with $tc2_t$, $tc1_t$, tc_t, $fc2_t$, $fc1_t$, and fc_t respectively designating P2, P1, and legal male bycatches in the groundfish trawl and fixed-gear fisheries.

Year t trawl-survey biomass, Bt_t, and pot-survey biomass index, Bp_t, are estimated by

$$Bt_t = q(st_2 P2_t w_1 + st_1 P1_t w_2 + Rw_3 + Pw_4)$$

$$Bp_t = \frac{1}{q_p}(sp_2 P2_t w_1 + spP1_t w_2 + Rw_3 + Pw_4),$$

where q represents trawl-survey catchability and q_p is a scaling factor; st_2, st_1, sp_2, and sp_1 are the appropriate selectivities; and w_j is stage j mean crab weight. Estimated groundfish trawl and fixed-gear bycatch biomasses are obtained analogously by applying the w_j to the estimated stage bycatch numbers given above. Year t directed fishery retained catch weight is estimated by $Bc_t = rc_t\, avg\_w_t$, where rc_t is the estimated retained catch already described, and avg_w_t is the annual fishery reported mean weight of retained crabs.

Main Model Assumptions

The following list outlines main model assumptions under the scenario used in this assessment and as recommended by the CPT in May 2010. Some additional details are provided in subsequent sections of this report.

1. The NMFS trawl survey date and start of the crab year is taken to be July 1.

2. Fishing mortality attributable to the directed pot fishery occurs at the midpoint of the legal fishing season. For 2009/2010 this was taken to be Dec 8, 2009.

3. Instantaneous natural mortality equals 0.18 across stages and all years except 1998/99, for which it is estimated in the model.

4. Trawl survey catchability for legal males is equal to 1.0 over all years; pot survey catchability is independent of survey year.

5. Fishing mortality attributable to the groundfish trawl and fixed-gear fisheries occurs following the directed pot fishery on January 1, the beginning of the second half of the crab year.

6. Fishery and survey prerecruit selectivities relative to legal males are a function of stage and constant over time. P2 and P1 selectivities in the directed pot fishery are respectively 0.4 and 0.6 based on similar values estimated for Bristol Bay red king crabs (Zheng and Siddeek 2008) and are otherwise estimated in the model.

7. The handling mortality rate is 0.20 in crab pot fisheries, including the directed fishery, and 0.50 and 0.80 respectively in the groundfish fixed-gear and trawl fisheries.

8. Prerecruit molting probabilities are a function of stage and change over time according to a constrained random walk process, with the model estimated ratio of P2 to P1 molting probabilities constant across years.

9. Growth is constant over time and is adequately quantified by crab-stage transition probabilities based on Otto and Cummiskey (1990) (Table 7).

10. Observed crab-stage proportions in both the trawl and pot surveys reflect a systematic misclassification such that 20% of the reported number of recruits are properly postrecruits; these data are adjusted accordingly within the model. (This adjustment was made because model estimates of the proportion of recruits were systematically lower than observed in the surveys.)

11. Crab-stage mean weights are constant over time, both across and within years, and are adequately characterized using previously estimated length-weight relationships.

12. Legal male bycatch in the groundfish fisheries consists of 35% recruits and 65% postrecruits.

13. Neither the NMFS trawl survey nor the ADF&G pot survey contributes to crab mortality, and incidental bycatch in other crab pot fisheries has been inconsequential. Aside from natural mortality, only the directed pot fishery and the groundfish fisheries impact the stock.

14. Reported retained catch and observed trawl-survey, pot-survey, and total groundfish trawl and fixed-gear bycatch biomasses have a log normal distribution.

15. Observed trawl-survey, pot-survey, and groundfish trawl and fixed-gear stage proportions are approximately normally distributed.

16. First-year trawl-survey observed stage proportions suitably approximate the true proportions.

17. Mature male crabs are precisely those with a CL of 105mm or greater, i.e. all P1, R, and P-stage crabs.

Natural Mortality

The estimate of instantaneous natural mortality for all species of king crabs in the eastern Bering Sea is 0.2 as defined by the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). Siddeek et al. (2002) estimated overall natural mortality for SMBKC to be 0.19 after reexamining tagging experiments conducted around St. Matthew Island in 1995 and 1998. One other effort to estimate natural mortality for SMBKC based on tagging data has been reported, with values ranging from 0.19 to 2.04 for adult male blue king crabs (Otto and Cummiskey 1990). In the analysis described here, for all years except 1999 natural mortality was assumed to be 0.18 based on a maximum age of 25 and the 1% rule (Zheng 2005). Natural mortality in 1999 was estimated in the model.

Handling Mortality

Discard mortality rates have been established by the NPFMC (1999) as either species or fishery specific. 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 directed pot fishery bycatch mortality rate was used for development of the current ADF&G harvest strategy, and the results reported here assume a mortality rate of 20% for discarded blue king crab in the directed pot fishery. Handling mortality rates from 0 to 50% have previously shown comparatively little impact on estimates of legal male abundance and mature male biomass (Zheng et al. 2008).

Crab Stage Mean Weights

Based on a sample of 136 blue king crabs collected in 1978 to 1981 from St. Matthew Island, Somerton and MacIntosh (1983) described the carapace length-weight relationship for blue king crab males using the equation $W = 0.000329\ CL^{3.175}$, with carapace length (CL) measured in millimeters and weight (W) in grams. This equation was applied to the midpoints of the P2, P1, and R stage size intervals and to an assumed P stage representative CL of 144 mm to obtain estimates of mean stage weight for calculating model estimates of crab biomass. (It should be noted that the estimate of average weight of retained crabs computed using the above relationship and data from dockside size-frequency sampling of retained catch is consistently lower than the fishery reported value derived from fish-ticket data, and in 2009/10 was 16% less.)

Male Size at Maturity

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 CL, and ADF&G considers as mature all male crabs with a carapace length of 105 mm or more when estimating total mature male biomass. This convention was likewise employed in the analysis presented here.

Model Estimated Parameters

Five model scenarios differing in the choice of model estimated parameters were

previously reviewed by the CPT in May 2010. The analysis described here is based on the scenario recommended at that time, which is the same one used for the 2009/10 assessment. Under this scenario, instantaneous mortality is set at 0.18 across all stages and years except 1998/99, and trawl survey catchability is assumed equal to 1.0 irrespective of year. Together with instantaneous mortality in 1999, the selected scenario requires model estimation of 148 primary parameters (Table 8).

All other model estimated quantities were computed from the set of directly estimated primary parameters through the stage dynamics model or in subsidiary calculations. P2 and P1 selectivities relative to legal males for the trawl survey, pot survey, and groundfish trawl and fixed-gear fisheries were determined using a logistic function of stage mid-length l by $s_l = \frac{1}{1+e^{-\varphi(l-\omega)}}$, with a separate set of coefficients φ and ω for each of the four cases, requiring model estimation of eight primary parameters.

P2 molting probabilities were modeled as a constrained random-walk process according to $m_{t+1} = \frac{1}{1+(\frac{1}{m_t}-1)e^{\eta_t}}$, where m_t denotes P2 molting probability in year t and the η_t represent iid zero-mean normal random variates. Note that this formulation ensures that the process will lie in the interval (0, 1), provided such holds true for the initial value m_1, which was separately estimated in the model. P1 molting probability in each year was then obtained from that of P2 using their ratio, assumed to be constant with respect to time and likewise a separately estimated primary model parameter.

The sequence F_i of yearly instantaneous fishing mortalities in the directed pot fishery and in the groundfish trawl and fixed-gear fisheries was each assumed to satisfy $logF_i = logF + \epsilon_i$ subject to $\sum \epsilon_i = 0$. Model estimates of the primary parameters $log\ F$ and ϵ_i then yield immediate estimates of the F_i. Estimation of yearly numbers of P2 recruits, i.e new crabs entering the model, relied on the same approach. Whereas instantaneous fishing mortality was estimated in the directed fishery for each year from 1978/79, in the groundfish fisheries it was directly estimated only for the crab years 1992-2009 for which groundfish bycatch total biomass data are available. The 1992-1996 5-year average estimated value was assumed for the years 1978-1991; the 2005-2009 5-year average estimated value was assumed for the 2010 crab year when calculating projected quantities.

Estimation Method

Primary parameter estimation was implemented in AD Model Builder (ADMB Project 2009) by way of a maximum likelihood approach involving minimization of a suitably chosen objective function depending on both the unknown primary parameters and the observed data, i.e. the negative of the "loglikelihood" function. This function was constructed using a weighted sum of 5 terms incorporating model biomass estimates of directed fishery, groundfish fishery, and survey measures of biomass; 4 terms based on model estimates of observed groundfish fishery and survey stage proportions; and another 5 "penalty" terms associated with yearly variation in fishing mortalities, P2 recruitment, and molting probability (Table 9). Where distributionally plausible estimates of variance were available, as for the two survey biomass measures and the proportions data, these were used in assigning corresponding weights, though in the latter case the natural weighting was modified by a function of the sample size (number of observed crabs) to account for statistical dependence in the data. Weights for additional terms, as well as the overall weighting scheme, were developed in the process of model selection and in subsequent graphical exploration and sensitivity analysis.

It is of relevance to observe that the 2010 model was compiled using the MinGW GCC C++ compiler inasmuch as choice of compiler can substantially affect model behavior.

G. Model Results

Abundance and Parameter Estimates

Model estimated crab-stage abundances for the years 1978/79-2010/11 are shown in Table 10, which also gives yearly estimates of P2-recruit abundance, P2 molting probability, and instantaneous fishing mortalities in the directed pot fishery and groundfish trawl and fixed-gear fisheries. Estimated abundances of all four stages generally increase over the past several years, and current estimates are uniformly high, with estimated 2010 P2 abundance markedly higher than for any other year. These numbers undoubtedly reflect the similarly high abundance estimates coming from the 2010 NMFS trawl survey (Table 2). Although results from the 2010 ADF&G pot survey were not available for use in this assessment, preliminary reports regarding the 2010 survey CPUEs for both fishery-legal and sublegal crabs (R. Gish, ADF&G, pers. comm.) offer confirmatory indication of improving stock conditions.

In keeping with the high estimates of recent crab-stage abundances, the time series of both estimated Feb 15 MMB and legal abundance at the time of the survey (Figure 4) exhibit consistent upward trends since the 1998/99 stock collapse. MMB in 2009/10 is estimated to be 12.762 million pounds (standard error 1.978), which is well above the existing MSST (= ½B_{MSY} proxy) of 3.431 million pounds and thus provides strong evidence that the stock is not currently overfished. Projected 2010/11 MMB is 15.292 million pounds, which is near the estimated historical high. This projection assumes that fishing mortality in the directed fishery equals natural mortality (0.18yr^{-1}) and that fishing mortalities in the groundfish trawl and fixed-gear fisheries equal their most recent five-year average estimated values, as given in Table 10. It should be noted, however, that considerable uncertainty characterizes this estimate. Figure 5 depicts the ADMB-computed profile likelihood for projected 2010/11 MMB, as well as for estimated 2010 legal abundance. The ADMB reported profile-likelihood 95% confidence interval for 2010/11 MMB is 9.513 to 22.737 million pounds. Alternately, ADMB reports an asymptotic normal 95% confidence interval of 8.657 to 21.647 million pounds based on standard likelihood theory. Estimated 2010 legal abundance is 2.904 million crabs, with associated 95% confidence intervals 1.731 to 4.353 million crabs from the estimated profile likelihood and 1.621 to 4.133 million crabs by way of normal approximation to the likelihood.

Model results require estimation of 148 primary parameters (Table 8). Table 11 lists estimates and standard errors of primary parameters other than deviations determining yearly P2-recruit abundances, P2 molting probabilities, and fishing mortalities in the directed pot and groundfish trawl and fixed-gear fisheries. The latter parameters are more meaningfully accounted for in terms of estimated P2-recruit abundance, P2 molting probability, and fishing mortality themselves (Table 10). All primary parameter estimates are within the interior of the model specified parameter space. The relative contributions of the terms in the loglikelihood to the solution offer some insight into what features of the model and data are driving the estimation procedure (Table 9). The term associated with crab-stage proportions in the trawl survey dominates the solution of -258.93 with an individual contribution of -202.49. Note that the contributions both of the five biomass terms and of the five deviation or penalty terms are bounded below by zero in the minimization procedure.

Agreement of Model and Data

Model estimates of directed fishery retained catch are generally very close to fishery reported values throughout the period 1978-2009 (Figure 6). Estimated (male) bycatch over the same time, for which corroborating data are mostly unavailable, remains comparatively small under the model postulated 20% handling mortality and P2 and P1 selectivities of 0.4 and 0.6. In 2009/10, after a 10-year closure, the fishery reported landings (including deadloss) amounted to 0.461 million pounds. The model estimate is 0.466 million pounds, contributing to an estimated 2009 total catch of 0.550 million pounds (standard error 0.040). Estimated harvest rate in the directed fishery, defined as the ratio of estimated retained catch to estimated legal abundance at the time of the fishery, and its relation to estimated MMB (Figure 7) provide further characterization of the directed fishery. There is, for example, some suggestion of a moderately stable equilibrium fishery in the decade or so prior to the abrupt changes of 1998/99. During these years annual retained catch averaged on the order of 3 million pounds (Figure 6).

The fit of model estimated values to observed trawl-survey biomass measures appears acceptable given the assessed level of imprecision in each (Figure 8). Agreement between model and observed pot-survey biomass appears more questionable, with two of the five pairs of values displaying presumably unlikely differences. It should be noted, however, that the corresponding loglikelihood term is down weighted relative to that associated with trawl-survey biomass (Table 9), effectively assuming a higher level of imprecision in the observed values over that depicted in Figure 8. Model fit to observed measures of groundfish trawl and fixed-gear bycatch are shown in Figure 9. No estimates of the inherent variability of the observed quantities are available, but it is likely large compared to the magnitude of the quantities involved, which typically have comparably limited impact on the modeled stock.

The residual plots of Figure 10 provide a means of examining model fit with respect to crab-stage composition data. The observed survey proportions used to construct these plots were adjusted as in model computations to account for an assumed shell-condition misclassification resulting in some P-stage crabs being improperly assigned to stage R. Even so, there remains some indication of systematic overestimation of the proportion of P-stage crabs at the expense of R-stage crabs in the pot survey, as was also noted in the 2009 assessment. Some similarly troubling patterns are evident among the residuals coming from the trawl survey, which exhibit signs of temporal dependence in both sign and magnitude. They are, for example, mostly small throughout much of the 1990s by comparison with the much larger residuals occurring, often in successive years, outside of this period.

Retrospective Analyses

We present two types of graphical retrospective analysis, one based on historical results from previous assessment models (Figure 11) and the other based on results from the 2010 model confronted with historical datasets constructed by sequentially omitting one year's data at a time (Figure 12). For both approaches, this report focuses on estimated legal abundance at the time of the survey. In past reports (e.g. 2009 SAFE), estimated Feb 15 MMB was also considered, but historical model results for MMB were unavailable at the time this document was drafted.

The 2010 model differs in several respects from previous SMBKC assessment models. For one thing, it makes use of groundfish bycatch data. For another, it separately incorporates quantities for biomass and crab-stage composition into the analysis. Such changes have led to increased model complexity, which in turn has triggered secondary modifications, including the current likelihood weighting scheme, designed to arrange acceptable model performance. Still other changes include, for example, adjustments to account for an assumed crab-stage misclassification in both sets of survey data and the use of an alternative compiler. A single, simpler model was in place prior to this year, though different scenarios governed its use before 2008 and thereafter. In addition, the historical data itself were modified after 2009 when NMFS revised slightly the area-swept estimation methodology used with the trawl survey. In spite of these differences, the 2010 model legal-abundance trajectory closely tracks the mostly coherent bundle of those from the previous five assessment models, with the notable exception of the period 1986/87-1998/99 (Figure 11). Over this period it appears to exercise a substantial smoothing effect by comparison with the estimates of the other trajectories and with those from the trawl survey. On the other hand, taking the 2010 trajectory as baseline, terminal year estimates from the historical model results are mostly on target; there is little evidence of any systematic bias.

Figure 12 displays legal-abundance estimates produced using the 2010 model applied to datasets with terminal years 2005/06 through the current assessment year, 2010/11. With the exception of 2008/09, there is fair agreement between terminal year estimates from the reduced datasets and the trajectory based on the complete data, but overall there is wide ranging and sometimes extreme disagreement between the 2010 trajectory and the others, as well as among the others themselves. Even more notable is the erratic appearance of the disparity when considered in conjunction with the trawl-survey estimates, especially during the period 1989-1997. Despite the consistency between 2010 and historical model results seen in the first part of this analysis (Figure 11), the present observations suggest underlying model instability. Further work will be directed at understanding and addressing this issue so that the model can be relied upon to provide useful guidance when confronted with future data.

H. Calculation of The OFL

The SMBKC stock is currently considered a Tier 4 stock (NPFMC 2007). For such stocks abundance estimates are available, but complete population parameters needed for computer simulation studies and spawning biomass per recruit analyses as required for Tier 3 stocks are not. Average estimated biomass with respect to a reference time period is used to define a B_{MSY} proxy, and the F_{MSY} proxy is taken to be γM, where M is the stock instantaneous natural mortality, for a suitably chosen value of γ. These two parameters are required for determination of the OFL (Over Fishing Level).

Given stock parameters B_{MSY} and F_{MSY} or suitable proxy values, the OFL is the level of catch associated with fishing mortality F_{OFL} determined as a function of an appropriate measure of biomass B and two additional parameters α and β according to the control rule

$$a)\quad F_{OFL} = F_{MSY}\,,\ when\ \ B/B_{MSY} > 1;$$
$$b)\quad F_{OFL} = F_{MSY}\,(B/B_{MSY} - \alpha)/(1-\alpha),\ when\ \ \beta < B/B_{MSY} \le 1;$$
$$c)\quad F_{OFL} < F_{MSY}\ \ with\ directed\ \ fishery\,F = 0,\ when\ \ B/B_{MSY} \le \beta.$$

For the SMBKC stock, B is presently taken to be Feb 15 MMB, with α and β specified by their respective default values 0.10 and 0.25. Current CPT recommendations for the stock are to use the period 1989-2009 in defining a B_{MSY} proxy in terms of average estimated Feb 15 MMB, which was updated for this assessment to include 2009/10 fishery and 2010 trawl-survey results, and to set $\gamma = 1$ with assumed $M = 0.18$ in defining the F_{MSY} proxy. Note that as B = MMB is itself a function of fishing mortality, in case b) numerical approximation of F_{OFL} is required.

As was true in each of the last two years, SMBKC stock status for the current year, 2010/11, falls under case a) above, so that F_{OFL} equals the F_{MSY} proxy, presently 0.18. With fishing mortality equal to F_{OFL}, MMB is projected to be 15.292 million pounds (standard error 2.996), which is above the current estimated B_{MSY} proxy of 6.861 million pounds (standard error 0.469) (Figure 4). The corresponding model estimated OFL assigns a total male catch of 2.293 million pounds, the legal retained component of which is 1.989 million pounds, with discard mortalities of 0.263, 0.003, and 0.038 million pounds respectively in the directed pot and groundfish trawl and fixed-gear fisheries (Table 11). In addition to F_{OFL} equal to 0.18, this analysis postulates the average of the most recent 5-year estimated values (Table 10) for 2010/2011 fishing mortality in each of the latter two fisheries.

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Table 1. The St. Matthew Island directed blue king crab fishery, 1977/78-2009/10. (Source: Bowers et al. 2010 and ADF&G/Dutch Harbor, pers. comm.)

			Harvest[b]					
Season	Dates	GHL/TAC[a]	Crabs	Pounds	Pot Lifts	CPUE[c]	Avg Wt[d]	Avg CL[e]
1977/78	06/07-08/16		281,665	1,202,066	17,370	16	4.3	130.4
1978/79	07/15-09/03		436,126	1,984,251	43,754	10	4.5	132.2
1979/80	07/15-08/24		52,966	210,819	9,877	5	4.0	128.8
1980/81	07/15-09/03				CONFIDENTIAL			
1981/82	07/15-08/21		1,045,619	4,627,761	58,550	18	4.4	NA
1982/83	08/01-08/16		1,935,886	8,844,789	165,618	12	4.6	135.1
1983/84	08/20-09/06	8	1,931,990	9,454,323	133,944	14	4.8	137.2
1984/85	09/01-09/08	2.0-4.0	841,017	3,764,592	73,320	11	4.5	135.5
1985/86	09/01-09/06	0.9-1.9	441,479	2,200,781	47,748	9	5.0	139.0
1986/87	09/01-09/06	0.2-0.5	219,548	1,003,162	22,073	10	4.6	134.3
1987/88	09/01-09/05	0.6-1.3	227,447	1,039,779	28,230	8	4.6	134.1
1988/89	09/01-09/05	0.7-1.5	302,098	1,325,185	23,058	30	4.4	133.3
1989/90	09/01-09/04[f]	1.7	247,641	1,166,258	30,803	8	4.7	134.6
1990/91	09/01-09/07	1.9	391,405	1,725,349	26,264	15	4.4	134.3
1991/92	09/16-09/20	3.2	726,519	3,372,066	37,104	20	4.6	134.1
1992/93	09/04-09/07[f]	3.1	545,222	2,475,916	56,630	10	4.6	134.1
1993/94	09/15-09/21	4.4	630,353	3,003,089	58,647	11	4.8	135.4
1994/95	09/15-09/22	3.0	827,015	3,764,262	60,860	14	4.6	133.3
1995/96	09/15-09/20	2.4	666,905	3,166,093	48,560	14	4.8	135.0
1996/97	09/15-09/23	4.3	660,665	3,078,959	91,085	7	4.7	134.6
1997/98	09/15-09/22	5.0	939,822	4,649,660	81,117	12	4.9	139.5
1998/99	09/15-09/26	4.0	635,370	2,968,573	91,826	9	4.7	135.8
1999/00-2008/09				FISHERY CLOSED				
2009/10	10/15-02/01	1.17	103,376	460,859		9.9	4.5	134.9

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Average number of retained crabs per pot lift.
[d] Pounds.
[e] Average Carapace Length of retained crabs in millimeters.
[f] Actual season length was 60 hours.

Table 2**.** NMFS EBS summer trawl survey area-swept estimates of abundance (millions of crabs) and total biomass (millions of pounds) and associated CV for the four crab stages of the catch-survey analysis. In this table and elsewhere, P2, P1, R, and P respectively denote prerecruit-2, prerecruit-1, recruit, and postrecruit crab-model stages. See text for stage definitions. 2009/2010 data were obtained from Robert Foy, NMFS/AFSC/Kodiak Lab.

Year	P2	P1	R	P	Mature[a]	Legal[b]	Biomass	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
2010[c]	3.927	3.253	1.783	0.675	5.711	2.458	24.538	0.466

[a] All prerecruit-1, recruit, and postrecruit stage crabs.
[b] All recruit and postrecruit stage crabs.
[c] 2010 estimates based on 394 crabs with CL ≥ 90mm.

Table 3. Crab-stage CPUE and estimates of mean pot biomass (pounds) and its CV from the 96 common stations surveyed during the six 1995-2010 ADF&G triennial SMBKC pot surveys. (Source: Doug Pengilly, ADF&G/Kodiak)

Year	P2	P1	R	P	Biomass	CV	Number of Crabs
1995	1.919	3.198	3.214	3.708	38.2186	0.130	4,624
1998	0.964	2.763	3.906	4.898	44.4576	0.062	4,812
2001	1.266	1.737	2.378	3.109	28.9935	0.079	3,255
2004	1.719	0.453	0.299	0.826	5.8859	0.152	640
2007	0.5	2.721	2.773	2.063	26.8409	0.097	3,319
2010	---------------------------------------Not yet available--						

Table 4. Groundfish fishery trawl SMBKC bycatch proportions data.
Year designations refer to the crab year.

Year	P2	P1	Legal[a]	Sample Size[b]
1989	0.0000	0.0000	1.0000	3
1990	0.0000	0.0000	1.0000	27
1991	0.0385	0.2692	0.6923	26
1992	0.0370	0.0741	0.8889	27
1995	0.2917	0.1905	0.5179	168
1996	0.0000	0.1429	0.8571	7
1998	0.0000	0.0000	1.0000	3
1999	0.0000	0.2500	0.7500	4
2002	0.0000	0.0769	0.9231	13
2003	0.0455	0.1364	0.8182	22
2004	0.2000	0.2000	0.6000	5
2006	0.1667	0.2083	0.6250	24

[a] All recruit and postrecruit crabs.
[b] Number of observed crabs.

Table 5. Groundfish fishery fixed-gear SMBKC bycatch proportions data. Year designations refer to the crab year.

Year	P2	P1	Legal[a]	Sample Size[b]
1996	0.0000	0.0000	1.0000	3
1997	0.0270	0.0649	0.9081	185
1998	0.1006	0.1538	0.7456	169
1999	0.0167	0.1172	0.8661	239
2000	0.0264	0.0793	0.8943	416
2001	0.1083	0.1529	0.7388	471
2002	0.1310	0.2018	0.6672	1,893
2003	0.0703	0.1333	0.7964	825
2004	0.0321	0.0856	0.8823	374
2005	0.0330	0.0858	0.8812	303
2006	0.0824	0.1412	0.7764	340
2007	0.3835	0.1770	0.4395	1,017
2008	0.1905	0.2381	0.5714	21

[a] All recruit and postrecruit crabs.
[b] Number of observed crabs.

Table 6. SMBKC groundfish fishery bycatch total biomass (pounds) data. Year designations refer to the crab year. (2009/2010 numbers are courtesy of Robert Foy, NMFS/AFSC/Kodiak Lab.)

	Biomass	
Year	Trawl	Fixed Gear
1992	993	5,355
1993	5,232	57
1994	808	199
1995	2,191	446
1996	64	30
1997	18	769
1998	0	2,566
1999	24	6,922
2000	46	91
2001	70	4,380
2002	3,157	2,154
2003	3,510	4,914
2004	394	3,087
2005	0	2,845
2006	5,962	6,783
2007	286	299,895
2008	705	25,797
2009	3,443	36,560

Table 7. SMBKC stock model growth matrix. The entry in the i^{th} row and j^{th} column is the probability of growing from stage i into stage j after molting. It is assumed in the analysis that surviving recruits always become postrecruits after one year, which remain so indefinitely.

	Prerecruit-2	Prerecruit-1	Recruit	Postrecruit
Prerecruit-2	0.11	0.83	0.06	0
Prerecruit-1	0	0.11	0.83	0.06
Recruit	0	0	0	1
Postrecruit	0	0	0	1

Table 8. Primary model estimated parameters.

Parameter	Number
Instantaneous natural mortality in 1999	1
Log first-year abundance	1
Average log annual abundance of P2 recruits for years 1979 – 2010	1
Pot-survey scaling factor	1
Trawl-survey, pot-survey, and groundfish trawl and fixed-gear selectivity coefficients (2 each)	8
P2 molting probability in 1978	1
P2-to-P1 molting probability ratio	1
Average log directed fishery fishing mortality for years 1978 – 2009	1
Average log groundfish trawl fishing mortality for years 1992 – 2009	1
Average log groundfish fixed-gear fishing mortality for years 1992 – 2009	1
Recruit deviations	32
P2 molting probability deviations for years 1979 – 2009	31
Directed fishery fishing mortality deviations	32
Groundfish trawl fishing mortality deviations	18
Groundfish fixed-gear fishing mortality deviations	18
Total Number of Primary Model Estimated Parameters	**148**

Table 9. Model objective function structure and term contributions to the solution.

Likelihood component	Form	Loglikelihood Weight	-Loglikelihood Contribution[a]
Trawl-Survey Biomass	Lognormal Var = $\log(CV^2+1)$	1	15.88
Pot-Survey Biomass	Lognormal Var = $\log(CV^2+1)$	0.2	12.22
Directed Pot Fishery Retained Catch Biomass	Lognormal kernel	100	1.02
GF Trawl Fishery Bycatch Biomass	Lognormal kernel	2	0.20
GF Fixed-Gear Fishery Bycatch Biomass	Lognormal kernel	2	0.08
Trawl-Survey Stage Proportions	Normal Var = $n_{eff}\, p(1-p)$	via effective sample sizes n_{eff}[b]	-202.49
Pot-Survey Stage Proportions	Normal Var = $n_{eff}\, p(1-p)$	via effective sample sizes n_{eff}[b]	-38.19
GF Trawl Bycatch Stage Proportions	Normal Var = $n_{eff}\, p(1-p)$	via effective sample sizes n_{eff}[b]	-15.84
GF Fixed-Gear Bycatch Stage Proportions	Normal Var = $n_{eff}\, p(1-p)$	via effective sample sizes n_{eff}[b]	-46.11
Recruitment Deviations[c]	Normal kernel	0.01	0.27
Directed Fishery Fishing Mortality Deviations[c]	Normal kernel	0.01	7.74
GF Trawl Fishing Mortality Deviations[c]	Normal kernel	0.01	0.28
GF Fixed-Gear Fishing Mortality Deviations[c]	Normal kernel	0.01	0.64
Molting Probability Deviations[c,d]	Normal kernel	2.0	5.37

[a] Minimized solution value = -258.93.
[b] The effective sample size n_{eff} for the class proportions in a given year equals the minimum of n/2 and 100, where n is the total number of observed crabs.
[c] Deviations are additive on the logarithmic scale.
[d] Constrained so that molting probabilities lie in the interval (0,1).

Table 10. Model estimates of P2-recruit and crab-stage abundances, P2 molting probability, and instantaneous fishing mortalities. The directed fishery was closed for ten years during 1999/00-2008/09. Shaded values were imputed rather than directly estimated. See text for details.

	Abundance						Fishing Mortality		
Year	P2 Recruits	P2	P1	R	P	P2 Molting Probability	SMBKC Directed Fishery	Groundfish Trawl	Groundfish Fixed-Gear
1978/79	--	949	2,629	1,096	949	0.53	0.243	2.05E-04	8.79E-05
1979/80	4,206	4,617	1,472	966	1,403	0.67	0.023	2.05E-04	8.79E-05
1980/81	3,092	4,662	2,625	830	1,982	0.70	0.012	2.05E-04	8.79E-05
1981/82	421	1,878	3,090	1,442	2,413	0.76	0.315	2.05E-04	8.79E-05
1982/83	1,419	1,922	1,780	1,634	2,453	0.77	0.630	2.05E-04	8.79E-05
1983/84	613	1,096	1,429	971	1,862	0.78	1.081	2.05E-04	8.79E-05
1984/85	419	684	896	751	819	0.77	0.761	2.05E-04	8.79E-05
1985/86	1,023	1,193	569	475	633	0.80	0.589	2.05E-04	8.79E-05
1986/87	1,032	1,308	767	345	525	0.83	0.292	2.05E-04	8.79E-05
1987/88	1,182	1,460	900	482	569	0.84	0.251	2.05E-04	8.79E-05
1988/89	986	1,283	1,021	573	714	0.84	0.264	2.05E-04	8.79E-05
1989/90	2,365	2,627	942	632	861	0.82	0.179	2.05E-04	8.79E-05
1990/91	1,779	2,355	1,687	635	1,076	0.81	0.259	2.05E-04	8.79E-05
1991/92	1,524	2,060	1,681	1,017	1,161	0.80	0.404	2.05E-04	8.79E-05
1992/93	1,714	2,201	1,498	970	1,260	0.78	0.279	1.09E-04	3.40E-04
1993/94	1,895	2,446	1,538	871	1,454	0.78	0.321	5.53E-04	1.87E-05
1994/95	1,730	2,336	1,673	900	1,448	0.80	0.444	1.00E-04	2.64E-05
1995/96	2,327	2,880	1,640	972	1,299	0.79	0.341	2.42E-04	3.70E-05
1996/97	1,214	1,906	1,934	981	1,394	0.77	0.323	2.28E-05	1.73E-05
1997/98	1,161	1,648	1,485	1,071	1,490	0.70	0.449	2.15E-05	5.65E-05
1998/99	753	1,256	1,223	745	1,390	0.65	0.340	4.03E-05	3.78E-04
1999/00	377	503	279	163	337	0.63	1.08E-05	6.06E-05	0.001511
2000/01	458	644	321	137	426	0.59	9.73E-06	5.89E-05	5.11E-05
2001/02	683	940	390	150	479	0.35	8.77E-06	5.75E-05	7.58E-04
2002/03	112	653	452	111	532	0.32	8.60E-06	8.83E-04	3.66E-04
2003/04	454	844	415	110	544	0.41	8.46E-06	9.68E-04	8.17E-04
2004/05	99	546	460	136	554	0.52	8.05E-06	1.18E-04	4.89E-04
2005/06	982	1,227	404	181	588	0.65	7.28E-06	3.95E-05	4.06E-04
2006/07	1,480	1,909	697	223	655	0.68	6.43E-06	0.001200	8.14E-04
2007/08	1,866	2,498	1,128	392	755	0.57	5.00E-06	5.66E-05	0.026747
2008/09	3,560	4,580	1,450	518	965	0.60	3.93E-06	8.89E-05	0.001771
2009/10	2,649	4,436	2,467	739	1,280	0.64	0.053	3.08E-04	0.001917
2010/11	6,127	7,702	2,845	1,236	1,668	0.64	--	3.39E-04	0.006331

Shaded values were imputed using most proximate 5-year averages rather than estimated directly. See text for further explanation.

Table 11. Model primary parameter estimates other than P2-recruit, P2 molting probability, and fishing mortality deviations.

Parameter	Estimate	Standard Error
Natural mortality in 1999	1.416	0.2095
Log first-year combined P2, P1, R, P abundance (thousands)	8.914	0.1212
Average log annual abundance of P2 recruits 1979-2010 (thousands)	7.002	0.1080
Initial (1978) P2 molting probability	0.53	0.0999
P2-to-P1 molting probability ratio	1.000	0.0001
Pot-survey scaling factor	0.243	0.0298
Average log directed fishery fishing mortality 1978-2009	-4.634	0.1876
Average log groundfish trawl fishing mortality 1992-2009	-8.000	0.0008
Average log groundfish fixed-gear fishing mortality 1992-2009	-8.088	0.0382
Trawl-survey selectivity coefficients	0.133	0.0201
	110.4	2.5934
Pot-survey selectivity coefficients	0.147	0.0555
	98.3	2.4097
Groundfish trawl selectivity coefficients	0.188	0.1189
	120.6	5.9114
Groundfish fixed-gear selectivity coefficients	0.101	0.0183
	125.3	3.7248

Table 12. SMBKC 2010/11 OFL (millions of pounds).

		OFL				
		Directed Fishery		Groundfish Bycatch		
Tier	F_{OFL}	Retained	Discarded[a]	Trawl[b]	Fixed Gear[c]	Total Male
4a	$0.18yr^{-1}$	1.989	0.263	0.003	0.038	2.293

[a] Assumes 0.20 handling mortality.
[b] Assumes 0.80 handling mortality.
[c] Assumes 0.50 handling mortality.

Figure 1. Distribution map of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters.

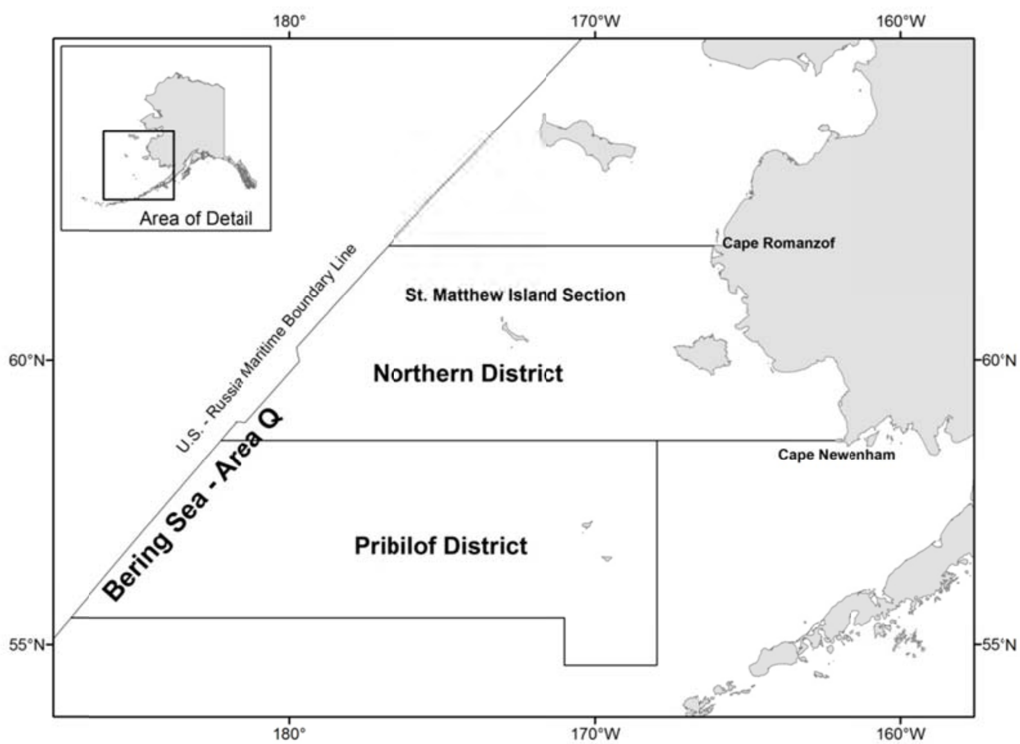


Figure 2. King crab Registration Area Q (Bering Sea).

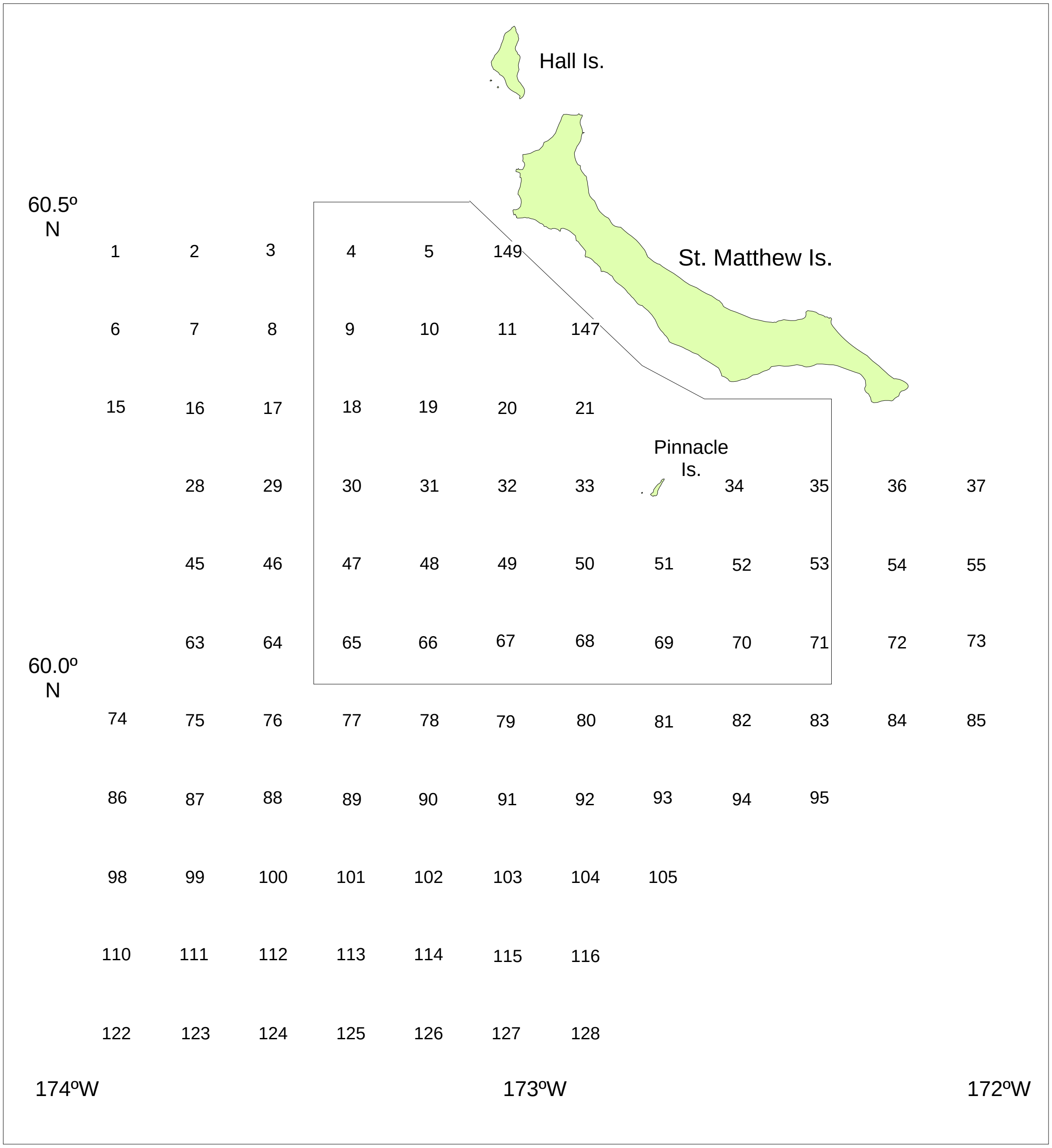
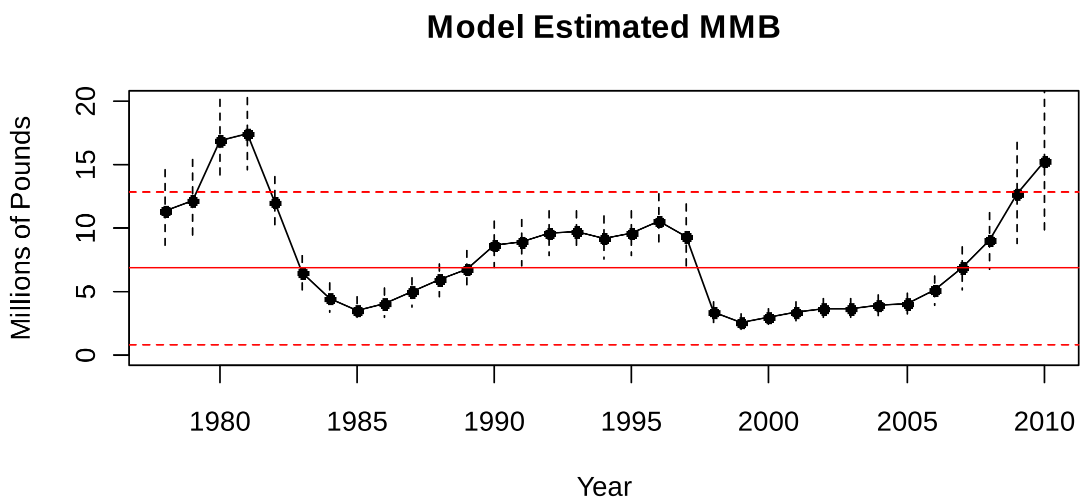


Figure 3. Location of the 96 stations fished in common during the six triennial SMBKC surveys, 1995 - 2010. (Source: Watson 2008)



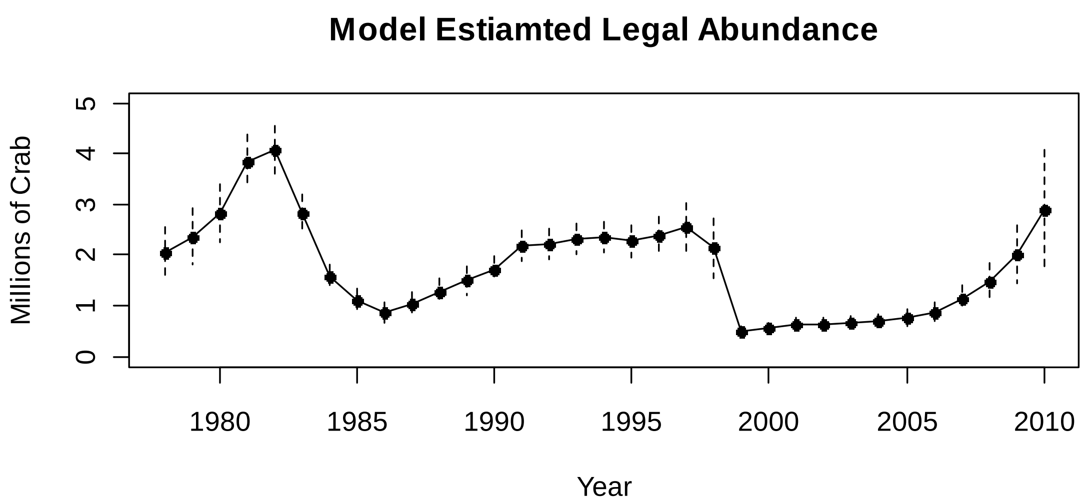


Figure 4. Model estimates of Feb 15 mature male biomass (MMB) and legal abundance at survey time for the years 1978/79-2010/11. Dashed vertical lines represent approximate 95% confidence intervals of point estimates. Horizontal lines in top panel indicate the current estimated B_{MSY} proxy and approximate 95% confidence interval.

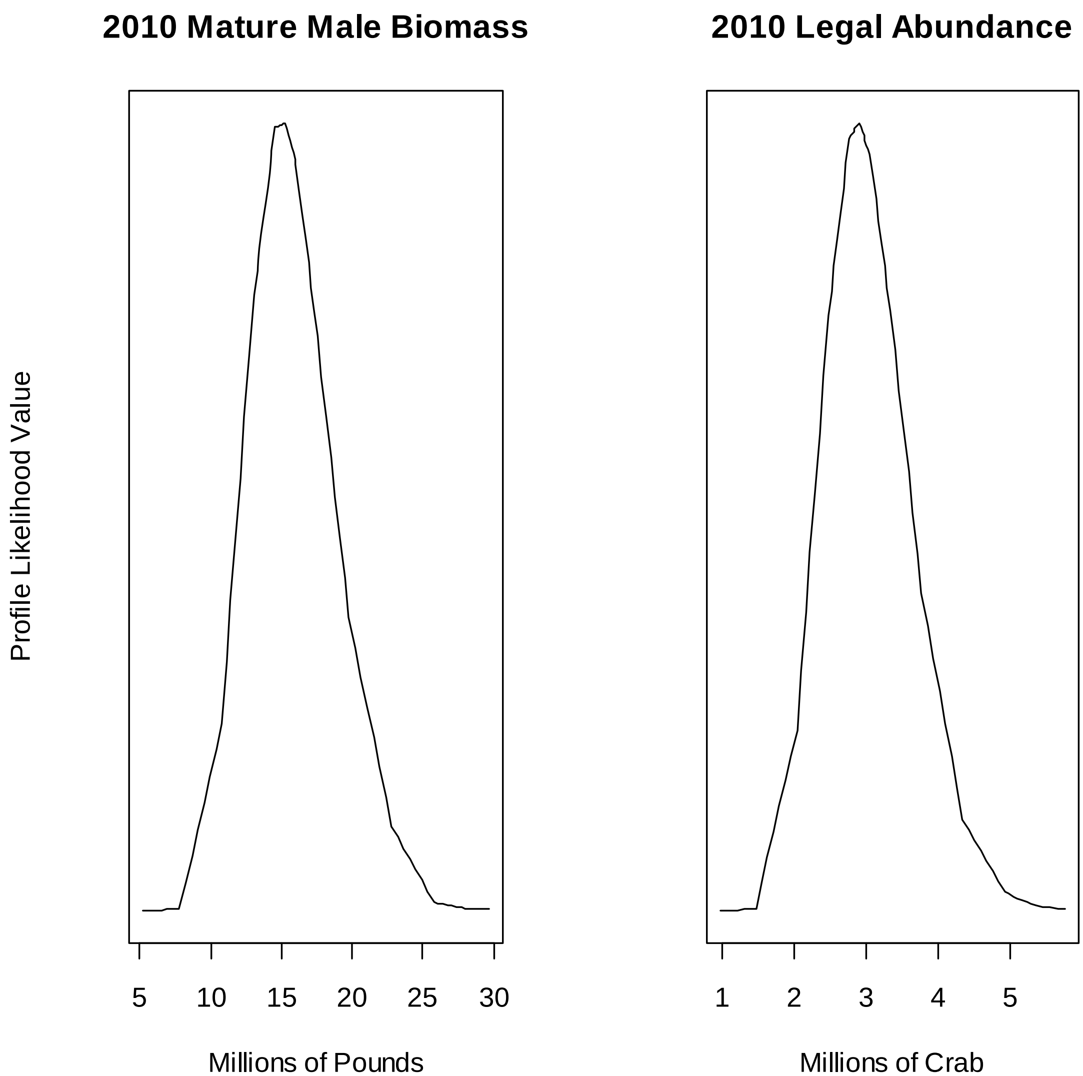


Figure 5: ADMB profile likelihood functions for model estimated 2010/11 MMB and legal abundance.

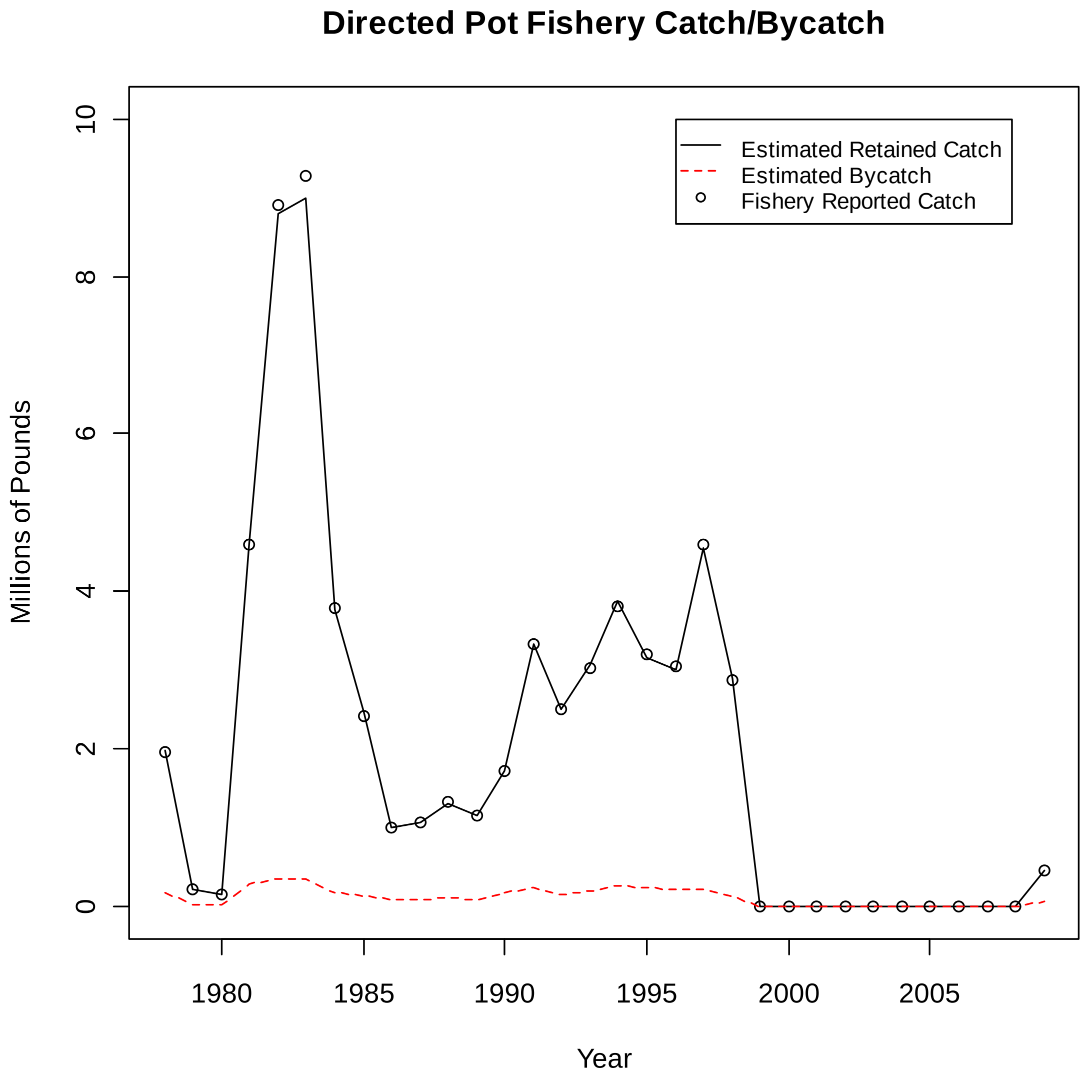
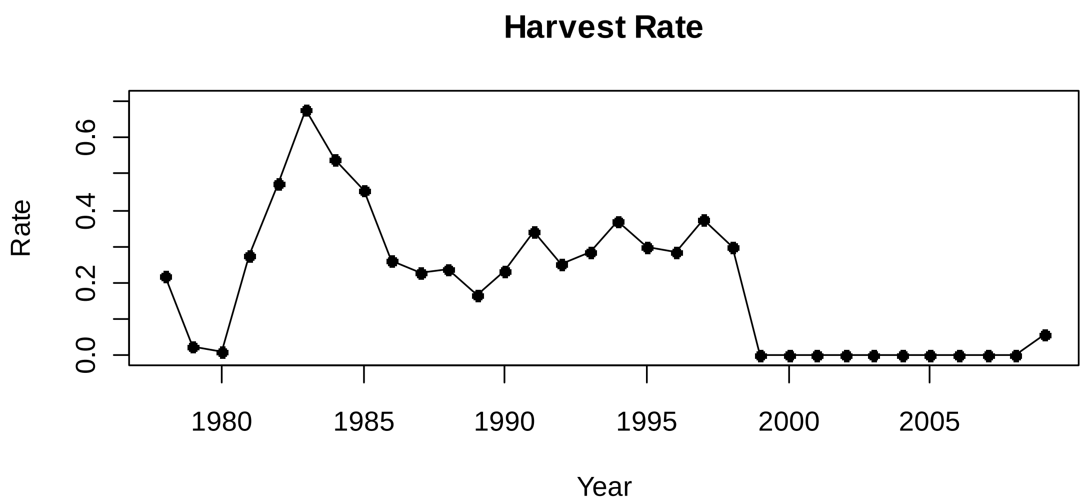


Figure 6. Model estimated and fishery reported catch in the 1978/79-2009/10 SMBKC directed pot fishery. Model estimated bycatch assumes a 0.20 handling mortality. The fishery was closed during 1999/00-2008/09.



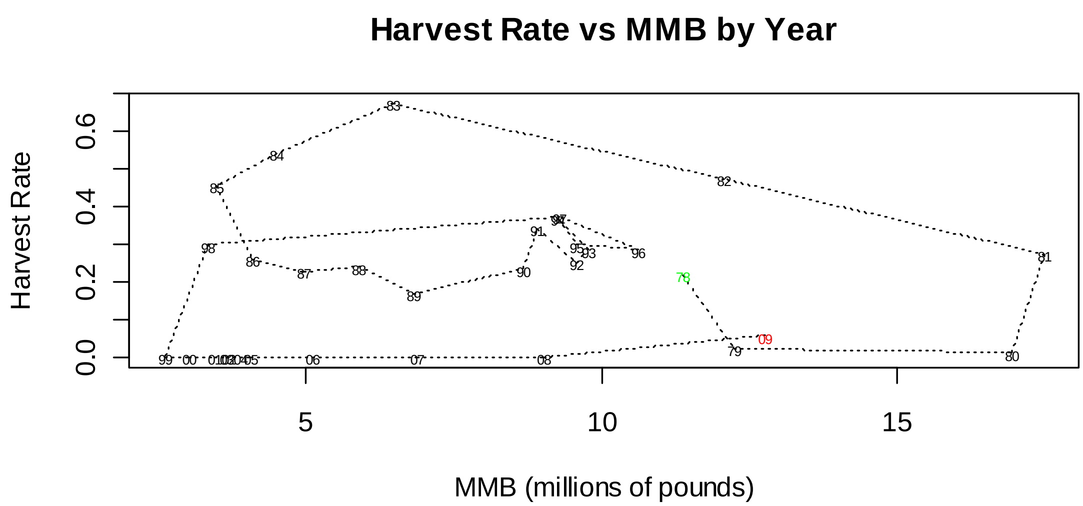
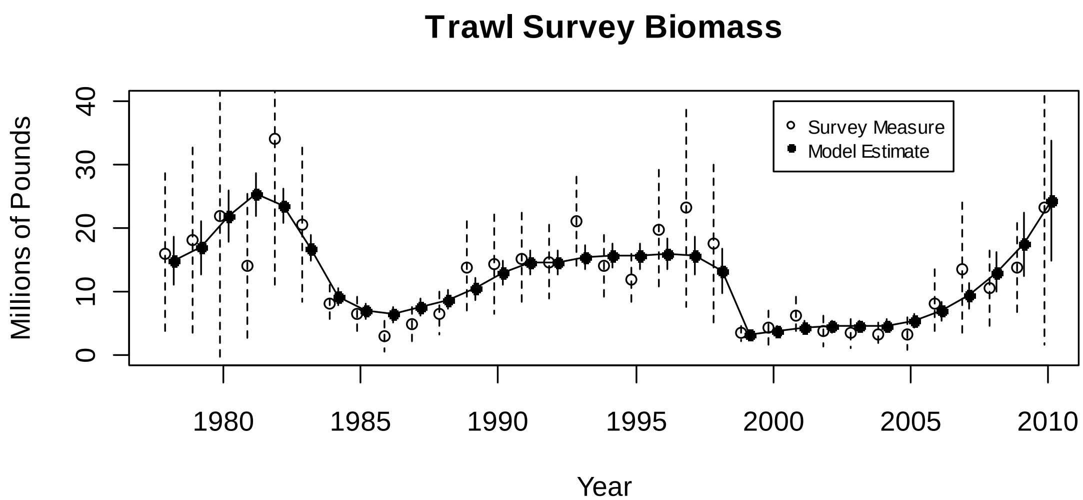


Figure 7. Model estimated harvest rate for the years 1978/79-2009/10 and its relation to estimated MMB. See text for definitions. The fishery was closed for the ten years 1999/00-2008/09.



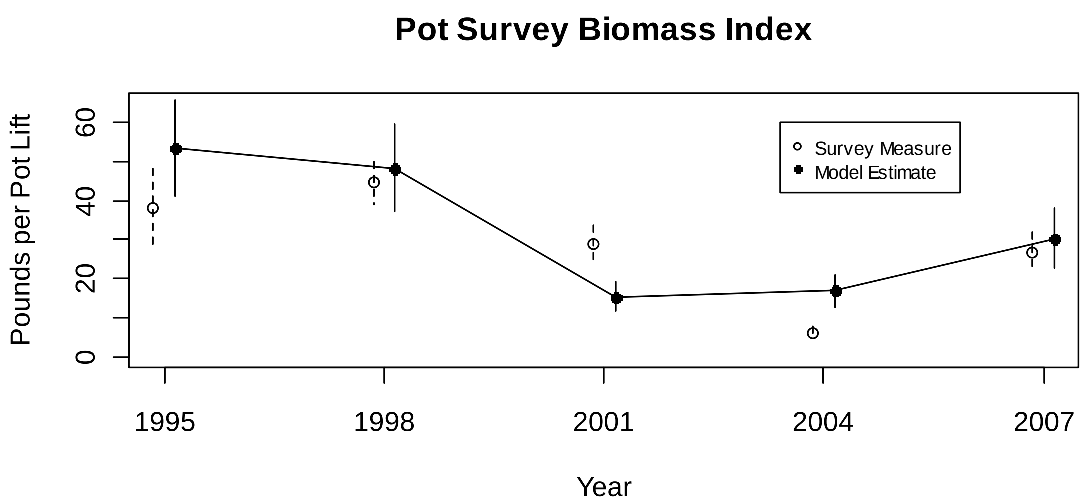
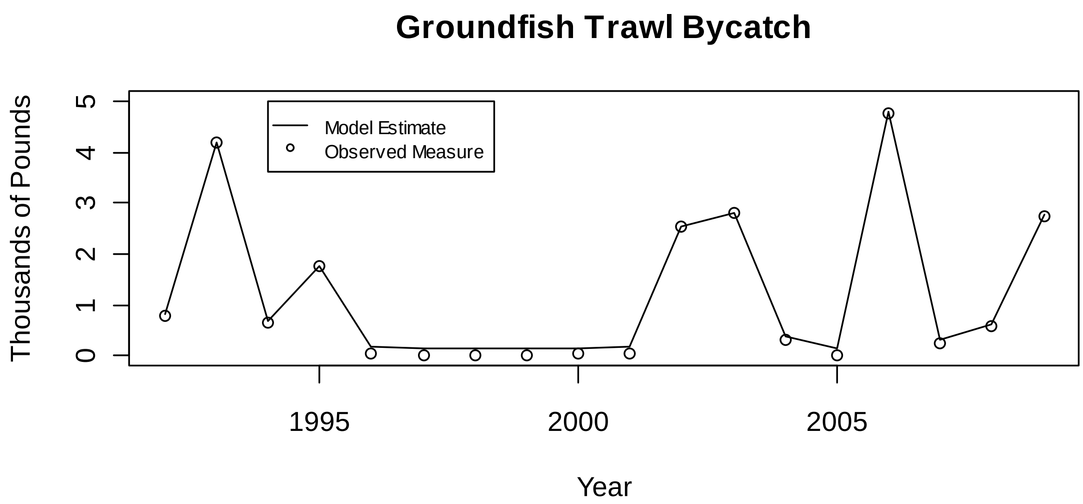


Figure 8. Observed survey biomass measures and model estimates. Vertical lines represent approximate 95% confidence intervals.



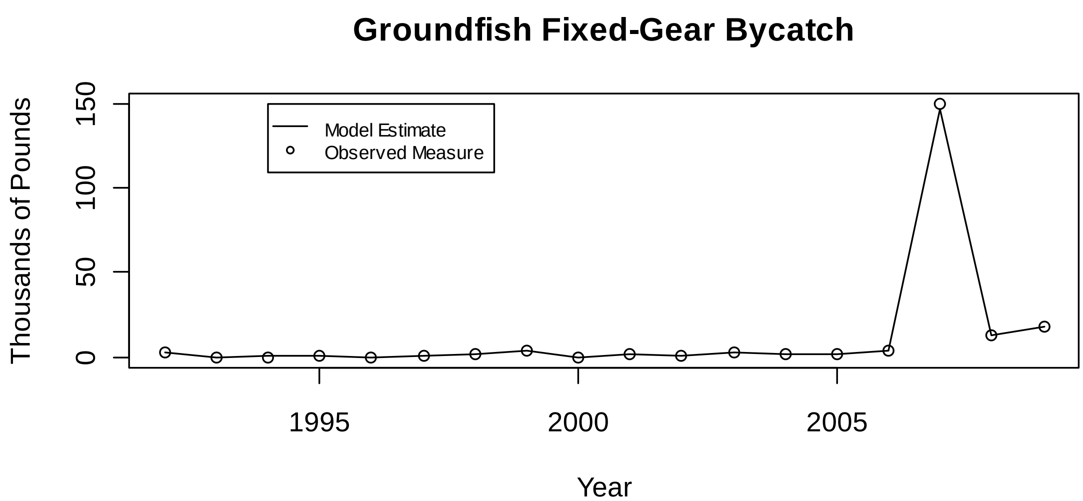


Figure 9. Groundfish trawl and fixed-gear bycatch from 1992/93 to 2009/10. Observed biomass measures have been adjusted assuming handling mortalities of 0.80 and 0.50 respectively.

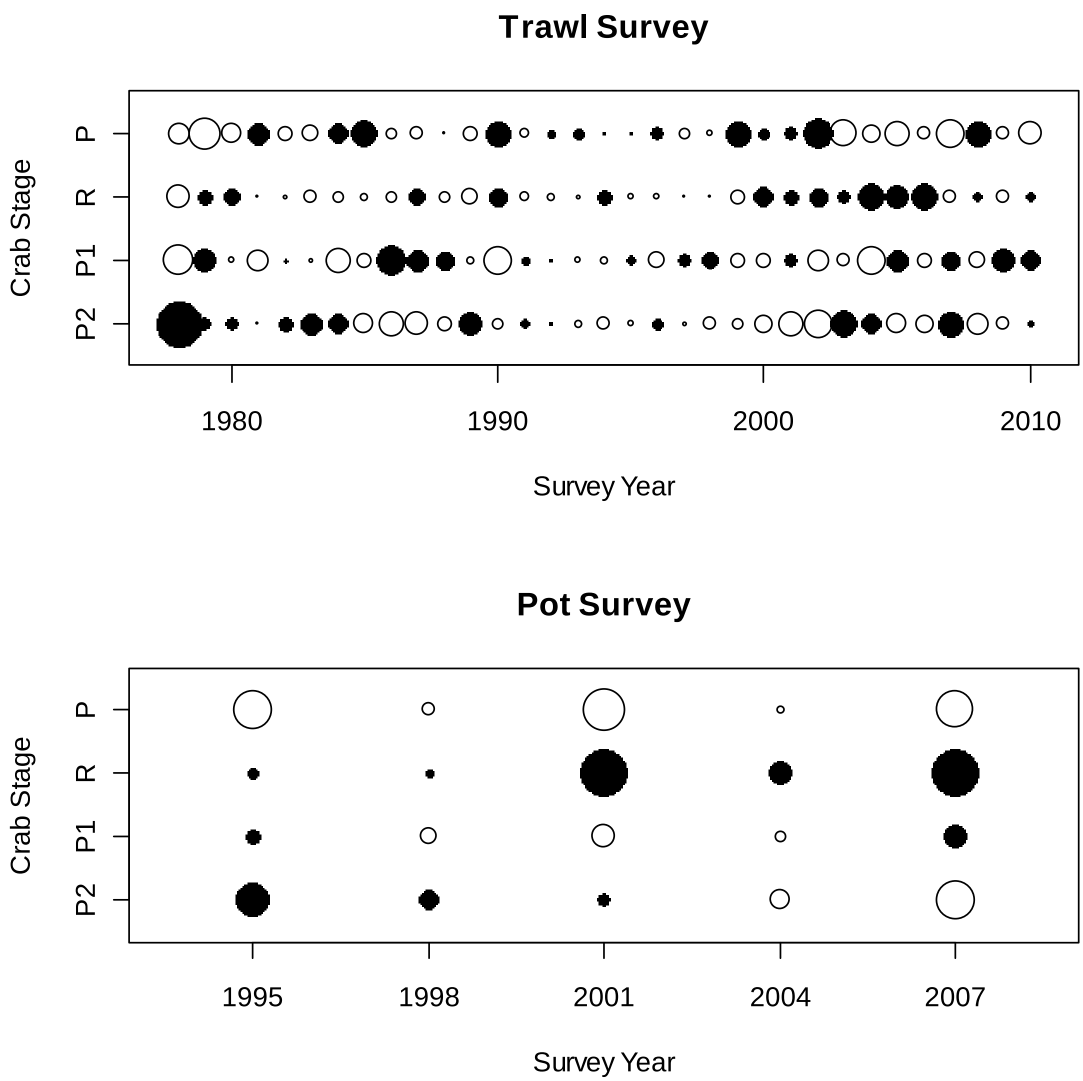


Figure 10. Survey crab-stage proportion residuals. Bubble areas are proportional to residual magnitude; solid indicates the residual is positive, i.e. the observed proportion exceeds the model estimated value. The two plots are at different scales.

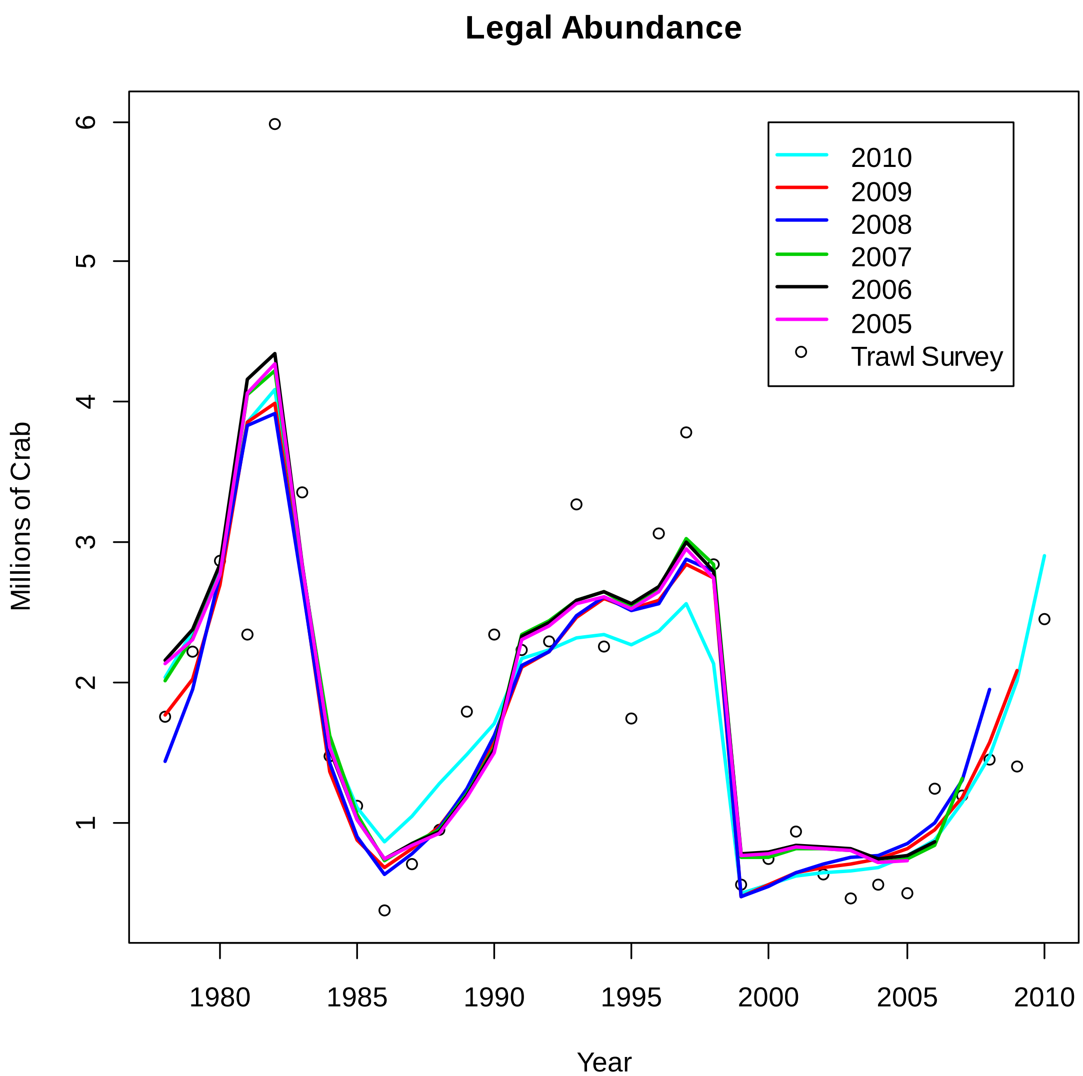


Figure 11. Comparison of 2010 model estimates of 1978/79-2010/11 legal abundance with results from the last five historical models. Legend shows the year in which the assessment was conducted. NMFS trawl-survey estimates are also shown.

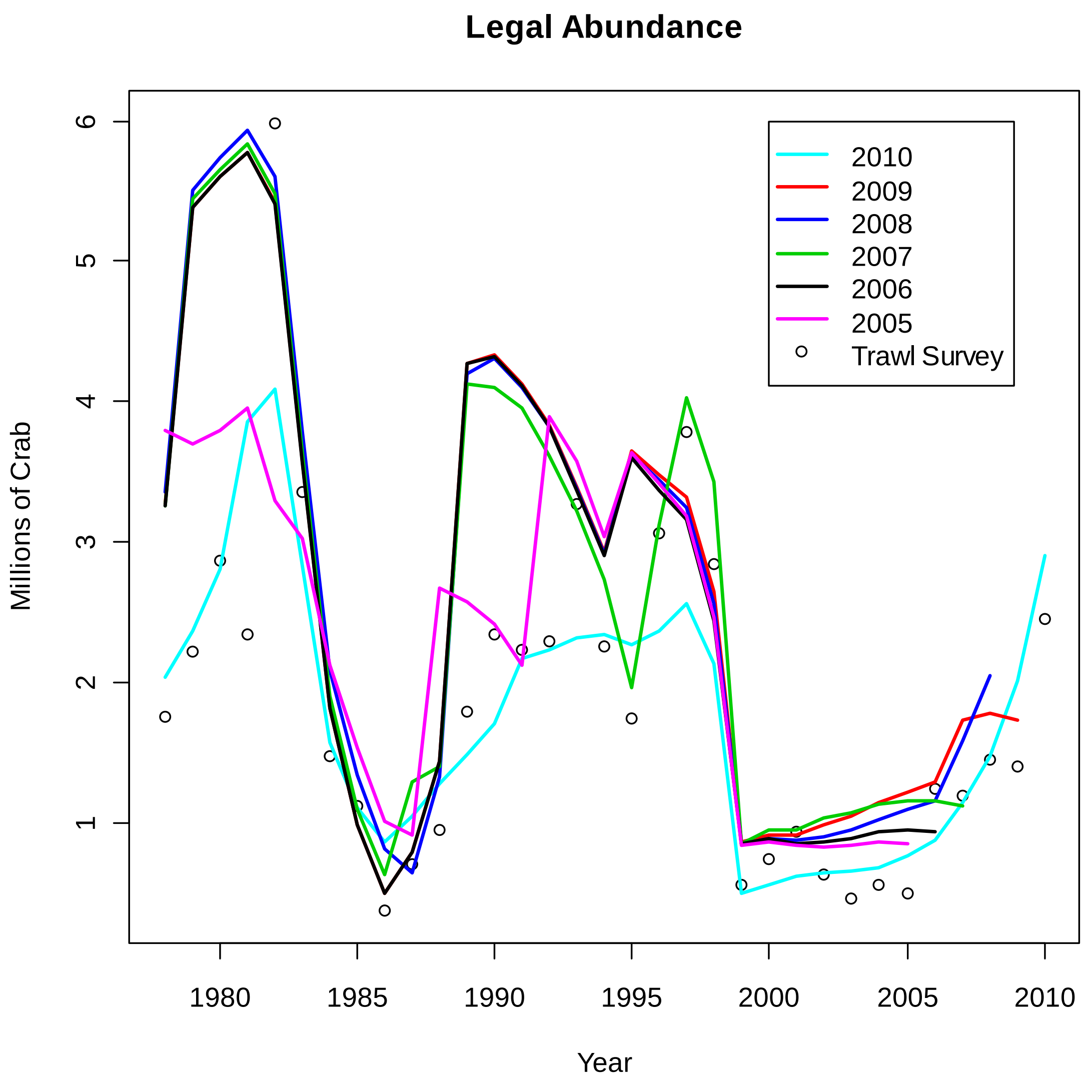


Figure 12. Comparison of 2010 model estimates of legal abundance with results from the 2010 model confronted with historical data. See text for explanation. Legend shows the terminal year of the dataset used in generating the trajectory. NMFS trawl-survey estimates are also shown.

Norton Sound Red King Crab Stock Assessment in Spring 2010

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. 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).

   <u>Summer Commercial Fishery</u>

   A large-vessel summer commercial crab fishery existed in the Norton Sound Section from 1977 through 1990. No summer commercial fishery occurred in 1991 because there was no staff to manage the fishery. In 1992, the summer commercial fishery resumed. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Regulation changes and location of buyers resulted in harvest distribution moving eastward in Norton Sound in the mid 1990s. Commercial fisheries history and catch data are summarized in Table 1.

   <u>CDQ Fishery</u>

   The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before they make their first delivery.

Fishers operate under authority of the CDQ group and each CDQ group decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations were adopted that affected the CDQ crab fishery and relaxed closed-water boundaries in eastern Norton Sound and waters west of Sledge Island. At its March 2008 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)

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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	CDQ	Total Number (incl. CDQ) Vessels	Permits	Landings	Total Pots Registered	Pulls	Total Exvessel Price/lb	Total Fishery Value (millions $)	Season Length Days	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

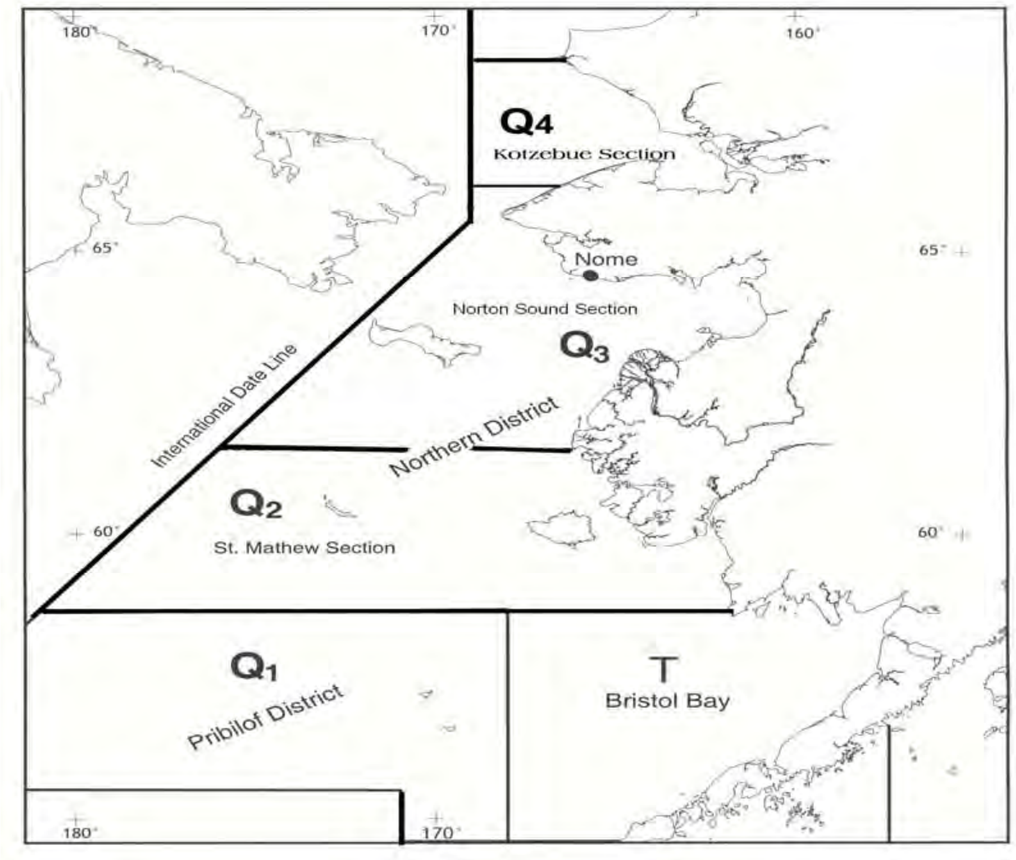


Figure 1. King crab fishing districts and sections of Statistical Area Q.

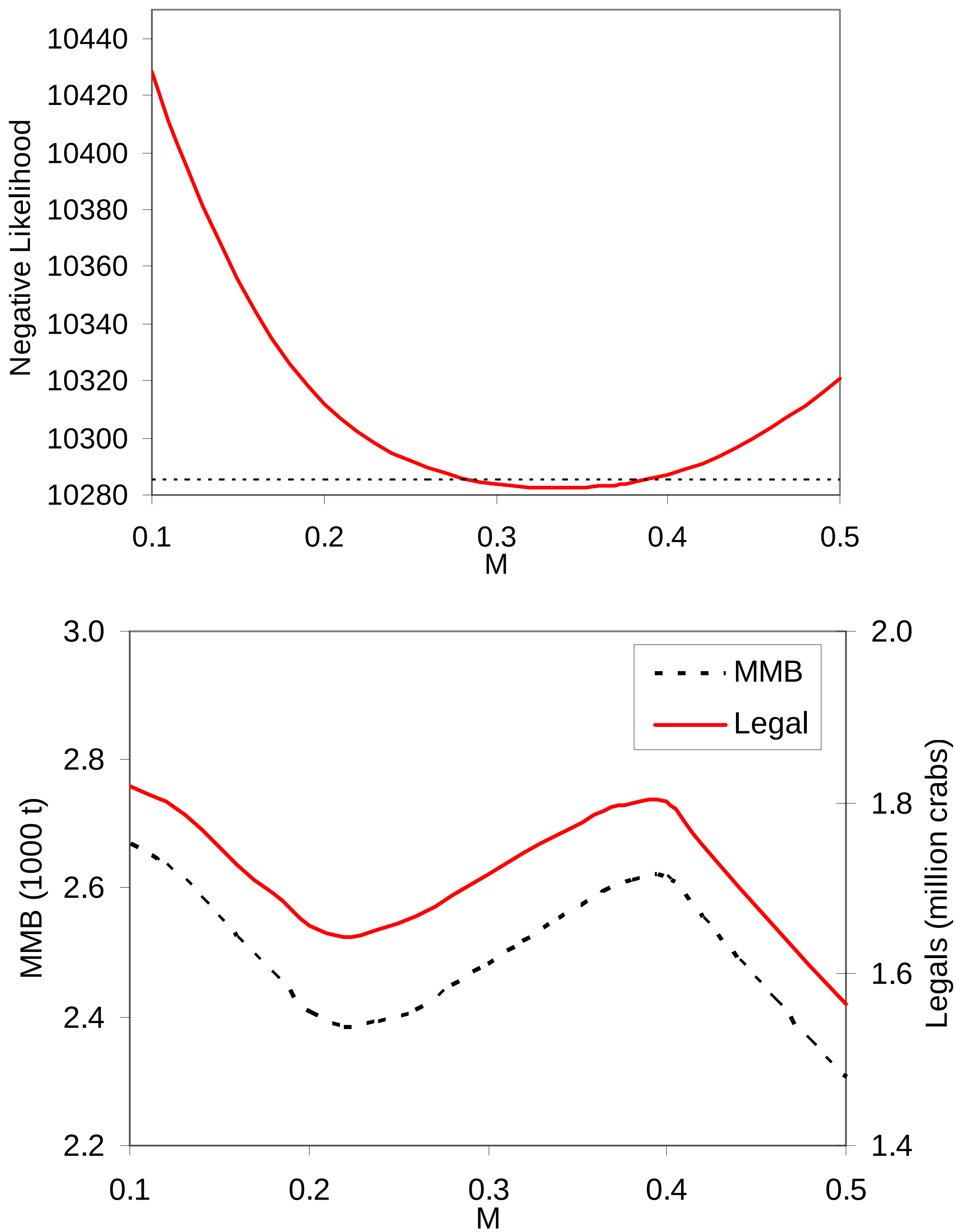


Figure 2. Likelihood profile for natural mortality, estimated legal abundance and mature male biomass in 2010 under different natural mortality values. The dotted line in the upper plot is the minimum negative likelihood plus 2.0.

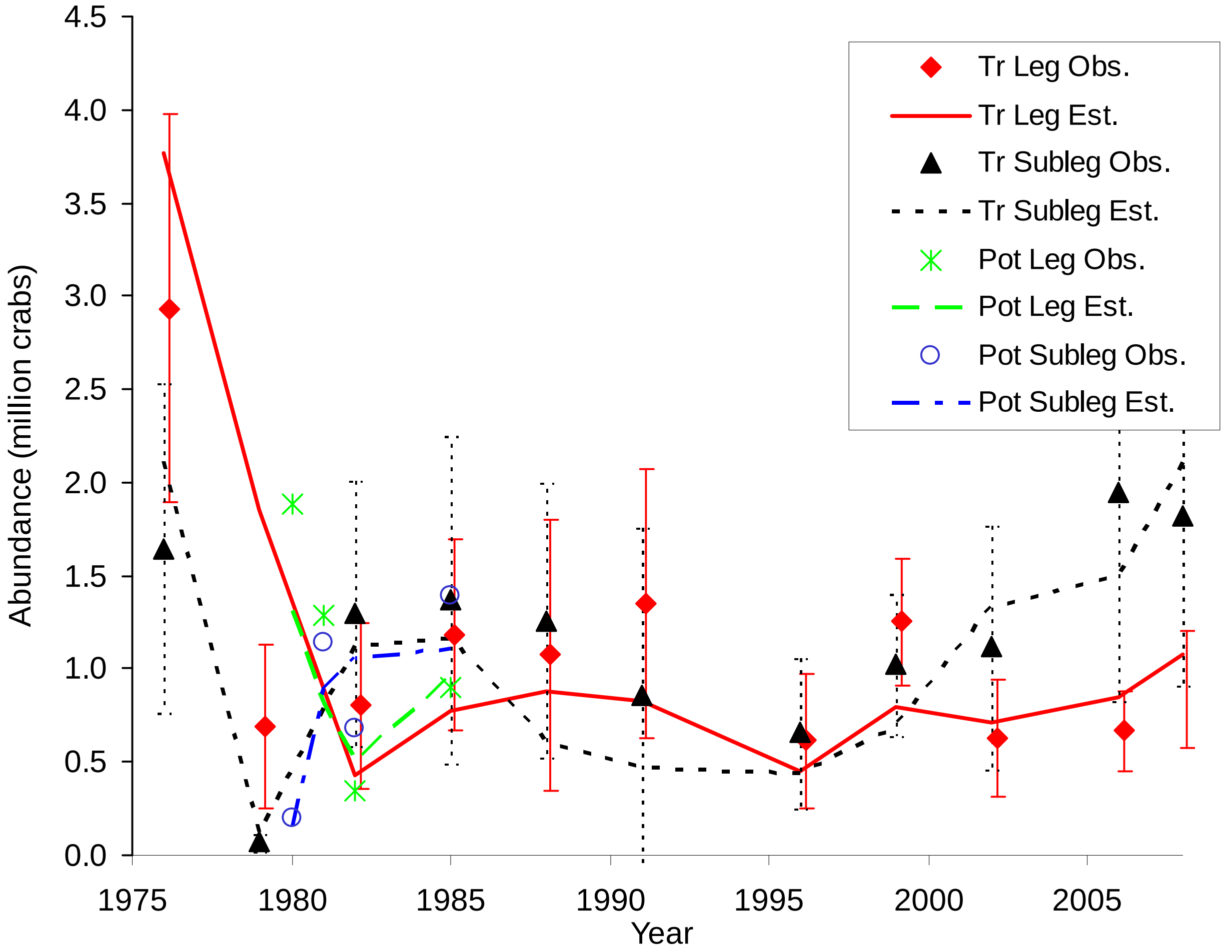
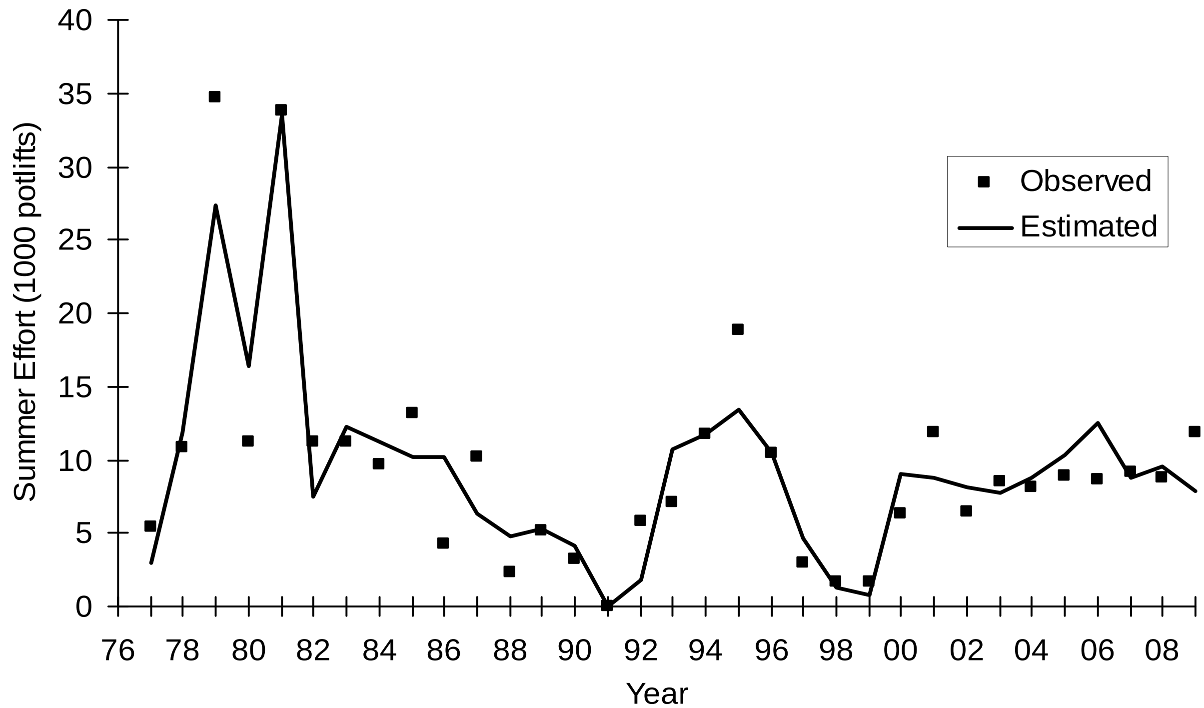


Figure 3a. Comparison of observed and estimated Norton Sound red king crab abundances (legal and sublegal males) by summer trawl and pot surveys (upper plot). “Tr” is trawl, “Leg” is legal, “Obs.” is observed or survey abundance, and “Est.” is estimated catchable abundance. The 95% C.I. were plotted separately for sublegal and legal crabs from the summer trawl surveys.



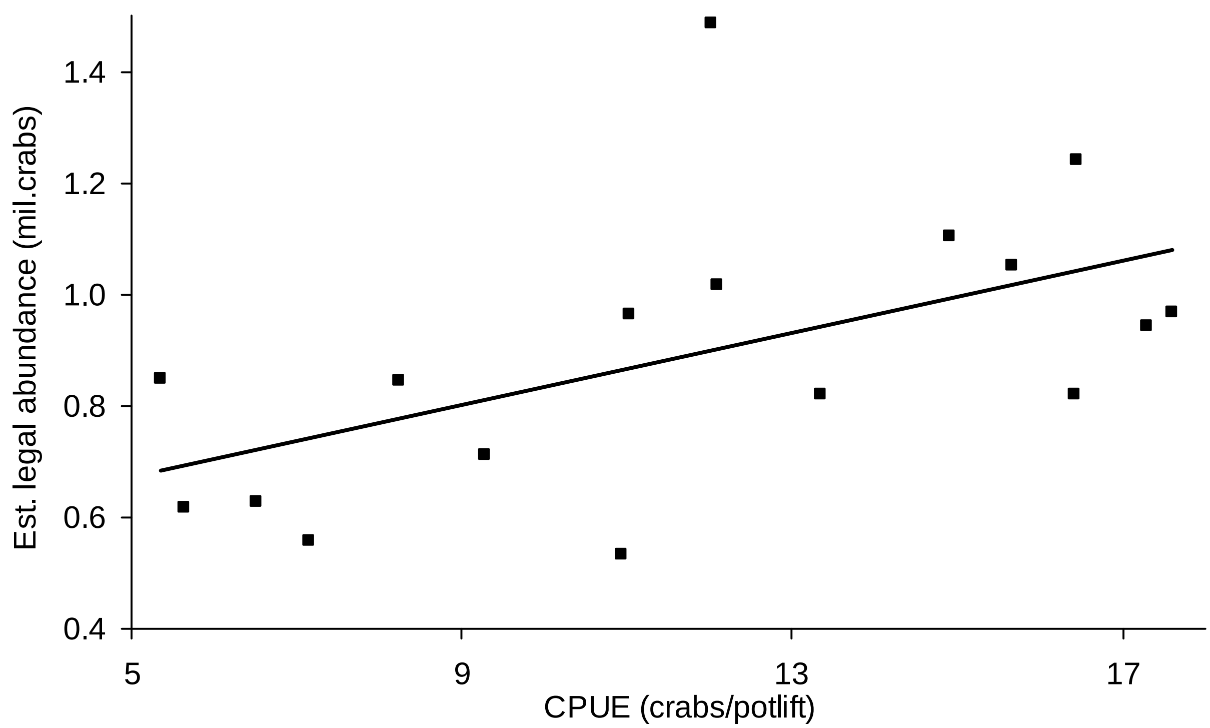


Figure 3b. Comparison of observed and estimated summer fishing efforts (upper plot) during 1977-2009 and the relationship between estimated legal male abundance and summer commercial catch per potlift during 1993-2009 (lower plot).

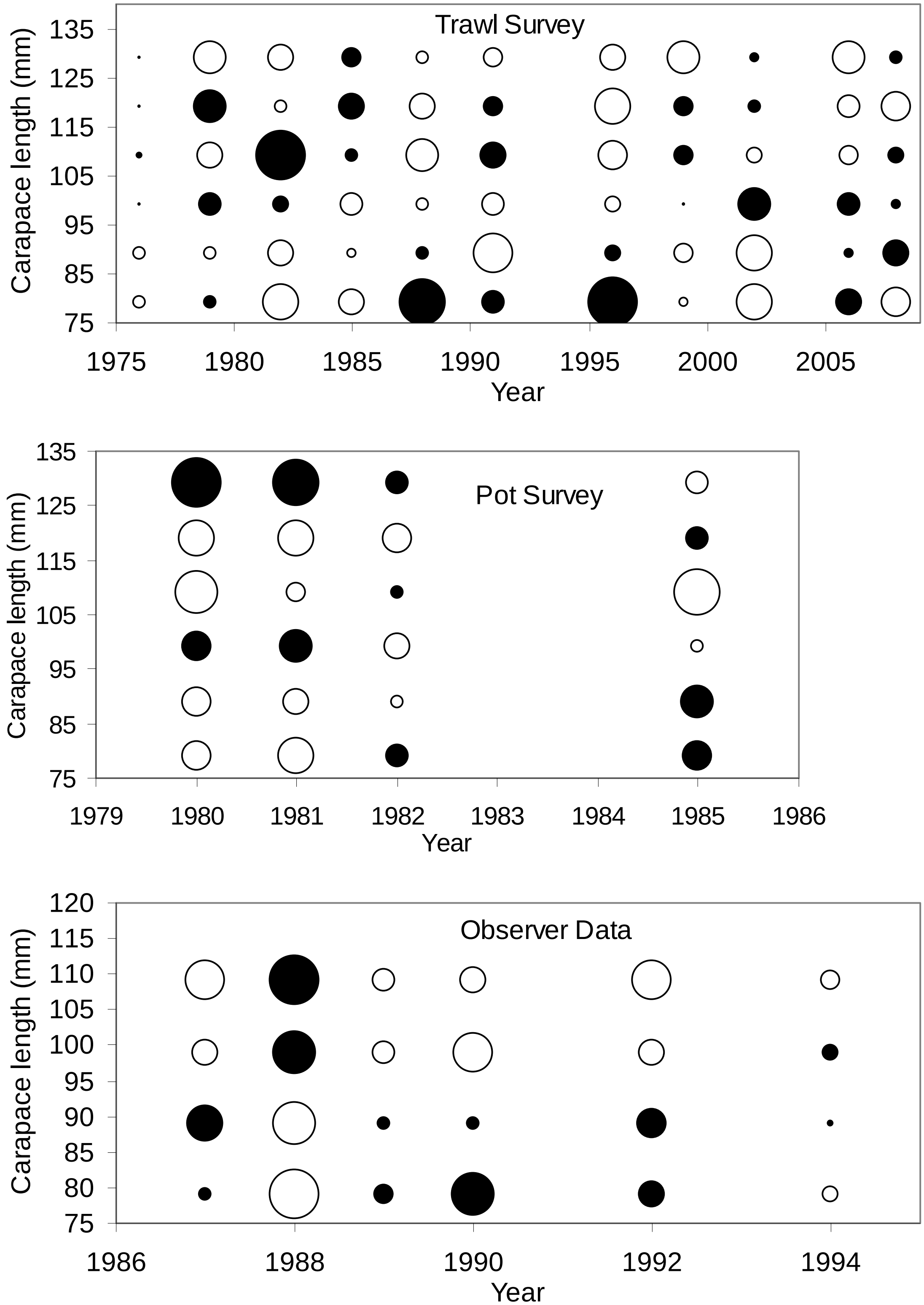


Figure 4. Residuals of length compositions by year for summer trawl and pot surveys and observer data for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.

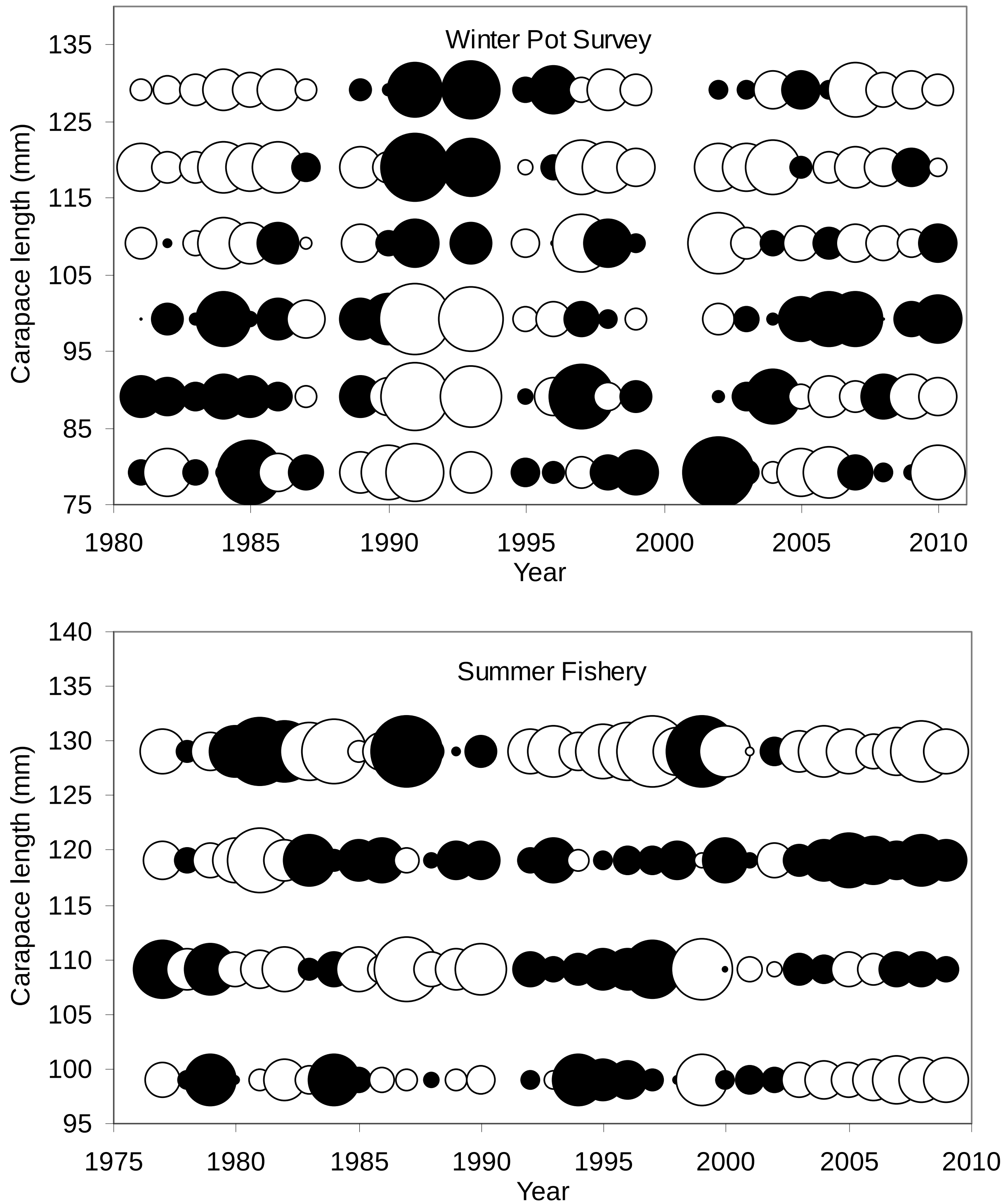


Figure 5. Residuals of length compositions by year for winter pot surveys and summer fishery for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.

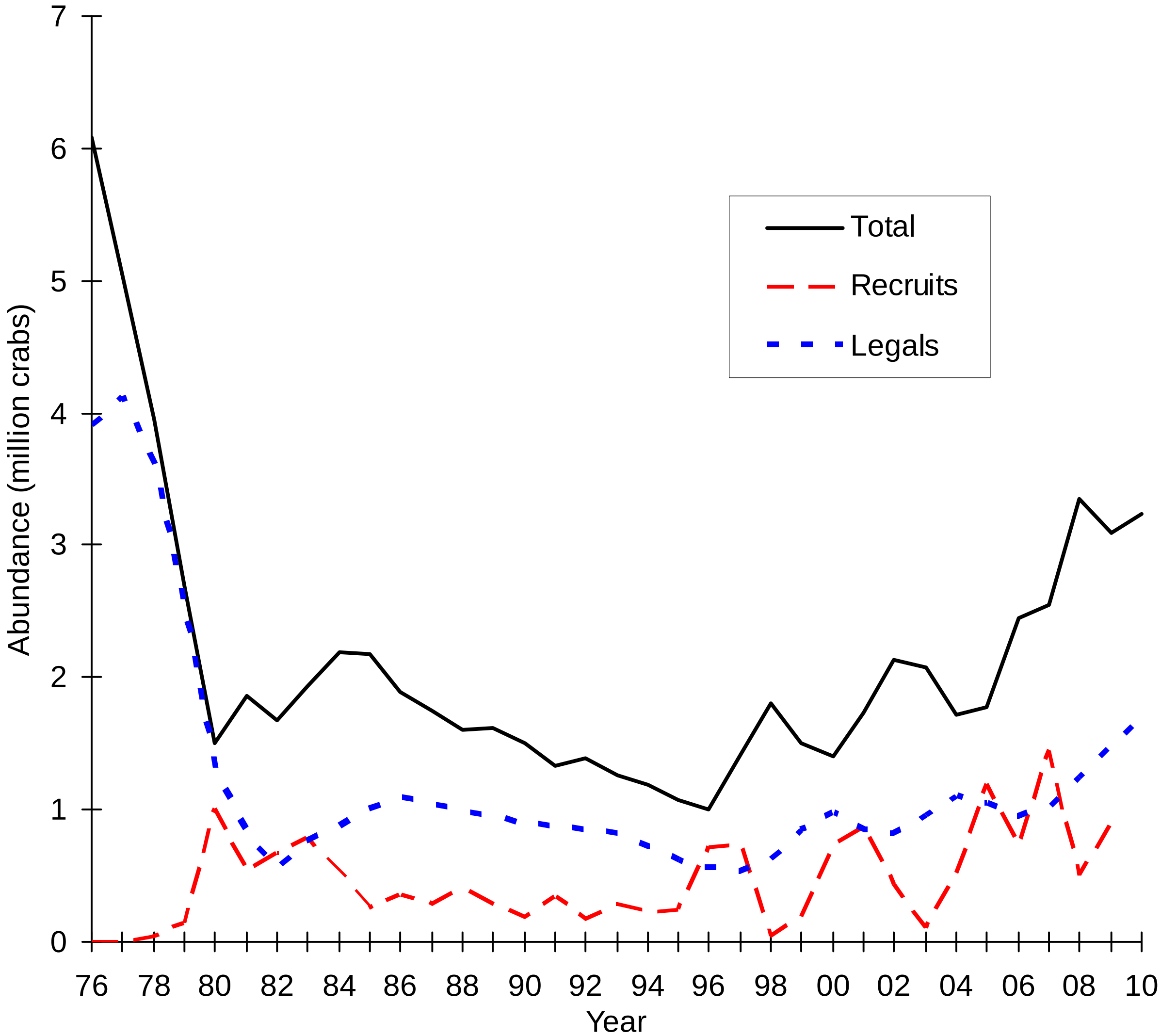
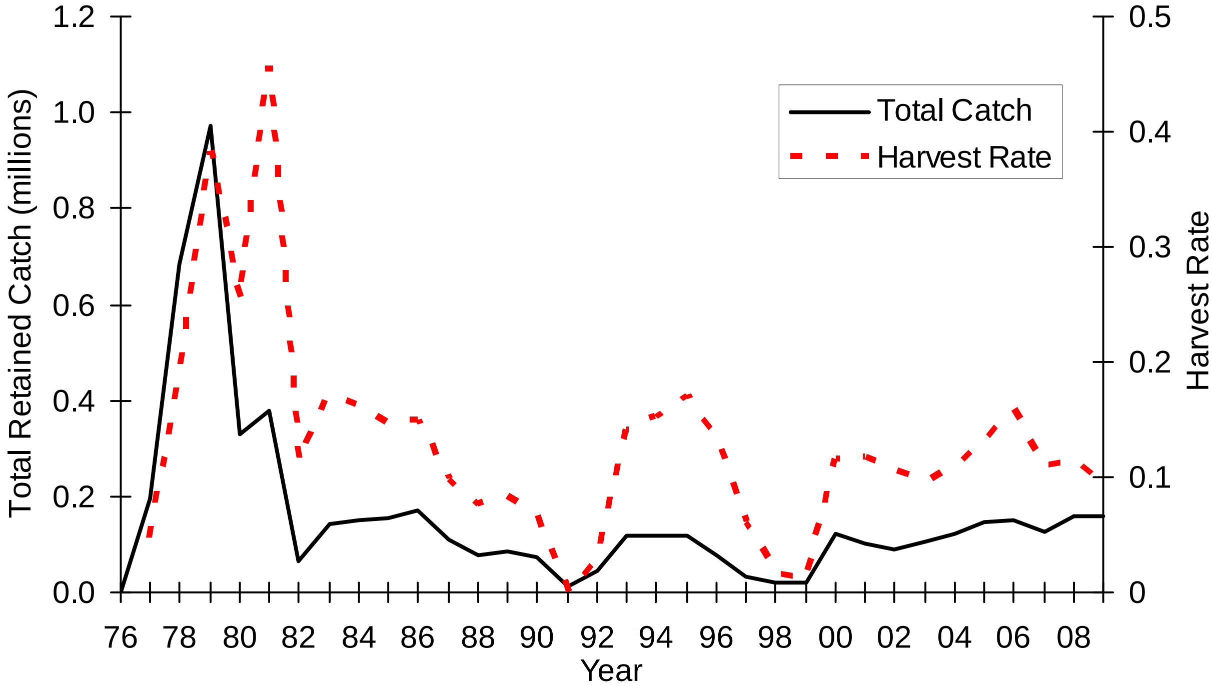


Figure 6. Estimated total (crabs>73 mm CL) and legal male abundances and recruits from 1976 to 2010.



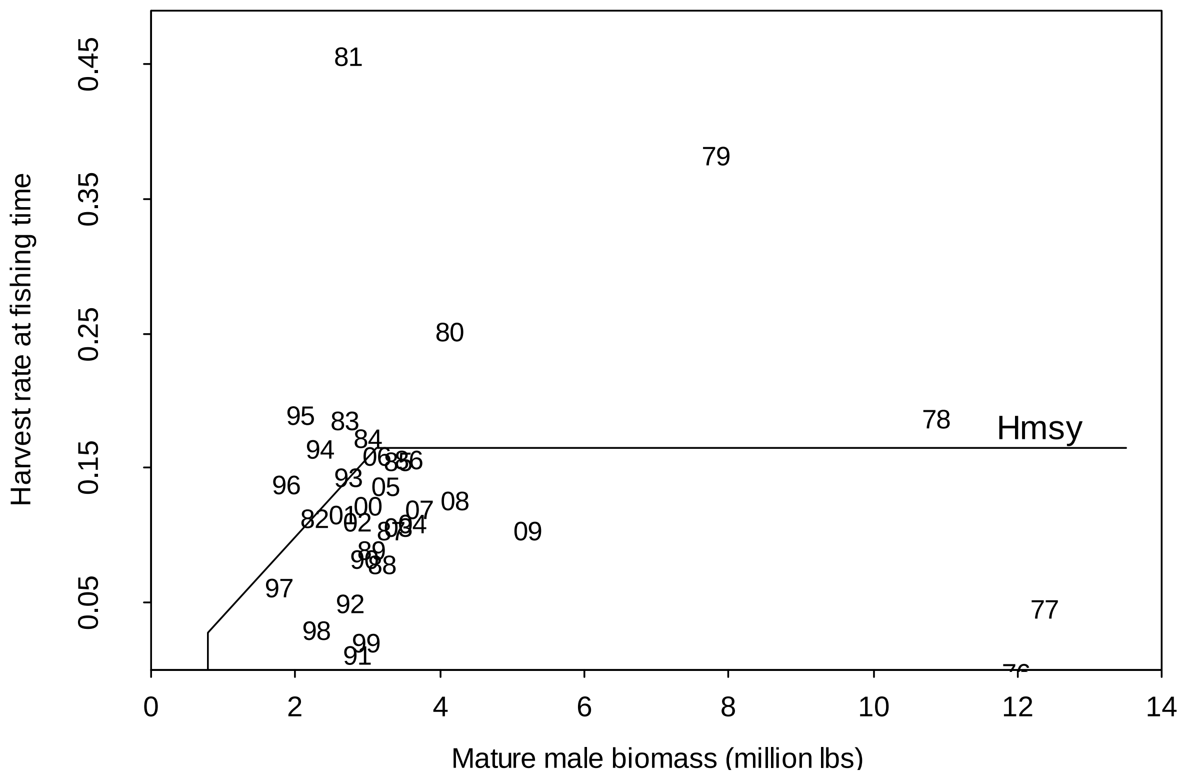


Figure 7. Total retained catches and harvest rates (upper plot) and relationship between harvest rates and mature male biomass (lower plot) of Norton Sound red king crab from June 1, 1976 to May 31, 2010. *Hmsy* is a proxy MSY harvest rate corresponding to *Fmsy* with γ=1.0 and M=0.18.

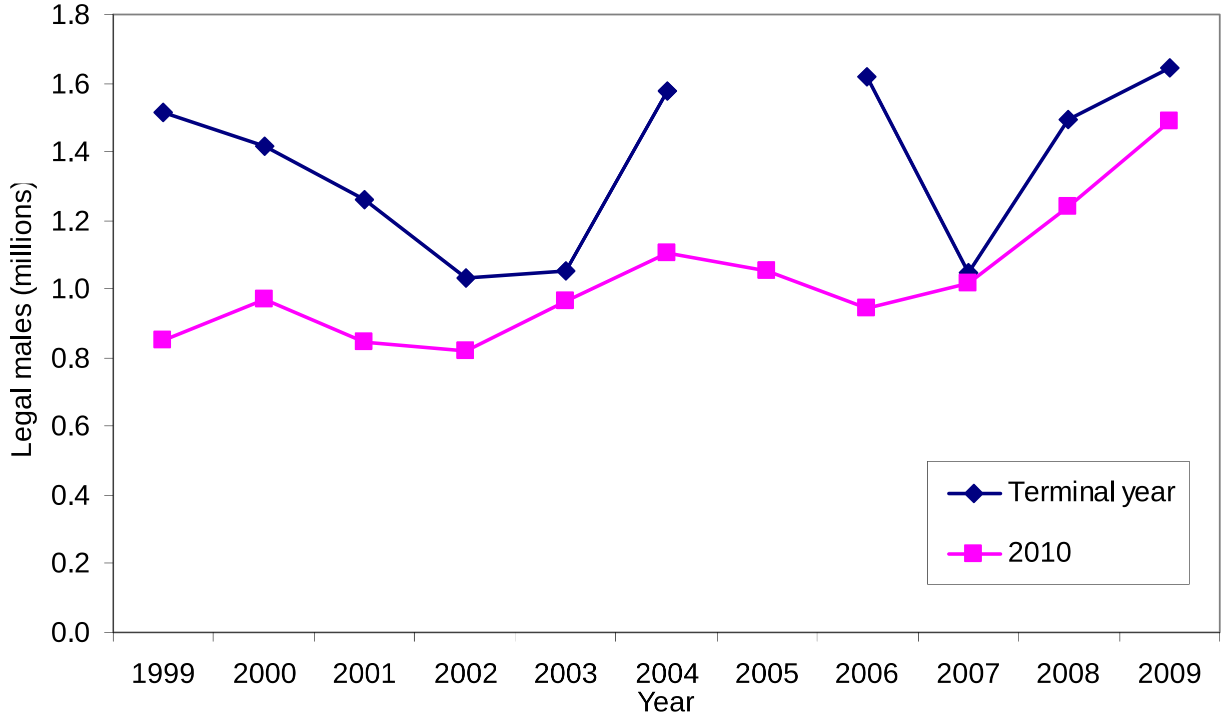
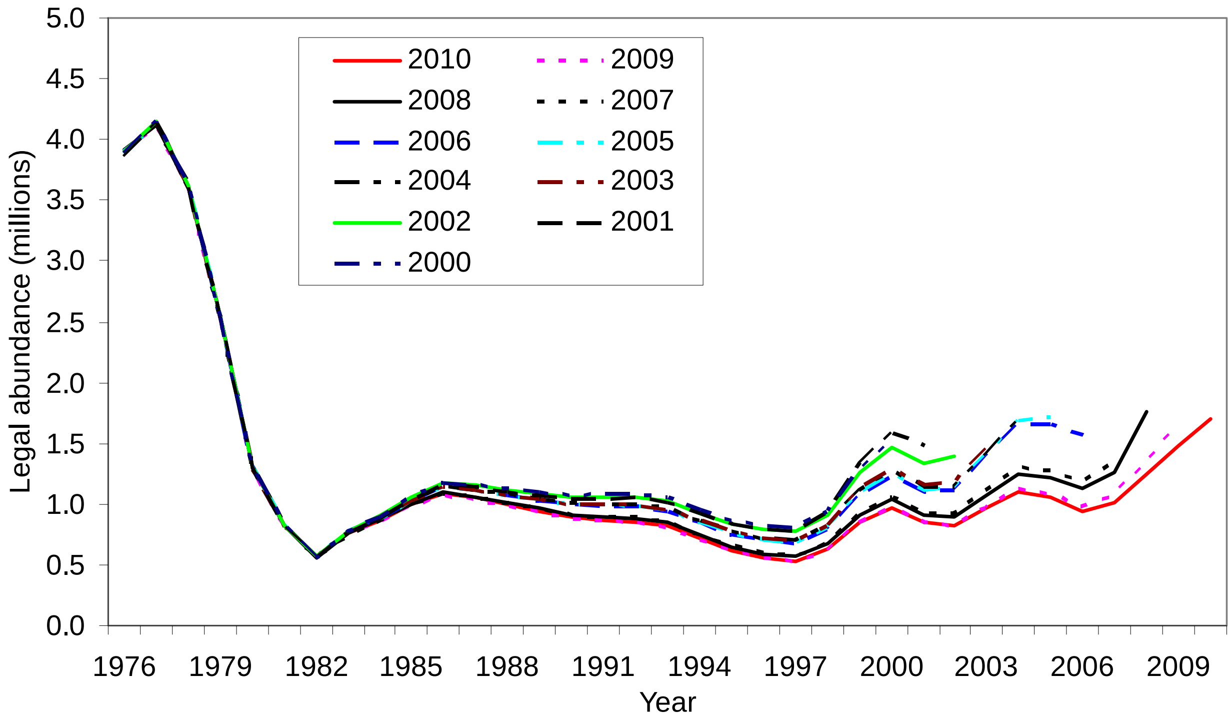


Figure 8. Comparison of estimates of legal male abundance of Norton Sound red king crab with terminal years 1999-2010. These are results of historical assessments. Legend shows the year in which the assessment was conducted.



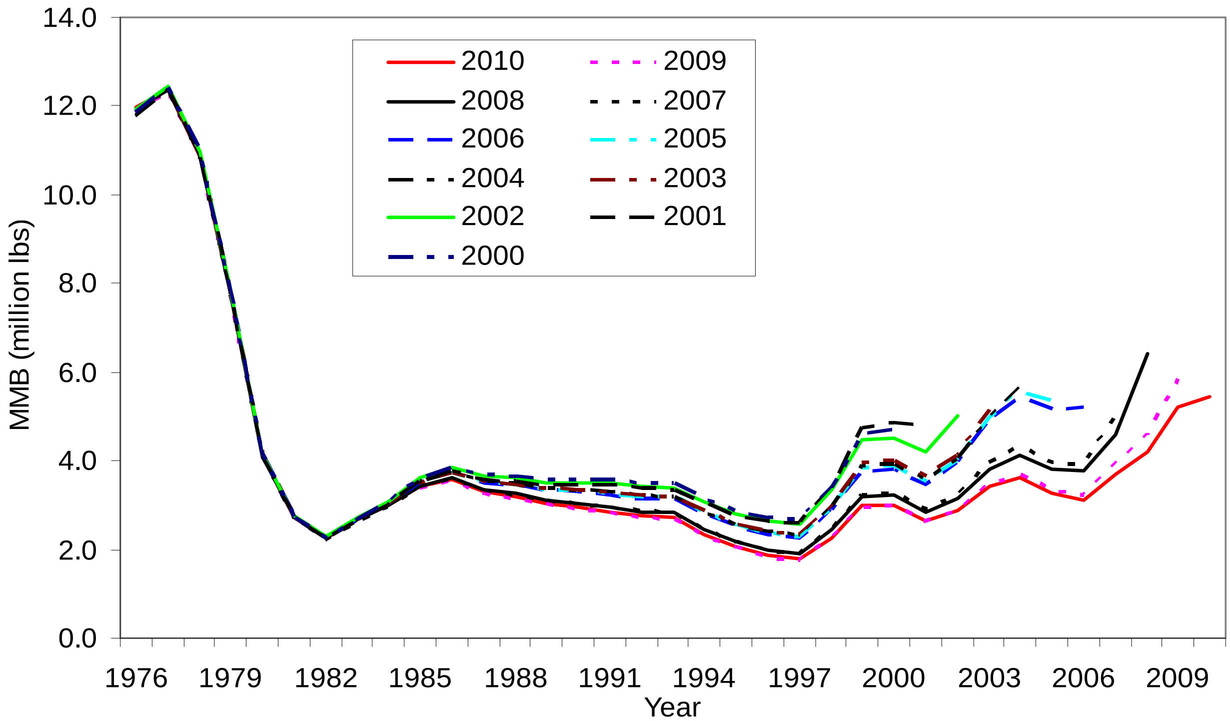


Figure 9. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of Norton Sound red king crab from 1976 to 2010 made with terminal years 2000-2010. These are results of the 2010 model. Legend shows the year in which the assessment was conducted.

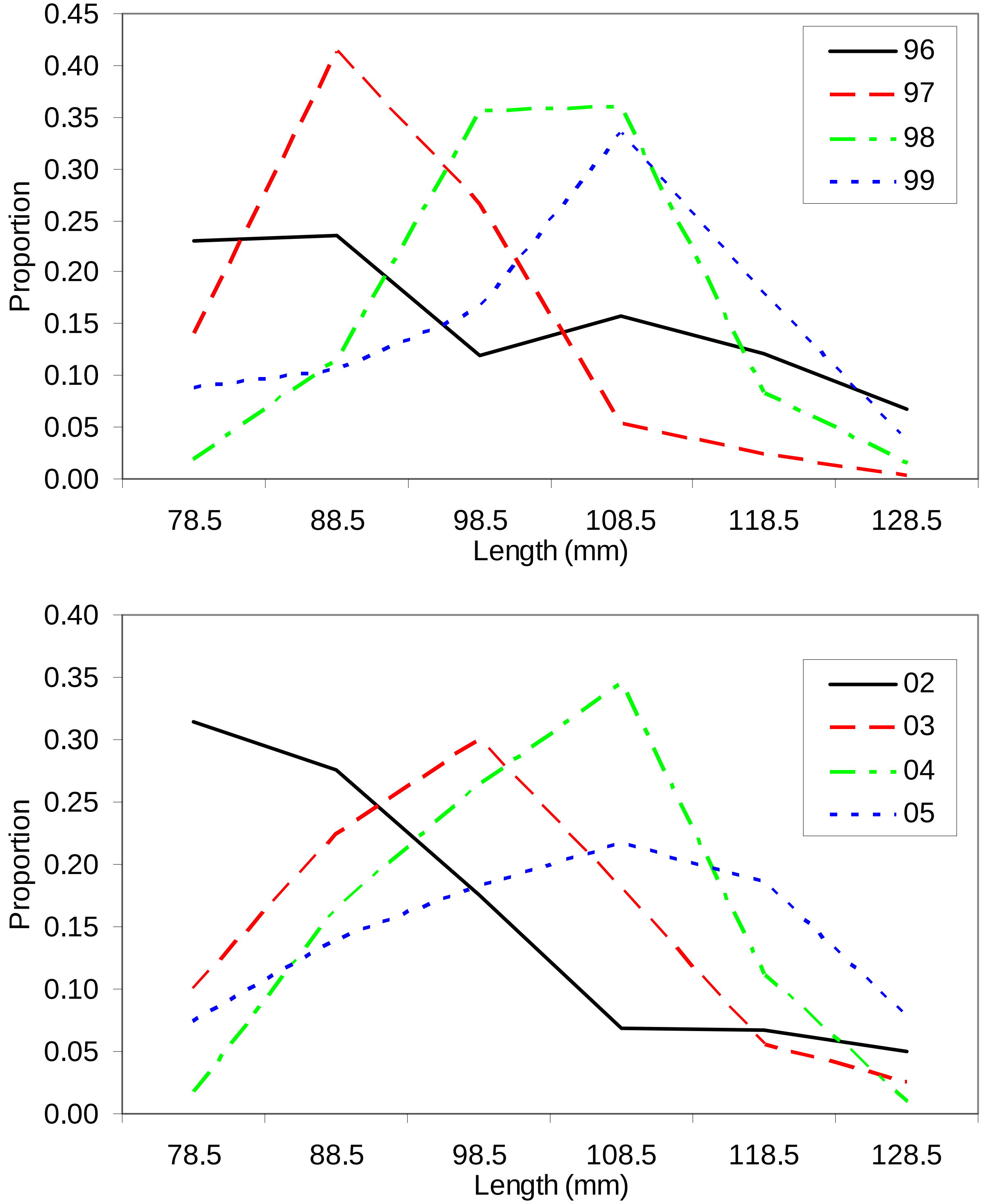
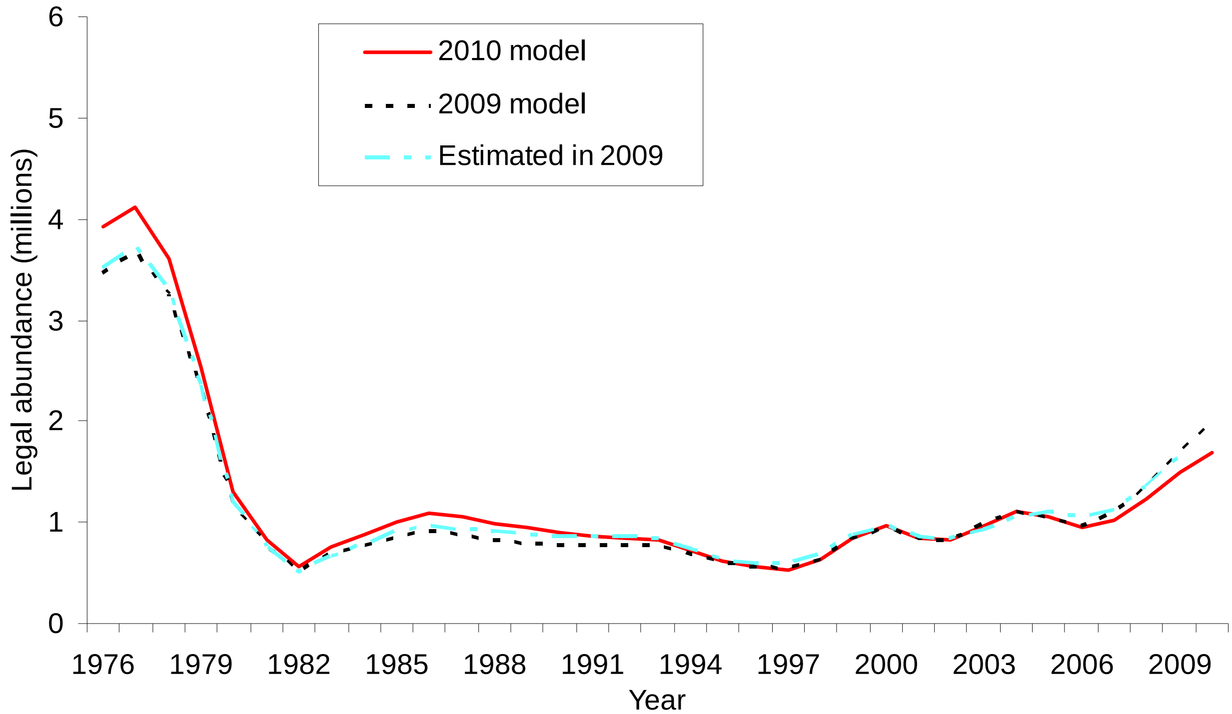


Figure 10. Length frequency of newshell crabs from the winter survey during two periods: 1996-1999 and 2002-2005.



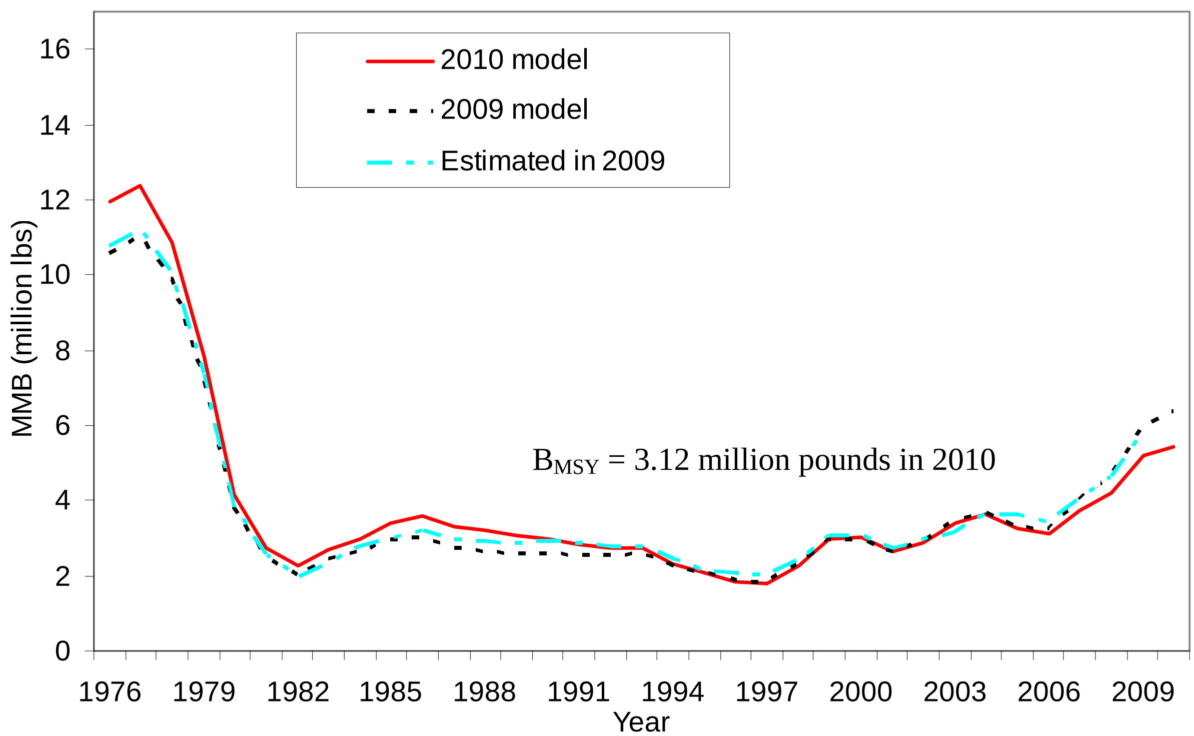


Figure 11. Comparison of legal abundance and mature male biomass estimates made in 2009 (dashed-dotted line), in 2010 by the 2009 model (dotted line), and in 2010 by the 2010 model (solid line). BMSY in the lower plot is 3.12 million pounds in 2010.

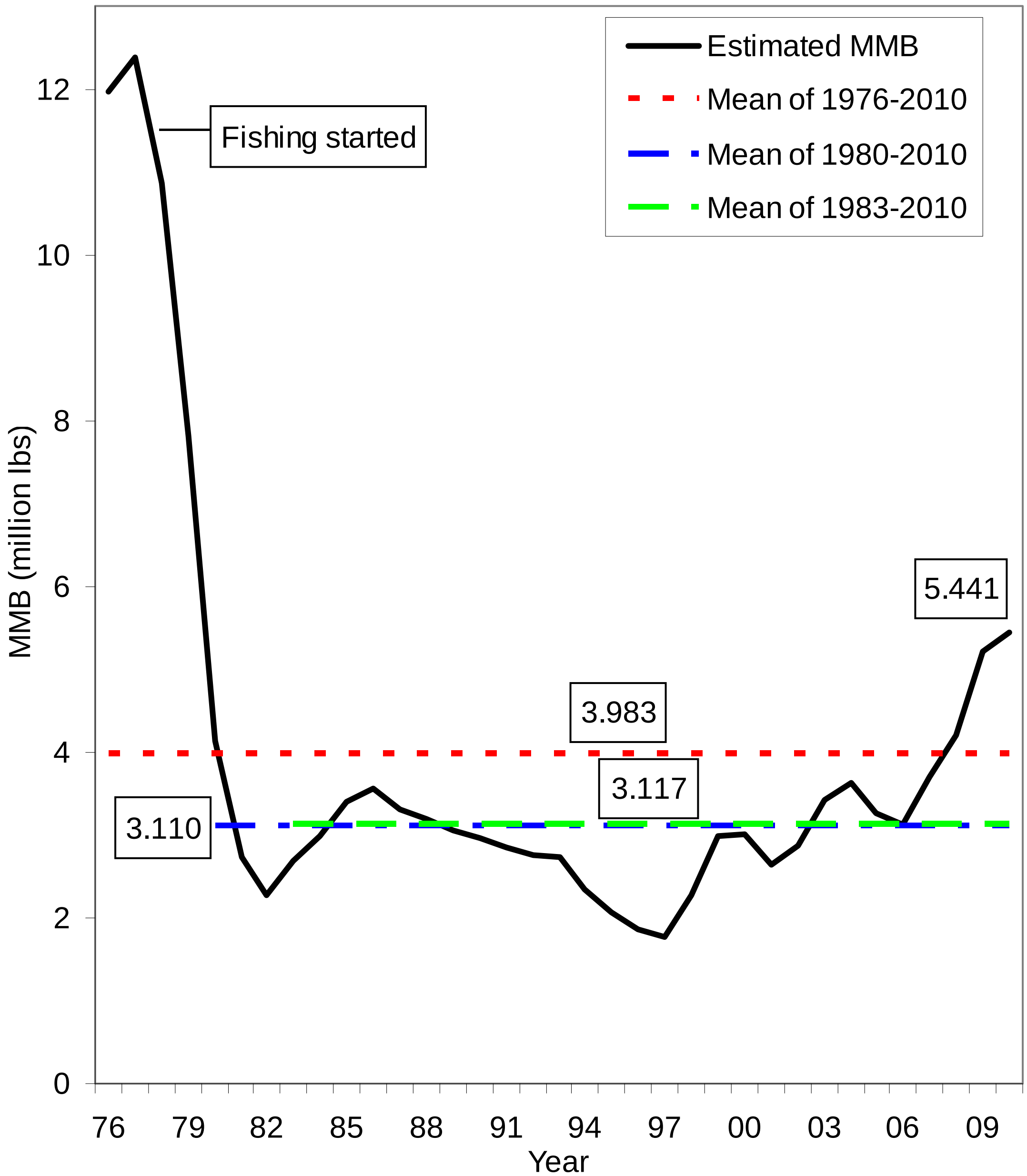


Figure 12. Comparison of estimated mean mature male biomasses during different periods of Norton Sound red king crab.

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:

$$\begin{aligned} N_{s,l,t+1} &= (N_{w,l,t} - C_{w,t} P_{w,n,l,t} - C_{p,t} P_{p,n,l,t}) e^{-0.417 M_l}, \\ O_{s,l,t+1} &= (O_{w,l,t} - C_{w,t} P_{w,o,l,t} - C_{p,t} P_{p,o,l,t}) e^{-0.417 M_l}, \end{aligned} \tag{1}$$

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

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} [G_{l',l}((N_{s,l',t} + O_{s,l',t}) e^{-y_t M_l} - C_{s,t}(P_{s,n,l',t} + P_{s,o,l',t}) - D_{l',t}) m_{l'} e^{-(0.583-y_t)M_l}] + R_{l,t}, \tag{2}$$

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:

$$O_{w,l,t} = [(N_{s,l,t} + O_{s,l,t}) e^{-y_t M_l} - C_{s,t}(P_{s,n,l,t} + P_{s,o,l,t}) - D_{l,t}] (1 - m_l) e^{-(0.583-y_t)M_l}. \tag{3}$$

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_ι 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:

$$P_{s,n,l,t} = N_{s,l,t} S_{s,l} L_l / A_t,$$
$$P_{s,o,l,t} = O_{s,l,t} S_{s,l} L_l / A_t, \tag{10}$$

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:

$$S_{s,l} = \frac{1}{1 + e^{-\phi(l-\omega)}}. \tag{11}$$

$S_{s,l}$ 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:

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} L_l]. \tag{12}$$

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:

$$f_t = C_t / [q(A_t - 0.5C_t)]. \tag{13}$$

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:

$$P_{b,n,l,t} = N_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)],$$
$$P_{b,o,l,t} = O_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)]. \tag{14}$$

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:

$$P_{sf,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}],$$
$$P_{sf,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]. \tag{15}$$

Estimated length/shell condition compositions of summer pot survey abundance were:

$$P_{sp,n,l,t} = N_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}],$$
$$P_{sp,o,l,t} = O_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}] \tag{16}$$

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:

$$\sum_{i=1}^{i=5}\sum_{t=1}^{t=n_i}\{K_{i,t}\sum_{l=1}^{l=6}[\hat{P}_{i,l,t}\,ln(P_{i,l,t}+\kappa)]\} - \sum_{i=1}^{i=2}\sum_{k=1}^{k=2}\sum_{t=1}^{t=n_i}[ln(\hat{B}_{i,k,t}+\kappa) - ln(B_{i,k,t}+\kappa)]^2/(2*ln(CV^2_{i,k,t}+1))$$
$$-W_f\sum_{t=1}^{t=32}[ln(\hat{f}_t+\kappa) - ln(f_t+\kappa)]^2 - W_R\sum_{t=1}^{t=32}\tau_t^2, \qquad (17)$$

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).

Aleutian Islands Golden King Crab

May 2010 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak

Executive Summary

1. **Stock:** Golden king crab *Lithodes aequispinus*/Aleutian Islands

2. **Catches:**

The fishery has been prosecuted as a directed fishery since the 1981/82 season and has been open every season since then. Retained catch peaked during the 1985/86–1989/90 seasons (average annual retained catch = 11,875,811 pounds), but the retained catch dropped sharply from the 1989/90 to 1990/91 season and average annual retained catch for the period 1990/91–1995/96 was 6,930,627 pounds. Management towards a formally established guideline harvest level (GHL) was introduced for the first time in the 1996/97 season. A GHL of 5.9-million pounds was established for the 1996/97 season, which was subsequently reduced to 5.7-million pounds beginning with the 1998/99 season. The GHL (or, since the 2005/06 season, the total allowable catch, or TAC) remained at 5.7 million pounds through the 2007/08 season, but was increased to 5.985-million pounds for 2008/09 season. Average annual retained catch for the period 1996/97–2007/08 was 5,622,808 pounds. Retained catch in 2008/09, the most-recently completed season, was 5,580,084 pounds. Catch per pot lift of retained legal males decreased from the 1980s into the mid-1990's, but increased steadily since the 1996/97 season and increased markedly in 2005/06 with the advent of the Crab Rationalization program. Non-retained bycatch occurs mainly during the directed fishery. Although some minor levels of bycatch can occur during other crab fisheries, there have been no such fisheries prosecuted since 2004/05. Bycatch also occurs during fixed-gear and, to a smaller extent, trawl groundfish fisheries. Although bycatch during groundfish fisheries exceed 100-thousand pounds for the first time during 2007/08 and 2008/09, that bycatch was less than 10% of the weight of bycatch during the directed fishery for those seasons. Non-retained catch of sublegal and female golden king crabs during the directed fishery has decreased relative to the retained catch and in absolute numbers since the late-1990's. Estimated weight of discarded bycatch (sublegal and female golden king crabs) during the directed fishery decreased from 9,075,548 pounds in 1996/97 (representing 156% of the retained catch for that season) to 4,321,014 pounds in the 2004/05 season (representing 78% of the retained catch for that season). During the four seasons prosecuted as rationalized fisheries, estimated weight of discarded bycatch has ranged from 2,523,737 pounds for the 2005/06 season (representing 46% of the retained catch for that season) to 3,034,631 pounds for the 2007/08 season (representing 55% of the retained catch for that season). Estimates of the annual weight of bycatch mortality have correspondingly decreased since 1996/97, both in absolute value and relative to the retained catch weight. Estimated total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) has ranged from 5.82-million to 7.80-million pounds during 1996/97–2008/09, the period for which such estimates can be made.

3. **Stock biomass:**

Estimates of stock biomass are not available for this Tier 5 assessment.

4. **Recruitment:**

Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment. Fishery CPUE (catch number of legal retained males per pot lift) increased from 6 crabs per pot lift in the 1994/95 season to 25 crabs per pot lift in the 2008/09 season. However, the likely effects of changes in fishery practices on fishery CPUE make it difficult to view that strongly increasing trend in CPUE as a direct index of the trend in the abundance of legal males. Strong indices of recruitment to legal size that would be consistent with a strong increase in abundance of legal males in recent years have been lacking in the average weights of crabs captured during recent commercial fishery seasons. However, the size distribution of crabs captured during recent commercial fishery seasons is likely also affected by changes in fishery practices and the CPUE did indeed continue to increase through the 2008/09 season.

5. <u>Management performance</u>:
No overfished determination (i.e., MSST) is possible for this Tier 5 stock. Overfishing did not occur during 2008/09. See table, below.

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a] [retained]
2006/07	N/A	N/A	5.70	5.26	5.82	
2007/08	N/A	N/A	5.70	5.51	6.25	
2008/09	N/A	N/A	5.99	5.68	6.31	9.18
2009/10	N/A	N/A	5.99	TBD	TBD	9.18
2010/11	N/A	N/A	5.99	TBD	TBD	9.18

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

6. <u>Basis for the OFL</u>: See table, below.

Year	Tier	Years to define[a] Average catch (OFL)	Natural Mortality[b]
2009/10	5	1985/86–1995/96	0.18
2010/11	5	1985/86–1995/96	0.18

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. **<u>A summary of the results of any rebuilding analyses</u>:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. <u>Changes to the management of the fishery</u>: None.

2. <u>Changes to the input data</u>:
- Fishery data has been updated with the results for 2008/09.

3. <u>Changes to the assessment methodology</u>: None.

4. <u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:

- The OFL for 2009/10 was 9.18-million pounds of retained catch and was estimated by the average annual retained catch (not including deadloss) for the period 1985/86–1995/96. The recommended retained-catch OFL for 2010/11 is the same.
- New to this assessment are total catch estimates (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) for the 1996/97–2008/09 seasons, which were computed by applying assumed handling mortality rates to the estimated biomass of bycatch during crab fisheries and federal groundfish fisheries to obtain an estimate of discard mortality in all fisheries and adding that to the biomass of the retained catch. Computation of total catch was afforded by new availability of estimates of bycatch during federal groundfish fisheries that were summarized by crab-fishing years.

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 Teir 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 CPT recommends the use of the time period from 1990/91–1995/96 for a retained catch OFL of 6.93 million* [pounds], *although this recommendation was not unanimous."*
  - Response: See SSC June 2009 comments and response.
- SSC, June 2009: *"The SSC agrees with Tier 5 designation for this stock, but had much discussion over the time period to be used to calculate average catch."* [and] *"The SSC recommends a retained catch OFL of 9.18 million pounds (i.e., same as last year under Tier 5, based on average catch over 1985/86 to 1995/96."*
  - Response: The stock assessment author for the May 2009 report and the CPT in May 2009 recommended a lower OFL (6.93-million) based on the average

annual retained catch during 1990/91 – 1995/96. For this May 2010 report, the assessment follows the recommendation made by the SSC.

- CPT, September 2009: None – this stock was not reviewed at the September 2009 CPT meeting.
- SSC, October 2009: None – this stock was not reviewed at the October 2009 SSC meeting.

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 Aleutian Islands king crab stock boundary is defined by the boundaries of the Aleutian Islands king crab Registration Area O (Figure 1). Bowers et al. (2008, page 6) define those boundaries:

> The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W long.), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W long., north to 55° 30' N lat., and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea (0–3 nautical miles) and waters of the Exclusive Economic Zone (3–200 nautical miles).

During the 1984/85–1995/96 seasons, the Aleutian Islands king crab populations had been managed using the Adak and Dutch Harbor Registration Areas, which were divided at 171° W longitude (Figure 2), but from the 1996/97 season to present the fishery has been managed using a division at 174° W longitude (Figure 1; Bowers et al. 2008). At its March 1996 meeting, the Alaska Board of Fisheries (BOF) replaced the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and directed ADF&G to manage the golden king crab fishery in the areas east and west of 174° W longitude as two distinct stocks. That re-designation of management areas was intended to more accurately reflect golden king crab stock distribution, as is shown by the longitudinal pattern in fishery production prior to the 1996/97 season (Figure 3). The longitudinal pattern in fishery production during recent fisheries since that change in management is shown in Figure 4. The In this chapter we use "Aleutian Islands Area" to mean the area described by the current definition of Aleutian Islands king crab Registration Area O.

Commercial fishing for golden king crabs in the Aleutian Islands Area typically occurs at depths of 100–275 fathoms (183–503 m). During the 2008/09 season the pots sampled by at-sea observers were fished at an average depth of 191 fathoms (349 m; N=613) in the area east of 174° W longitude and 178 fathoms (326 m; N=979) for the area east of 174° W longitude (summary from ADF&G Crab Observer Database, 28 April 2010).

Evidence of stock structure: Given the expansiveness of the Aleutian Islands Area and the existence of deep (>1,000 m) canyons between some islands, at least some weak structuring of the stock within the area would be expected. Data for making inferences on stock structure of golden king crabs within the Aleutian Islands is largely limited to the geographic location of commercial fishery catch and effort. Effort and catch by statistical area since 1982 and locations of over 70,000 fished pots that were sampled by observers since 1996 seasons indicate that habitat for legal-sized males may be continuous throughout the waters adjacent to the Aleutian Islands. However, regions within the area in which available habitat is attenuated are suggested by regions of low fishery effort and catch (Figures 3 and 4); for example the southern side of islands between 174° W longitude and 177° W longitude (i.e., from Atka I. west to Adak I.) as compared to the area surrounding islands between 170°W longitude and 173° W longitude (i.e., between the Islands of the Four Mountains and Seguam Pass). Additionally, there is a gap of catch and effort in statistical areas between Petrel Bank/Petrel Spur and Bowers Bank, both of which areas have reported effort and catch. Recoveries during commercial fisheries of golden king crab tagged during ADF&G surveys (Blau and Pengilly 1994, Blau et al. 1998, Watson and Gish 2002, Watson 2004, Watson 2007) have provided no evidence of substantial movements by crabs in the size classes that were tagged (males and females ≥90-mm CL). Maximum straight-line distance between release and recovery location of 90 golden king crabs released prior to the 1991/92 season and recovered through the 1992/93 season was 33.1 nm (61.2 km; Blau and Pengilly 1994). Of the 4,053 recoveries reported through 14 March 2008 of the golden king crabs tagged and released between 170.5° W longitude and 171.5° W longitude during the 1997, 2000, 2003, and 2006 triennial ADF&G Aleutian Island golden king pot surveys, none were recovered west of 174° W longitude and only four were recovered west of 172° W longitude (L. J. Watson, Fishery Biologist, ADF&G, Kodiak, retired; personnel communication).

3. Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):

The following review of molt timing and reproductive cycle of golden king 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 crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crabs may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crabs without eating; Shirley and Zhou 1997).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crabs likely makes scoring shell conditions very difficult and especially difficult to relate to "time post-molt," posing problems for inclusion of shell condition data into assessment models.

5. <u>Brief summary of management history</u>:

A complete summary of the management history is provided in Bowers et al. (2008, pages 11–15). The first commercial landing of golden king crabs in the Aleutian Islands was in 1975/76, but directed fishing did not occur until 1981/82. Peak harvest occurred during 1986/87 when 14.7-million pounds were harvested. Between 1981/82 and 1995/96 the fishery was managed as two separate fisheries in two separate registration areas, the Adak and Dutch Harbor areas, with the two areas divided at 172° W longitude through 1983/84 and at 171° W longitude after 1983/84. Prior to the 1996/97 season no formal preseason harvest target or limit was established for the fishery and average annual retained catch during 1981/82 – 1995/96 was 8.5-million pounds.

The Aleutian Islands golden king crab fishery was restructured beginning with the 1996/97 season to replace the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and the golden king crabs in the areas east and west of 174° W longitude were managed separately as two stocks. The 1996/97–1997/98 seasons were managed under a 5,900,000-pound guideline harvest level (GHL), with 3,200,000 pounds apportioned to the area east of 174° W longitude and 2,700,000 pounds apportioned to the area west of 174° W longitude. The 1998/99–2004/05 seasons were managed under a 5,700,000-pound GHL, with

3,000,000 pounds apportioned to the area east of 174° W longitude and 2,700,000 pounds apportioned to the area west of 174° W longitude. The 2005/06–2007/08 seasons were managed under a 5,700,000-pound total allowable catch (TAC), with 3,000,000 pounds apportioned to the area east of 174° W longitude and 2,700,000 pounds apportioned to the area west of 174° W longitude. By state regulation (**5 AAC 34.612**), the TAC for retained catch for the Aleutian Islands golden king crab fishery beginning with the 2008/09 is 5,985,000 pounds (apportioned as 3,150,000 pounds for the area east of 174° W longitude and 2,835,000 pounds for the area west of 174° W longitude). Over the period 1996/97–2007/08 the total retained catch has been 2% below the total of the annual GHL/TACs. By season, retained catch has been as much as 13% below the GHL/TAC (the 1998/99 season) and as much as 6% above the GHL/TAC (the 2000/01 season). The retained catch for the most recently completed season (2008/09) was 5% below the 5.985-million pound TAC.

A summary of relevant fishery regulations and management actions pertaining to the Aleutian Islands golden king crab fishery is provided below.

The 2005/06 season was the first Aleutian Islands golden king crab fishery to be prosecuted under the Crab Rationalization Program. Accompanying the implementation of the Crab Rationalization program was implementation beginning in the 2005/06 season of a community development quota (CDQ) fishery for golden king crabs in the eastern Aleutians (i.e., east of 174° W longitude) and Adak Community Allocation fishery for golden king crabs in the western Aleutians (i.e., west of 174° W longitude; Milani 2008). The CDQ fishery in the eastern Aleutians is allocated 10% of the golden king crab TAC for the area east of 174° W longitude and the ACA fishery in the western Aleutians is allocated 10% of the golden king crab TAC for the area west of 174° W longitude. Note that, because Adak is not a CDQ community, the ACA fishery in the western Aleutians is not a formal CDQ fishery. Both the CDQ fishery in the eastern Aleutians and the ACA fishery in the western Aleutians are prosecuted concurrently with the IFQ fishery and managed by ADF&G.

Only males of a minimum legal size may be retained by the commercial golden king crab fishery in the Aleutian Islands Area. By State of Alaska regulation (**5 AAC 34.620 (b)**), the minimum legal size limit is 6.0-inches (152 mm) carapace width (CW), including spines. A carapace length (CL) ≥135 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007b). Note that size limit for golden king crabs has been 6-inches CW for the entire Aleutian Islands Area only since the 1985/86 season. Prior to the 1985/86 season the legal size limit was 6.5-inches for at least one of the now-defunct Adak or Dutch Harbor Registration Areas.

Golden king 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 Aleutian Islands Area my be operated only from a shellfish longline and, since 1996, must have at least four escape rings of five and one-half inches minimum inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crabs (5 AAC 34.625 (b)). Prior to the regulation requiring an escape mechanism on pots, some participants in the Aleutian Islands golden king crab fishery voluntarily sewed escape rings (typically 139-mm or 5.5") into their gear or, more rarely, included panels with escape mesh (Beers 1992). With regard to the gear used by fishers since the establishment of 5 AAC 34.625 (b) in 1996, Linda Kozak, a representative of the industry, reported in a 19 September 2008 email to the Crab Plan Team that, "… the golden king crab fleet has modified their gear to allow for small crab sorting," and provided a written statement from Lance Nylander, of Dungeness

Gear Works in Seattle, who "believes he makes all the gear for the golden king crab harvesting fleet," saying that, "Since 1999, DGW has installed 9" escape web on the door of over 95% of Golden Crab pot orders we manufactured."

By State of Alaska regulation (**5 AAC 34.610 (b)**), the commercial fishing season for golden king crabs in the Aleutian Islands Area is August 15 through May 15.

Current regulations stipulate that onboard observers are required during the harvest of 50% of the total golden king crab weight harvested by each catcher vessel and 100% of the fishing activity of each catcher-processor during each of the three trimesters as outlined in 5 AAC 39.645 (d)(4)(A).

D. Data

1. Summary of new information:

- Fishery data on retained catch and non-retained bycatch during 2008/09 has been added to the retained catch time series.
- Data on bycatch during groundfish fisheries in reporting areas 541, 542, and 543 have been updated with data grouped by crab fishery year, 1996/97–2008/09.
- Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 1996/97–2008/09 have been added.

2. Data presented as time series:

a. Total catch and b. Information on bycatch and discards:

- Fish ticket data on retained catch numbers, retained catch weight, pot lifts, CPUE, and average weight of retained catch for the 1981/82–2008/09 seasons are presented (Table 1).
- Data on bycatch of golden king crabs obtained from pot lifts sampled by at-sea observers during crab fisheries are presented for 1996/97–2008/09 (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 golden king crabs by applying a weight-at-length estimator (see below). Data on bycatch of golden king crabs obtained by at-sea observers during groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5) for crab fishery years 1996/97–2008/09 are presented (Table 3).
- Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 1996/97–2008/09 are presented (Table 4). Following Siddeek et al. (2008), the handling mortality rate of king crabs captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2; that value was also applied as the handling mortality during other crab fisheries. 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.

c. Catch-at-length:

None are presented.

d. Survey biomass estimates:

None.

e. Survey catch at length:

None.

f. ***Other data time series:*** See section D.4 on other time-series data that are available, but not presented here.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

Growth per molt and probability of molt estimates are not used in a Tier 5 assessment. However, growth per molt and probability of molt has been estimated for Aleutian Islands golden king crabs by Watson et al. (2002) based on information received from recoveries during the 1997/98 – 2000/01 commercial fisheries in the area east of 174° W longitude of male and female golden king crabs tagged and released during July–August 1997 in the area east of 174° W longitude (see Tables 24–28 *in* Pengilly 2009).

Watson et al. (2002) used logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released in new-shell condition would molt within 12–15 months after release:

$$P(\text{molt}) = \exp(17.930 - 0.129{*}CL)/[1 + \exp(17.930 - 0.129{*}CL)].$$

Based on the above logistic regression Watson et al. (2002) estimated that the size at which 50% of new-shell males would be expected to molt within 12–15 months is 139-mm CL (S.E. = 0.81-mm CL).

Watson et al. (2002) used logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released as a sublegal ≥ 90-mm CL in new-shell condition would molt to legal size within 12–15 months after release:

$$P(\text{molt to legal size}) = 1 - \exp(15.541 - 0.127{*}CL)/[1 + \exp(15.541 - 0.127{*}CL)].$$

Based on the above logistic regression Watson et al. (2002) estimated that the size at which 50% of sublegal ≥90-mm CL, new-shell males would be expected to molt to legal size within 12–15 months is 123-mm CL (S.E. = 1.54-mm CL).

See section C.4 for discussion of evidence that mature female and the larger male golden king 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. **<u>Information on any data sources that were available, but were excluded from the assessment:</u>**
   - Data from triennial ADF&G pot surveys for Aleutian Islands golden king crabs in a limited area east of 174° W longitude (between 170° 21' and 171° 33' W longitude) that were performed during 1997 (Blau et al. 1997), 2000 (Watson and Gish), 2003 (Watson 2004), and 2006 (Watson 2007) are available, but were not used in this Tier 5 assessment.
   - Non-confidential observer data collected from catcher-processors only during the 1988/89–1992/93 golden king crab seasons (see Table 5) and from all vessels participating in the 1995/96 golden king crab season in the now-defunct Adak and Dutch Harbor Areas exist, but were not accessed for this analysis.
   - Observer data from groundfish fisheries in reporting areas 541, 542, and 543 during 1992/93–1995/96 were accessed, but are not included in this analysis (the data from 1992/93 appears questionable).

E. Analytic Approach

1. **<u>History of modeling approaches for this stock</u>:** This is a Tier 5 stock. There is an assessment model in development for this stock (Siddeek 2008).

2. **<u>Model Description</u>:** *Subsections a–i are not applicable to a Tier 5 stock.*

It has been recommended by NPFMC (2007) and by the CPT and SSC in 2009 that the Aleutian Islands golden king crab stock be managed as a Tier 5 stock until the assessment model is accepted for use. For Tier 5 stocks only an OFL is estimated, because it is not possible to estimate MSST without an estimate of biomass, and "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (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?"

Prior to 2008, two time periods considered for computing the average retained catch for Aleutian Islands golden king crab: 1985–2005 (NPFMC 2007a) and 1985–1999 (NPFMC 2007b). NPFMC (2007b) suggested using the average retained catch over the years 1985 to

1999 as the estimated OFL for Aleutian Islands golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching during the 1976/77 "regime shift" and growth to legal size. With regard to excluding data from years after 1999, NPFMC (2007b) states, "Years from 2000 to 2005 were excluded for Aleutian Islands golden king crab when the TAC was set below the previous average catch." Note, however, that there was no TAC or GHL established for the entire Aleutian Islands Area prior to the 1996/97 season (see above) and the GHL for the Aleutian Islands Area was reduced from 5.9-million pounds for the 1996/97 and 1997/98 seasons to 5.7-million pounds for the 1998/1999 season; the GHL or TAC has remained at 5.7-million pounds for all subsequent seasons until it was increased to 5.985-million pounds for the 2008/09 season.

Pengilly (2008) discussed nine periods, spanning periods as long as 26 seasons (1981/82–2006/07) to as short as 6 seasons (1990/91–1995/96), for computing average annual retained catch to estimated the OFL for the 2008/09 season. Only periods beginning no earlier than 1985/86 were recommended for consideration, however, due to the size limit change that occurred prior to the 1985/86 season. Of those, the Crab Plan Team at the May 2008 recommended using the period 1990/91–1995/96 for computing the 2008/09 OFL to address concerns raised by a decline in retained catch and CPUE that occurred from 1985/86 into the mid-1990's, the first five seasons of the full period of unconstrained catch under the current size limit. The SSC recommended using the period 1985/86 – 1995/96 for computing the 2008/09 OFL, however. Although the not explicitly stated in the SSC minutes their choice was apparently based on the desire for the longest possible period of unconstrained catch under the current size limit ("Earlier years were not recommended for inclusion because of a difference in the size limit regulations prior to 1985/86." (Minutes of the NPFMC SSC meeting, 2–4 June 2008)**.**

Pengilly (2009) discussed only three time periods to consider for setting the 2009/10 OFL: 1985/86–1995/96 (the time period recommended by the SSC for the 2008/09 OFL); 1990/91–1995/96; (the time period recommended by the CPT for the 2008/09 OFL); and 1987/88–1995/96. The period 1987/88–1995/96 was offered for consideration on the basis of having the longest period of unconstrained catch under the current size limit, while excluding the two seasons with the highest retained catch in the history of the fishery (the 1985/86–1986/87 seasons). Trends of declining catch, declining CPUE, and declining average weight of landed crabs that occurred from 1985/86 into the mid-1990's could be interpreted as resulting from fishery that relied increasingly on annual recruitment to legal size as it fished on a declining stock of legal-size males. Hence the catches during the full period of unconstrained catch under the current size limit, 1985/86–1995/96, could be viewed as unsustainable. Removal of the two highest-catch seasons, 1985/86–1986/87, at the beginning of that time period was offered as a compromise between the desire for the longest period possible for averaging catch and the desire for a period reflecting long-term production potential of the stock. Of those, the Crab Plan Team at the May 2009 again recommended using the period 1990/91–1995/96 for computing the 2009/10 OFL, whereas the SSC again recommended 1985/86–1995/96, noting that "the management system was relatively constant from 1985 onward" and that a "longer time period likely provides a more robust estimate than a shorter time period." (Minutes of the NPFMC SSC meeting, 1–3 June 2009).

3. Model Selection and Evaluation:

a. Description of alternative model configurations

The recommended OFL is set as a retained-catch OFL due to lack of data on bycatch of golden king crabs during the Aleutian Islands golden king crab fishery prior to 1988/89 and the limitations and confidentiality of bycatch data during 1988/89–1994/95. Information on bycatch and discards during the Aleutian Islands golden king crab fishery is obtained by observers deployed on fishing vessels by the State of Alaska shellfish observer program (Schwenzfeier et al. 2008). During the 1988/89–1994/95 seasons observers were required only on vessels processing golden king crabs at sea, including catcher-processor vessels, and in four out of those seven seasons the observer data are confidential due to the data being collected from less than 3 vessels (Table 5). 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 catcher-only vessels (C/Vs) 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 (August 15–November 15, November 15–February 15, and February 15–May 15). Observer coverage for catcher-processor vessels (C/Ps) and floater-processor vessels (F/Ps) is set at 100%.

Three alternative configurations for computing average retained catch to estimate a retained-catch OFL for 2009/10 were considered and described below (the "Base" and Alternatives 1 and 2). Periods that include seasons prior to the 1985/86 season are not included because of the change in size limits that occurred prior to the 1985/86 season. Periods that include seasons after the 1995/96 season are not included because the retained catch has been limited by either a GHL or TAC since the 1996/97 season. Hence only periods within 1985/86–1995/96 are considered as options for computing the 2009/10 OFL. Trends in annual retained catch and fishery CPUE may give some idea of the production potential of the stock and the effects of fishery removals during 1985/86–1995/96, although those trends may also be affected by changes in fishery practices. Annual season average weights of landed crabs and size distribution of the catch may give some idea of recruitment trends, although those may also be influenced by changes in fishery practices (e.g., use of escape mechanisms and soak times). Trends in those data are examined for the period 1985/86–1995/96 in the paragraph below.

Retained catch and catch (number of retained legal males) per pot lift (CPUE) in the entire Aleutian Islands Area both showed a declining trend during 1985/86–1995/96 (Table 1, Figure 6). Average weights of landed crabs also showed a declining trend from 1985/86 into the mid-1990's, followed by a sharp increase from the 1993/94 season through the 1995/96 season for the entire Aleutian Islands Area (Table 1, Figure 7). Average retained catch for the period 1985/86–1989/90 was 11.88-million pounds. Harvests dropped sharply from the 1989/90 to 1990/91 season (from 12.02-million pounds to 6.59-million pounds) and average retained catch for the period 1990/91–1995/96 was 6.93-million pounds. By the 1993/94 season, the harvest in the Aleutian Islands golden king crab fishery was 44% of that for the 1985/86 season, the CPUE was 48% of that for the 1985/86 season, and the average weight of landed crabs was 89% of that for the 1985/86 season. The trends in declining catch, declining CPUE, and declining average weight of landed crabs from 1985/86 into the mid-1990's in a fishery that was, with the exception of the area east of 171° W longitude, managed on a "size-sex-season" may be evidence that the harvest during that period was not "representative of the production potential of the stock." Acknowledging the usual caveats in interpreting fishery data, the three declining trends together during this period could be interpreted as resulting from fishery that relied increasingly on annual recruitment to legal size as it fished on a declining stock of legal-size males.

The "Base" period and the two alternatives are described below:

- The "Base" period (1985/86–1995/96) is that recommended by the SSC for computing the OFL for 2008/09 and 2009/10. It is the longest possible time period within the constraints noted above, although it contains features that gave concern to the Crab Plan Team in the past that are noted in the descriptions of the alternatives.

- The Alternative 1 period (1987/88–1995/96) is that originally recommended in May 2008 by the 2008 assessment author for computing the OFL for the 2008/09 season. The reasoning was based on the desire to have longest period of unconstrained catch under the current size limit, while excluding the two seasons with the highest retained catch in the history of the fishery (the 1985/86–1986/87 seasons). Trends of declining catch, declining CPUE, and declining average weight of landed crabs that occurred from 1985/86 into the mid-1990's could be interpreted as resulting from fishery that relied increasingly on annual recruitment to legal size as it fished on a declining stock of legal-size males. Hence the catches during the full period of unconstrained catch under the current size limit, 1985/86–1995/96, could be viewed as unsustainable. Removal of the two highest-catch seasons, 1985/86–1986/87, at the beginning of that time period was offered as a compromise between the desire for the longest period possible for averaging catch and the desire for a period reflecting long-term production potential of the stock.

- The Alternative 2 period (1990/91–1995/96) is that recommended by the Crab Plan Team at for computing the OFL for 2008/09 and 2009/10. The Team felt that, given the decline in retained catch and CPUE that occurred from 1985/86 into the mid-1990's, the first five seasons of the full period of unconstrained catch under the current size limit should be removed from the period for computing OFL. The first five seasons had the highest catches of the period 1985/86–1995/96 (9.3-million pounds to 14.7-million pounds). During the next six seasons, 1990/95–1995/96, catches stabilized with low variability (5.6-million pounds to 8.1-million pounds) and without a discernable deceasing trend. Although fishery CPUE continued to decline through the 1995/96 season, fishery CPUE has increased and the fishery has been able to sustain annual retained catches of 4.9-million pounds to 6.0-million pounds in the 12 seasons completed since then.

Model	**Retained-vs. Total-catch**	**Time Period (n of years)**	**Description/Comments**
Base	Retained	1985/86–1995/96 (11)	• SSC recommendation to determine the 2008/09 and 2009/10 OFLs • Catch, CPUE, and average weight of landed catch decline from peak values in 1985/86–1986/87
Alt. 1	Retained	1987/88–1995/96 (9)	• Balances CPT's past concerns about use the Base period with SSC's recommendation to use the longest time period possible
Alt. 2	Retained	1990/91–1995/96 (6)	• CPTs recommendation for 2008/09 and 2009/10 • Addresses concerns raised by decline in catch, CPUE, and average weight during 1985/86–1995/96

Being as the OFL is being determined for the 2009/10 season (and not the 1996/97 season), consideration should also be given to the post-1995/96 condition of the stock. Fishery data for the period 1996/97–2008/09 are reviewed below.

Since the 1996/97 season, catches stabilized between 4.94-million and 6.02-million pounds with management of the fishery to a pre-season GHL and CPUE increased steadily from the 1996/97 season through the 2004/05 season (Table 1, Figure 6). The CPUE for the Aleutian Islands Area increased from 6.0 crabs per pot lift in 1996/97 to 14.2 in 2004/05. The trend in increasing CPUE over this period could be indicative of an increase in legal male abundance since the mid-1990’s. Average weights of landed crabs during the 1996/97–1997/98 seasons were comparable to those of the 1985/86–1986/87 seasons (Table 1, Figure 7). Post-1997/98 average weight of landed crabs declined and remained below the 1996/97–1997/98 average weight through the 2004/05 season (Table 1, Figure 7). The decline in average weight of landed crabs after the 1997/98 season could be indicative of increase in recruitment to legal size during the late 1990’s and early 2000’s.

Since rationalization of the fishery, annual retained catch towards the 5.7-million pound TAC during 2005/06–2007/08 ranged from 5.26-million pounds to 5.52-million pounds, only a slight decrease relative to the average for the period 1996/97–2004/05 (5.69-million pounds). Fishery CPUE increased markedly to values of 22–23 crabs per pot lift or more during 2005/06–2007/08 (the previous high for fishery CPUE was 14 crabs per pot lift in the 2004/05 season; Table 1, Figure 6). The increase in CPUE was not accompanied by a decrease in average weight of landed crabs; in fact, average weight of landed crabs increased (Table 1, Figure 7). A TAC of 5.985-million pounds was established for the 2008/09 season. During the 2008/09 season the retained catch increased slightly to 5.68-million pounds, the CPUE increased to 25 crabs per pot lift, and average weight of retained crabs increased to 4.53 pounds (Table 1, Figure 7). Fishery CPUE and average weight of retained catch in 2008/09 were the highest over the period 1985/86–2008/09.

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** See the table, below.

Model	**Retained-vs. Total-catch**	**Time Period (n of years)**	**Resulting OFL (millions of pounds)**
Base	Retained	1985/86–1995/96 (11)	9.18
Alt. 1	Retained	1987/88–1995/96 (9)	8.17
Alt. 2	Retained	1990/91–1995/96 (6)	6.93

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:***

All alternatives assume that catch is indicative of stock productivity. The reality of that assumption and the search between realism and simpler (“more years are better”) was discussed for the time periods considered in section E.3.a.

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 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 8.

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.
   - Recommended time period for computing retained-catch OFL: 1985/86–1995/96.
     - The recommended time period follows the recommendation of the SSC in June 2009. The SSC found that the declines in CPUE and average weight that concerned the CPT are, "rather small, relative to variability over the history of the fishery." Moreover, the SSC noted that, "the fishery may have been

affected by other factors, such as changes in fishing effort, market price, and other BSAI crab fishing alternatives." The SSC also noted that, "the management system was relatively constant from 1985 onward," providing another justification for using the longer time period to calculate catch averages." Overall, the SSC argued that a "longer time period likely provides a more robust estimate than a shorter time period." (Minutes of the NPFMC SSC meeting, 2–4 June 2008)**.**

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	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a] [retained]
2006/07	N/A	N/A	5.70	5.26	5.82	
2007/08	N/A	N/A	5.70	5.51	6.25	
2008/09	N/A	N/A	5.99	5.68	6.31	9.18
2009/10	N/A	N/A	5.99	TBD	TBD	9.18
2010/11	N/A	N/A	5.99	TBD	TBD	9.18

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

4. Recommendation for F_{OFL}, OFL total catch (or OFL retained catch) for the coming year:

Recommended OFL = 9.18-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

Currently, there are no biomass estimates for this stock. The process of development and annual use of an assessment model (e.g., Siddeek 2008) to estimate spawning biomass or a proxy will identify data gaps and research priorities.

I. Ecosystem Considerations

1. Ecosystem Effects on Stock:

a. Prey availability/abundance trends (historically and in the present and foreseeable future): Existence and availability of such information is not known to the author.

b. Predator population trends (historically and in the present and foreseeable future): 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 species composition (bycatch) during the 2008/09 Aleutian Islands golden king crab fishery is provided in Table 6. See Pengilly (2009) for similar data collected during 2002/03–2007/08.

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 effort occurs typically at depths of 100–275 fathoms (183–503 m; see section C.2) and occurs during August 15 through May 15.

c. Fishery-specific effects on amount of large size target crab:
The fishery can only retain males ≥ 6.0-inches CW. Although the weight of the catch of sublegal males (not discounting for mortality) during 1996/97–2004/05 (i.e., prior to fisheries rationalization) is estimated to have been 45%–87% of the weight of retained catch, since 2005/06 estimated catch (not discounting for mortality) of sublegal males has been 24%–27% of the weight of retained catch (see Pengilly 2009). Hence the fishery, when prosecuted, would be expected to decrease the amount of males ≥ 6.0-inches CW relative to males < 6.0-inches CW and relative no fishing. However, without background information on the available biomass of large size males, the magnitude of the effect cannot be estimated.

d. Fishery-specific contribution to discards:
Estimated contribution of discards of golden king crabs in the Aleutian Islands golden king crab fishery relative to the retained catch and to the bycatch in other Bering Sea crab fisheries during 1996/97–2008/09 is provided in Table 2. See Table 3 for comparison with the estimated bycatch of Aleutian Islands golden king crabs in federal groundfish fisheries during 1996/97–2008/09. Total fishery mortality portioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries during 1996/97–2008/09 is provided in Table 4.

***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.

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 Aleutian Islands golden king crab fishery, 1985/86–2008/09 is plotted in Figure 9 (see also Table 1). Number of pot lifts has declined from several hundred-thousand 1985/86–1996/97 to approximately 50-thousand pot lifts during 2005/06–2008/09.

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Table 1. Harvest history for the Aleutian Islands golden king crab fishery (GHL/TAC, pounds and number of retained crabs, pot lifts, fishery catch per unit effort, and average weight of landed crabs) by fishery season from the 1981/82 season through the 2007/08 season (includes the CDA and ACA fisheries for the 2005/06–2007/08 seasons; from Pengilly 2009, updated with 2008/09 data from J. Alas, ADF&G, 27 April 2010).

Season	GHL/TAC Millions of Pounds	Harvest Pounds[a]	Harvest Number[a]	Pot lifts	CPUE[b]	Average Weight[c]
1981/82	-	1,319,666	242,407	28,263	8.4	5.4[d]
1982/83	-	9,236,942	1,746,206	179,888	9.4	5.3[d]
1983/84	-	10,495,045	1,964,772	267,519	7.2	5.3[d]
1984/85	-	4,819,347	995,453	90,066	10.7	4.8[e]
1985/86	-	12,734,212	2,811,195	236,281	11.9	4.5[f]
1986/87	-	14,738,744	3,340,627	433,020	7.7	4.4[f]
1987/88	-	9,257,005	2,174,576	306,730	7.1	4.2[f]
1988/89	-	10,627,042	2,488,433	321,927	7.6	4.3[f]
1989/90	-	12,022,052	2,902,913	357,803	8.0	4.1[f]
1990/91	-	6,950,362	1,703,251	214,814	7.7	4.1[f]
1991/92	-	7,702,141	1,847,398	234,857	7.7	4.2[f]
1992/93	-	6,291,197	1,528,328	203,221	7.4	4.1[f]
1993/94	-	5,551,143	1,397,530	234,654	5.8	4.0[f]
1994/95	-	8,128,511	1,924,271	386,593	4.8	4.2[f]
1995/96	-	6,960,406	1,582,333	293,021	5.2	4.4[f]
1996/97	5.9	5,815,772	1,334,877	212,727	6.0	4.4[f]
1997/98	5.9	5,945,683	1,350,160	193,214	6.8	4.4[f]
1998/99	5.7	4,941,893	1,150,029	119,353	9.4	4.3[f]
1999/00	5.7	5,838,788	1,385,890	186,169	7.2	4.2[f]
2000/01	5.7	6,018,761	1,410,315	172,790	8.0	4.3[f]
2001/02	5.7	5,918,706	1,416,768	168,151	8.3	4.2[f]
2002/03	5.7	5,462,455	1,308,709	131,021	9.8	4.2[f]
2003/04	5.7	5,665,828	1,319,707	125,119	10.3	4.3[f]
2004/05	5.7	5,575,051	1,323,001	91,694	14.2	4.2[f]
2005/06	5.7	5,520,318	1,263,339	54,685	22.9	4.4[f]
2006/07	5.7	5,262,342	1,178,321	53,065	22.0	4.5[f]
2007/08	5.7	5,508,100	1,233,848	52,609	23.5	4.5[f]
2008/09	5.985	5,680,084	1,254,607	50,666	24.8	4.5[f]

a. Includes deadloss.
b. Catch (number of crabs) per pot lift.
c. Average weight (pounds) of landed crabs, including deadloss.
d. Managed with 6.5" CW minimum size limit.
e. Managed with 6.5" CW minimum size limit west of 171° W longitude and 6.0" minimum size limit east of 171° W longitude.
f. Managed with 6.0" minimum size limit.

Table 2. Estimated weight (pounds) of the catch of retained legal males, non-retained legal male, non-retained sublegal male, non-retained female, and total non-retained Aleutian Islands golden king crabs during commercial crab fisheries by season for the 1996/97–2008/09 seasons (from Pengilly 2009, updated with 2008/09 bycatch estimates from W. Gaeuman, ADF&G, using data from the ADF&G Crab Observer Database, 27 April 2010). All non-retained catch occurred during the commercial Aleutian Islands golden king crab fishery unless noted.

		Non-retained catch			
Season	Retained Catch	Legal male	Sublegal male	Female	Total
1996/97	5,815,772	0	4,221,753[a]	4,853,795[b]	9,075,548[a,b]
1997/98	5,945,683	0	4,198,607[d]	4,494,061[e]	8,692,668[d,e]
1998/99	4,941,893	41,325	4,303,406	3,043,543	7,388,274
1999/00	5,838,788	63,877	3,930,277	3,557,417	7,551,570
2000/01	6,018,761	35,432	4,782,427	4,083,675	8,901,534
2001/02	5,918,706	26,541	3,787,239	3,074,681[f]	6,888,462[f]
2002/03	5,462,455	41,621	3,113,341	2,516,355[g]	5,671,318[g]
2003/04	5,665,828	38,870	2,663,899	2,270,716[h]	4,973,484[h]
2004/05	5,575,051	76,100	2,511,523	1,733,391	4,321,014
2005/06	5,520,318	140,493	1,478,601	904,642	2,523,737
2006/07	5,262,342	119,590	1,263,303	1,190,147	2,573,040
2007/08	5,508,100	127,560	1,504,738	1,402,333	3,034,632
2008/09	5,680,084	174,866	1,365,338	1,223,469	2,763,673

a. Includes 99,579 pounds from crab fishing not directed on golden king crabs.
b. Includes 202,745 pounds from crab fishing not directed on golden king crabs.
c. Includes 70,075 pounds from crab fishing not directed on golden king crabs.
d. Includes 66,373 pounds from crab fishing not directed on golden king crabs.
e. Includes 83 pounds from crab fishing not directed on golden king crabs.
f. Includes 65 pounds from crab fishing not directed on golden king crabs.
g. Includes 2,303 pounds from crab fishing not directed on golden king crabs.
h. Includes 7 pounds from crab fishing not directed on golden king crabs.

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 541, 542, and 543, 1995/96–2008/09 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office through R. Foy AFSC, Kodiak Laboratory, 7 August 2009).

Year	Fixed	Trawl	Total Bycatch	Total Bycatch Mortality
1996/97	26	13,862	13,887	11,102
1997/98	539	1,071	1,610	1,126
1998/99	3,901	1,381	5,282	3,055
1999/00	10,572	1,422	11,995	6,424
2000/01	7,166	669	7,836	4,119
2001/02	1,387	417	1,804	1,027
2002/03	75,952	871	76,823	38,673
2003/04	86,186	1,498	87,684	44,291
2004/05	2,450	2,452	4,903	3,187
2005/06	1,246	4,151	5,397	3,944
2006/07	72,306	3,077	75,382	38,614
2007/08	254,225	3,641	257,867	130,026
2008/09	108,683	22,712	131,395	72,511
Mean	48,049	4,402	52,451	27,546
CV of Mean	42%	41%	40%	38%

Table 4. Estimated annual weight (pounds) of total fishery mortality to Aleutian Islands golden king crab, 1996/97–2008/09, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries (see Tables 2 and 3).

		Bycatch Mortality by Fishery Type		
Season	Retained Catch	Crab	Groundfish	Total
1996/97	5,815,772	1,815,110	11,102	7,641,984
1997/98	5,945,683	1,738,534	1,126	7,685,343
1998/99	4,941,893	1,477,655	3,055	6,422,603
1999/00	5,838,788	1,510,314	6,424	7,355,526
2000/01	6,018,761	1,780,307	4,119	7,803,187
2001/02	5,918,706	1,377,692	1,027	7,297,425
2002/03	5,462,455	1,134,264	38,673	6,635,392
2003/04	5,665,828	994,697	44,291	6,704,816
2004/05	5,575,051	864,203	3,187	6,442,441
2005/06	5,520,318	504,747	3,944	6,029,009
2006/07	5,262,342	514,608	38,614	5,815,564
2007/08	5,508,100	606,926	130,026	6,245,052
2008/09	5,680,084	552,735	72,511	6,305,330
Mean, 96/97–04/05	5,686,993	1,410,308	12,556	7,109,857
CV of Mean	2%	8%	44%	3%
Mean, 05/06–08/09	5,492,711	544,754	61,274	6,098,739
CV of Mean	2%	4%	44%	2%
Mean, 96/97–08/09	5,627,214	1,143,984	27,546	6,798,744
CV of Mean	1%	12%	38%	3%

Table 5. Vessel participation and number of observed vessels in the Aleutian Islands golden king crab fishery east and west of 171° W longitude (i.e., in the now-defunct Dutch Harbor and Adak Registration Areas) 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 golden king crabs in the Aleutian Islands.

Fishery Season	Area	Vessel Effort	Vessels Observed	Comments
1988/89	East of 171° W long.	21	1	Data confidential
	West of 171° W long.	58	16	-
1989/90	East of 171° W long.	13	2	Data confidential
	West of 171° W long.	64	12	
1990/91	East of 171° W long.	16	5	-
	West of 171° W long.	13	6	-
1991/92	East of 171° W long.	11	4	-
	West of 171° W long.	16	8	-
1992/93	East of 171° W long.	10	5	-
	West of 171° W long.	17	5	-
1993/94	East of 171° W long.	5	0	No data
	West of 171° W long.	18	1	Data confidential
1994/95	East of 171° W long.	14	0	No data
	West of 171° W long.	24	1	Data confidential

Table 6. Summary of contents of 1,592 pot lifts sampled by observers during the 2008/09 Aleutian Islands golden king crab fishery (total fishery pot lifts was 50,666). (page 1 of 2)

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
Anthomastus sp.	26	0	0	0	0
arrowtooth flounder	2	0	0	0	0
Arthrogorgia sp.	22	0	0	0	0
Atka mackerel	2	0	0	0	0
Bamboo coral unident.	1	0	0	0	0
barnacle unident.	1	0	0	0	0
basket star	454	0	0	0	0
bigmouth sculpin	1	0	0	0	0
brittle star unident.	360	0	0	0	0
bryozoan unident.	60	0	0	0	0
Calcigorgia sp.	14	0	0	0	0
Caryophyllia sp.	1	0	0	0	0
Clavularia sp.	6	0	0	0	0
Crypthelia sp.	2	0	0	0	0
Cup coral unident.	5	0	0	0	0
Cyclohelia sp.	19	0	0	0	0
Distichopora sp.	11	0	0	0	0
Errinopora sp.	4	0	0	0	0
Fanellia sp.	48	0	0	0	0
flatfish unident.	2	0	0	0	0
giant octopus	2	0	0	0	0
golden king crab	6	16225	18086	41996	41061
grenadier (rattail) unident.	2	0	0	0	0
hairy triton (or Oregon triton)	1	0	0	0	0
hermit crab unident.	2	0	0	0	0
hydrocoral unident.	2	0	0	0	0
hydroid unident.	261	0	0	0	0
invertebrate unident.	2	0	0	0	0
Kamchatka coral	21	0	0	0	0
octopus unident.	2	0	0	0	0
Pacific cod	4	0	0	0	0
Pacific halibut	16	0	0	0	0
Pacific ocean perch	2	0	0	0	0
Plexauridae unident.	25	0	0	0	0
Primnoidae Group I	124	0	0	0	0
Primnoidae unident.	8	0	0	0	0
red king crab	0	3	2	1	0
red-tree coral	4	0	0	0	0
rockfish unident.	10	0	0	0	0
sablefish (or black cod)	1	0	0	0	0
scarlet king crab	0	3	20	17	8
sculpin unident.	1	0	0	0	0
sea anemone unident.	4	0	0	0	0
sea cucumber unident.	1	0	0	0	0
sea lily (or feather star) unident.	13	0	0	0	0
sea pen unident.	1	0	0	0	0

(continued)

Table 6. Page 2 of 2.

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
sea raspberry	1	0	0	0	0
sea spider unident.	7	0	0	0	0
sea urchin unident.	134	0	0	0	0
sea whip unident.	4	0	0	0	0
shortspine thornyhead	1	0	0	0	0
shrimp unident.	7	0	0	0	0
skate egg case unident.	5	0	0	0	0
skate unident.	13	0	0	0	0
snail unident.	48	0	0	0	0
sponge unident.	382	0	0	0	0
starfish unident.	159	0	0	0	0
stony coral unident.	1	0	0	0	0
Stylaster sp.	170	0	0	0	0
tunicate unident.	52	0	0	0	0
worm unident.	23	0	0	0	0
yellow Irish lord	3	0	0	0	0

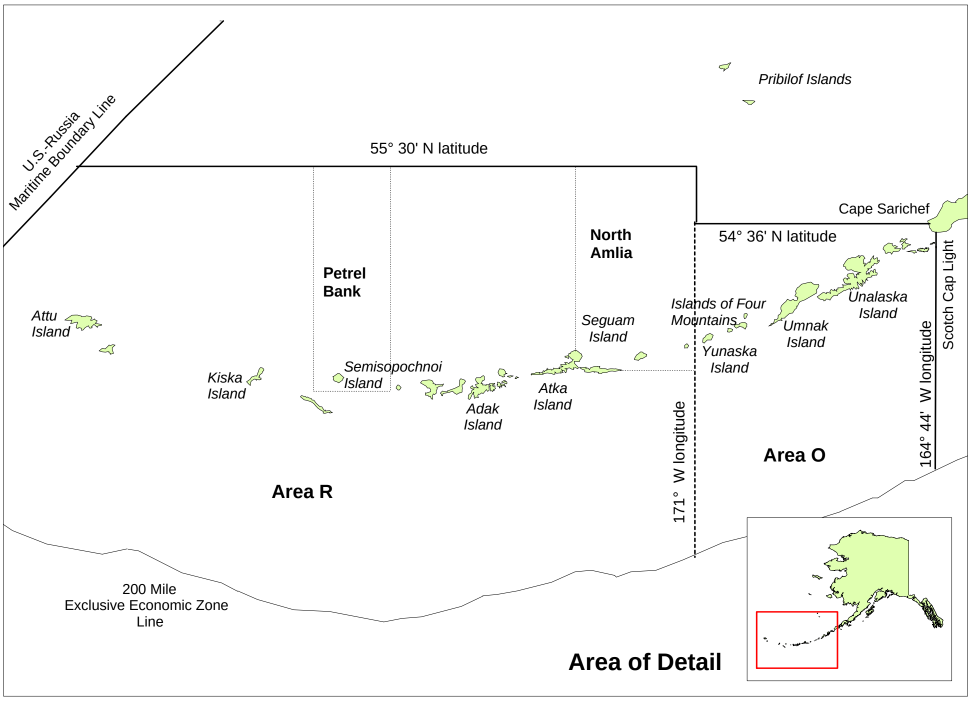

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Bowers et al. 2008).

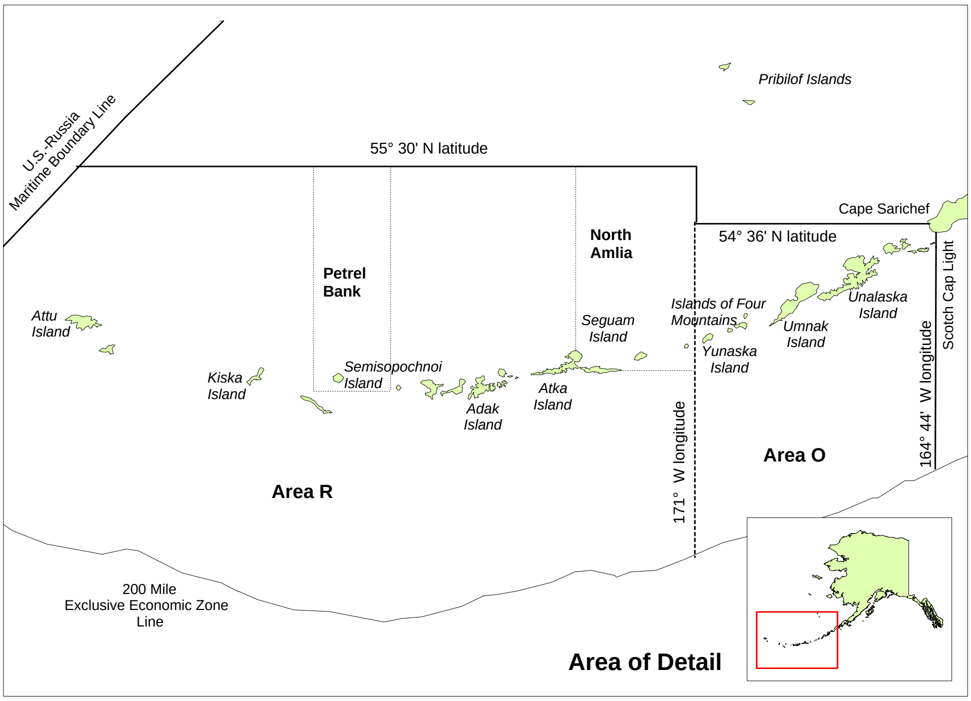

Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85 – 1995/96 seasons (Bowers et al. 2008).

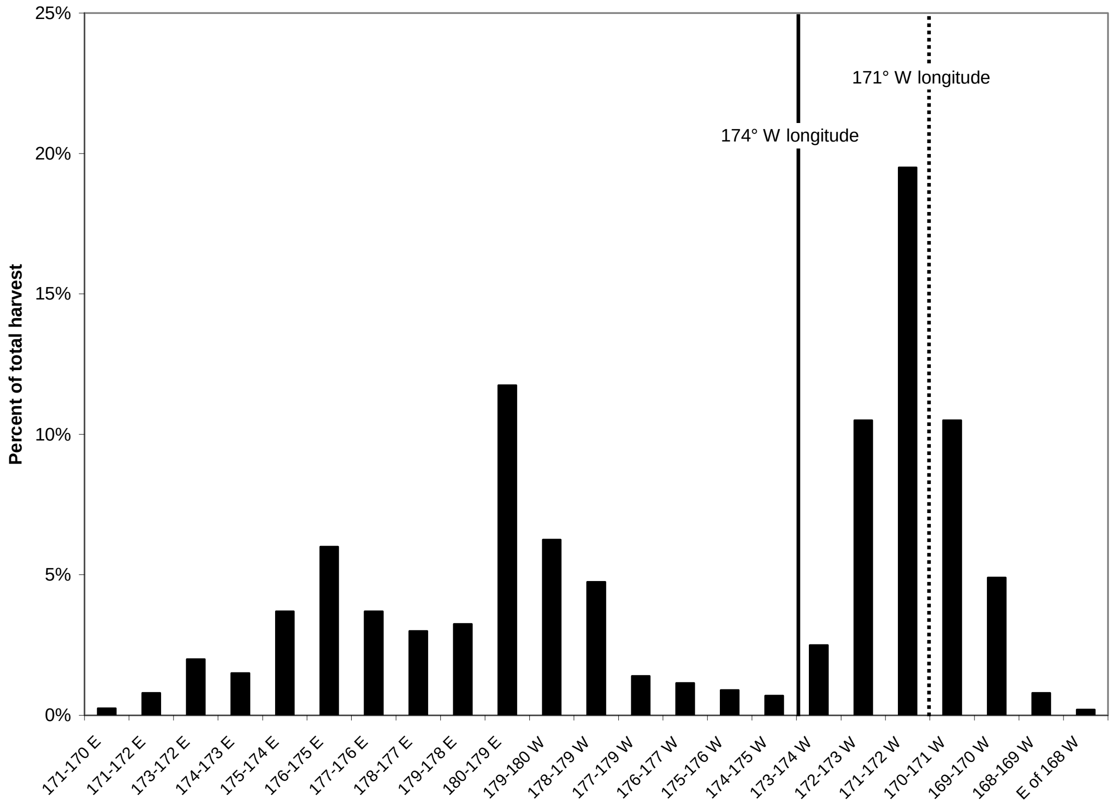

Figure 3. Percent of total 1982–1996 golden king crab harvest by one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude that was used until the end of the 1995/96 season to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude) and solid line denoting the border at 174° W longitude that has been used since the 1996/97 to manage Aleutian Island golden king crabs as separate stocks east and west of 174° W longitude (from Figure 4-2 *in* Morrison et al. 1998).

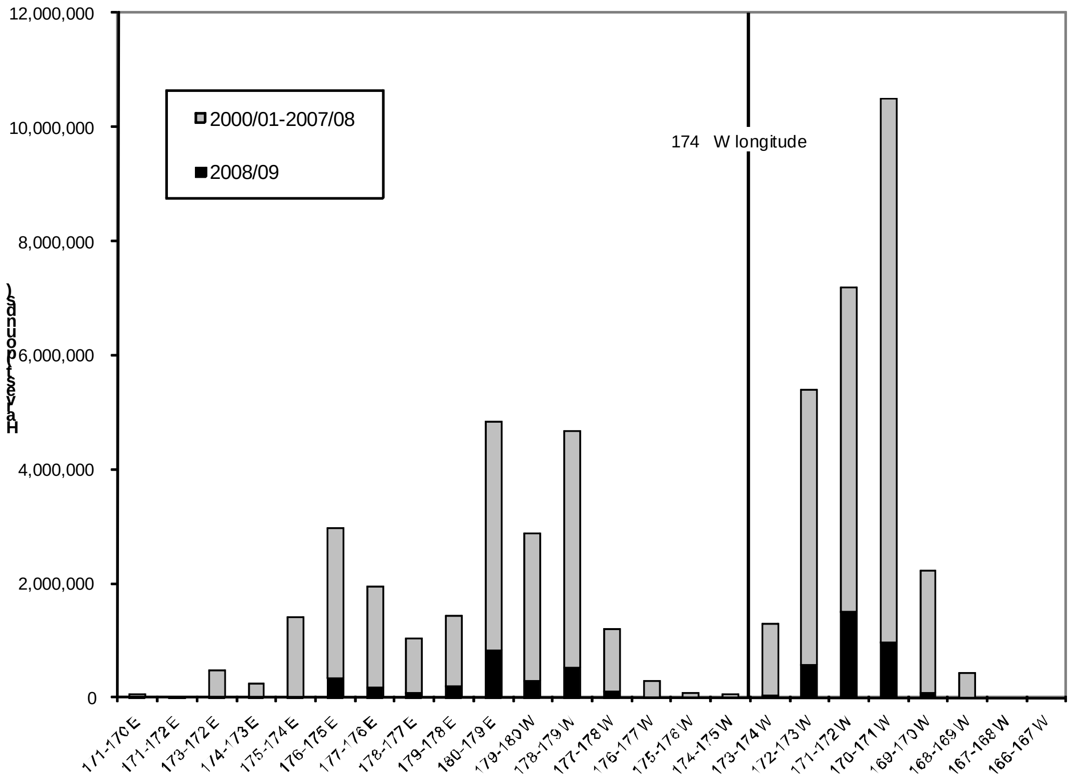

Figure 4. Harvest (pounds) of golden king crabs by one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2008/09 commercial fishery seasons, with the harvest for the 2008/09 season distinguished from the total harvest for the 2000/01–2007/08 seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crabs as separate stocks east and west of 174° W longitude (2000/01–2007/08 data from Pengilly 2009; 2008/09 data from J. Alas, ADF&G, 27 April 2010).

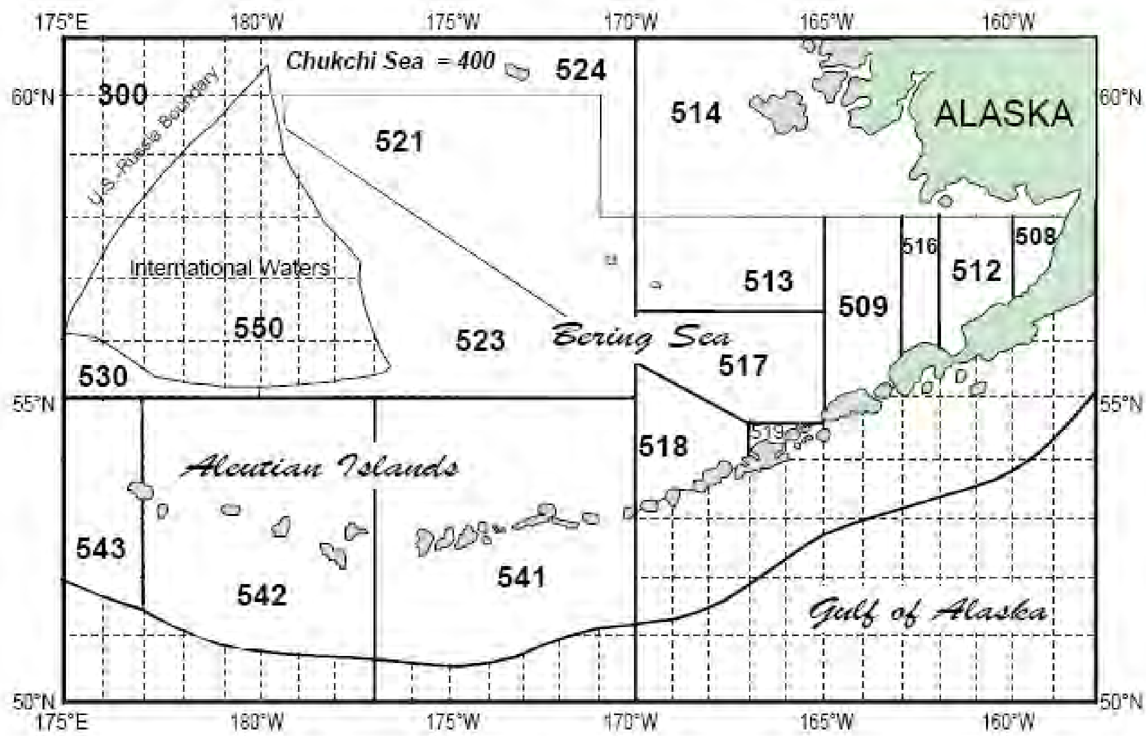

Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to obtain data on bycatch of Aleutian Islands golden king crabs during groundfish fisheries (from http://www.fakr.noaa.gov/rr/figures/fig1.pdf).

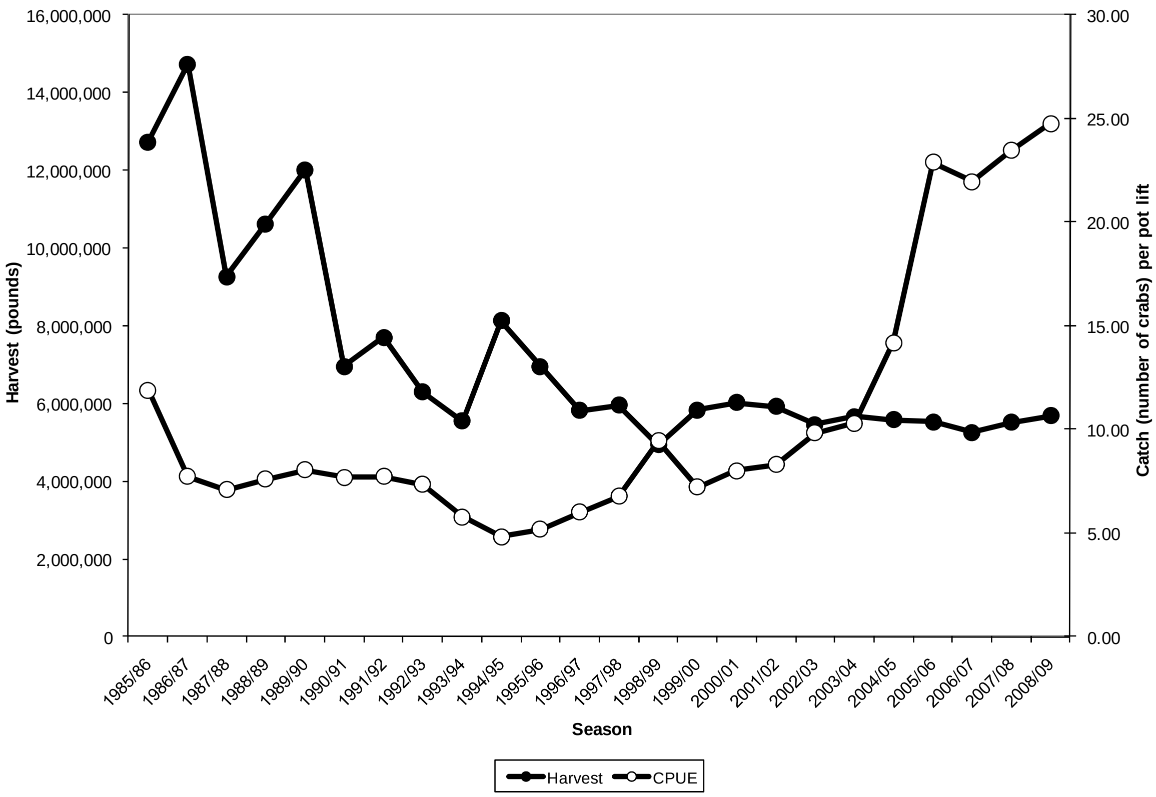

Figure 6. Retained catch (harvest in pounds) and catch (number of retained legal crabs) per pot lift (CPUE) in the Aleutian Islands golden king crab fishery, 1985/86–2008/09 seasons (from Pengilly 2009; 2008/09 data from J. Alas, ADF&G, 27 April 2010).

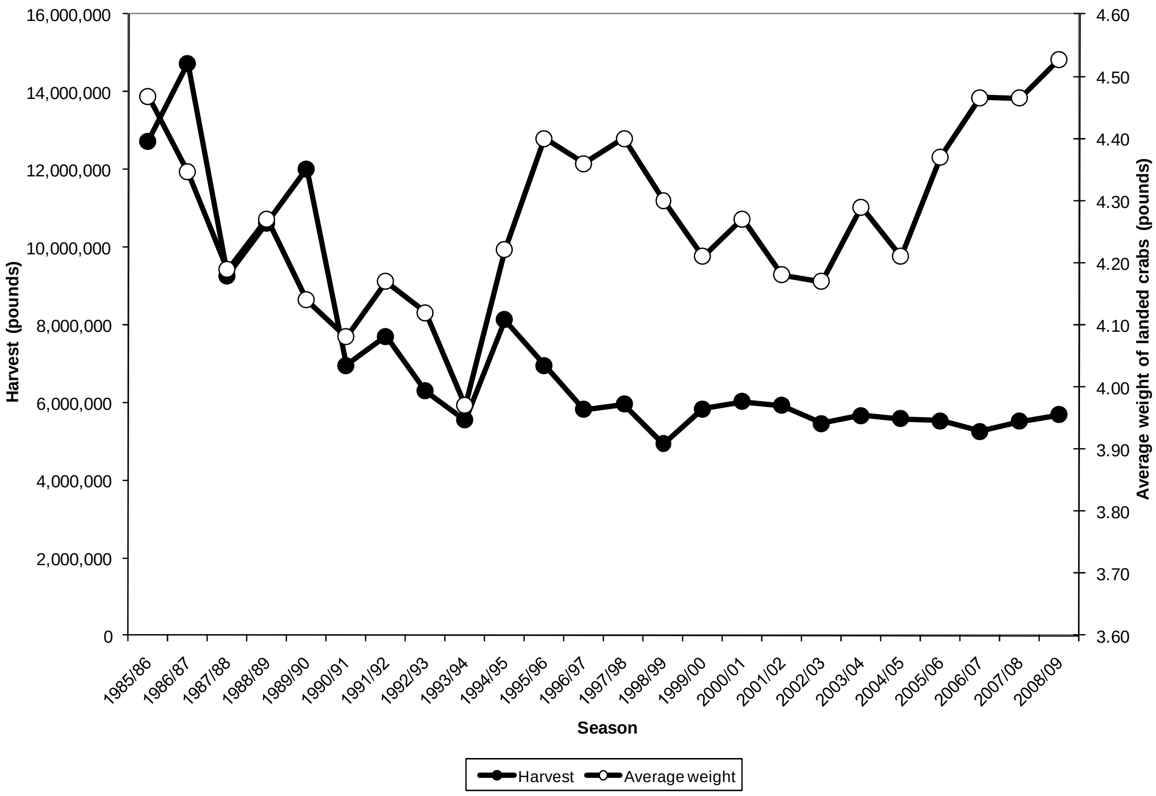

Figure 7. Retained catch (harvest in pounds) and average weight (pounds) of landed crabs in the Aleutian Islands golden king crab fishery, 1985/86–2008/09 seasons (from Pengilly 2009; 2008/09 data from J. Alas, ADF&G, 27 April 2010).

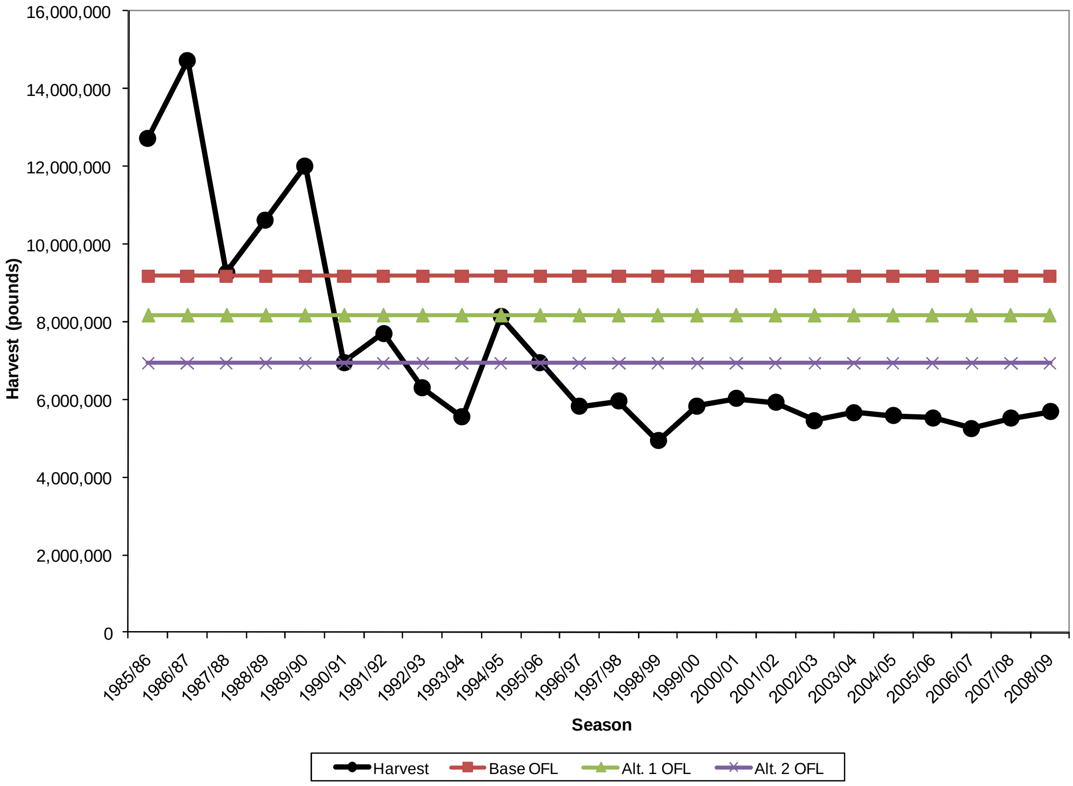

Figure 8. Alternative retained-catch OFLs (Base and Alternatives 1–2) compared with actual historical fishery retained catch for the Aleutian Islands golden king crab fishery, 1985/86–2008/09 (see Table 1 and section E.3.b).

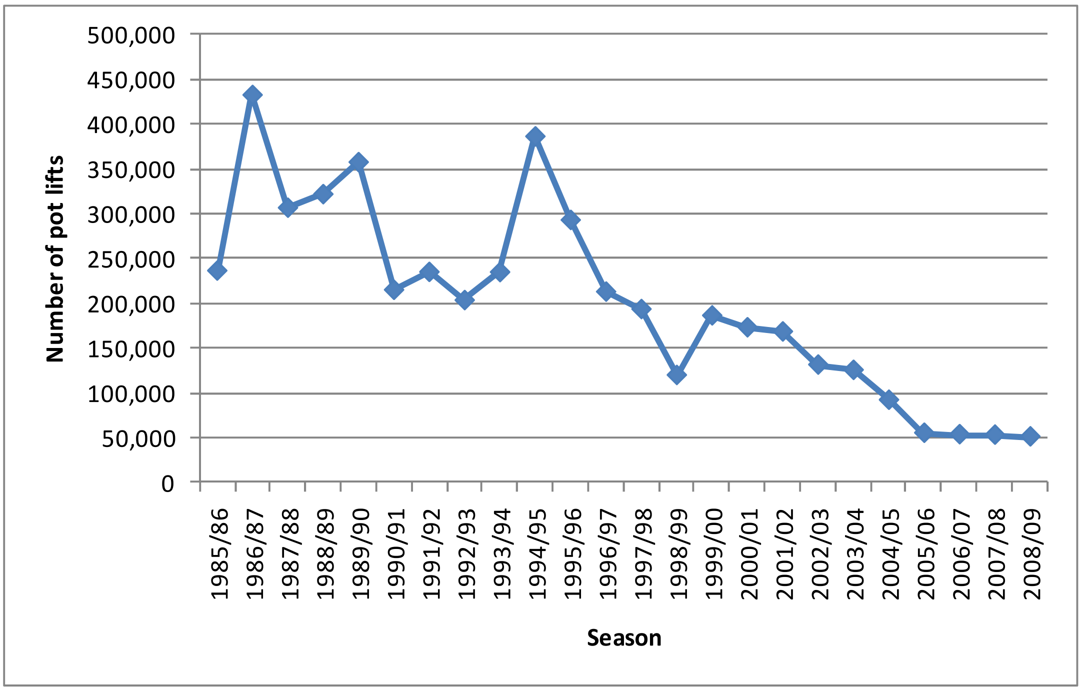

Figure 9. Number of pot lifts performed in the Aleutian golden king crab fishery, 1985/86–2008/09 (see Table 1).

DRAFT

Aleutian Islands golden king crab (*Lithodes aequispinus*) stock assessment

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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 $K_t = \frac{400 \times n_t}{\max n_t}$ where n_t is the number of length measurements in year t and 400 is the maximum cap placed on effective sample size (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.

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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.

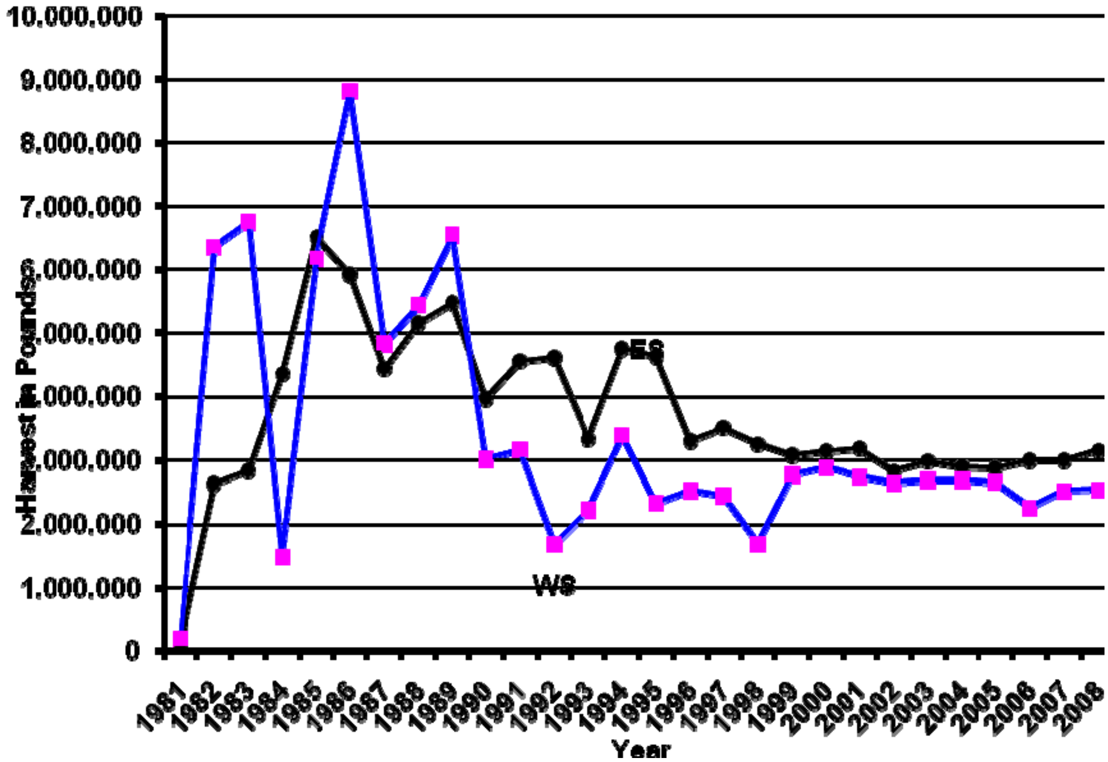

Figure 1. Historical commercial harvest (in pounds) of golden king crab east of 174°W longitude (ES, Eastern Segment) and west of 174°W longitude (WS, Western Segment), 1981-2008 (note: 1981 = 1981/82 fishery).

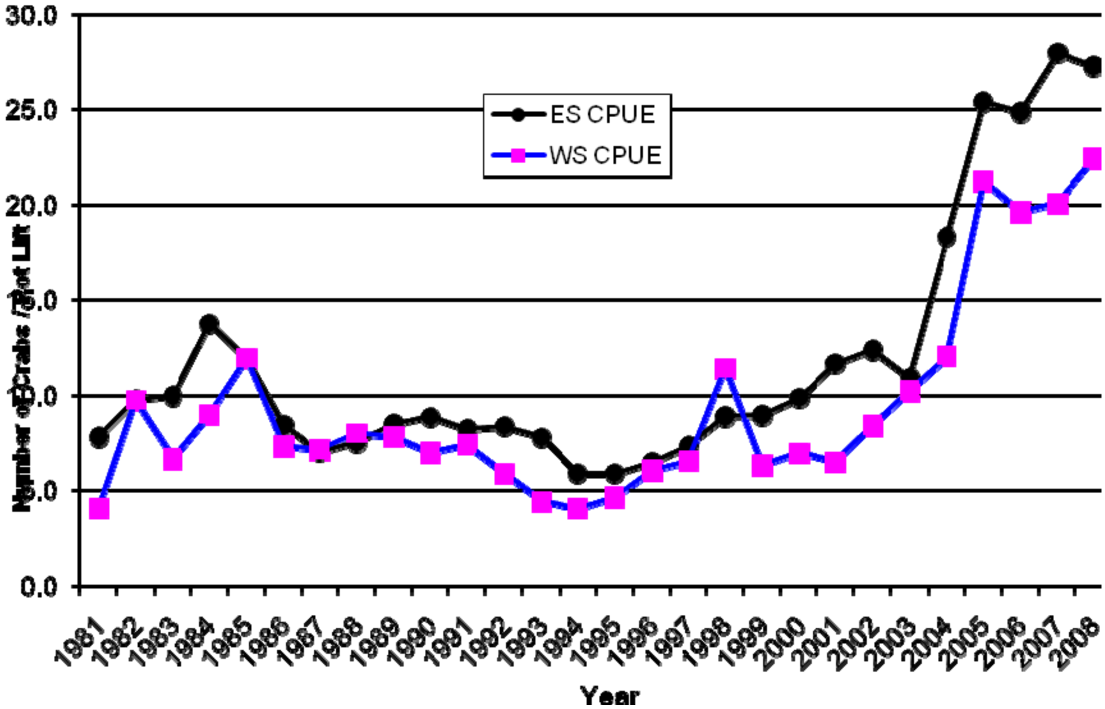

Figure 2. Historical catch-per-unit-effort CPUE (number of crabs per pot lift) in the commercial fishery for golden king crab in the ES and the WS, 1981-2008 (note: 1981 = 1981/82 fishery).

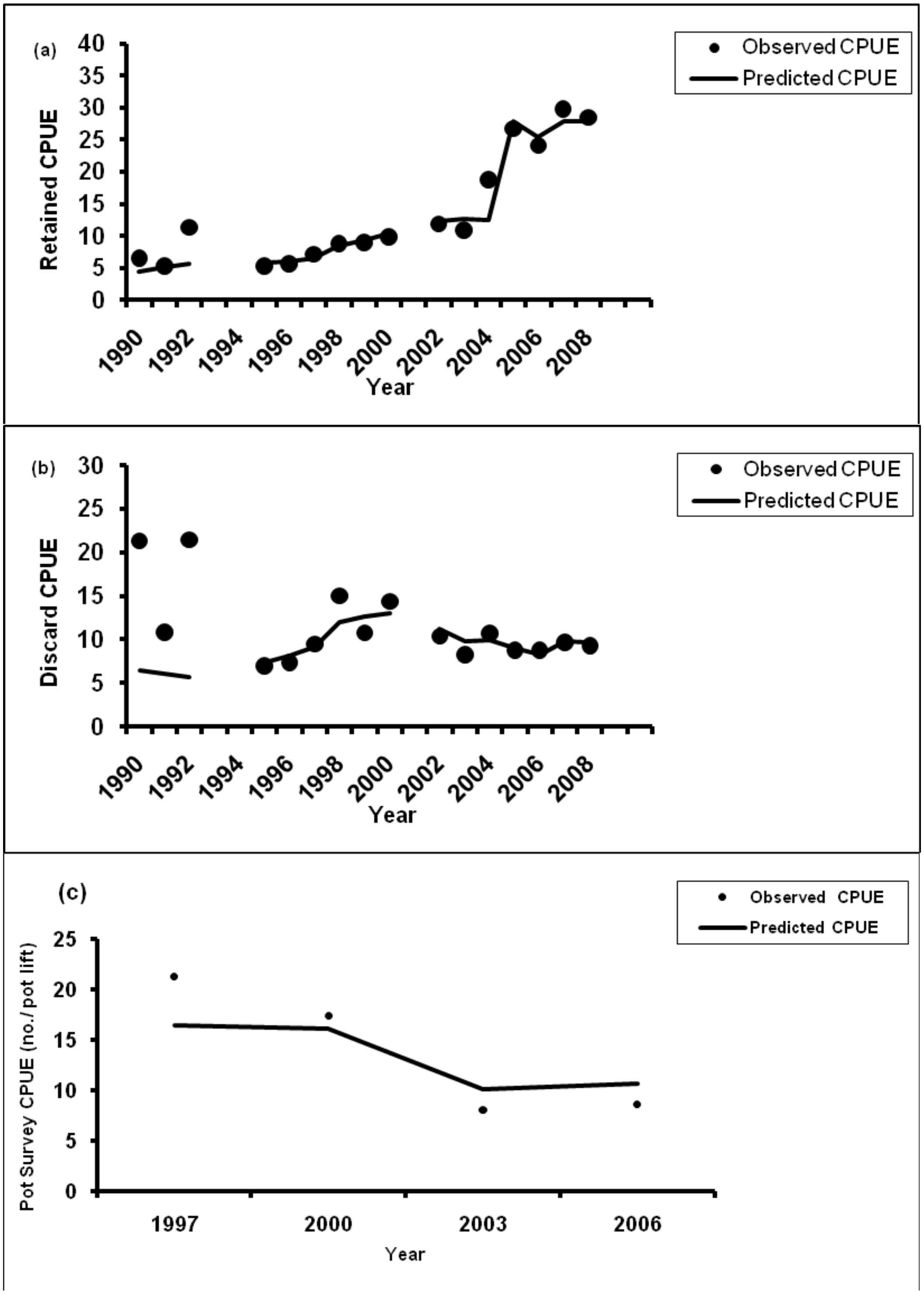

Figure 3. Predicted (line) versus observed (filled circle) (a) retained catch-per-unit-effort (CPUE), (b) discard CPUE, and (c) pot survey CPUE for golden king crab in the ES. Fishery CPUE values are for 1990-2008 (note: 1990 = 1990/91 fishery) and pot survey CPUE values are for 1997, 2000, 2003, and 2006.

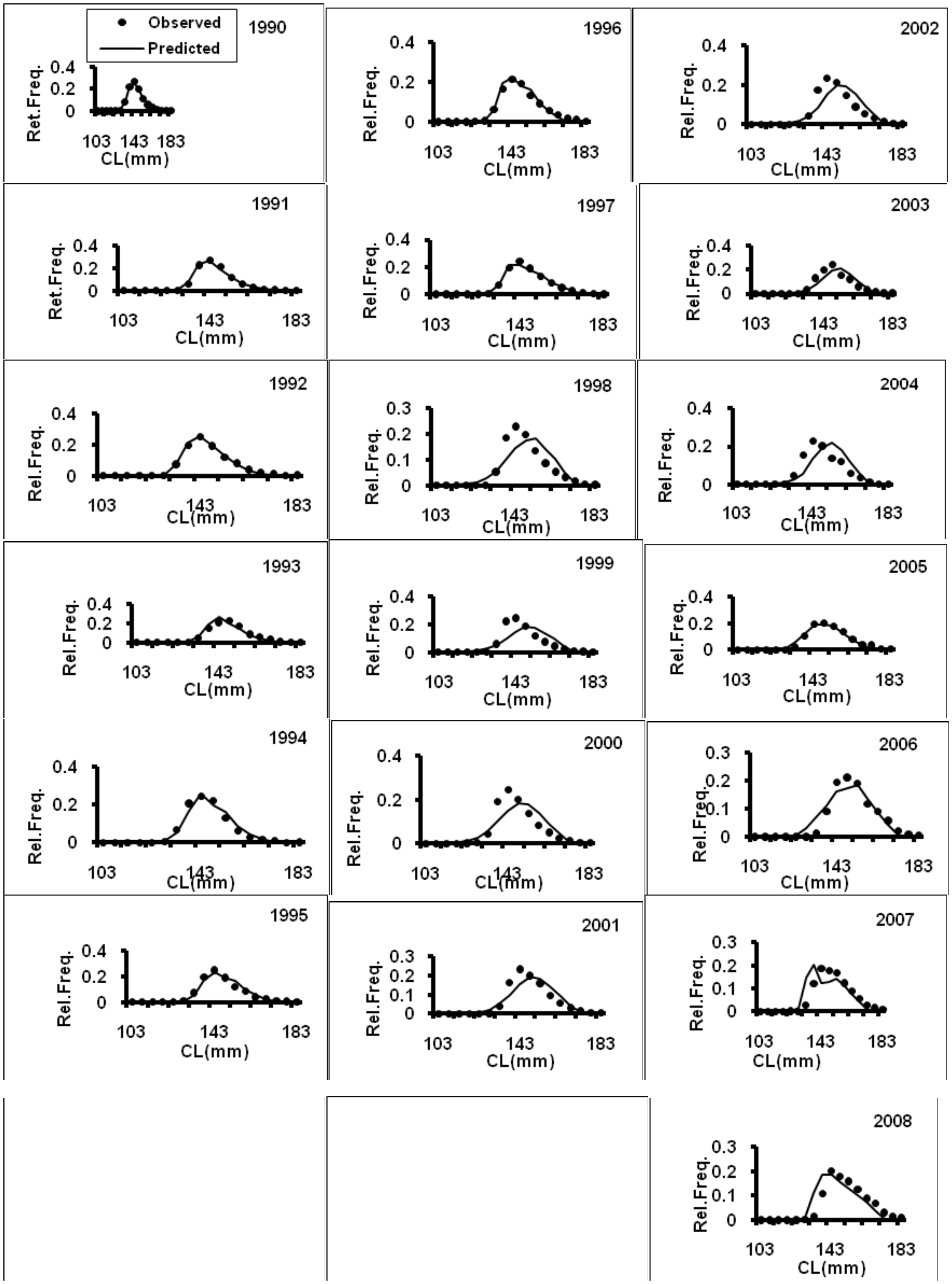

Figure 4. Predicted (line) vs. observed (filled circle) retained catch relative length frequency distributions of golden king crab in the ES, 1990 to 2008 (note: 1990 = 1990/91 fishery).

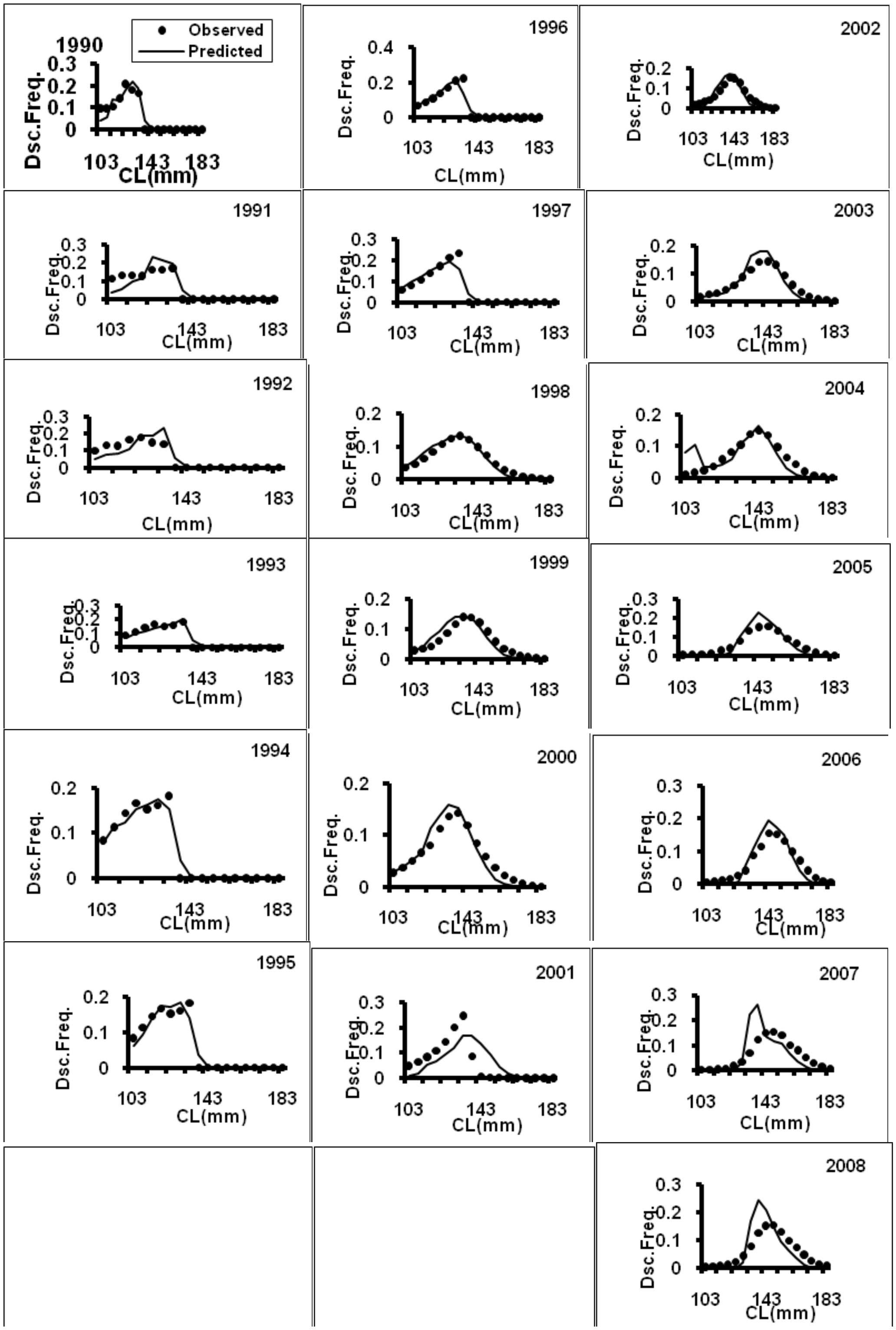

Figure 5. Predicted (line) vs. observed (filled circle) discarded catch relative length frequency distributions of golden king crab in the ES, 1990 to 2008 (note: 1990 = 1990/91 fishery).

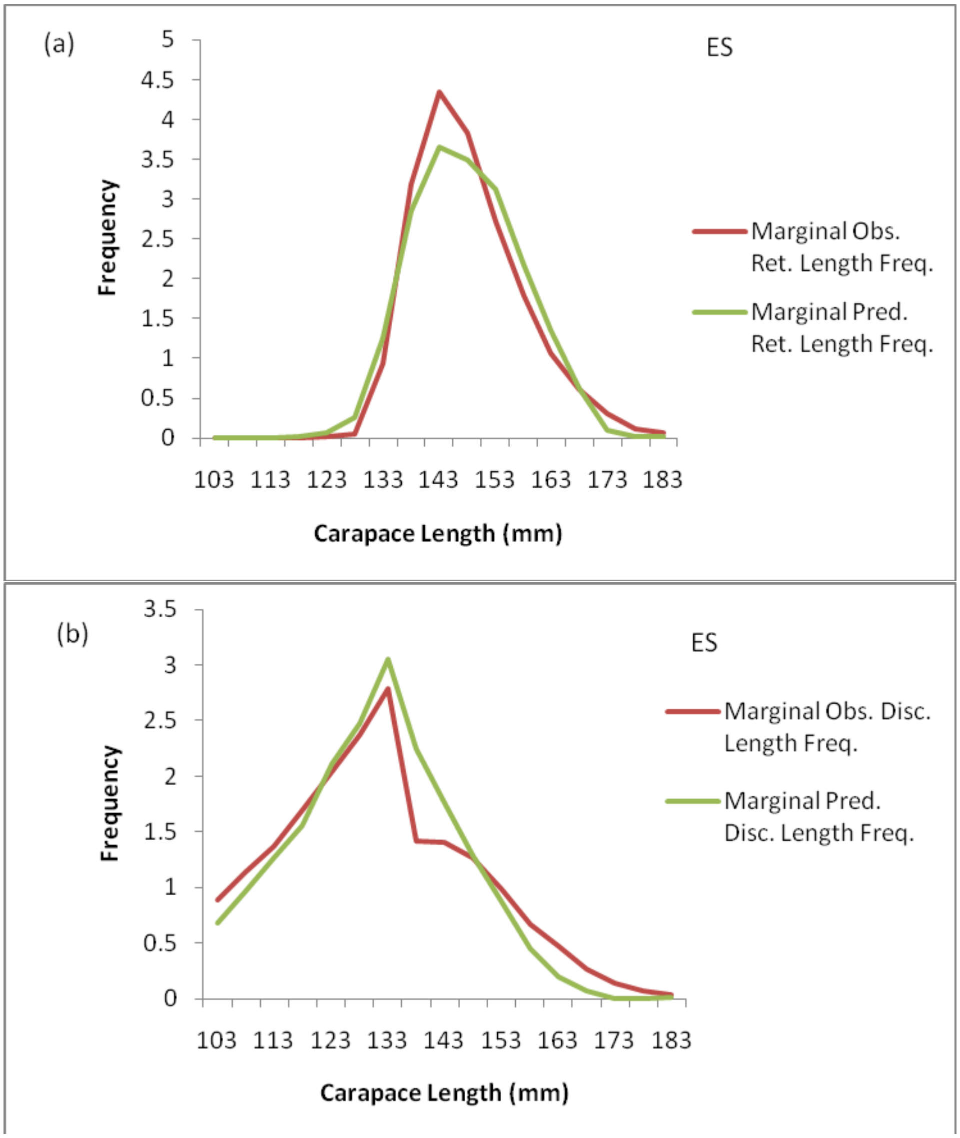

Figure 6. Observed (red line) and predicted (green line) marginal length frequency distributions of (a) retained and (b) discard catches vs. carapace length of golden king crab in the ES, 1990 to 2008 (note: 1990 = 1990/91 fishery).

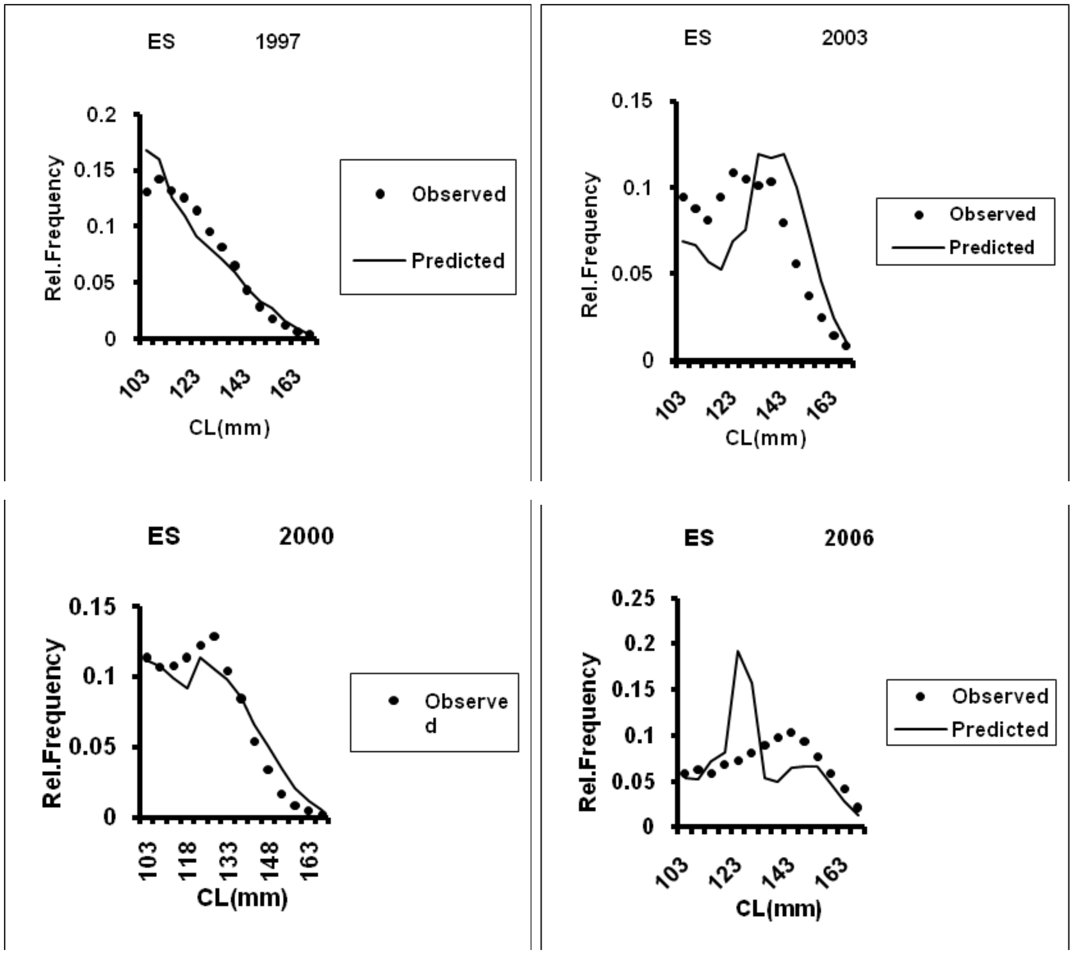

Figure 7. Predicted (line) vs. observed (filled circle) CPUE relative length frequency distributions of golden king crab in the triennial pot surveys in a restricted area in the ES, 1997 to 2006.

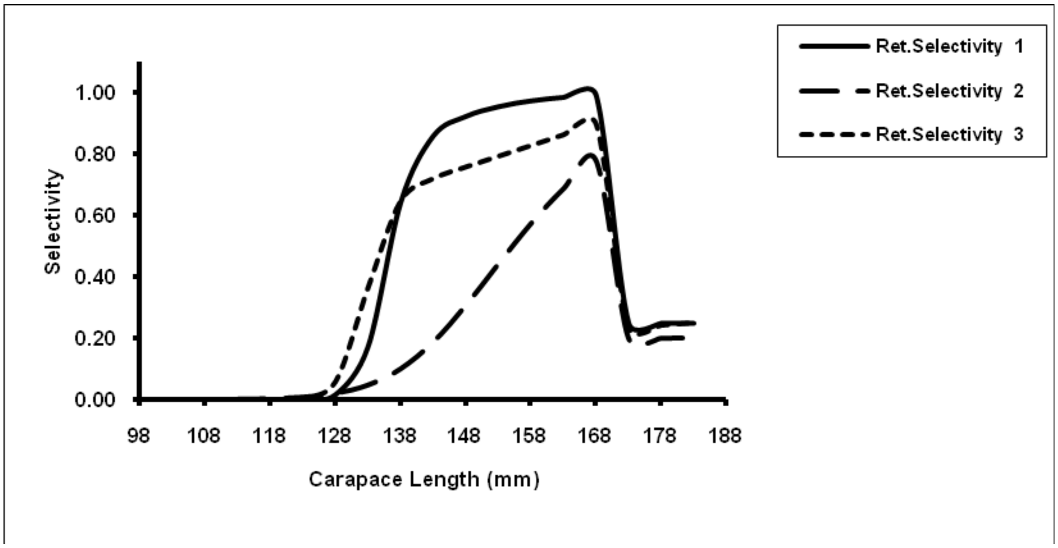

Figure 8. Estimated effective retained catch selectivity (total selectivity*retained selectivity) for the period 1990-97 (Ret. Selectivity 1), 1998-04 (Ret. Selectivity 2), and 2005- onwards (Ret. Selectivity 3) in ES golden king crab fishery.

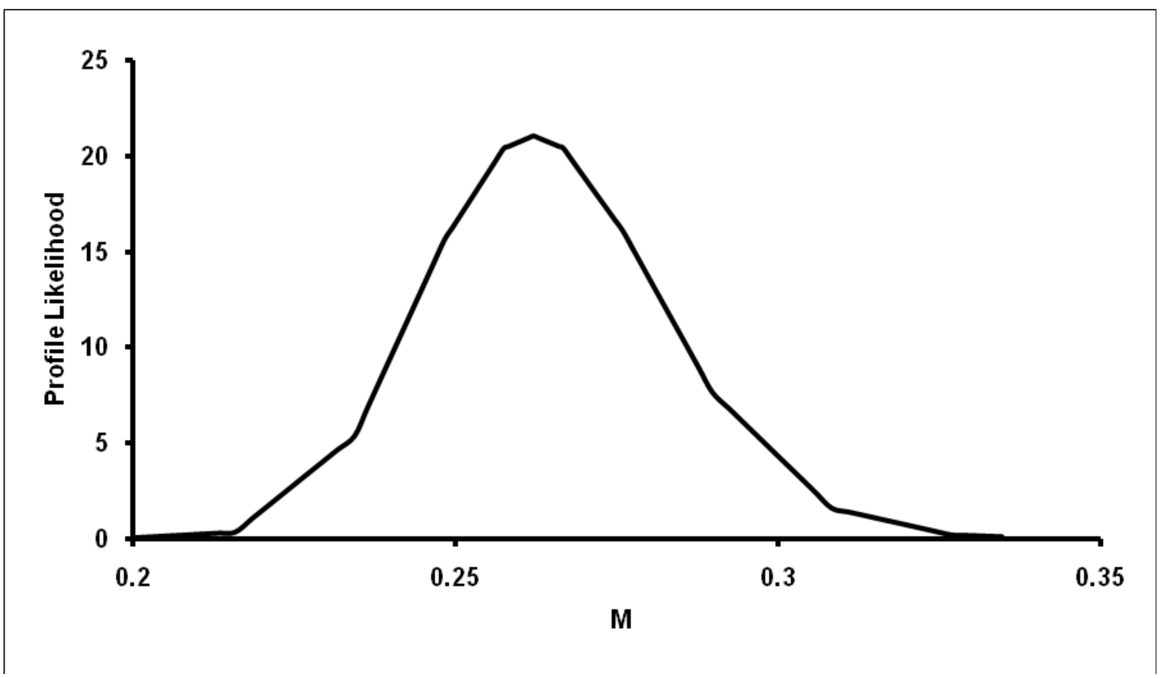

Figure 9. Profile likelihood of estimated natural mortality (*M*) based on 1990-2008 data for ES golden king crab.

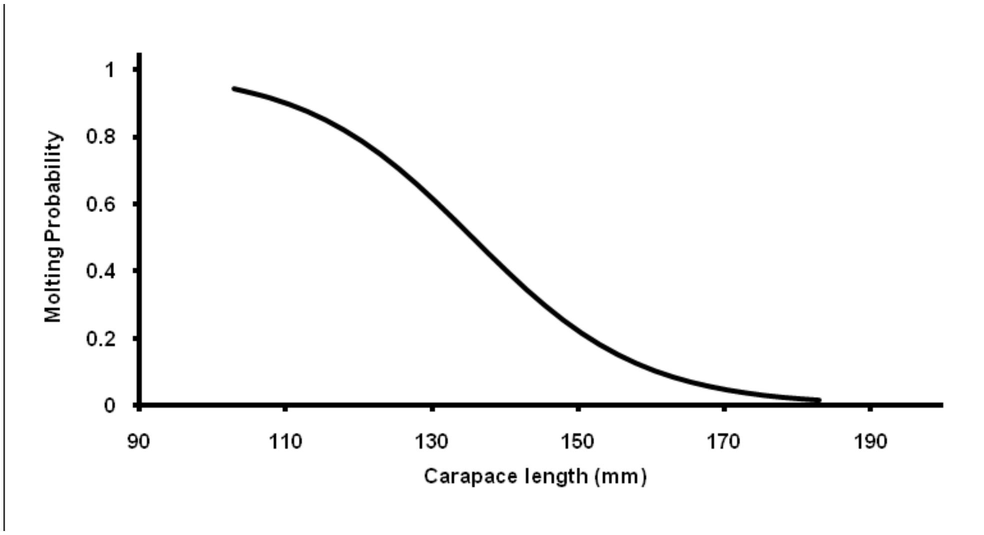

Figure 10. Estimated molt probability of ES golden king crab.

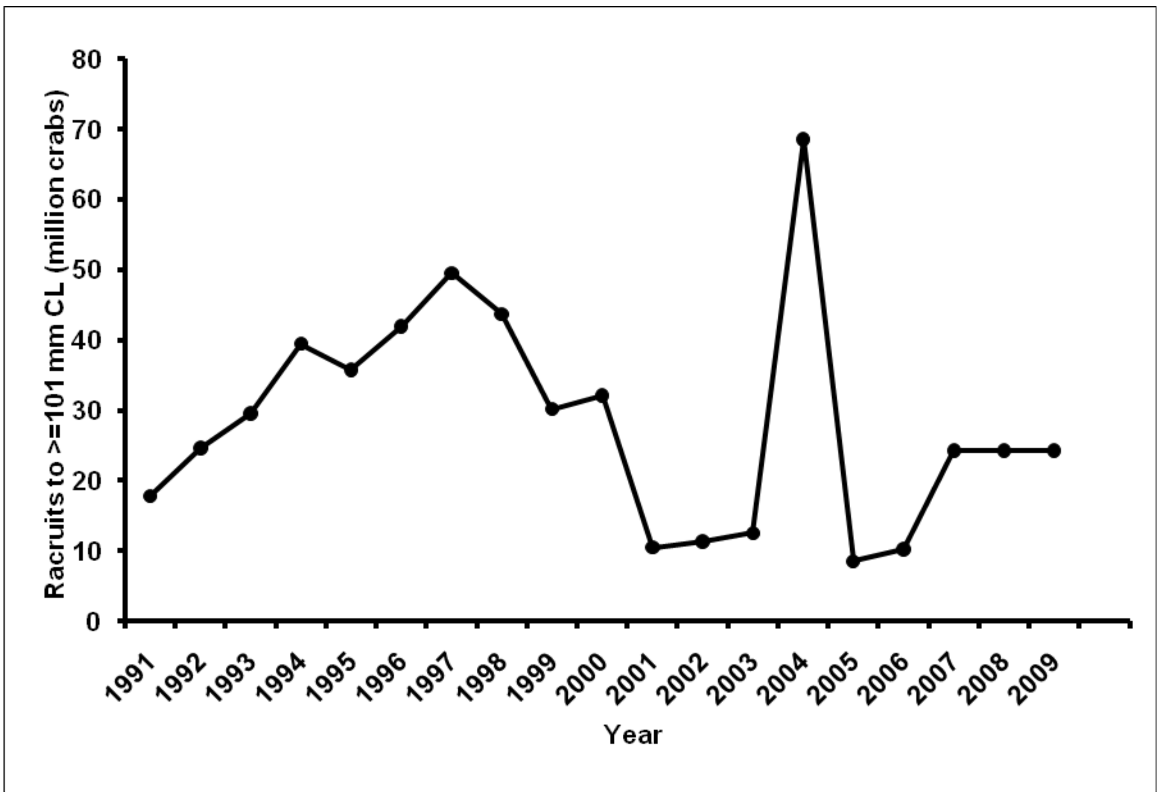

Figure 11. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab fishery in ES, 1991-2009.

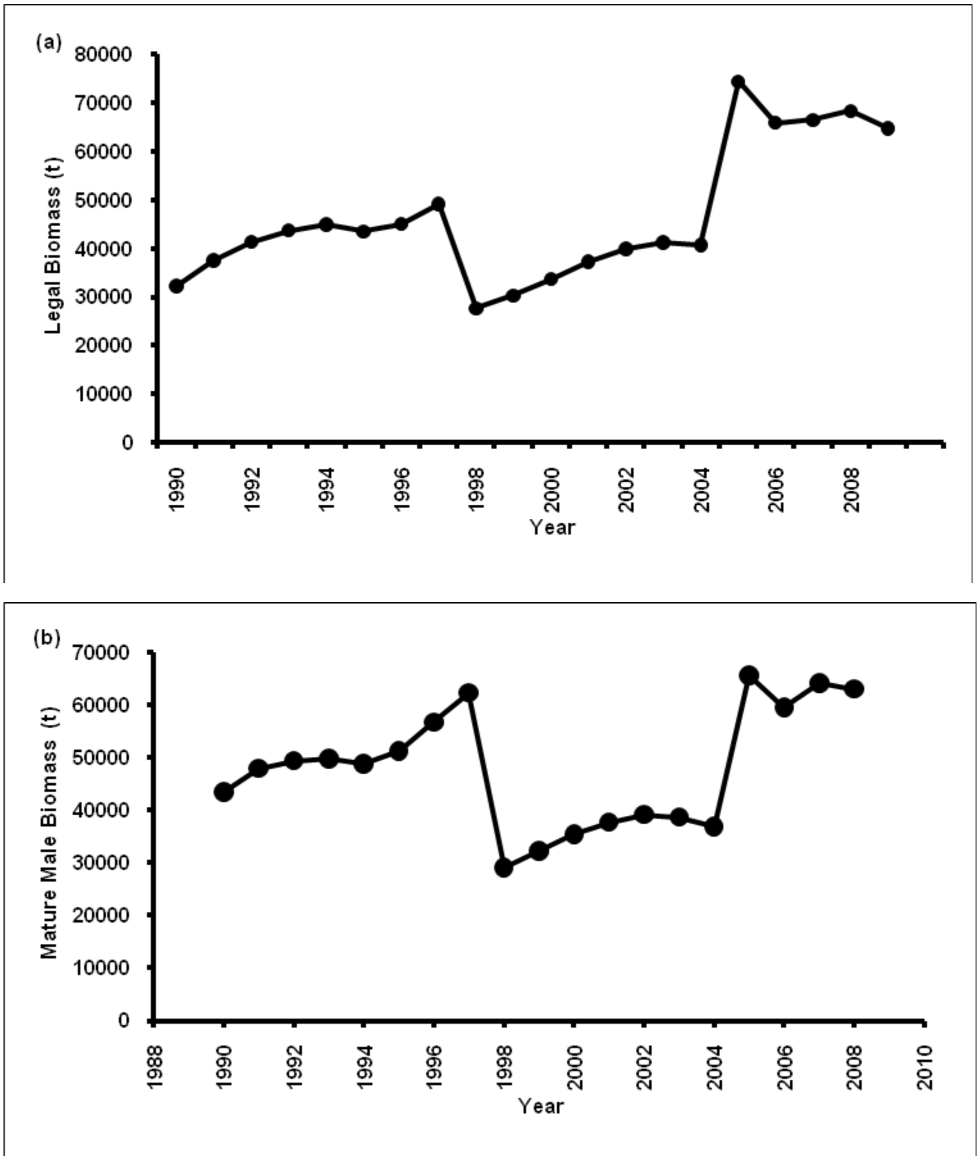

Figure 12. (a) Trends in available golden king crab (a) legal male biomass (t) and (b) mature male biomass in the ES, 1990-2009. Legal male crabs are ≥ 136 mm CL and mature male crabs are ≥ 121 mm CL.

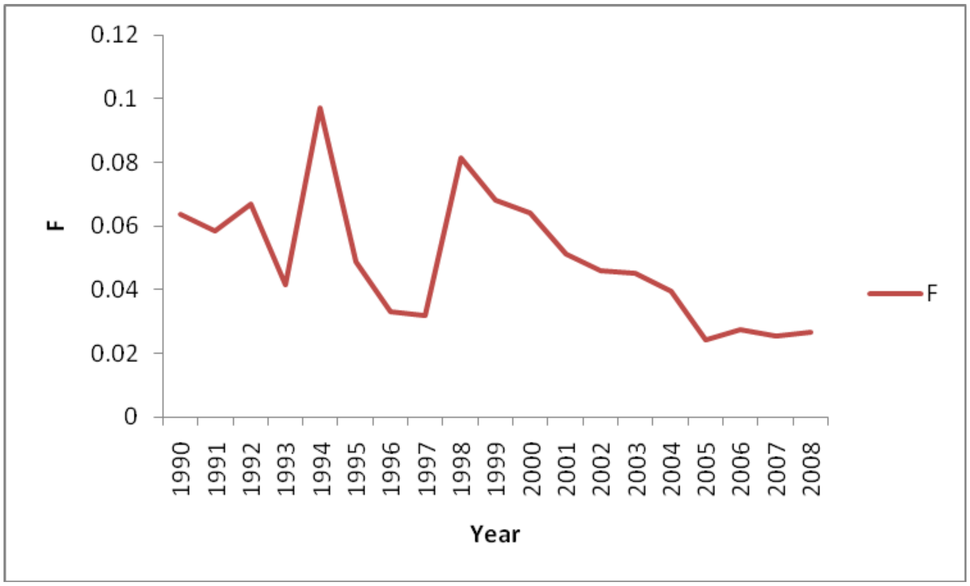

Figure 13. Trend in full selection fishing mortality of golden king crab in the ES, 1990-2008

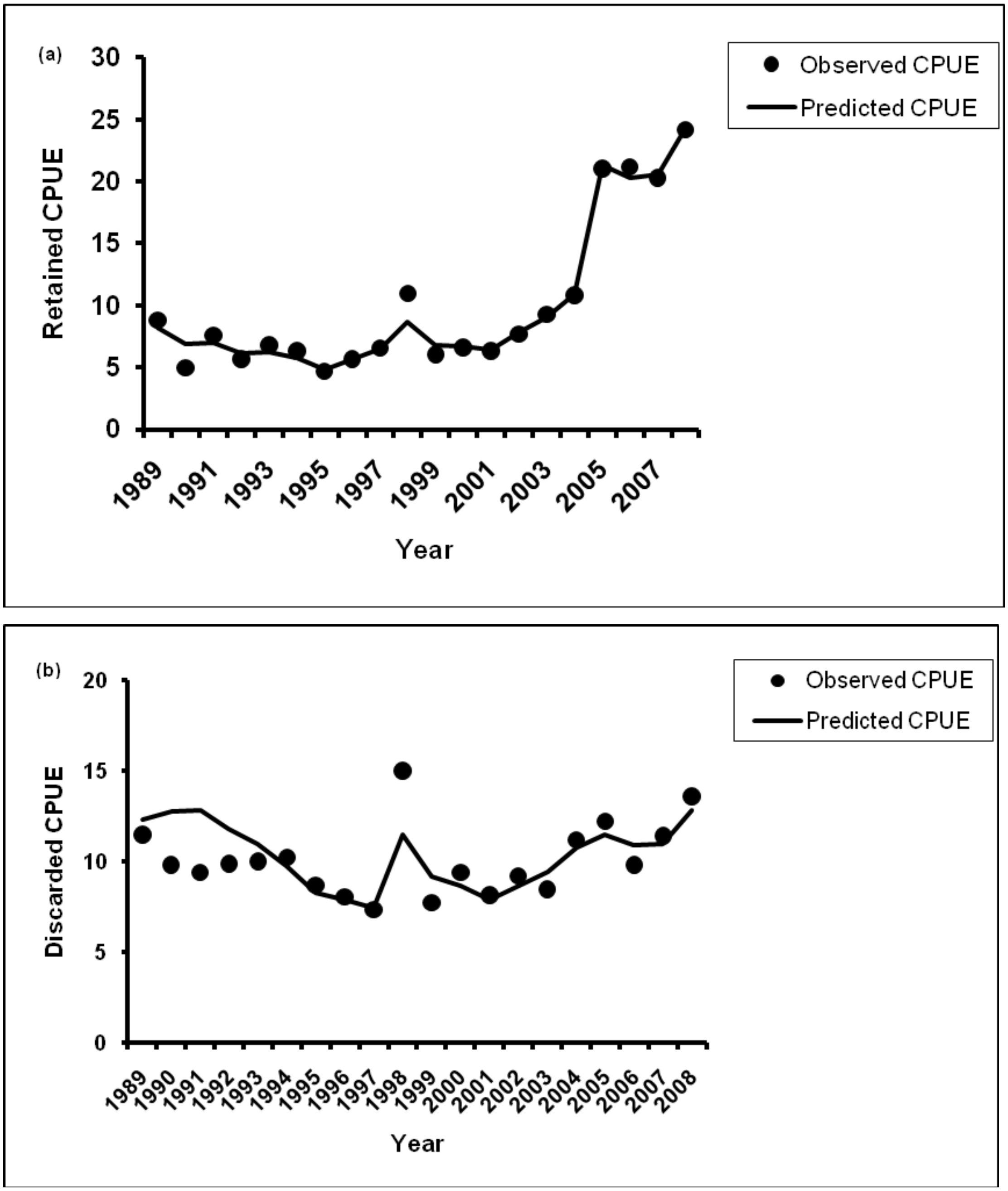

Figure 14. Predicted (line) versus observed (filled circle) (a) retained catch-per-unit-effort (CPUE), (b) discard CPUE for golden king crab in the WS, 1989 to 2008 (note: 1989 = 1989/90 fishery).

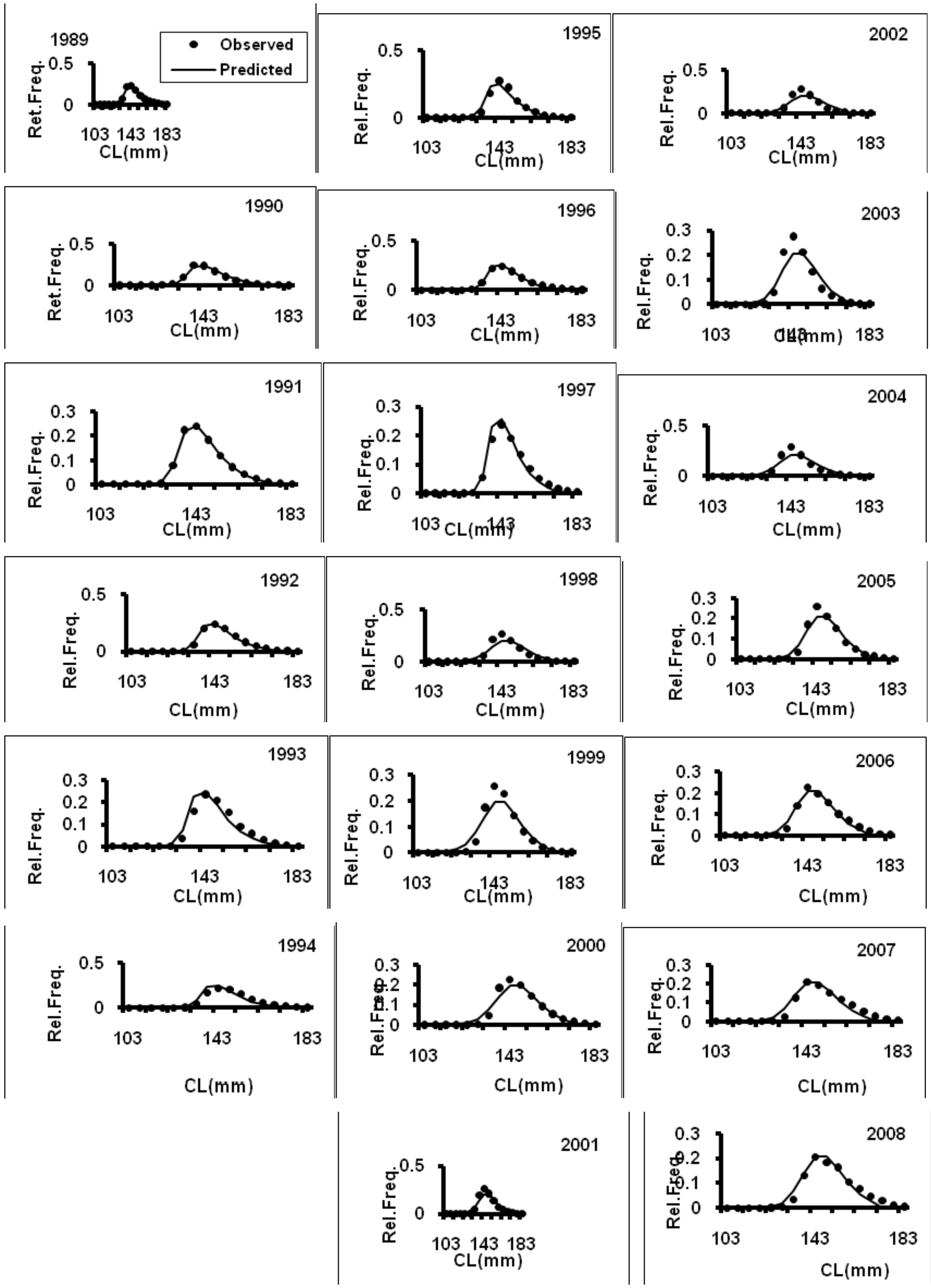

Figure 15. Predicted (line) vs. observed (filled circle) retained catch relative length frequency distributions of golden king crab in the WS, 1989 to 2008 (note: 1989 = 1989/90 fishery).

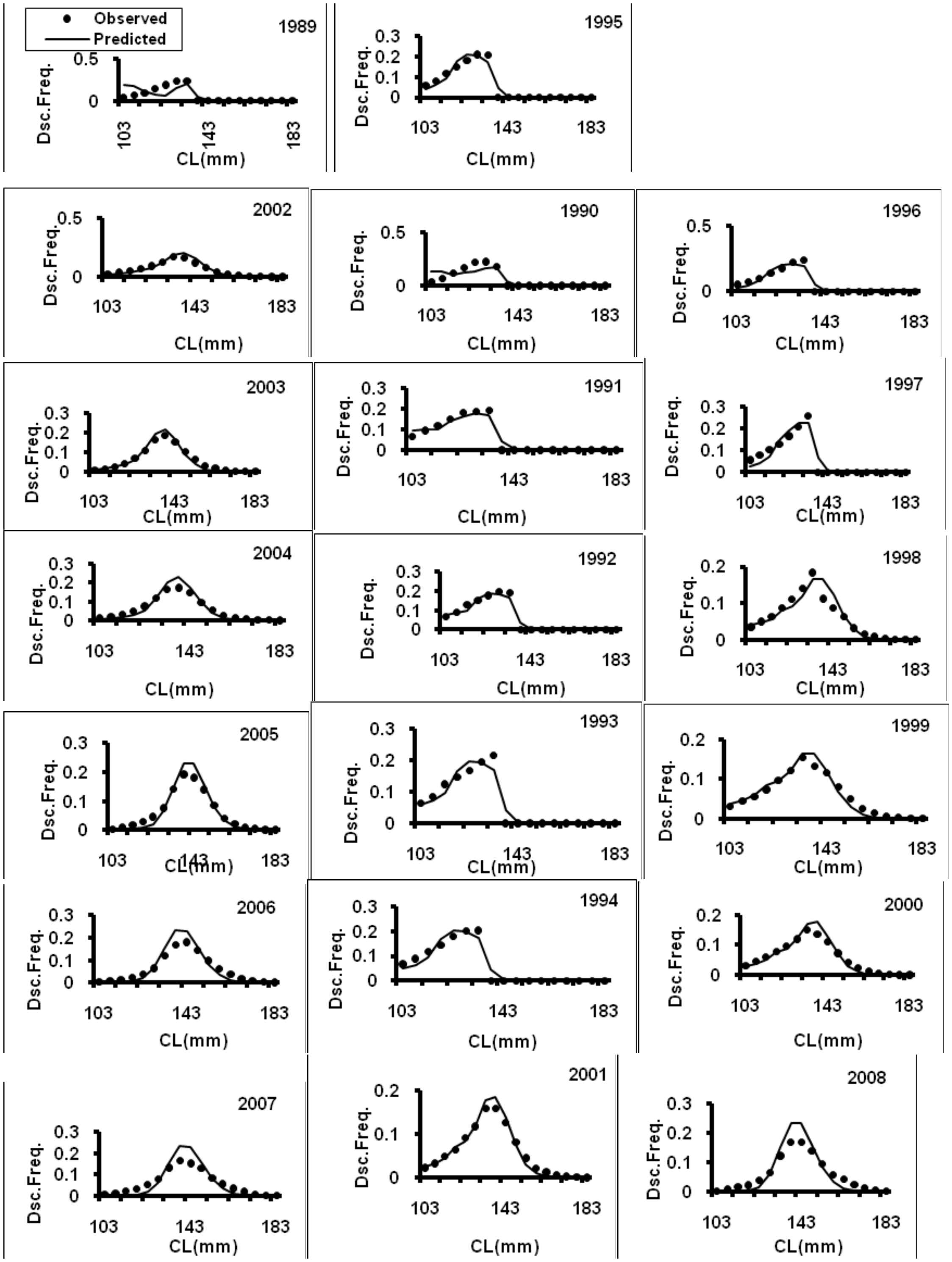

Figure 16. Predicted (line) vs. observed (filled circle) discarded catch relative length frequency distributions of golden king crab in the WS, 1989 to 2008.

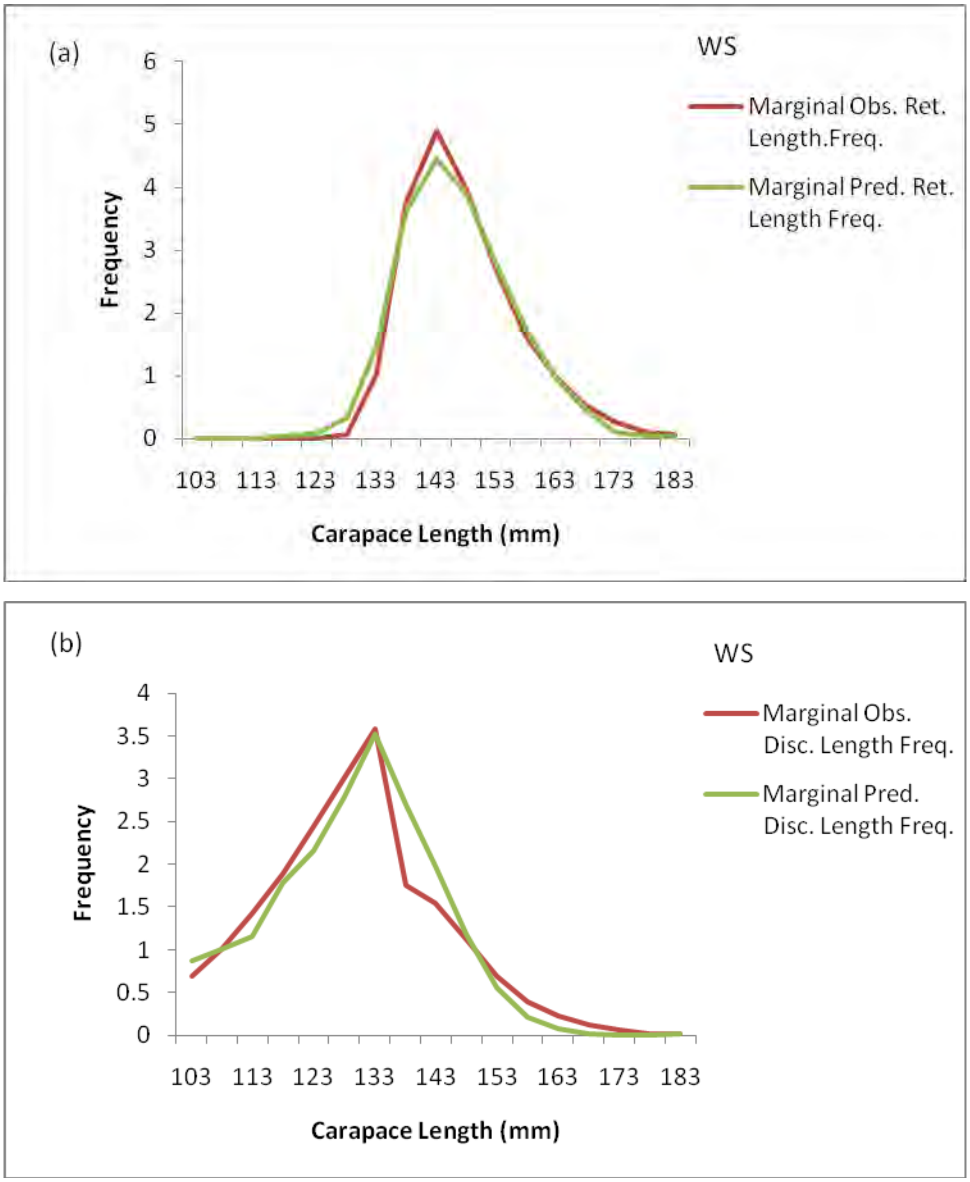

Figure 17. Observed (red line) and predicted (green line) marginal length frequency distributions of (a) retained and (b) discard catches vs. carapace length of golden king crab in the WS, 1989 to 2008 (note: 1989 = 1989/90 fishery).

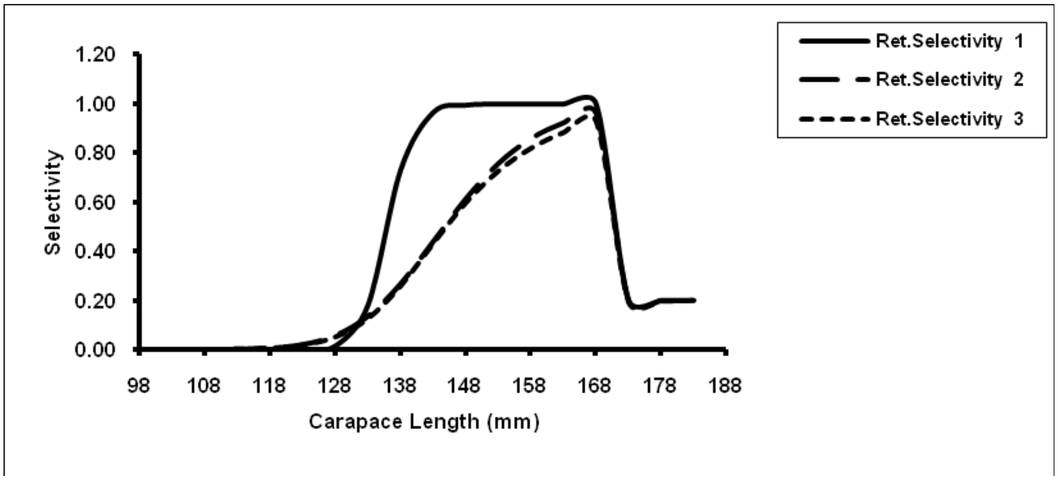

Figure 18. Estimated effective retained catch selectivity (total selectivity*retained selectivity) for the period 1989-97 (Ret. Selectivity 1), 1998-04 (Ret. Selectivity 2), and 2005- onwards (Ret. Selectivity 3) in WS golden king crab fishery.

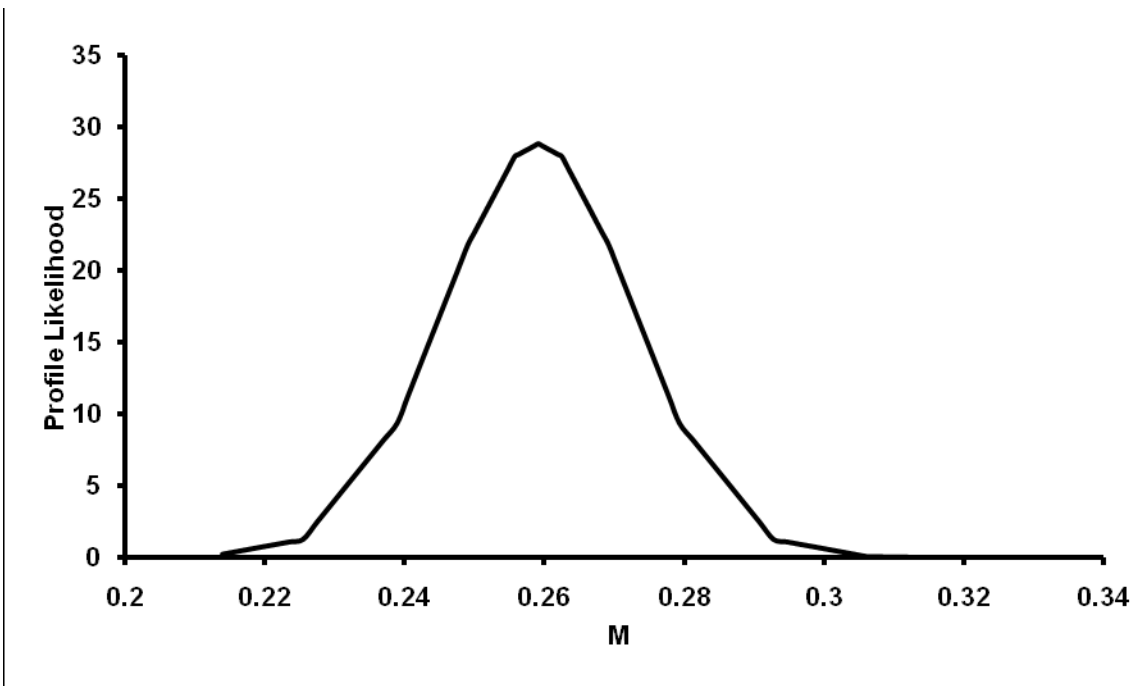

Figure 19. Profile likelihood of estimated natural mortality (*M*) based on 1989-2008 data for WS golden king crab.

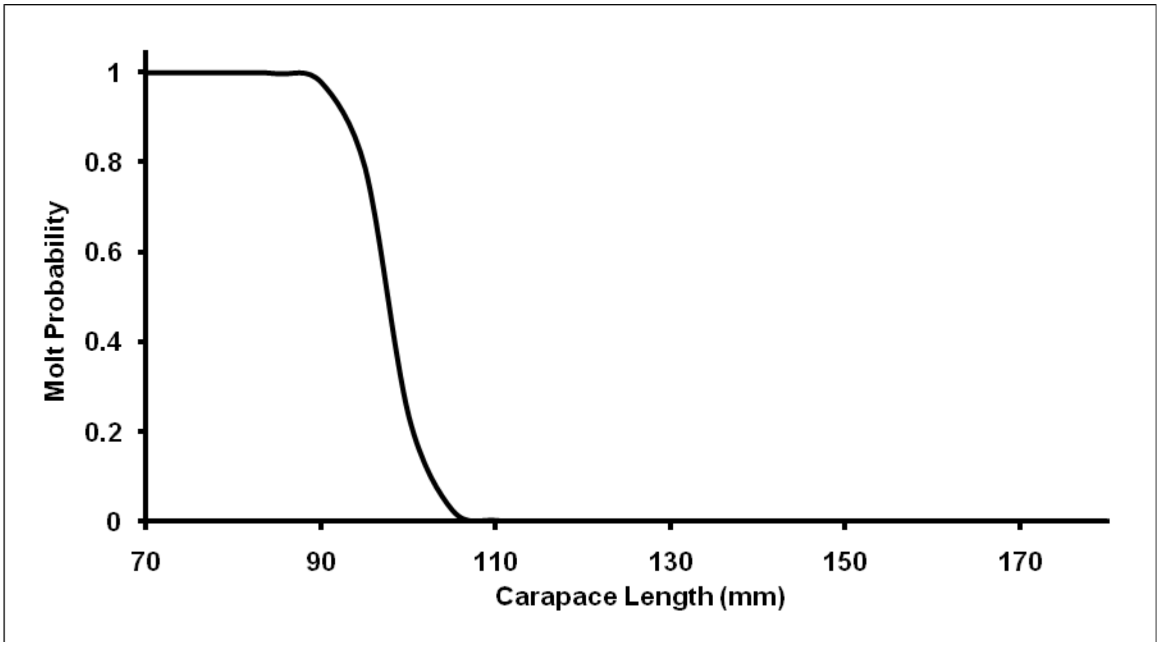

Figure 20. Estimated molt probability of WS golden king crab.

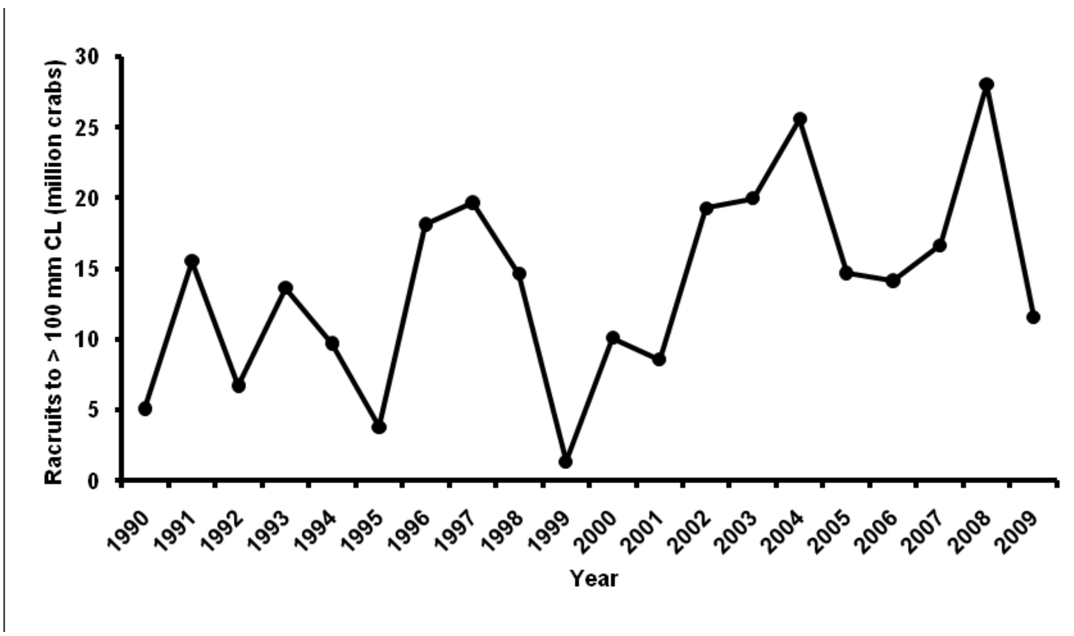

Figure 21. Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab fishery WS, 1990-2009.

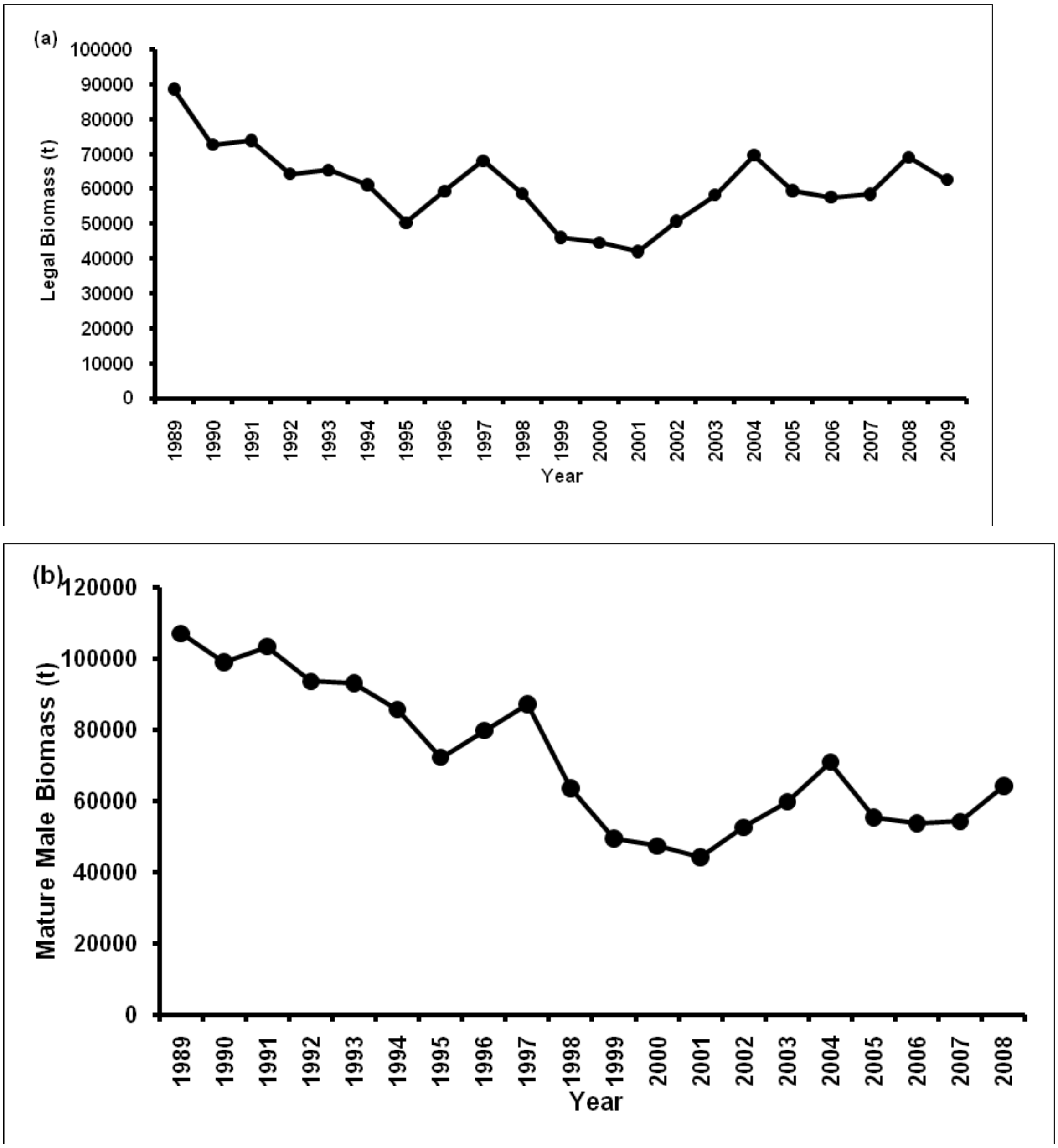

Figure 22. Trends in available golden king crab (a) legal male biomass (t) and (b) mature male biomass in the WS, 1989-2009. Legal male crabs are ≥ 136 mm CL and mature male crabs are ≥ 121 mm CL.

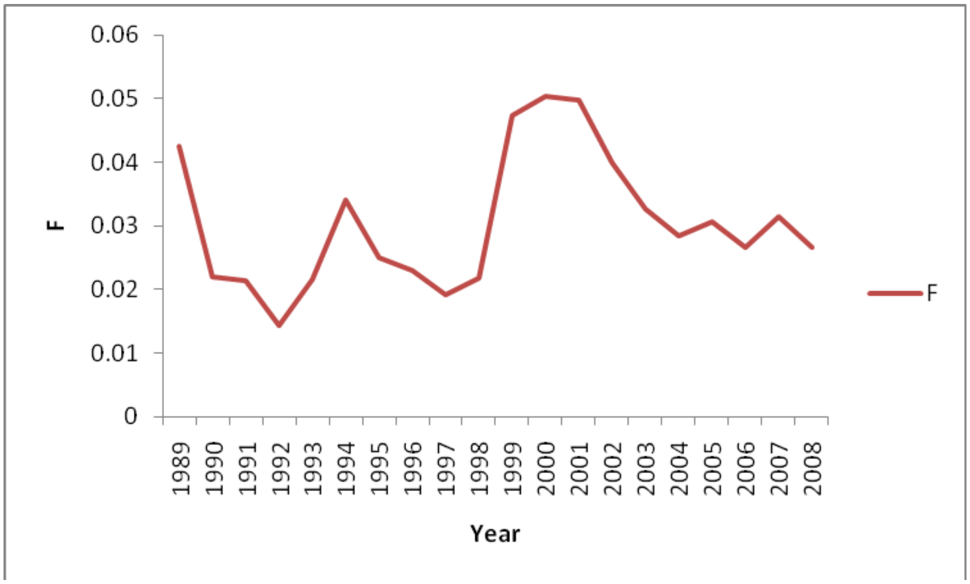

Figure 23. Trend in full selection fishing mortality of golden king crab in the WS, 1989-2008.

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

$$C\hat{P}UE^{T}_{t,j} = q_k[s^T_j\ (N_{t,j} + O_{t,j})e^{-y_tM} - 0.5(\hat{C}_{t,j} + \hat{D}_{t,j})] \tag{10}$$

Retained catch-per-unit-effort by length and year is estimated as

$$C\hat{P}UE^{r}_{t,j} = q_k[s^T_j s^r_j\ (N_{t,j} + O_{t,j})e^{-y_tM} - 0.5\hat{C}_{t,j}] \tag{11}$$

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

$$LL_F = \lambda_F \sum_t \{\log(F_t) - \log(\overline{F})\}^2 \tag{26}$$

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

$$LL_R = \lambda_R \sum_t \{\log(R_t) - \log(\overline{R})\}^2 \tag{27}$$

where $\overline{R}$ is the mean recruitment parameter and λ_R is the recruitment weight.

The initial relative length frequency penalty function is

$$LL_{LFQ} = \lambda_{LFQ}\left[\sum_i (pn_i - pn_i^{obs})^2 + (\sum_i po_i - po_i^{obs})^2 \right] \tag{28}$$

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

$$LL_M = \lambda_M (M - 0.18)^2 \tag{29}$$

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:

$$E_t = \frac{\hat{C}_t + \hat{D}_t}{\sum_j^n \{s_j^T \ (N_{j,t} + O_{j,t})e^{-y_t M} - 0.5(\hat{C}_{j,t} + \hat{D}_{j,t})\}} \tag{31}$$

where $\hat{C}$ and $\hat{D}$ are predicted retained and discarded catches.

Vulnerable legal male biomass at the survey time in year *t*:

$$LM_t = \sum_{j=legal\ size}^{n} s_j^T (N_{j,t} + O_{j,t}) w_j \quad (32)$$

Mature male biomass on 15 February spawning time (NPFMC 2007) in the following year:

$$MMB_t = \sum_{j=mature\ size}^{n} s_j^T \{(N_{j,t} + O_{j,t}) e^{-y'M} - (C_{j,t} + D_{j,t}) e^{-(y_t - y')M}\} w_j \quad (33)$$

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 $MMB_t > 0.25M\overline{M}B$,

$$F' = \gamma M \frac{\left(\frac{MMB_t}{M\overline{M}B} - \alpha\right)}{(1-\alpha)} \quad (34)$$

(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. <u>Basis for the OFL</u>: 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. **<u>A summary of the results of any rebuilding analyses</u>:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. <u>Changes to the management of the fishery</u>: None. 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. <u>Changes to the input data</u>:

- 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. <u>Changes to the assessment methodology</u>: 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. **<u>Evidence of stock structure</u>:** We are aware of no data for evaluating stock structure within this stock.

4. **<u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:**

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. Summary of new information:

- Retained catch (0 pounds) during 2009 has been added to the retained catch time series.

2. Data presented as time series:

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. **<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. ***<u>Basis for projecting MMB to the time of mating</u>:*** Not applicable for Tier 5 stock.

c. ***<u>Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring</u>:*** See table below.

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).

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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

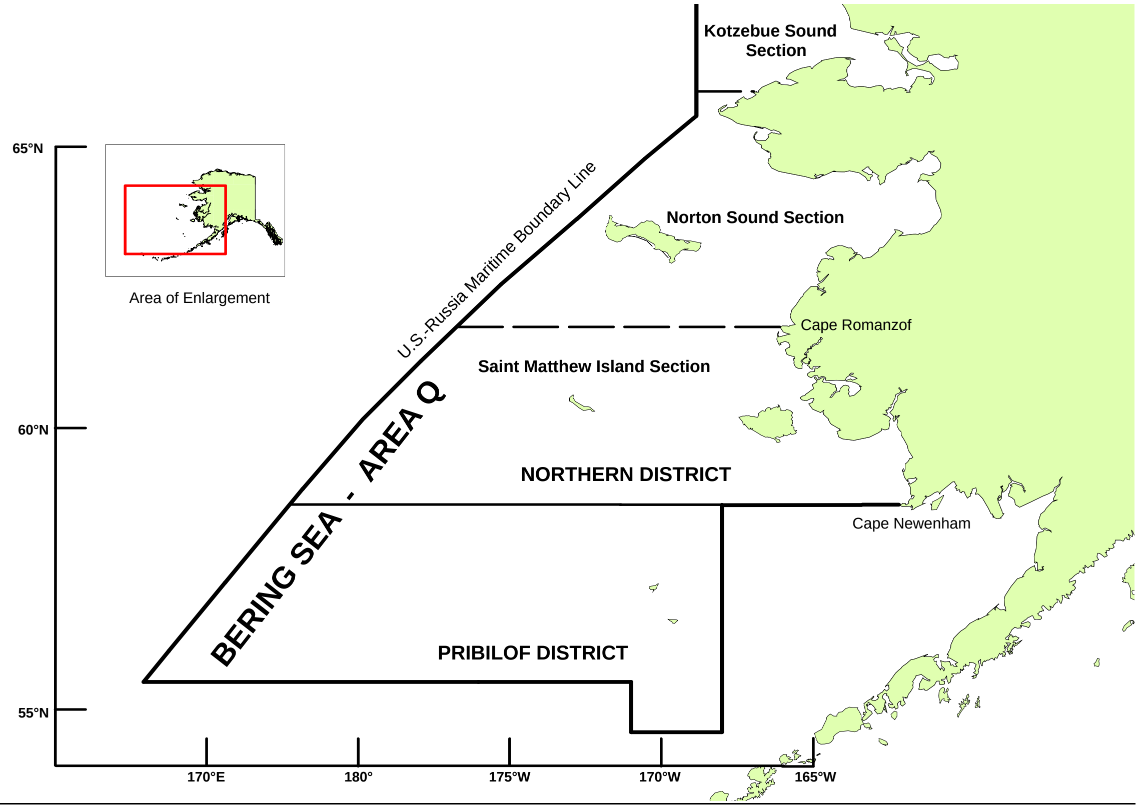

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Bowers et al. 2008).

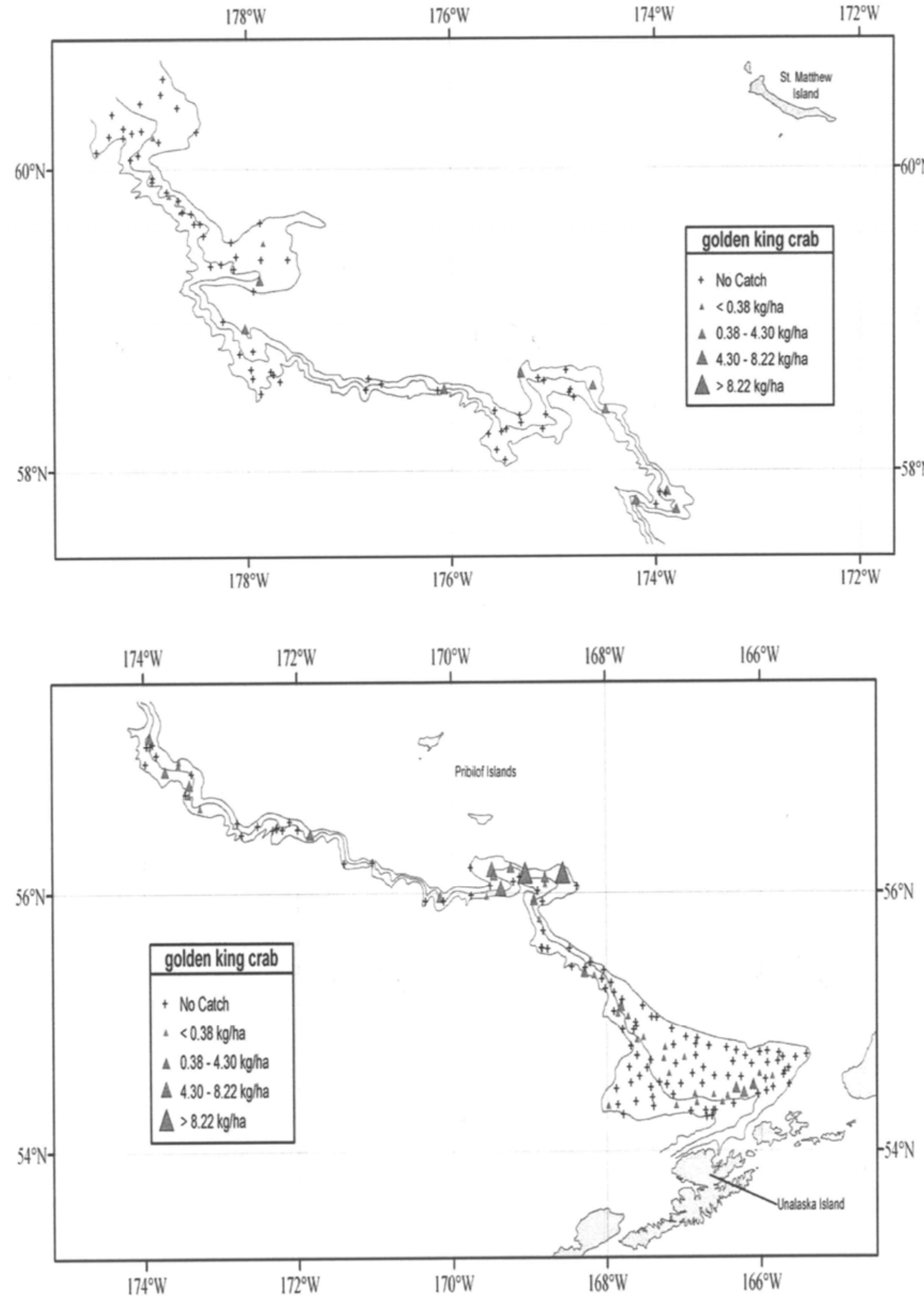

Figure 2. Distribution and relative abundance of golden king crabs from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey. Relative abundance is categorized by no catch, sample CPUE less than the mean CPUE, between the mean CPUE and two standard deviations above the mean CPUE, 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).

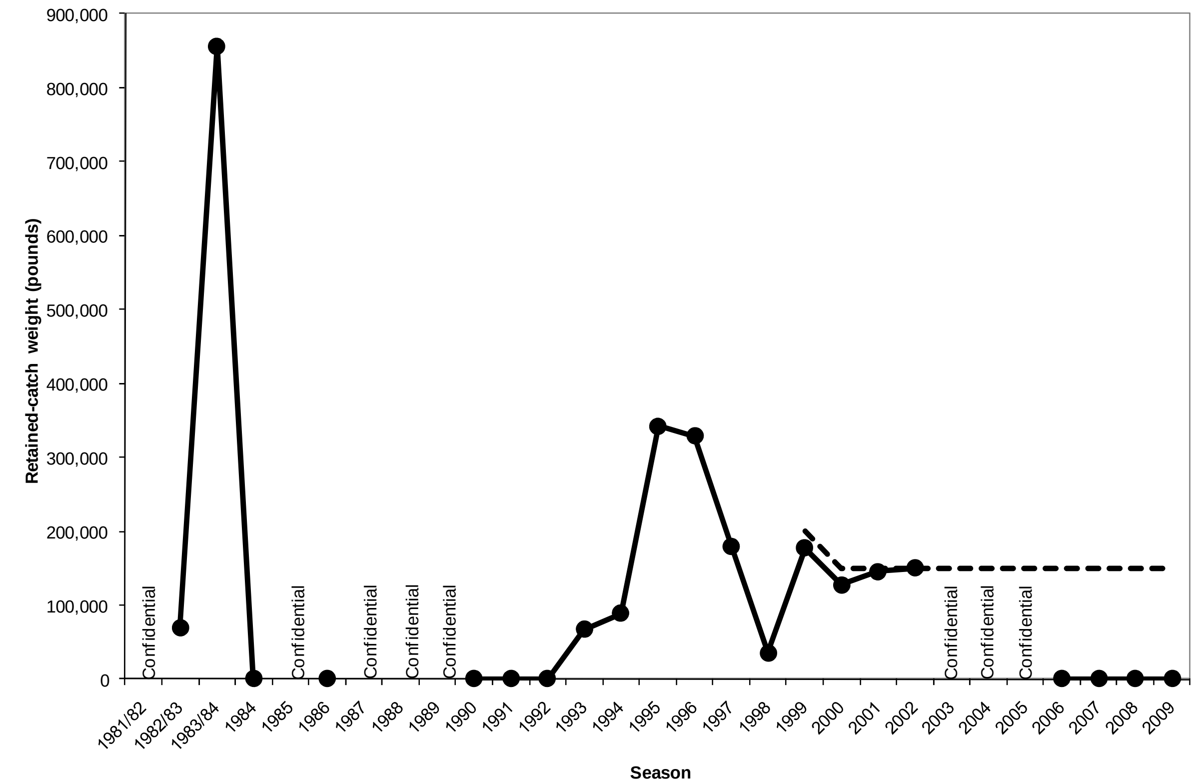

Figure 3. Retained catch (pounds; filled circles and solid line) during the 1981/82 through 2009 Pribilof Islands golden king crab fishery seasons compared with the GHL established for the fishery during the 1999–2009 seasons (dashed line; see Table 1).

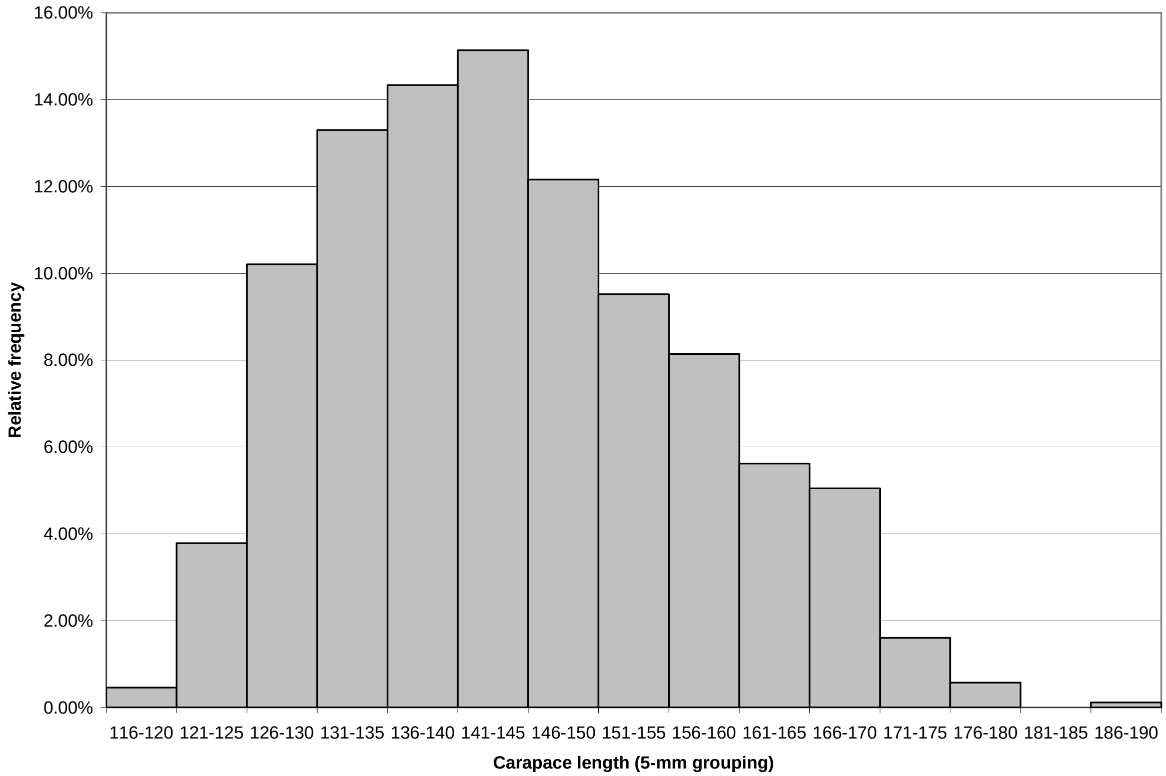

Figure 4. Relative frequency distribution for carapace length (mm) of retained golden king crabs sampled by season during the 2002 Pribilof Islands golden king crab fishery (N= 872; data from ADF&G shellfish observer database, Kodiak, April 2008).

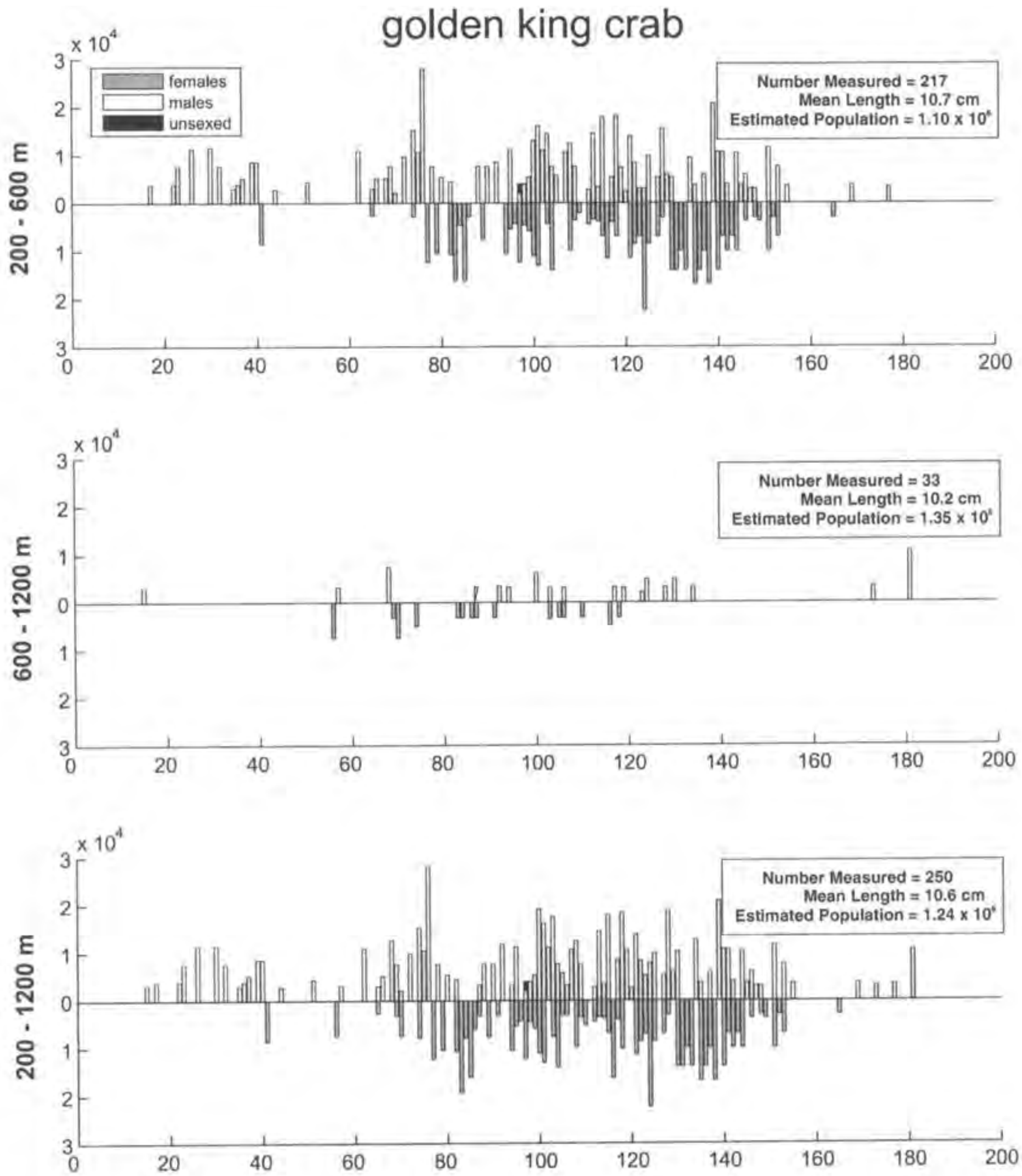

Figure 5. Size composition of the estimated golden king crab population from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey (all areas) by depth zone. The abscissa is scaled as total carapace length in millimetres and the ordinate represents the estimated total population.

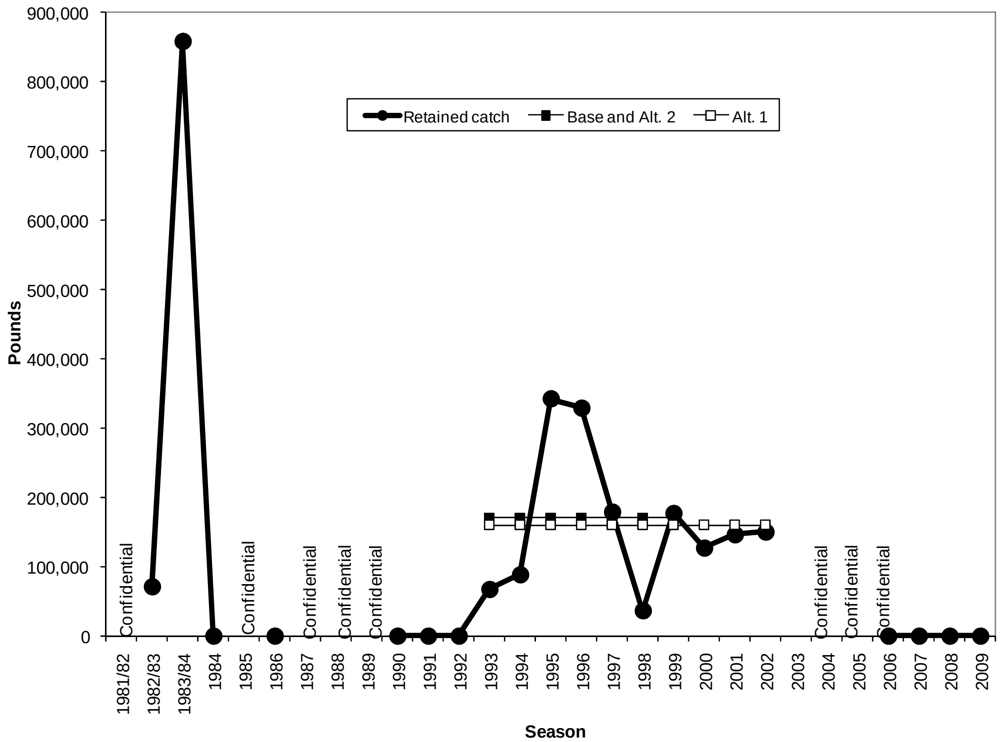

Figure 6. Alternative retained-catch OFLs (Base and Alternatives 1–2) compared with actual historical fishery retained catch for the Pribilof Islands golden king crab fishery, 1981/82–1983/84 and 1984–2009 (see Table 1 and section E.3.b).

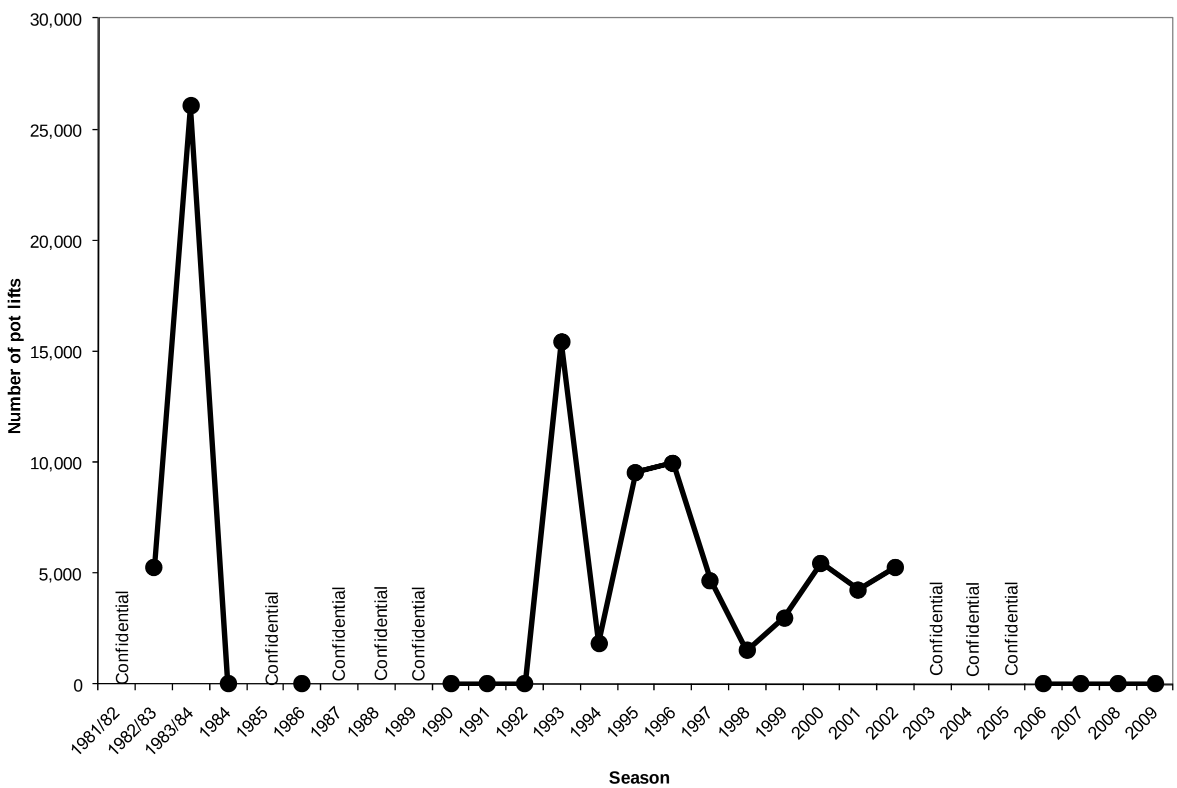

Figure 7. Number of pot lifts performed in the Pribilof District golden king crab fishery, 1981/82–1983/84 and 1984–2009 (see Table 1).

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. **<u>Changes to the input data</u>:**
   - 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. **<u>Changes to the assessment methodology</u>:** None.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:**
   - 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. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general</u>:**
   - <u>CPT, May 2009</u>: *"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."*
     - <u>Response:</u> That is being done.
   - <u>SSC, June 2009</u>: *"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."*
     - <u>Response</u>: The stock assessment author has not addressed this question yet and does not recall a larger discussion on this by the CPT as whole.
   - <u>CPT, September 2009</u>: None that I could find.
   - <u>SSC, October 2009</u>: *"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."*
     - <u>Response</u>: It is done.

2. **<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:**

- 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. Evidence of stock structure:

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. Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king 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. <u>Convergence status and convergence criteria for the base-case model (or proposed base-case model)</u>: Not applicable.

e. <u>Table (or plot) of the sample sizes assumed for the compositional data</u>: Not applicable.

f. <u>Do parameter estimates for all models make sense, are they credible?</u>:

- 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. <u>Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty</u>: See section E.3.c, above.

h. <u>Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach)</u>: 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. <u>Results (best model(s))</u>:

a. <u>List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties</u>: 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):*** 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. ***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: 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. **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	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. ***Prey availability/abundance trends (historically and in the present and foreseeable future):*** Existence and availability of such information is not known to the author.

b. ***Predator population trends (historically and in the present and foreseeable future):*** 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 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. ***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 – 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. ***Fishery-specific contribution to discards:***

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. **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 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).

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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.

		Number of					Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1974/75	East of 172° W	87	372	1,812,647	71,821	13,991,190	7.7	25		
	West of 172° W	36	97	532,298	32,620	2,774,963	5.2	16	148.6	NA
	TOTAL		**469**	**2,344,945**	**104,441**	**16,766,153**	**7.1**	**22**		
1975/76	East of 172° W	79	369	2,147,350	86,874	15,906,660	7.4	25		
	West of 172° W	20	25	79,977	8,331	411,583	5.2	10	147.2	NA
	TOTAL		**394**	**2,227,327**	**95,205**	**16,318,243**	**7.3**	**23**		
1976/77	East of 172° W	72	226	1,273,298	65,796	9,367,965 [f]	7.4	19		
	East of 172° W	38	61	86,619	17,298	830,458 [g]	9.6	5	NA	NA
	West of 172° W	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

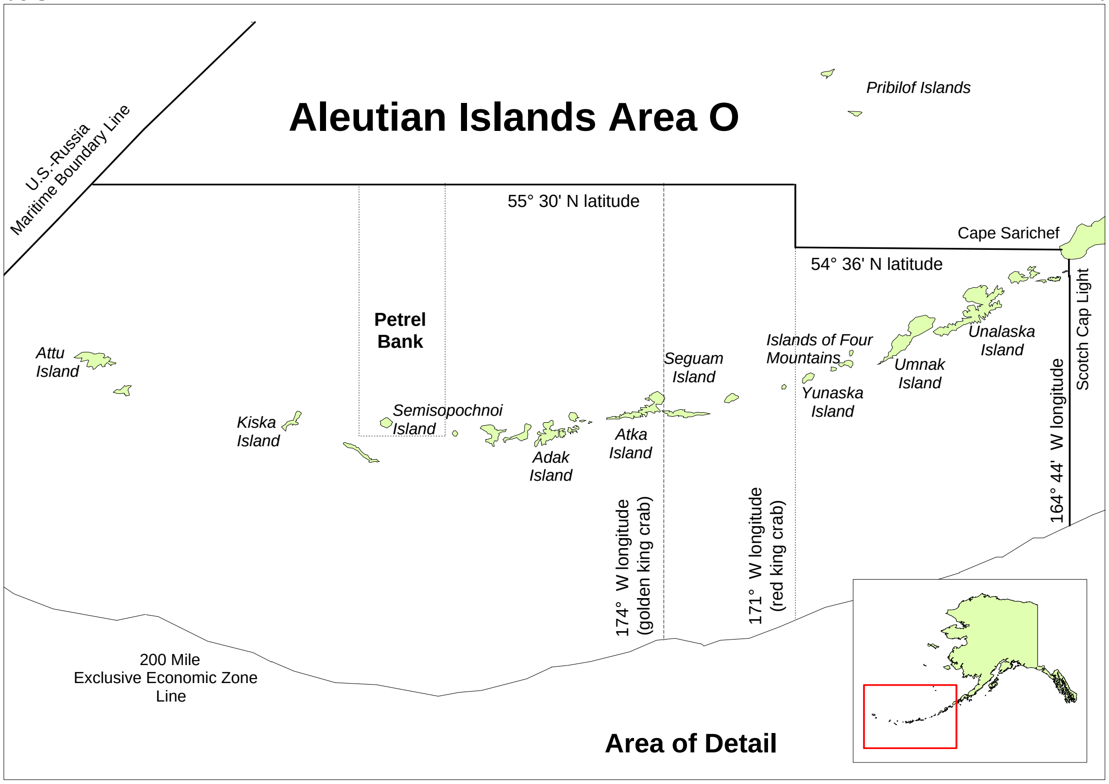

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Bowers et al 2008).

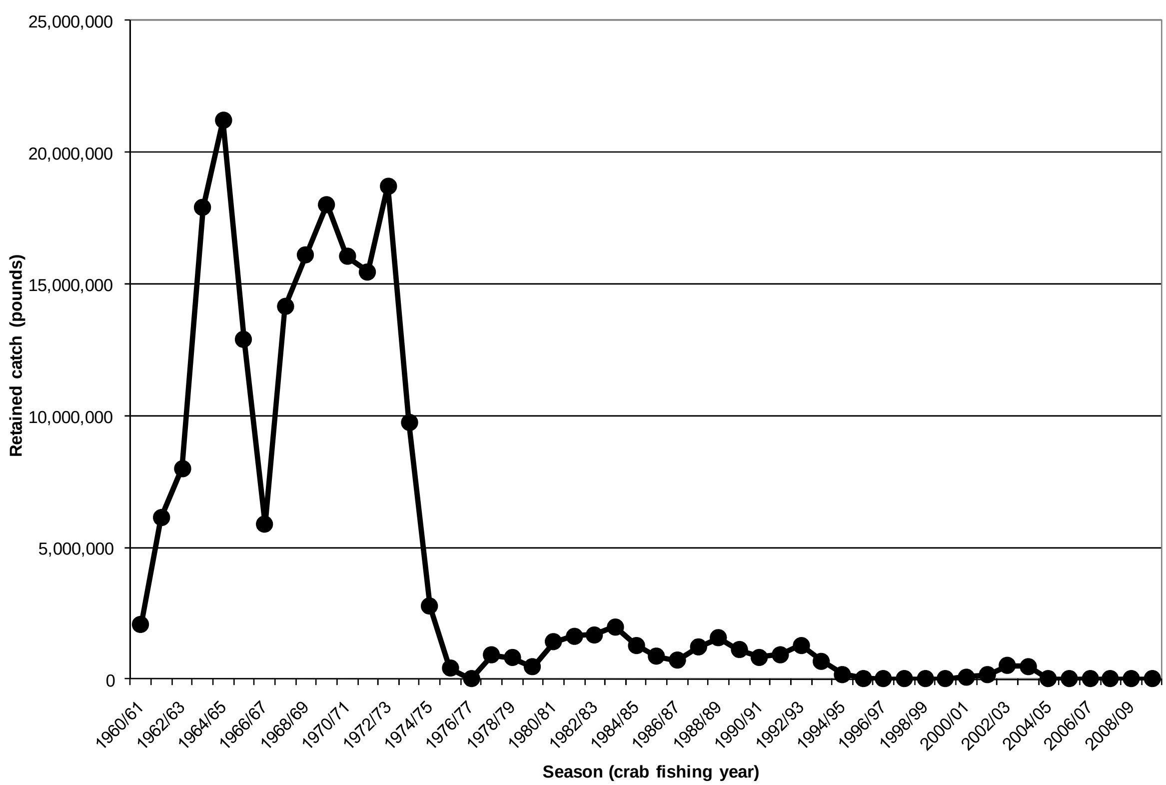

Figure 2. Retained catch in the Adak red king crab fishery, 1960/61–2009/10 (catch is for the area west of 172º W longitude during 1960/61–1983/84 and for the area west of 171º W longitude during 1984/85–2009/10; see Table 1).

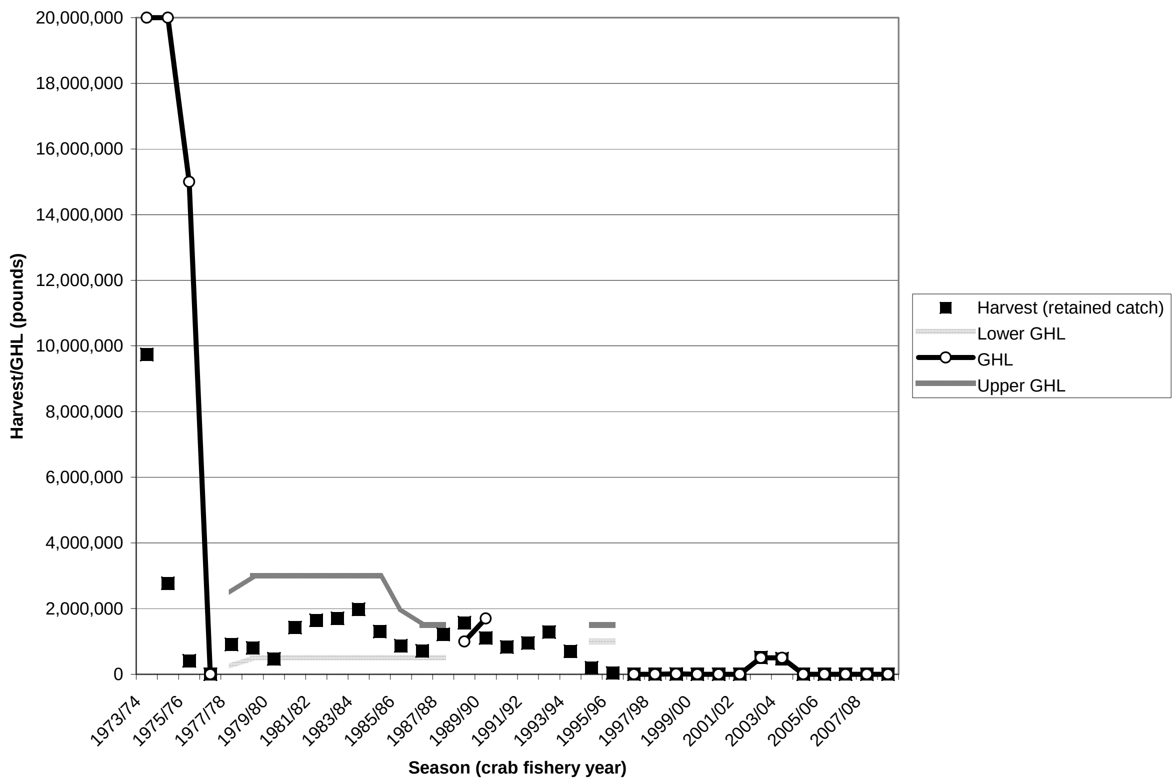

Figure 3. Guideline harvest levels (GHL, pounds) for the 1973/74–2008/09 Adak red king crab fishery seasons, with retained catch (harvest, pounds); the 2009/10 fishery was closed and retained catch was 0 pounds; the retained catch graphed for the 2000/01–2001/02 seasons does not include the catch retained 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).

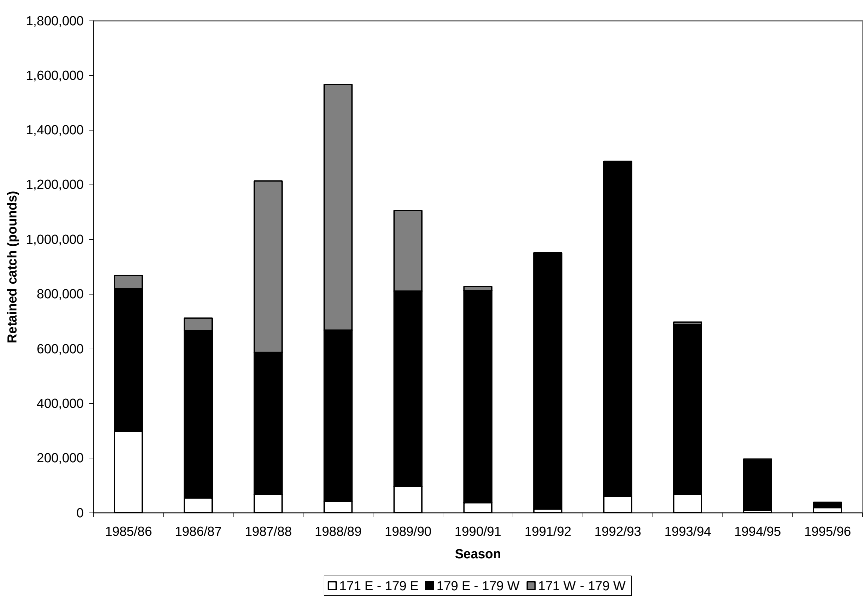

Figure 4. Retained catch (pounds) in the Adak red king crab fishery for the 1984/85–1995/96 seasons, partitioned into three longitudinal zones (171º W longitude to 179º W longitude, 179º W longitude to 179º E longitude, and 179º E longitude to 171º E longitude; from ADF&G fish ticket summary provided by F. Bowers, ADF&G).

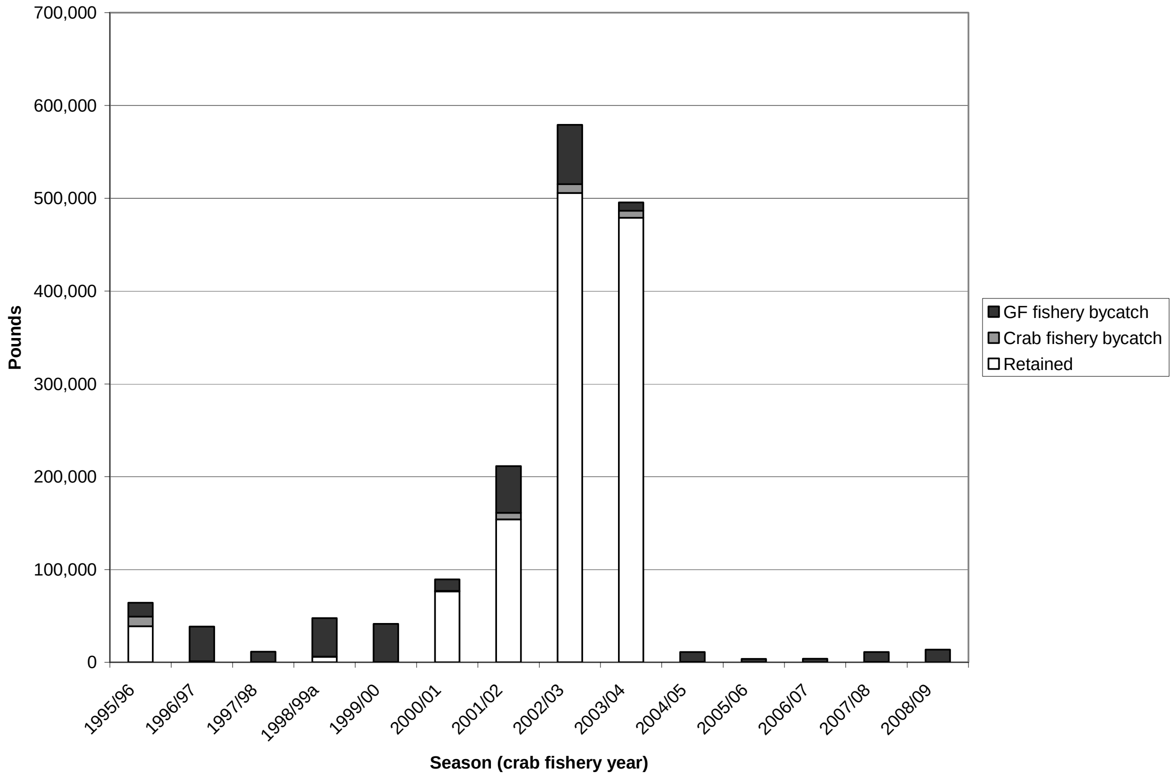

Figure 5. Estimates of total fishery mortality (pounds) for red king crabs in the Adak Area, 1995/96–2008/09, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries (see Table 5).

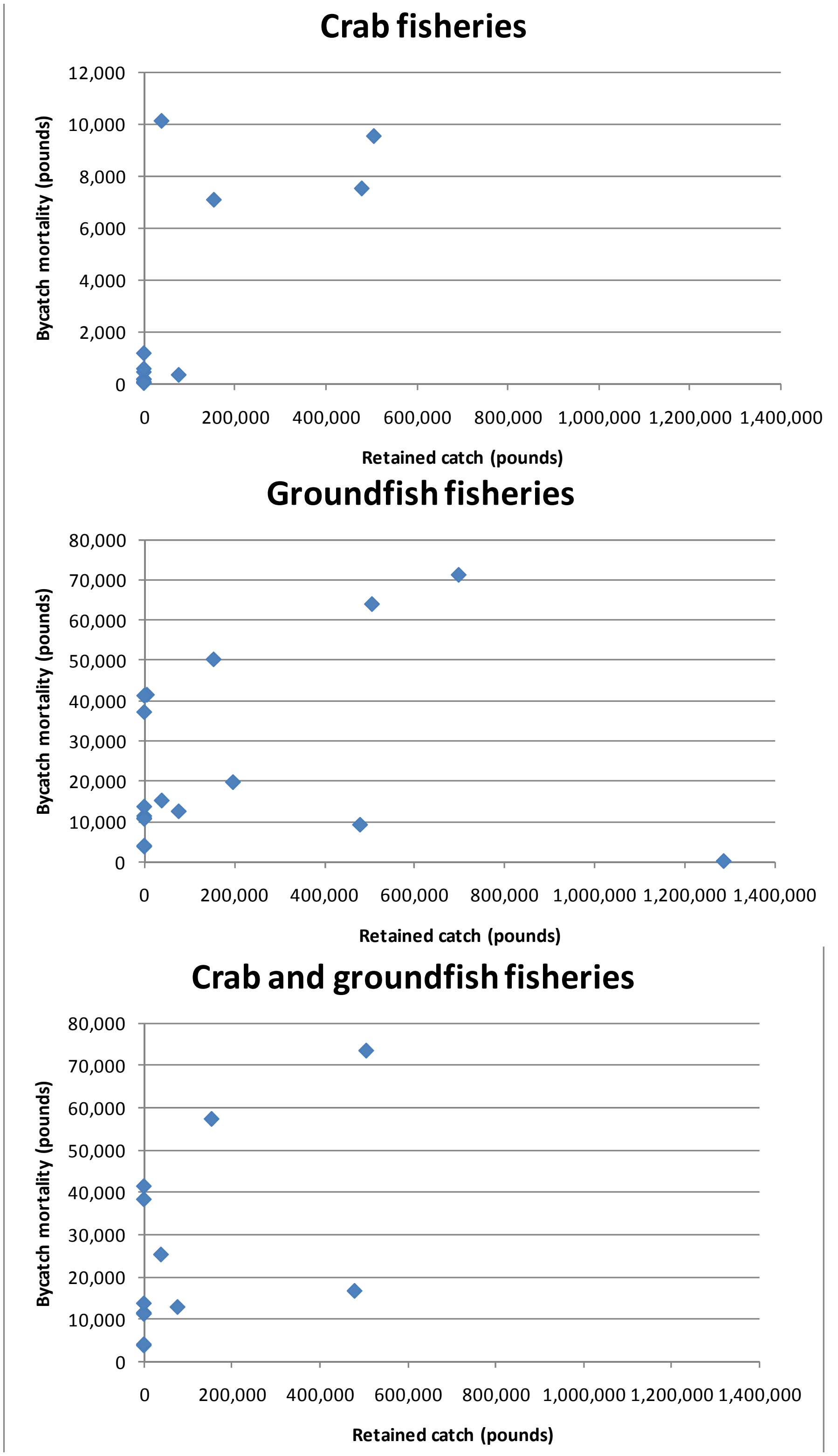

Figure 6. Estimated bycatch mortality of Adak red king crabs in crab fisheries (top panel), groundfish fisheries (middle panel), and crab and groundfish fisheries combined (bottom panel) as a function of the retained catch in the directed Adak red king crab fishery.

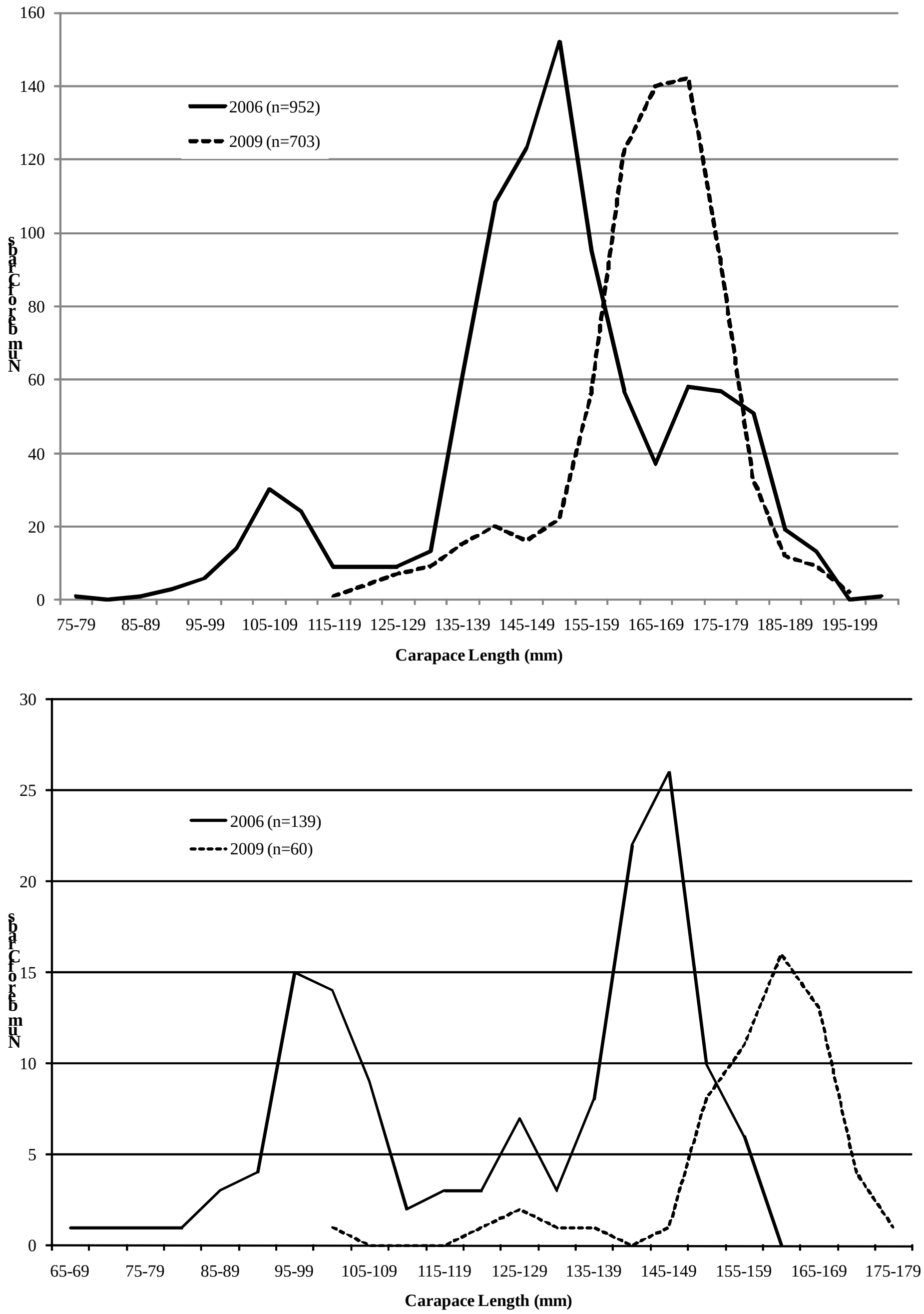

Figure 7. The size-frequency distributions of male (top panel) and female (bottom panel) red king crabs by 5-mm carapace length groups captured during the 2006 and 2009 ADF&G pot surveys for red king crabs in the Petrel Bank area (from Gish 2010).

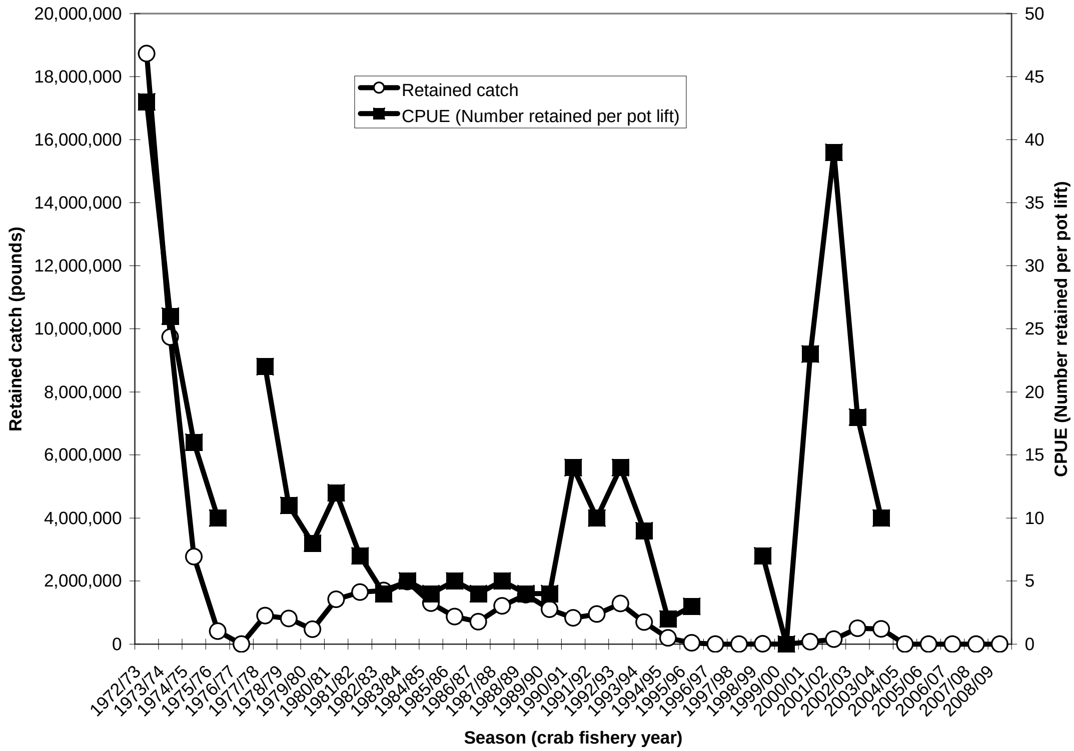

Figure 8. Retained catch (pounds) and CPUE (number of retained crabs per pot lift) of red king crabs during the 1972/73–2008/09 fishery seasons for red king crabs in the Adak Area (see Table 1); data from the closed (0 pounds retained catch) 2009/10 season are not included in the graph. Data for the 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.

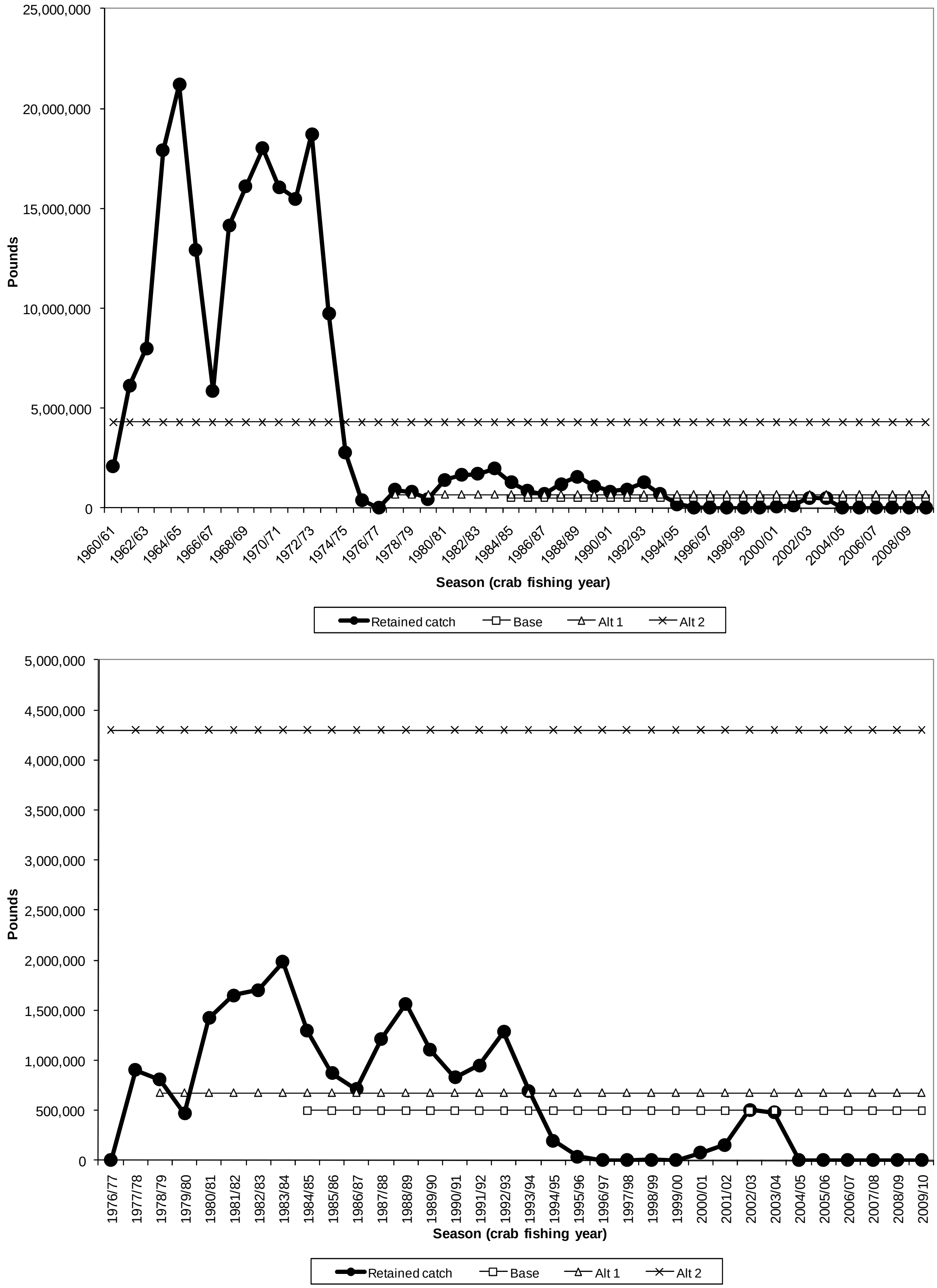

Figure 9. Alternative retained-catch OFLs (Base and Alternatives 1–2) compared with actual historical fishery retained catch for the Adak red king crab fishery, 1960/61–2009/10 in the top panel and 1976/77–2009/10 in the bottom panel (see Table 1 and section E.3.b).

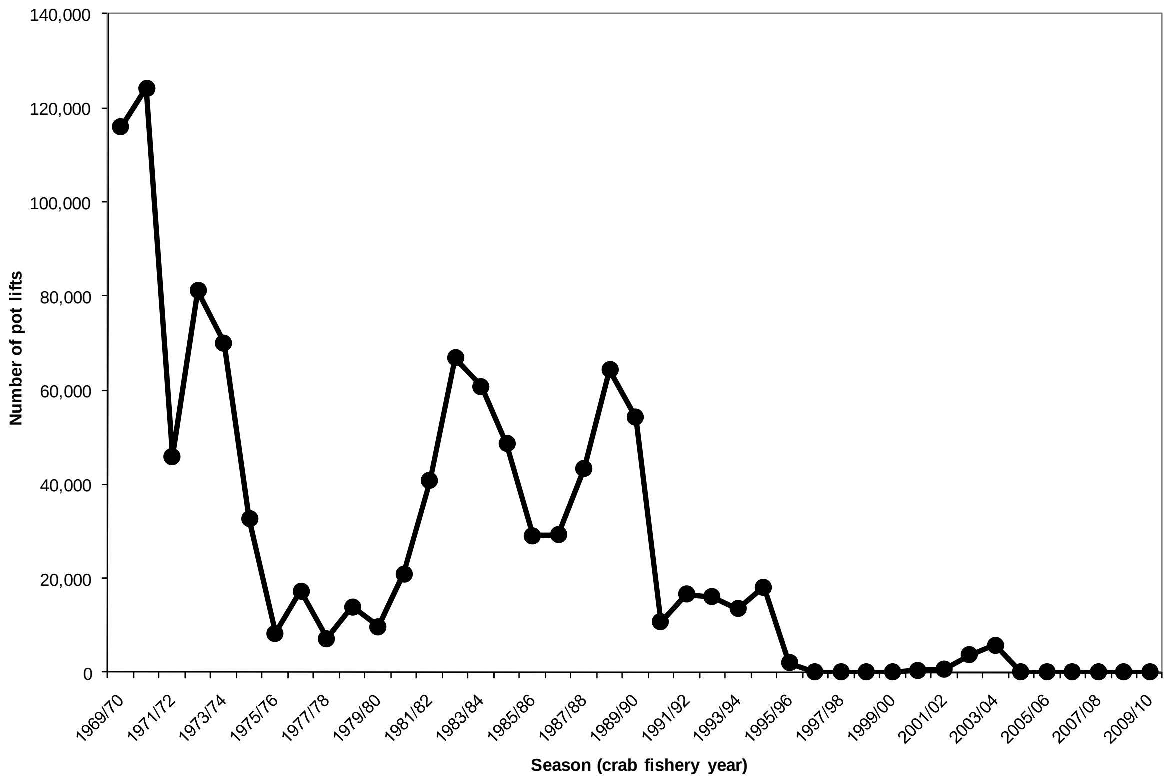

Figure 10. Number of pot lifts performed in the Adak red king crab fishery, 1969/70–2009/10 (see Table 1).

ECOSYSTEM CONSIDERATION INDICATORS FOR BERING SEA AND ALEUTIAN ISLANDS KING AND TANNER CRAB SPECIES

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Introduction

The purpose of the Crab Ecosystem Considerations and Indicators (CECI) report is to consolidate ecosystem information specific to the crab stocks in the Bering Sea and Aleutian Islands (BSAI) Fishery Management Plan. BSAI Fishery Management Plans cover 10 stocks of crab representing five species: red king crab (*Paralithodes camtschaticus*; RKC), blue king crab (*Paralithodes platypus*; BKC), golden king crab (*Lithodes aequispinus*; GKC), Tanner crab (*Chionoecetes bairdi*), and snow crab (*Chionoecetes opilio*). The CECI report will serve as an appendix to the BSAI king and Tanner crab stock assessment and fisheries evaluation (SAFE) document.

The objectives of the appendix are to assess the BSAI ecosystem trends, identify and provide annual updates of ecosystem status indicators and research priorities for BSAI crab stocks, and to update management status indicators. The format and organization of the CECI appendix is adapted from the Ecosystem Considerations Appendix to the BSAI and Gulf of Alaska Groundfish SAFE documents and also the North Pacific Marine Science Organization (PICES) workshop on integrating ecological indicators of the North Pacific (Kruse et al. 2006). In order to avoid duplication of effort, sections in this document may occasionally refer to detailed reports from the Groundfish Ecosystem Considerations Appendix on topics specifically impacting crab ecology.

The CECI is composed of three main sections. First, the **Ecosystem Assessment** portion of the document provides a historical overview of the physical and biological environment of the BSAI ecosystem utilized by crab species as well as aspects of crab life history such as survival, recruitment, growth, maturity and natural mortality which are known to be impacted by changes in the BSAI ecosystem. The second section of the CECI, **Current Status of Ecosystem Indicators**, provides current information and updates on the status of the physical and biological components of the BSAI ecosystem. Physical components include pelagic and benthic habitat variables while biological components include prey availability and their abundance as well as distribution and abundance of competitors and predators. This section updates current research and identifies future research priorities for BSAI crab stocks with respect to ecosystem interactions. The final section, the **Ecosystem-based Management Indicators**, provides trends which could indicate early warning signals of direct fishery effects on crab-oriented BSAI ecosystem components, warranting management intervention or providing evidence of the efficacy of previous management actions. Specific indicators include the magnitude of directed fishery effects on BSAI habitat and resulting management efforts, and spatial and temporal removals of the target catch affecting other biological predators. In this section, we also review potential fishery effects on crab biology such as changes in age and size at maturity, and reproduction.

Ecosystem Assessment

Purpose

This section provides a historic overview of the physical and biological components in the BSAI ecosystem that are utilized by crab species at specific life stages. Three major crab life history stages, larval, juvenile and adult, utilize distinct components of the physical environment, both pelagic and benthic, as well as exhibit unique species interactions within the biological environment as prey, competitors and predators. The duration of the major life history stages are specific to each crab species (Fig. 1).

Crab Life History

Larval stages are distributed according to vertical swimming abilities, the oceanographic currents, and mixing or stratification of the water column. Generally, the larval stages occupy the mixed layer near the sea surface except golden king crab larvae, which are fully lecithotrophic (yolk-nourishing) and are considered demersal (Shirley and Zhou 1997). Egg extrusion and hatching is relatively synchronous in RKC and BKC, although alternate year hatching has been observed in BKC (Somerton and MacIntosh 1985). Larval hatching in GKC is asynchronous with no apparent seasonal mating period in mature adults (Shirley 2006). After molting through multiple larval stages, crabs settle on the seafloor. Settlement on habitat with suitable shelter, food, and temperature is imperative for survival of first settling crabs. Young of the year RKC and BKC require nearshore shallow habitat with significant cover that offers protection (e.g., sea stars, anemones, macroalgae, shell hash, cobble, and shale). Early juvenile stage Tanner and snow crab also occupy shallow waters and are found on mud habitat. Juvenile GKC have been observed on structure-forming sessile invertebrates growing on the sea floor, such as corals, sponges and sea-whips, which provide protection (Stone 2006).

King crab reproduction occurs between a soft-shelled female and hard-shelled male while Tanner and snow crab females exhibit a terminal molt and can store sperm to fertilize subsequent clutches or mate while hard-shelled. Tanner and snow crab mate in the middle shelf of the EBS while RKC and BKC mate in relatively shallow (< 50 m) nearshore areas (Somerton and MacIntosh 1985; Loher and Armstrong 2005; Orensanz et al. 2007). Golden king crab mate in deepwater canyons, along the slope of the EBS and on isolated seamounts (Shirley 2006). All crab species are highly vulnerable to predation and damage during molting. The benthic environment or habitat occupied by molting and mating crab differs from that occupied by mature crabs during the remainder of the year.

Physical Environment of the BSAI Ecosystem

The Bering Sea is only semi-enclosed with a total area of 2.3 million km^2, of which 44% is continental shelf, 13% is continental slope, and 43% is deep-water basin. The Aleutian Islands (AI) lie in an arc that forms a partial geographic barrier to the exchange of northern Pacific marine waters with EBS waters. The AI continental shelf is narrow compared with the EBS shelf, ranging in width on the north and south sides of the islands from about 4 km or less to 46 km; the shelf broadens in the eastern portion of the AI arc. The AI comprises approximately 150 islands and extends about 2,260 km in length (Johnson 2003) (Fig. 2).

North Pacific Climate Historic Overview

Variation in climate and ocean dynamics have been implicated as important factors influencing crab recruitment in Alaska, with cold periods partially explaining strong recruitment events (Zheng and Kruse 2000). Temperature anomalies over the last four decades in the EBS are characterized by a 1971-1976 cold period, a 1977-1988 warm period, a weaker cold period from 1989-1998, followed by warm years in 2000-2005 with a transitional year in 2006 to the cold period from 2007 to the present (Schumacher et al. 2003, NPFMC 2008). The past decade has been warmer in the Bering Sea compared to the pre-1977 temperatures; however, winter and spring 2007 surface air temperatures were colder than normal and 2006 was close to normal, but these anomalies were not as cold as the mid-1970's (Wang et al. 2008). Overland et al. (1999) found three shifts of wintertime climate forcing patterns identified as: 1) 1967-1976 a positive Aleutian Low and mixed Arctic Oscillation, 2) 1977-1988 a negative Aleutian Low and negative Arctic Oscillation, and 3) 1989-1998 a mixed Aleutian Low and positive Arctic Oscillation. The negative Aleutian Low and negative Arctic Oscillation period from1977-1988 is coincident with the warm period in the EBS.

It is generally acknowledged that the global climate is changing and those changes are driving marine ecosystems toward conditions not seen in historic times. The effects on BSAI crab stocks will be both direct and indirect due to changes in temperatures, winds, storm intensity, salinity, stratification, pH, and abundance of suitable physical habitat. There is, however, considerable uncertainty over the spatial and temporal distribution of the effects (Brander 2010, Hoegh-Guldberg and Bruno 2010). In the EBS, increases in air temperature, storm intensity, storm frequency, southerly wind, humidity, and precipitation are anticipated. The increased precipitation, plus snow and ice melt, leads to an increase in freshwater runoff (Barange and Perry 2009). The only atmospheric changes showing a decrease is sea level pressure, which is associated with the northward shift in the storm track. Ocean circulation decreases are likely to occur in the major current systems: the Alaska Stream, Near Strait Inflow, Bering Slope Current, and Kamchatka Current. Competing effects make changes in the Unimak Pass inflow, the shelf coastal current, and the Bering Strait outflow unknown. Changes in hydrography should include increases in sea level, sea surface temperature, shelf bottom temperature, and basin stratification. Decreases should occur in mixing energy and shelf break nutrient supply, while competing effects make changes in shelf stratification and eddy activity unknown. Ice extent, thickness, and brine rejection are all expected to decrease (Barange and Perry 2009).

When considering the effect of climate change on BSAI crab stocks, differing time scales will have different management implications (Brander 2010). At short time scales (i.e., 1-5 years), the effects of long-term climate change can be relatively unimportant but the frequency of extreme conditions such as abnormally warm winters with minimal ice cover in the Bering Sea or a regime shift can have major consequences on the recruitment of a particular year class of crab. At medium-term time scales (~ 5-25 years) which span several generations of crab, changes in climate affect the basic productivity of the marine ecosystem (King 2005) and consequently crab rebuilding plans and biological reference points used in the assessment process. The long term impact of climate change on crab stocks will undoubtedly be very large, but the uncertainty associated with that change is also very large. Responses may be nonlinear and have greater impact on populations that may be less resilient (Brander 2007).

Sea Ice Trends in the Eastern Bering Sea

The extent and timing of the retreat of sea ice in the Bering Sea determines the strength and fate of the spring phytoplankton bloom which in turn can have a major impact on the survival of larval crab and the whole food web structure (Hare et al. 2007). The extent of sea ice coverage is variable and related to the location of the Aleutian Low and Siberian High which typically produce northeast winds in the winter that freeze the seawater and push the ice southwestward (Stabeno et al. 2001). During 1971-1976, extensive ice coverage on the Bering Sea shelf extended south and west, beyond the slope, and remained around St. Paul Island for more than a month in the spring. During the next cold phase from 1989-1998, 2-4 more weeks of ice were observed at the 59°N parallel than during the previous decade (Schumacher et al. 2003). The Ice Retreat Index, defined by Overland et al. (2008) as the number of days with sea ice coverage after March 15th within the vicinity of king crab mooring 2A (KC-2A, Fig. 2), increased in 2006-2009 compared to the previous five years which reflects the recent trend in colder water temperatures and high ice coverage, suggesting a weak Aleutian Low Pressure Index (ALPI) in the EBS. If the ice cover is not extensive or retreats early in the spring, a shift occurs from ice-edge blooms to later open-water blooms. The Ice Cover Index represents the average ice concentration from Jan 1 to May 31st in a 2-deg x 2-deg box (56-58°N, 163-165°W) for 1978-2008 relative to the 1981-2000 mean of 7.15 (SD = 4.01) (Overland 2008). The presence of sea ice in 2007 (Fig. 3) along with below normal ocean temperatures likely resulted in the first ice-edge bloom since 1999 (Wang et al. 2008).

The seasonal melt and retreat of the sea ice edge leaves low saline and less dense water at the surface and the increased warming creates a stratified water mass of cold, dense seawater at the bottom of the seafloor. This cold pool (< 2°C) extends over a large portion of the EBS and has extended into Bristol Bay during the summer months, particularly in 1999-2000 and again in 2007-2009 as shown by bottom temperatures recorded at KC-2A (Fig. 4). The southern edge of the cold pool marks the boundary between the arctic and subarctic marine communities. Changes in the location of the cold pool alter the composition of those communities but the response among taxa is variable and difficult to predict (Aydin and Muter 2007; Mueter and Litzow 2008).

As a response to changing water temperatures, the ecosystem in the Bering Sea is shifting northward (Overland and Stabeno 2004). Wang et al. (2010) predict an approximately 40% reduction in Bering Sea sea ice coverage by 2050. Long-term changes in sea ice cover may affect benthic communities because much of the production from retreating ice edge spring blooms sink to the bottom, but if these blooms do not occur there may not be sufficient phytoplankton falling to the benthos to support abundant communities (Lovvorn et al. 2005).

Pelagic Habitat

During their larval stages, crab utilize the pelagic habitat of the Bering Sea and Aleutian Islands (Fig. 1, except Golden King Crab-see *Crab Life History* above). The pelagic habitat is vast and dynamic but many of the aspects of this habitat that affect larval survival are poorly understood. Kinney et al. (2009) present an updated description of the general circulation of the Bering Sea and Aleutian Islands based upon recent modeling. The Alaskan Stream is the strongest current in the region and brings water from the North Pacific through Unimak Pass and Amukta Pass northward into the Bering Sea. The Alaska Coastal Current also supplies water from the North Pacific to the Bering Sea through Unimak Pass. The shelf break region is characterized by the Bering Slope Current which extends from the eastern Aleutian Islands along the shelf break toward the coast of Siberia near Cape Navarin and flows to the northwest (Fig. 2).

The shelf of the Bering Sea is divided into three depth domains each with distinct circulation patterns and hydrographic (temperature and salinity) characteristics. The coastal shelf domain (0-50 m) is characterized by one well mixed layer. In the middle shelf domain (50 to 100 m), a two-layer temperature and salinity structure exists because of wind which mixes the upper water column and tidal currents which mix the lower layer. In the outer shelf domain (100 to 180 m), a three-layer temperature and salinity structure exists due to wind mixing the upper water column, tidal currents mixing the lower layer and a middle layer that is not well mixed (Stabeno et al. 2001). The majority of the Norton Sound bathymetry is dominated by shallow depths, between 0 and 50 m, with one well mixed layer influenced by the freshwater driven Alaska Coastal Current as it flows north to the Bering Strait (Fig. 2).

The larvae of both snow crab and RKC have been shown to have strict survival tolerances to extremes in salinity (Shirley and Shirley 1989, Charmantier and Charmantier-Daures 1995) but the effects on survival due to salinity variability in the BSAI have not been demonstrated. Along the edge of the shelf in the Alaska Stream, a low salinity tongue-like feature (less than 32.0 psu) protrudes westward. On the south side of the central AI, nearshore surface salinities can reach as high as 33.3 psu, as the higher salinity EBS surface water occasionally mixes southward through the AI passes. Proceeding south and west, a minimum of approximately 32.2 psu is usually present over the slope in the Alaska Stream and values rise to above 32.6 psu in the oceanic water offshore with salinity increasing towards the west as the influence of fresh water from the land decreases (Ladd et al. 2005).

High primary productivity along the shelf edge is maintained by vertical nutrient supply to the subsurface layer and shelf to slope exchange occurring with an increase in the Bering Slope Current transport and eddy fluctuations (Mizobata and Saitoh 2004). Vertical mixing of nutrient-rich deep Bering Sea water can enhance productivity in regions of the Bering Sea including around St. Lawrence Island and the Pribilof Islands (Stabeno et al. 2008, Kinney et al. 2009). In the Aleutian Island passes, Bering Sea deep-water high in nutrients is mixed with surface water. Water within the passes is highly mixed resulting in low productivity, but this water moves northward and becomes stratified thus introducing high-nutrient surface water to the Bering Sea (Ladd et al. 2005).

Benthic Habitat

McConnaughey and Smith (2000) and Smith and McConnaughey (1999) synthesized the available sediment data for the EBS shelf. These data were used to describe four habitat types (Fig. 5). The first, situated around the shallow eastern and southern perimeter and near the Pribilof Islands, has primarily sand substrates with a little gravel. The second, across the central shelf out to the 100 m contour, has mixtures of sand and mud. A third, west of a line between St. Matthew and St. Lawrence islands, has primarily mud (silt) substrates, with some mixing with sand. Finally, the areas north and east of St. Lawrence Island, including Norton Sound, have a complex mixture of substrates. The AI region has complicated mixes of substrates, including a significant proportion of hard substrates (pebbles, cobbles, boulders, and rock), but data are not available to describe the spatial distribution of these substrates.

Shell hash habitat may be important to juvenile BKC as a refuge from predators, their white carapace blends in with shell hash and juvenile BKC likely require cover afforded by shell hash due to a lack of long spines that juvenile RKC have (Armstrong et al. 1985; 1987; Palacios et al. 1985). Juvenile BKC have a mottled color pattern that blends into the background epifauna. Survival in juvenile BKC is linked to the abundance of shells of certain mollusk species, including mussels *(Modiolus modiolus),* scallops *(Chlamys sp.),* rock oysters *(Pododesmus macrochisma),* and hairy tritons *(Fusitriton oregonensis)* (Palacios et al. 1985). Such material is scarce in offshore, sandy environments.

Juvenile red king crab have been shown to prefer nearshore habitats of high complexity (Loher and Armstrong 2000) which includes a well-developed community of living substrate such as hydroids, bryozoans and sponges. These organisms are used by juvenile RKC for feeding and refuge. Adults move to soft bottom substrates further offshore (Rodin 1989). Tanner and snow crab juveniles are reported to prefer homogenous mud substrate (Dionne et al. 2003) or mud, silt, and sand (Rosenkranz et al. 1998). Adults prefer a similar habitat, with Tanner crab found primarily in a sand-mud substrate (Zhou and Shirley 1998) and snow crab generally occuring in cooler waters although their ranges overlap (Slizkin 1989). Juvenile GKC have been seen associated with hexactinellid sponges *Aphrocallistes vastus* and *Heterochone calyx* (Stone 2006) while adults are associated with cold-water corals including *Primnoa* (Krieger and Wing 2002).

Changes in bottom water temperatures impact the amount of benthic habitat available to crab species. Over the last three decades, distribution of mature female snow crab in the EBS shifted in relation to changing water temperatures. Increased water temperatures mid 1980s resulted in a shift of mature females to the northwest EBS shelf while the more recent temperature decrease in the last decade did not result in a return of mature females to their historical distribution (Orensanz et al. 2004).

The Bristol Bay mean bottom water temperature collected over the last decade in early June on the NMFS Alaska Fisheries Science Center (AFSC) EBS bottom trawl survey ranged from lows of 1.5°C (SD = 0.5) in 2009 to 2.2°C (SD = 0.7) in 2006 compared to warmer temperatures ranging from 3.5°C (SD = 0.3) in 2001 to 4.3°C (SD = 0.5) in 2005. These cold temperatures in the summer reflect the extent of the sea ice coverage from 2006 to 2009 compared to the warmer bottom water temperatures from 2001 to 2005. Based on data collected during the biennial AI bottom trawl survey from 1994 to 2006 and standardized to a median date of July 10th, water temperatures both at the surface and in deeper depths were warmest in 1997, followed by 2004 compared to the other years (Martin 2007).

Ocean Acidification

Dissolution of anthropogenic CO_2 has reduced global mean surface water 0.1 pH units below pre-industrial levels, a change of about 26% (Caldeira and Wickett 2003, Orr et al. 2005), and in the North Pacific the pH is likely to decrease an additional 0.3 pH units over the next century (Feely et al. 2009). In addition, deep oceanic waters are depleted in carbonate due to respiration resulting in a saturation depth below which calcium carbonate dissolves (Fabry et al. 2009). In the North Pacific Ocean the saturation depth is relatively shallow due to the cold temperature and age of advected deep water masses. This combination of factors means that these waters may become constantly undersaturated for aragonite by mid-century and for calcite by the end of the century (Fabry et al. 2009, Feely et al. 2009).

<u>Biological Environment of the BSAI Ecosystem</u>

Commercial Crab Stocks

No one cause has been identified to explain the magnitude of fluctuations in some commercial crab stocks and the precipitous decline from the 1970s and 1980s in other stocks. Mature male biomass for seven of the ten stocks has been estimated from survey and commercial catch data (Fig. 6). Bristol Bay RKC estimates of total survey abundance of mature male biomass increased to 150.1 thousand mt in 1977, decreased sharply to a low of 9.5 thousand mt in 1983, and fluctuated between 14.0 and 42.5 thousand mt through 2009. Pribilof Island RKC were not prevalent in the Pribilof Islands until the early 1990s. The mature male biomass peaked in the 1990s at 24.3 thousand mt and then declined to between 2.3 and 8.6 thousand mt between 1998 and 2009. Norton Sound RKC mature male biomass was highest at 5.4 thousand mt in 1977, dropping to 3.6 thousand mt in 1979 and fluctuating between 2.2 and 1.8 thousand mt in the 1980s, 1990s, and 2000s. Pribilof Islands BKC mature male biomass peaked in the late 1970s between 34.0 and 38.5 thousand mt before declining to less than 0.9 thousand mt in 1988 and 1989. This crab stock has been designated overfished with abundance estimates averaging less than 0.25 million crab. St. Matthew Island BKC mature male biomass fluctuated over three periods: 1978 to 1985, 1986 to 1999, and 2000 to present. Historical peaks in mature male biomass were 14.0 thousand mt in 1982 and 9.1 thousand mt in 1997. Currently the stock has increased from a low of 2.1 thousand mt in 2003 to the current biomass estimate of 4.6 thousand mt. Tanner crab mature male biomass peaked in the 1970s at 149.7 thousand mt but declined to a low of 7.7 thousand mt in the early 1990s and began increasing in the early 2000s to a peak of 49.9 thousand mt in 2007. Snow crab mature male biomass peaked in 1990 at 356.5 thousand mt and again in 1997 at 232.7 thousand mt. After a decline in mature male biomass to 44.5 thousand mt in 2004, the stock has gradually increased to the current mature male biomass of 103.4 million crab.

Abundance estimates are not available for GKC stocks in the BSAI and Aleutian Islands RKC. Fluctuations in Aleutian Islands GKC and Pribilof Islands GKC fishery catch per unit effort have led to speculation about changes in recruitment. In the Pribilof Islands, commercial catches ranged from 0.01 and 0.09 million crab in the late 1990s and early 2000s and have dropped to < 0.01 in recent years. In the Aleutian Islands, catches of GKC averaged 1.5 million in the 1980s, 0.6 million in the 1990s and 2000s. Fishery catches of Aleutian Islands RKC decreased from a 9.5 thousand mt peak in the 1960s to less than 0.4 thousand mt in the late 1990s. Since the end of the 2003/2004 fishing season the fishery has been closed due to poor recruitment indices from periodic pot surveys.

Crab Prey

Information on BSAI crab food habits is limited; however it is known that crab diets vary with life stage and in general crabs are opportunistic omnivorous feeders, eating a wide variety of microscopic and macroscopic plants and animals. Red king crab, BKC, Tanner and snow crab larvae are planktonic feeders and consume both phytoplankton and zooplankton including diatoms, algae and copepods (Bright 1967, Paul et al. 1979, Abrunhosa and Kittaka 1997). Golden king crab larvae are considered lecithotrophic which are non-feeding and survive on yolk reserves (Shirley and Zhou 1997). The glaucothoe stage of RKC and BKC, their last larval stage, is non-feeding (Epelbaum et al. 2006).

Increased primary production could result in increased phytoplankton prey items for crab larvae. Nutrient supply and productivity in the Bering Sea is related to ice coverage, currents and eddies (see above, *Sea Ice Trends in the Eastern Bering Sea)*. When sea ice coverage over the southeast Bering Sea shelf occurs in March/April, a strong phytoplankton bloom occurs. In the absence of sea ice, the bloom does not occur until May/June and is typically weaker (Stabeno et al. 2001). For example; timing of the expansion and contraction of EBS sea ice coverage in1997 was favorable for a phytoplankton bloom but not in 1998 or 1999 (Rho et al. 2005). The premature contraction of the sea ice coverage in 1998 and 1999, combined with strong mixing due to high winds, may have prevented the development of density-driven stratification, and resulted in higher nitrate concentrations with a lack of an obvious spring bloom (Rho et al. 2005).

A decline of the euphausiid *Thysanoessa raschii* throughout the middle domain of the EBS shelf as well as coastal areas was discovered in the diet of short-tailed shearwaters during the late 1990s (Hunt et al. 2002). More recently, declines in summer zooplankton biomass have been linked to the warm years of 2001-2005 in the eastern Bering Sea (Renner et al. 2008). Part of the decrease in biomass over the middle shelf was most likely due to decreases in the abundance of *Calanus marshallae*, the only “large” copepod found in that area, and euphausiids (Renner et al. 2008). After a six year period of relatively low biomass, the EBS zooplankton began returning to average levels in 2006-2007 (Napp and Yamaguchi 2008).

Juvenile and adult crabs are opportunistic omnivorous scavengers. Juveniles consume benthic prey such as diatoms, foraminifera, copepods, algae, sponge, bryozoans, hydroids, polychaetes, small bivalves, snails, seastars, ophiuroids, echinoids, barnacles, crab, and sediment; detritus may also be a major component of their diet (Feder et al. 1980, Feder and Jewett 1981, Paul 1982). The predominant prey of adult red king crab are bivalves, barnacles, polychaetes, hydroids, gastropods, amphipods, crabs, brittle stars, sand dollars and sea urchins (reviewed in Jewett and Onuf 1988). The predominant prey of adult Pribilof Islands blue king crab are fish, barnacles, hydroids, brittle stars, bivalves, crabs, polychaetes, sea stars, and amphipods (ADFG unpublished data). Stomach contents of Tanner crab near Kodiak Island had predominatly arthropods by weight (primarily juvenile Tanner crab) followed by fish and mollusks (Jewett and Feder 1983). Adult snow crab in the EBS eat polychaetes, bivalves, detritus and other benthic prey (Aydin 2007), which is similar to the most frequently occurring prey of adult snow crab from the Newfoundland shelf of polychaetes, shrimp, crab, small crustaceans, infaunal clams, and fishes (Squires and Dawe 2003). Additionally, cannibalism was found to provide a major food source for adult snow crab in the Gulf of the St. Lawrence River (Lovrich and Sainte-Marie 1997).

The most recent description of benthic infaunal crab prey distribution in the EBS, such as polychaetes, other worms, and bivalves, comes from grab samples collected in 1975 and 1976 (Halflinger 1981) followed by a description of polychaete assemblages collected from a small section of the south-eastern portion of the Bering Sea in 2006 (Yeung et al. 2010). Polychaete families were associated with sediment type or benthic substrate based on their functional ecology such as burrowers in mud and sand or mobile species distributed on hard substrate. Coyle et al. 2007 compared late 1950s and mid 1970s benthic infaunal data from the southeastern Bering Sea shelf and found a trend toward higher overall infaunal biomass during the mid 1970s among carnivores, omnivores and surface detritivores. The 1970s data was collected during a cold period which suggests a link between temperature and infaunal biomass. During cold periods, infaunal biomass is predicted to be elevated due to elevated carbon flux to the benthos and a reduction in groundfish predators due to cold bottom water (Coyle et al. 2007).

On the annual EBS bottom trawl survey, the catchability of most epibenthic crab prey is low but still accounted for 23% of the total demersal animal biomass (15.4 million mt) in 2007 and 24% (14.3 million mt) in 2008. The majority of the epifaunal invertebrates in 2008 were asteroid seastars, brittle stars and sea urchins at 1.6 million t followed by crustaceans at 0.75 million mt. (Acuna and Lauth 2008; Lauth and Acuna 2009).

Competitive Interactions

Forage fish are planktonic feeders and may be competitors with larval crabs as well as predators. Abundance trends of forage fish species for the EBS have been examined using data obtained on the AFSC EBS bottom trawl survey from 1982-2009. In general, abundance estimates of stichaeids and Pacific sand lance (*Ammodytes hexapterus*) were higher from 1982-1998 and lower from 1999-2009. Eulachon (*Thaleichthys pacificus*) abundance has been variable from 1982-2009 with the lowest years of abundance observed in 1985, 1989, 2008 and 2009 and the highest abundance years were 1984, 1991, and 1997 while capelin (*Mallotus villosus*) abundance has been low except for 1993 (Lauth 2009).

Abundance indices of other planktonic feeders in the EBS such as juvenile sockeye salmon (*Oncorhynchus nerka*), age-0 walleye pollock (*Theragra chalcogramma*), and age-0 Pacific cod (*Gadus macrocephalus*) were estimated from surface trawl data collected in the fall of 2002-2007 on the Bering-Aleutian Salmon International survey (BASIS). In warm water years, 2002-2005, juvenile sockeye salmon and age-0 pollock abundance increased and were widely distributed throughout the EBS shelf compared to decreased abundances in cold water years, 2006 and 2007, when juvenile sockeye salmon were primarily found in the inner Bristol Bay waters and age-0 pollock were restricted to the middle domain of the EBS The abundance of age-0 Pacific cod fluctuated throughout the six year period with a relatively high number caught in 2005 and again in 2006 (Farley et al. 2008).

Benthic foraging epibenthic invertebrates are likely competitors with juvenile and adult king, Tanner and snow crab for food. Examination of epibenthic invertebrate catches from the AFSC EBS bottom trawl survey 1982-2002 found distinct inshore and offshore communities that are separated by an oceanographic front occurring at the 50 m isobath. The biomass of the inshore community is dominated by seastars and the offshore community is dominated by snails, hermit crabs and snow crab (Yeung and McConnaughey 2006). Variations in this inshore and offshore community structure occur with a reduction in the spatial extent of the inshore community when mean bottom temperatures in the survey area were higher than normal the preceding summer. During these events, epibenthic invertebrates such as red king crab in Bristol Bay shifted from inshore communities to either offshore or undefined communities (Yeung and McConnaughey 2006). Yeung and McConnaughey (2006) concluded that epibenthic communities in the EBS may be rearranged by mobile epibenthic invertebrates, primarily crabs, migrating offshore toward cooler water in warm years.

Benthic foragers such as flatfish, skates, and other invertebrates including crab species may compete with juvenile and adult crab for food. Juvenile flatfish including rock sole (*Lepidopsetta* spp*.)*, yellowfin sole *(Limanda aspera*), Pacific halibut (*Hippoglossus stenolepis)* and flathead sole (*Hippoglossoides elassodon*) consume polychaetes, bivalves, snails, and crustaceans (Holladay and Norcross 1995). Adult flatfish and skates consume benthic prey such as snails, clams, shrimp, crabs, fish, brittlestars, and polychaetes (Yang 2003). Refer to the *Predation by Groundfish, Marine Mammals and Seabirds* section for population trends as these species are both competitors and predators of crabs.

Predation by Groundfish, Marine Mammals and Seabirds

During each life history stage, from the pelagic larvae to benthic adults, crab are consumed by different predators contributing in part to the natural mortality of these species. Other factors contributing to natural mortality in crab is discussed in the *Physical and Biological Environmental Impacts on Crab Biology* below. For king crab, numerous planktivorous fishes prey on Paralithodid larvae (Livingston et al. 1993; Wespestad et al. 1994). The size of Paralithodid prey in yellowfin sole and walleye pollock stomachs indicates they feed on larval and very early juvenile king crab (Livingston et al. 1993). Juvenile king crab may fall prey to Arrowtooth flounder (*Atheresthes stomias*), Irish lords (*Hemilepidotus* sp), snailfish (*Liparis* sp.), and octopus (*Enteroctopus dofleini*) (Livingston and Goiney 1983) but as the crab grow larger, they begin to exceed the mouth gape of many of these predators (NPFMC 2003). Juvenile RKC experienced mortality due to cannibalism by older RKC in laboratory experiments (Stevens and Swiney 2005). However, juvenile king crab are usually found in shallow, nearshore waters (RKC, and BKC) or deepwater canyons (GKC) and outside of the annual bottom trawl survey area where a majority of the stomach samples are collected for food habits analysis.

A high number of early juvenile Tanner and snow crab age 0 to age 1 are consumed by Pacific cod (Lang et al. 2005). It was estimated that cod removed up to 94% of age 1 Tanner crab and up to 57% of snow crab in the Bering Sea in a single year (Livingston 1989). Other groundfish species such as; Alaska plaice (*Pleuronectes quadrituberculatus*), Arrowtooth flounder, flathead sole, northern rock sole (*Lepidopsetta polyxystra*), Pacific halibut, and yellowfin sole, also consume juvenile snow and Tanner crab, based on stomach contents data (Lang et al. 2003). Tanner crab were observed as a small percentage in the diet of Big skates (*Raja binoculata*), Aleutian skates (*Bathyraja aleutica*), Bering skate (*Bathyraja interrupta*) and Alaska skates (*Bathyraja parmifera*) collected on the AFSC Aleutian Island bottom trawl survey in 1994, 1997, 2000 and 2002 (Yang 2007).

Pacific cod and large sculpins prey on adult king, Tanner and snow crab (NPFMC 2003, Aydin 2007) but adult crab are relatively invulnerable to predation except after molting when they are in a soft shell state (Blau 1986; Livingston 1989, Loher et al. 1998). Because molting typically occurs in the spring and stomach samples are collected during the summer EBS and AI surveys, records of predation on adult crab occur infrequently in the Alaska Fisheries Science Center's (AFSC) food habits database.

Records of predation on golden and blue king crab are also rare. The Resource Ecology and Ecosystem Modeling Program at AFSC collected stomachs on the EBS bottom trawl survey from over 100 species, yet BKC were found only in Pacific cod, walleye pollock and yellowfin sole stomachs. From 1981 to 2005, 5 Pacific cod, 27 walleye pollock and 8 yellowfin sole contained BKC prey from a total of 13,831 stomach samples with Pacific cod having the largest amount of BKC by weight (AFSC, REEM food habits database). One golden king crab was found in a white-blotched skate (*Bathyraja maculata*) stomach from the 612 samples collected from along the Kuril Islands and southeast Kamchatka during 1996 (Orlov 1998). Simenstad et al. (1977) assessed the AI marine food web in the vicinity of Amchitka Island and reported 6 instances of GKC and RKC in 69 halibut stomachs examined from inshore areas.

Coincident with the decline of Pribilof Islands blue king crab in the early 1980s, the abundance of Pacific cod and flatfish species increased dramatically in the late 1970s and early 1980s and has generally been high ever since; the influx of rock sole in the Pribilof Islands area has been particularly high (NPFMC 2003). A cause and effect relationship between the decline in BKC stock and the increase in the stocks of groundfish that are predators of and competitors with king crab remains speculative. Time series analysis of BKC year classes compared with Pacific cod, yellowfin sole, and rockfish (*Sebastes* spp.) year classes have not revealed any correlation between groundfish predation or competition and the decline in BKC stocks. Increases in Pacific cod and yellowfin sole biomass was associated with lower RKC recruitment (Zheng and Kruse 2000; Zheng and Kruse 2006). Correlations between Pacific cod biomass and Bristol Bay RKC recruitment with recruitment time lags from ages 0 to 3 and yellowfin sole biomass with recruitment time lags from ages 0 to 2 were statistically significant (Zheng and Kruse 2006). The spatial distribution of yellowfin sole and Bristol Bay RKC overlap in the southeastern section of Bristol Bay and this area of overlap has not changed substantially over time.

As benthic foragers, Arctic ice seals, such as bearded seals (*Erignathus barbatus*) and ribbon seals (*Phoca fasciata*), could be both competitors as well as predators of snow crab. Bearded seals are primarily found on ice floes in circumpolar arctic and subarctic waters migrating as far south as 57°N with the advancing ice edge in the spring. Ribbon seal stayed in the ice-free waters out towards the shelf break in the late spring and summer, after the ice edge begins to retreat (Cameron and Boveng 2009; Cameron et al. 2009). Bearded seals feed at depths less than 200 m with a diet composed of shrimp, crabs, clams and gastropods such as whelks while ribbon seals primarily eat groundfish, shrimp and some crustacean species (Lowry et al. 1980; Cameron et al. 2009).

The short-tailed shearwater (*Puffinus tenuirostris*) represents a major portion of the marine bird biomass in the southeastern Bering Sea. In the late 1990s the bird's diet was examined after a rapid decline of the species in the southeastern Bering Sea. The expected prey species, euphausiids (*Thysanoessa raschii),* was not predominant after 1997. The birds were feeding primarily on Pacific sandlance in the summer as well as crab zoea and copepods in the inner domain of the EBS (Hunt et al 2002).

Predator Population Trends

Estimates from EBS bottom trawl surveys show a steady increase in Pacific cod biomass from the late 1970s through the mid 1980s, fluctuating from 1988 through 1994 (peak observed) then steadily declining with the 2008 estimate of 403,125 metric tons being the lowest on record (Thompson et al. 2009). Although recent biomass estimates of Pacific cod have been declining, there has been an increase in the number of smaller sized fish, suggesting the emergence of a strong year class (Acuna and Lauth 2008). Yellowfin sole biomass was at low levels during most of the 1960s and early 1970s after a period of high exploitation then increased and peaked in 1984. Although the biomass has been in slow decline, it has remained stable in recent years (Wilderbuer et al. 2009). The abundance of EBS pollock remained at a fairly high level from 1982 through 1988. The stock is characterized by peaks in the mid 1980s and mid 1990s with a substantial decline by 1991 and the lowest point occurring at present. The stock has continued to decline substantially since 2003 due to apparently poor recruitment between 2000 and 2005 although the 2006 and 2008 year classes showed positive signs of recruitment (Ianelli et al. 2009). Biomass estimates of EBS skate species have not been reported with the exception of Alaska skate, which is the dominant skate on the EBS shelf between the 50 and 200 m isobaths (Stevenson 2004). Alaska skate biomass fluctuated from 1982 through 1986, increased from 1986 through 1990 (peak), decreased from 1991 through 1999, and demonstrated an increasing trend from 353 thousand t in 1999 to 480 thousand t in 2007, followed by a dramatic decrease to 362 thousand t in 2008 (Ormseth et al. 2009) (Fig. 7). Other skate species found in the EBS have no reliable estimates of biomass due to lack of survey data and are managed using average catch data.

Abundance trends of Pacific halibut showed an increase in biomass from 1982 through 1988 with a decrease in 1989. An upward trend with some fluctuation was observed through 2001 followed by a decrease in 2002. Low commercial and survey catch rates from the International Pacific Halibut Commission support a general decline in abundance estimates of Pacific halibut in the eastern Bering Sea (Clarke and Hare 2008). In 2006-2007, the under-40 cm halibut size class dominated the overall catch, but in 2008, the 40-79 cm size class regained that position (Sadorus and Lauth 2009).

Early biomass estimates of bearded seal in the EBS and Chukchi Sea ranged from 250,000 to 300,000 animals. Surveys flown from Shishmaref to Barrow, Alaska, during May-June 1999 and 2000 provided preliminary results indicating densities up to 0.652 seals km^2. These densities cannot be converted into an abundance estimate, however, without information on the proportion of the population hauled out during the survey (Cameron and Boveng 2009). Surveys conducted in the 1970s estimated the Bering Sea population of ribbon seals between 60,000 to 100,000 animals. More recent population estimates are not currently available.

Physical and Biological Environmental Impacts on Crab Biology

Recruitment of King and Tanner Crab

Recruitment trends for RKC in Alaska may be partly related to decadal shifts in climate and physical oceanography. Strong year classes for eastern Bering Sea RKC were observed when temperatures were low and weak year classes occurred when temperatures were high, but temperature alone cannot explain year class strength trends for RKC (Zheng and Kruse 2000). In Bristol Bay, there is a relationship between RKC brood strength and the intensity of the Aleutian Low atmospheric pressure systems; during low pressure the brood strength is reduced (Tyler and Kruse 1996; Zheng and Kruse 2000). Gish (2006) suggested that the lack of king crab recruitment in the Pribilof Islands area may be the result of a large-scale environmental event affecting abundance and distribution.

The spatial distribution of mature females prior to larval release and locations of crab larvae settlement appear to be important for the recruitment success of crab in the EBS (Zheng and Kruse 2006). Both of these life history stages are affected by changes in the pelagic and benthic environment of the BSAI ecosystem. Bottom water temperatures may be important in structuring the distribution of ovigerous RKC (Loher and Armstrong 2005; Chilton et al. *in review*). Female RKC were found primarily in central Bristol Bay during 1980-1987 and 1992-2006 (Zheng and Kruse 2006). The distribution centers of mature females moved south slightly during 1988-1991 but did not reach the southern locations previously occupied in the 1970s. Distribution of ovigerous RKC in the southeastern Bering Sea shifted from the eastern edge of Bristol Bay to the northeast, central shelf area during the late 1970s and early 1980s and this distribution change coincided with increased early summer bottom temperatures (Loher and Armstrong 2005). When the cold pool extended onto the Bristol Bay shelf area in 2006-2009, the summer distribution of ovigerous RKC had moved from the central area of Bristol Bay to the nearshore areas along the Alaska Peninsula (Chilton et al. *in review*).

Strong year classes of Bristol Bay Tanner crabs are associated with warm seawater temperatures during gonadal development and embryo incubation along with northeast winds during the larval stages

(Rosenkranz et al. 2001). Northeast winds may promote upwelling providing Tanner crab larvae with food while advecting larvae to regions of preferred settling habitat (Rosenkranz et al. 1998; Rosenkranz et al. 2001).

Recruitment of king, Tanner and snow crab may be affected by ocean acidification because acidified waters can impact the development (Findlay et al. 2009, Parker et al. 2009), development time (Findlay et al. 2009), viability (Kurihara et al. 2004a), and even behavior (Ellis et al. 2009) of the embryos of marine invertebrates (though see Arnold et al. 2009). Further, acidified waters can reduce fertilization success (Parker et al. 2009), the hatching success of embryos (Kurihara et al. 2004a), and the fecundity of females (Kurihara et al. 2004b). However, no experiments examining the effects of ocean acidification specifically on crab reproduction or recruitment have been published.

Growth

Changes in both the physical and biological environment of the BSAI ecosystem utilized by crab species may have an effect on the individual growth of commercial crab species. Several studies have examined the direct effect of changing temperatures on the length of intermolt periods in juvenile Tanner crab and GKC (Paul and Paul 1996; Paul and Paul 2001a; Paul and Paul 2001b). Growth of juvenile RKC from Bristol Bay was found to be slower than that of juvenile RKC collected from Unalaska and Kodiak Island in the Gulf of Alaska (Loher and Armstrong 2000). One hypothesis for the protracted juvenile phase in Bristol Bay was related to water temperatures differences. Colder bottom temperatures in Norton Sound have been associated with the smaller size at maturity observed in RKC when compared to the Pribilof Islands and Bristol Bay RKC stocks (Blau 1990; Otto et al. 1990).

The potential of human induced ocean acidification could have drastic effects on the growth and reproduction of crab and other crustacean populations. Decreased carbonate ion concentration hinders the formation of shells and support structures by some calcifying organisms (Caldeira and Wickett 2003; Feely et al. 2004; Orr et al. 2005; Ries et al. 2009); however, some crustaceans seem to increase calcification rates under decreased pH conditions (Ries et al. 2009). The effects of ocean acidification on growth and calcification rates of juvenile and adult king and Tanner crab is currently being investigated.

Maturity

Causes for differences in size of maturity have not been well studied for EBS crab species, but are often attributed to temperature or oceanographic processes. Female snow crab in the EBS can reach maturity at four different instars and they reach size at maturity at smaller sizes at high latitudes in colder water and larger sizes at warmer low latitudes (Orensanz et al. 2007). Otto et al. (1990) found that among red king crab stocks, female size of maturity was lowest for Norton Sound, the northernmost stock studied, which may suggest that size of maturity is inversely correlated with latitude and therefore temperature. However, the Pribilof Islands and Bristol Bay are located at approximately the same latitude, the Pribilof Islands are slightly colder, but the female size of maturity is lower for Bristol Bay red king crab than Pribilof Islands crab (Otto et al. 1990). Furthermore, size of maturity among red king crab females is nearly identical for Bristol Bay and Adak stocks, but Adak is south of Bristol Bay and is warmer. Size at maturity for male and female EBS golden king crab decreases with increasing latitude which may be due to temperature differences resulting in a decrease in growth rate in colder water (Somerton and Otto 1986). Size at maturity of male and female golden king crab is lower at Bowers Ridge than Seguam Pass, two areas that occur over a narrow range of latitude with similar temperatures (Otto and Cummiskey 1985). Oceanographic processes may account for differences in maturity between these areas. Seguam Pass is characterized by strong currents and turbulent mixing of North Pacific and Bering Sea waters and may be more productive than Bowers Ridge which is characterized by gentle currents (Otto and Cummiskey 1985).

Natural Mortality

Several factors may influence the natural mortality of commercial crab stocks other than senescence. Predation on commercial crab stocks or mortality due to disease should also be considered, particularly when those factors are also influenced by the same physical and biological environment of the BSAI ecosystem utilized by crab species. Crab predation has been addressed in the *Predation by Groundfish, Marine Mammals, and Seabirds* section of this document while the effects of disease and parasitism on crab mortality are discussed here.

Mortalities are an obvious end-point of disease and parasitism, but these factors may affect individuals by less obvious means. Disease and parasitism may reduce growth rates and/or fecundity. Reproductive capability may be affected at several levels; failure of the ovary to develop or mature completely, and loss or failure of embryos to develop to hatching. Currently, several diseases and/or parasites are known to affect North Pacific crabs at all levels.

Potentially fatal diseases that may affect *Paralithodes* spp. *and Lithodes aequispinus* populations include a herpes-like viral disease of the bladder and antennal gland (Sparks and Morado 1986, Bower et al. 1994), a pansporoblastic microsporidian (*Thelohania* sp.) which infects the hepatopancreas, ovary and muscle tissue, and produces a cottage cheese appearance in the abdominal cavity (Morado 2010), and a parasitic barnacle or rhizocephalan (*Briarosaccus* sp.) (Sparks and Morado 1986; Hawkes et al. 1985). Symbiotic snailfish, *Careproctus* spp., deposit eggs into golden king crab gill chambers which interferes with respiration by compressing the gills, causing necrosis, and may lead to mortality (Somerton and Donaldson 1998). Otto et al. (1990) found three of 243 Bristol Bay RKC egg clutches containing nemertian worms, which are known predators of embryos. Although the amphipod *Ischyrocerus* sp. feeds on the eggs of king crab and could have a significant impact on fecundity they are usually never abundant enough to be a major predator (Kuris et al. 1991).

Bitter crab syndrome (BCS) in Tanner and snow crab is a fatal disease caused by a parasitic dinoflagellate of the genus *Hematodinium*, which infects the hemolymph (Meyers et al. 1987) and is widely distributed throughout the North Pacific (Meyers et al. 1996). The meat of crab infected with *Hematodinium* is not a public health concern but has a chalky texture and bitter taste, and is not marketable (Taylor and Khan 1995). Heavily infected crabs may be identified by the opaque, white appearance of the ventral side of the abdomen and legs, and the milky white color of the hemolymph. The AFSC Fisheries Resources Pathobiology group has been monitoring BCS since 1988, detecting BCS in EBS Tanner and snow crab for more than 20 years with no clear trends in prevalence. The overall occurrence of BCS in snow crab has been about 3.5% with a low of less than 1% to a high of over 20% in 2003 since monitoring began. Tanner and snow crab stock recruitment may be affected as BCS is more common in crab less than 50 mm and is present throughout much of their distribution range. Recent collections and analysis suggest that only one species of *Hematodinium* infects both North Pacific snow and Tanner crabs (Jensen 2010) although the frequency and distribution of occurrence in the two crab species suggest otherwise (Morado et al. 2000). The long-term effect of this syndrome on affected crab populations is only now being investigated. The disease is more prevalent in the western Bering Sea Tanner crab stock than in the eastern stock (stocks divide by longitude 166°W). Siddeek et al. (2010) determined recovery of the western stock would be delayed by 2-3 years because of BCS when compared to the eastern stock. However, this delay was negligible when compared to the impact of the disease on the Stephens Passage, southeast Alaska Tanner crab stock which under any scenario would not recover under either a medium and long-term recovery plan.

Another disease detected in EBS Tanner crab is black mat syndrome; a systemic fungal infection caused by *Trichomaris invadens*, which penetrates the carapace and affects the epidermis and muscle (Sparks and Hibbits 1979). It has only been observed in *C. bairdi* and seldom encountered in the Bering Sea, thus it is not considered an issue of concern in the EBS (pers comm. F. Morado, NOAA Fisheries).

Current Status of Ecosystem Indicators in 2008/2009

Purpose

The purpose of this section is to present current physical and biological environmental data within the BSAI ecosystem utilized by crab species and examine the trophodynamic interactions between crab and lower/upper trophic levels using information from the most recent publications or survey and research data. Current ecosystem oriented research projects and future research priorities for BSAI crab stocks are also presented here. A potential outcome of the CECI as the document develops is to identify key ecosystem status indicators and related research studies.

Physical Environment of the BSAI Ecosystem in 2008/2009

North Pacific Climate

A weak Aleutian low and relatively cool sea surface temperatures (SST) in the fall of 2008 contributed to a cold winter in the Bering Sea and extensive sea ice conditions persisted into the spring of 2009 with a prominent cold pool (< 2°C) residing on the middle shelf well into the summer (Bond and Overland 2009). The SST in the Aleutian Islands in the fall of 2008 was relatively warm compared to seasonal norms, then cooled to near normal temperatures by the summer of 2009. Southern wind anomalies prevailed throughout much of the winter of 2008/2009 in the western Aleutians followed by northern wind anomalies in the summer of 2009 compared to southeastern wind anomalies occurring for most of the winter and spring of 2009 in the eastern Aleutians. This difference in prevailing wind direction resulted in suppressed storm activity in the eastern Aleutians and along the Alaska Peninsula (Bond and Overland 2009).

Sea Ice Cover and EBS Climate

Both air and water temperatures in 2008/2009 contributed to an extensive sea ice coverage in 2009 persisting into late spring. The Bering Sea climate conditions are driven by local and North Pacific processes throughout the winter into spring, which are uncoupled from the warming trends and sea ice loss observed in the Arctic. The last four years, 2006-2009, have been the coldest average surface air temperatures on St. Paul Island since pre-1978 conditions. Moderate El Nino conditions have been developing, resulting in a slight warming of the water temperatures in the Bering Sea with less sea ice coverage expected in 2010 (Overland et al. 2009).

Summer Bottom and Surface Temperatures in the eastern Bering Sea

Bottom temperatures measured during the 2009 EBS trawl survey ranged from -1.7° to 6.3°C (Fig. 8a) while sea surface temperatures ranged from 1.1°C to 7.3°C (Fig. 8b). These temperatures were collected at 20 nmi intervals as the survey progressed from east to west, beginning on 2 June 2009 in the northeast corner of Bristol Bay and moving westward towards the shelf edge finishing on 19 July 2009. A cold pool of water < 2°C was prevalent between the 50 m and 100 m isobaths in the middle shelf and Bristol Bay area with cool temperatures persisting at the nearshore stations along the Alaska Peninsula. Warmer bottom temperatures were evident at the shelf break in the southwestern section of the survey area and in shallow water areas near Nunivak Island, while cold water temperatures persisted in the northwestern area between the 100 m and 200 m isobaths and the waters surrounding St. Matthew Island. Sea surface temperatures followed a similar pattern although colder temperatures were seen in Bristol Bay, along the southeastern Alaska Peninsula and the inner shelf of the EBS. Sea surface temperatures increased with increasing depths on the shelf but could be an artifact of the sample design where outer shelf stations were sampled later in the summer.

Summer Bottom and Surface Temperatures in Norton Sound and Aleutian Islands

Average bottom water temperatures collected on the Norton Sound trawl survey in late summer have fluctuated between 9.0 °C to 5.6 °C over the last two decades, with an average of 7.1°C bottom water temperature in 2008 (Hamazaki et al. 2006; Soong 2008). Data published from the most recent AI bottom trawl survey (2006) are detailed above in the **Ecosystem Assessment**, *Benthic Habitat* section of this document.

Biological Environment of the BSAI Ecosystem

Status of BSAI Epifaunal Prey and Competitors in 2009

The 2009 total demersal biomass of the eastern Bering Sea estimated from the annual EBS bottom trawl survey was 12.1 million mt, with benthic invertebrates representing 28% (3.3 million t) and composed primarily of echinoderms such as sea stars, sea urchins, and sea cucumbers at 1.5 million t (Lauth 2010).

The catch of forage species (gunnels, stichaeids, sandfish, smelts, lanternfish, sandlance) in the BSAI decreased in 2008-2009 and was comprised mainly of eulachon that was caught primarily in the pollock fishery (Gaichas and Bolt 2009). The 2008-2009 age-0 pollock year classes estimated from the EBS bottom trawl survey at 440 and 701 million fish respectively, decreased significantly compared to the 2007 estimate of 1,665 million fish (SAFE: Ianelli et al. 2009). The 2008-2009 year class of age-0 Pacific cod has been estimated to be a large year class by the Pacific cod stock assessment model, although the year class has only been observed once and the estimate is bounded by large confidence intervals (SAFE: Grant et al. 2009). Current abundance estimates of competitors, such as flatfish and skate species, are detailed in the *Current Status of Crab Predators* section.

Status of Crab Predators in 2009

The current biomass and abundance estimates for a group of likely crab predators common on the eastern Bering Sea shelf are reported by Lauth (2010) for the 2009 EBS bottom trawl survey, and are summarized in the next paragraph. The overall trend in crab predator abundance in the EBS appears to be decreasing although an increase in the number of smaller sized Pacific cod could point to an increased predation of juvenile crab.

The 2009 biomass estimate of 0.42 million t for Pacific cod has not increased relative to 2008, however the abundance estimate of 717 million fish increased by 47% due to an increase in the number of younger year classes. The total biomass and abundance of walleye pollock for the entire survey area in 2009 was 2.28 million t and 3.46 billion fish, which was 25% lower than the 2008 biomass estimate of 3.03 million t. Yellowfin sole biomass decreased from 2.1 million t in 2008 to 1.7 million t in 2009 and the population size also decreased slightly from 8.9 billion to 8.4 billion. Estimated biomass of northern and southern rock sole (*L. bilineata*) decreased by 24% from 2008 to 1.74 million t in 2009. Estimated population numbers decreased by 22%, to 8.2 billion, over this same period. Estimates of both biomass and population size for Arrowtooth flounder decreased from 2008 to 2009; biomass decreased from 0.53 million to 0.41 million t and population from 1.2 billion to 0.9 billion. Estimated biomass for the Bering skate increased from 10 thousand t in 2008 to 13.2 thousand t in 2009 and estimated population size also increased over this period from 6.6 million skates to 10.2 million.

The estimated biomass of Alaska skate decreased slightly from 362 thousand t in 2008 to 351 thousand t in 2009, while estimated population size increased slightly from 116 million to 119 million for this same period. Biomass estimates for other skate species in the BSAI region are not available (SAFE: Ormseth et al 2009).

The biomass estimate for Pacific halibut in the eastern Bering Sea was just over 130 million t in 2009. Total abundance as estimated by the trawl survey in 2009 was just over 102 million halibut. Abundance has been decreasing since achieving a record high of 134 million fish in 2006, but is still well above the values seen in the past 20 years (Sadorus and Lauth 2009).

Current Crab Ecosystem Research and Future Priorities

This section of the CECI provides an opportunity to highlight current ecosystem oriented crab research such as funded proposals without published results or recent presentations at scientific meetings as well as identify gaps in the data and future research priorities.

The Crab Plan Team creates a list of crab specific research priorities on an annual basis that is forwarded to the North Pacific Fishery Management Council (NPFMC) for inclusion into a larger document. Several of these priorities have evolved into research projects funded by various entities including but not limited to AFSC and NMFS, the North Pacific Research Board (NPRB), the University of Alaska and other Universities. Crab specific research priorities are also developed at the annual December Interagency Crab Meeting (IACM) held in Anchorage where a diverse number of research biologists from ADF&G, University of Alaska Fairbanks, University of Alaska Southeast, and AFSC present data from current projects and discuss potential collaborations (Webb and Woodby 2008). Currently, a number of crab ecosystem projects are being pursued which have developed from the research priorities discussed at these meetings.

Research topics discussed at the September 2009 CPT meeting were incorporated into the NPFMC five-year research priorities for 2010-2014 (adopted October 2009) and are listed below.

- Develop quantitative female reproductive indices to incorporate into stock assessment process particularity with respect to EBS snow and Tanner crab and Bristol Bay RKC

- Investigate current natural mortality estimators and develop longevity-based estimators based on maximum age or using tag-recapture methods

- Identify life history bottlenecks with respect to depleted stocks and lack of recovery despite rebuilding plans

- Identify as well as assess productivity trends which may impact crab stock recruitment

Ecosystem-based Management Indicators

<u>Purpose</u>

This section of the CECI provides early signals of direct human effects on BSAI crab ecosystem components via directed fishery affects on the ecosystem and summarizes current management actions such as; management efforts in response to directed fishery effects on BSAI habitat, and spatial and temporal removals of the target catch affecting other biological predators. In this section, we also review potential fishery effects on crab life history stages such as removal of legal sized males, age at maturity and reproduction.

<u>Fishery-Specific Impacts on the Physical Environment</u>

Effects of Fishing Gear on Seafloor Habitat

In the BSAI crab fisheries Final Environmental Impact Statement (EIS), the impact of pot gear on benthic EBS species is discussed (NMFS 2004). Benthic species examined included fish, gastropods, coral, echinoderms (sea stars and sea urchins), non-target crab, and invertebrates (sponges, octopuses, anemones, tunicates, bryozoans, and hydroids). It is likely that habitat is affected during both setting and retrieval of pots, but little research has been done. Physical damage to the habitat by pot gear depends on habitat type. Sand and soft sediments where the majority of EBS crab pot fishing occurs are less likely to be impacted, whereas coral, sponge, and gorgonian habitats are more likely to be damaged by commercial crab pots in the AI GKC fishery (Quandt 1999, NMFS 2004). The total portion of the EBS impacted by commercial pot fishing may be less than 1% of the shelf area (NMFS 2004). The report concludes that BSAI crab fisheries have an insignificant effect on benthic habitat. Considering that bycatch species impacted by commercial crab fisheries are widespread across the EBS shelf, the impacts of pot gear on benthic populations should be minimal.

Management Enacted Efforts

Habitat protection areas, prohibited species caps (PSC) and crab bycatch limits are in place to protect important benthic habitat for crab and other resources and reduce crab bycatch in the trawl and fixed gear fisheries. Beginning in 1995, the Pribilof Islands Conservation Area was closed to all trawling and dredging year-round to protect BKC habitat (NPFMC 1994). Also beginning in 1995, the Red King Crab Savings Area was established as a year-round bottom trawl and dredge closure area (NPFMC 1995). This area was known to have high densities of adult red king crab, and closure of the area greatly reduced bycatch of this species. The Red King Crab Savings Subarea is a portion of the Red King Crab Savings Area between 56° 00’ and 56° 10’ N lat. Within this Subarea, non-pelagic trawl gear may be used if GHLs were established for a Bristol Bay RKC fishery the previous year. The RKC bycatch limit will be established by NMFS after consultation with the Council and the limit will not exceed an amount equivalent to 25 percent of the RKC PSC allowance (Federal Register 679.21 Prohibited species bycatch management). To protect juvenile RKC and critical rearing habitat (stalked ascidians and other living substrate), another year-round closure to all trawling was implemented in 1996 for the nearshore waters of Bristol Bay. Specifically, the area east of 162° W (i.e., all of Bristol Bay) is closed to trawling and dredging, with the exception of an area bounded by 159° to 160° W and 58° to 58°43' N that remains open to trawling during the period April 1 to June 15 each year (NPFMC 2008, Fig. 9).

The Bering Sea Habitat Conservation Area, Northern Bering Sea Research Area, Nunivak Island, Etolin Strait, and Kuskokwim Bay Habitat Conservation Area, St. Lawrence Island Habitat Conservation Area, and St. Matthew Island Habitat Conservation Area were closed to non-pelagic gear in 2008. These areas include BKC habitat, locations that have not been fished with non-pelagic gear, nearshore bottom habitat that support subsistence marine resources and a research area (Federal Register Vol. 73, No 144, July 25, 2008, Rules and Regulations). A scientific research plan is currently being developed for the Northern Bering Sea Research Area to study the effects of bottom trawling on benthic species and habitat with the goal of providing information to assist in the development of future protection measures for crab, other species and subsistence needs of western Alaska communities (Fig. 10).

PSC limits are in place for RKC, Tanner and snow crab. If PSC limits are reached in predetermined bottom trawl fisheries executed in specific areas (Fig. 9), those fisheries are closed. Snow crab taken within the “Snow Crab Bycatch Limitation Zone” (COBLZ) accrue towards the PSC limits established for individual trawl fisheries. Upon attainment of a snow crab PSC limit apportioned to a particular trawl target fishery, that fishery is prohibited from fishing within the COBLZ. Annual crab bycatch limits (CBLs) are specified for RKC, Tanner and snow crab in the scallop fishery in the Bering Sea, Registration Area Q, and are calculated as a percentage of the most recent abundance estimate of RKC, Tanner and snow crab in Registration Area Q.

Fishery-Specific Impacts on Biological Environment

Directed Fishery Contribution to Competitor and Predator Mortality

The EBS crab fisheries catch a small amount of other species as bycatch. A limited number of groundfish, such as Pacific cod, Pacific halibut, yellowfin sole, and sculpin (*Myoxocephalus* spp.), are caught in the directed pot fishery (Barnard and Burt 2007; Barnard and Burt 2008; Gaeuman 2010). The invertebrate component of bycatch includes echinoderms (stars and sea urchin), snails, non-FMP crab (hermit crabs and lyre crabs), and other invertebrates (sponges, octopus, anemone, and jellyfish). Typically, low levels of bycatch of these species do not impact their abundance (NMFS 2004).

Mortality to fish and non-target invertebrates from ghost fishing of lost crab and groundfish pots in the EBS has not been evaluated. The term ghost fishing describes continued fishing by lost or derelict gear. Crab caught in lost pots may die of starvation; however, the impact of ghost fishing on crab stocks remains unknown. To reduce starvation mortality in lost pots, crab pots have been required to be fitted with degradable escape mechanisms such as cotton thread or twine since 1977. Pots without escape mechanisms could continue to catch and kill crabs for many years. High and Worlund (1979) estimated an effective fishing life of 15 years for king crab pots. The ADFG requires the use of a biodegradable twine panel in each crab pot intended to disable ghost fishing in lost pots after approximately 30 days. Recent work indicates that even biodegradable twine may remain intact for up to 89 days in lost pots (Barnard 2008), or 3 times the length of time (30 days) found to cause irreversible starvation in crabs (Paul et al. 1994). Testimony from crabbers and pot manufacturers indicate that all pots currently fished in Bering Sea crab fisheries contain escape mechanisms (NPFMC 2007).

NMFS conducted Endangered Species Act (ESA) Section 7 Consultations-Biological Assessments on the impact of the Bering Sea and Aleutian Island FMP crab fisheries on marine mammals (NMFS 2000) and on seabirds (NMFS 2002). As noted in the Endangered Species Act EIS report, crab fisheries do not adversely affect ESA listed species, destroy or modify their habitat, or comprise a measurable portion of their diet (NMFS 2004). Although the possibility of strikes of listed seabirds with crab fishing vessels does exist (NMFS 2000), NMFS concluded that available evidence is not sufficient to suggest that these interactions occur in today's fisheries or limit the recovery of seabirds. Of non-listed marine mammals, bearded seals (*Erignathus barbatus*) are the only marine mammal potentially impacted by crab fisheries insofar as crab are a measurable portion of their diet (Lowry et al. 1980; NMFS 2004). For non-listed seabirds, the Alaska Groundfish Fisheries Final Programmatic SEIS (NMFS 2004) provides life history, population biology and foraging ecology for marine birds. The SEIS concluded that crab stocks under the NPFMC fishery management plan (NPFMC 1998) have very limited interaction with non-listed seabirds.

Directed Fishery Contribution to Discards and Offal Production

The EIS for the BSAI crab fisheries summarizes some of the effects of discards and offal production (NMFS 2004). Returning discards, process waste, and the contents of used bait containers to the sea provides energy to scavenging birds and animals that may not otherwise have access to those energy resources. The total offal and discard production as a percentage of the unused detritus already going to the bottom has not been estimated.

Groundfish and Scallop Fisheries By-Catch of Commercial Crab

RKC, Tanner and snow crab, regardless of sex or size, are considered prohibited species in the groundfish and scallop fisheries with an estimated handling mortality of 50% in fixed gear, 80% in trawl gear and 40% dredge gear fisheries. Bottom trawl fisheries in specific areas are closed when PSC limits of RKC, Tanner and snow crab are reached (see *Management Enacted Efforts* section).

Bycatch data of commercial crab species caught in the groundfish fisheries was provided by NMFS, Alaska Regional Office from 1991 through 2010. Over the last two decades Bristol Bay RKC, Tanner and snow crab bycatch in the groundfish fisheries was taken primarily by trawl gear while the majority of St. Matthew BKC and Aleutian Islands GKC bycatch has occurred in the fixed gear fishery and these trends continued in the 2009/2010 groundfish fisheries (Fig. 11). Minor amounts of Pribilof Islands, Norton Sound and Aleutian Islands RKC as well as Pribilof Islands BKC and GKC have been caught in the groundfish trawl fisheries.

The scallop fishery in the Bering Sea (Registration Area Q,) is executed from July 1st through the end of February and closes if harvest guidelines or CBLs are reached. Since 1993, scallop observers have been required on all vessels participating in the fishery and collect biological data from the directed catch and bycatch species. The Bering Sea fishery within Area Q targets scallop beds in 90 to 106 m of water in a small area (13 nmi^2) north of Unimak Island (Rosenkranz 2010). Scallop fishery closures in Area Q resulting from CBLs have decreased in recent years mainly due to lower crab abundances in the EBS (Barnhart and Rosenkranz 2003, Table 2).

<u>Fishery-Specific Impacts on Crab Biology</u>

Directed Fishery Effects of the Target Catch Relative to Predators

The spatial and temporal removal of the target catch, legal sized male crab (Table 1), is dependent on the size of the vessel quota, weather conditions, advancing ice edge, processor demand, and Community Development Quotas (CDQ) deliveries distributed between St. Paul Island and Dutch Harbor, Alaska. Historically, Bristol Bay RKC is fished from late October through early December, and EBS Tanner and snow crab January through April. The St. Matthew Island BKC fishery opened in November of 2009 after a ten year rebuilding plan, although this fishery was historically executed in September and October just prior to the red king fishery. The Norton Sound RKC and Aleutian Islands GKC fisheries are conducted in the summer and fall.

There are few species identified as predators of legal sized male crab and specific information is limited due to the difficulty of identifying prey items to the species level with a partial carapace or dactyl pieces. Based on food habits data collected in the summer months during the annual EBS bottom trawl survey, Pacific cod, Pacific halibut and skates are the primary predators of large or legal size crabs although legal sized crab are a minimal component of these predators diets. Larger sized crabs are most vulnerable to predation just after molting, while still soft and easily ingested by predators.

Directed Fishery Effects on Target Crab, Age-At-Maturity and Reproduction

In the BSAI, minimum size limits for male crabs are established based upon the estimated average size-at-maturity with the intent of allowing males to mate at least once before becoming harvestable. Females are not harvested and fishing seasons are timed to protect the crabs when they are molting and mating (NPFMC 2008). It is possible that male-only fisheries with minimum size limits reduce the abundance of large crabs; however this has not been examined for Bering Sea crab stocks. In Glacier Bay National Park and Preserve, located at the northern end of the southeastern Alaska panhandle, the number and size of legal-sized male Dungeness crabs increased significantly after the closer of the park to commercial fishing. Females and sub-legal males were not targeted by the commercial fishery and these crabs did not increase in size or abundance following the closure of the fishery (Taggart et al. 2004). Commercial fishing in Glacier Bay National Park and Preserve appeared to have altered the size structure of male Dungeness crabs which may also be occurring within EBS crab stocks.

Over time, size-at-maturity may be reduced due to fishing-induced mating selection in male-only fisheries (Zheng 2008). A significant decline in size at 50% maturity of male Bristol Bay Tanner crabs may be the result of genetic responses to the fishery. Fast-growing males may not have an opportunity to mate prior to being harvested in the fishery, whereas slow-growing males may undergo their terminal molt to maturity before reaching the legal size limit and therefore mate (Zheng 2008). Recent analysis of the economic and biological impact of reducing the legal size of Tanner crab in the EBS concluded that a reduction would result in an increase in handling mortality of the terminally molted yet sublegal males. At sea discards would make up a greater proportion of the catch all due to an increase in the terminally molted, sublegal male biomass (Bechtol et al. 2010).

A reduction in the abundance of large males may result in the mating of less fecund males, reduced female mate choice and an increased chance of sperm limitation (Smith and Jamieson 1991; Sato et al. 2005a; Sato et al. 2006; Sato and Goshima 2006; Sainte-Marie et al. 2008). Male size and mating frequency affects reproductive success of many crab species. In general larger males are more successful at mating (production of a fertilized egg clutch) and can successfully mate with multiple females (Paul and Paul 1990; Paul and Paul 1997; Sato et al. 2005b; Sato and Goshima 2006). Based upon manipulation population studies of *Hapalogaster dentate*, a decrease in male size and sex ratio would result in sperm limitation (Sato and Goshima 2006). Laboratory research and field studies in eastern Hokkaido, Japan suggest that sperm limitation could occur in fished populations of *Paralithodes brevipes* (Sato et al. 2005b). Large male snow crab from heavily harvested stocks in the Gulf of St. Lawrence, Canada have small amounts of spermatophores in their vas deferens which is in contrast to higher levels observed in lightly or not fished stocks (Conan and Comeau 1986; Sainte-Marie et al. 1995). In heavily exploited snow crab stocks, a high percent of males may be harvested upon reaching morphometric maturity resulting in an inability of mature males to accumulate a sufficient number of spermatophores necessary to successful mate (Conan and Comeau 1986; Sainte-Marie et al. 1995). In the EBS, female snow crab sperm reserves increase with female size and appear to generally be lower than other snow crab stocks (Slater et al. *in press*). Limited sperm reserve data from EBS snow and Tanner crabs suggest that in 2005 less than one half of primiparous females sampled had sufficient sperm reserves to fertilize a full second clutch of eggs (Gravel and Pengilly 2007). Alternately, in northern California, nearly all molting female Dungeness crabs mate regardless of size despite intense fishing on males (Hankin et al. 1997). The short and long term effects of removing large male crabs from a population is not well understood and may vary by species and population.

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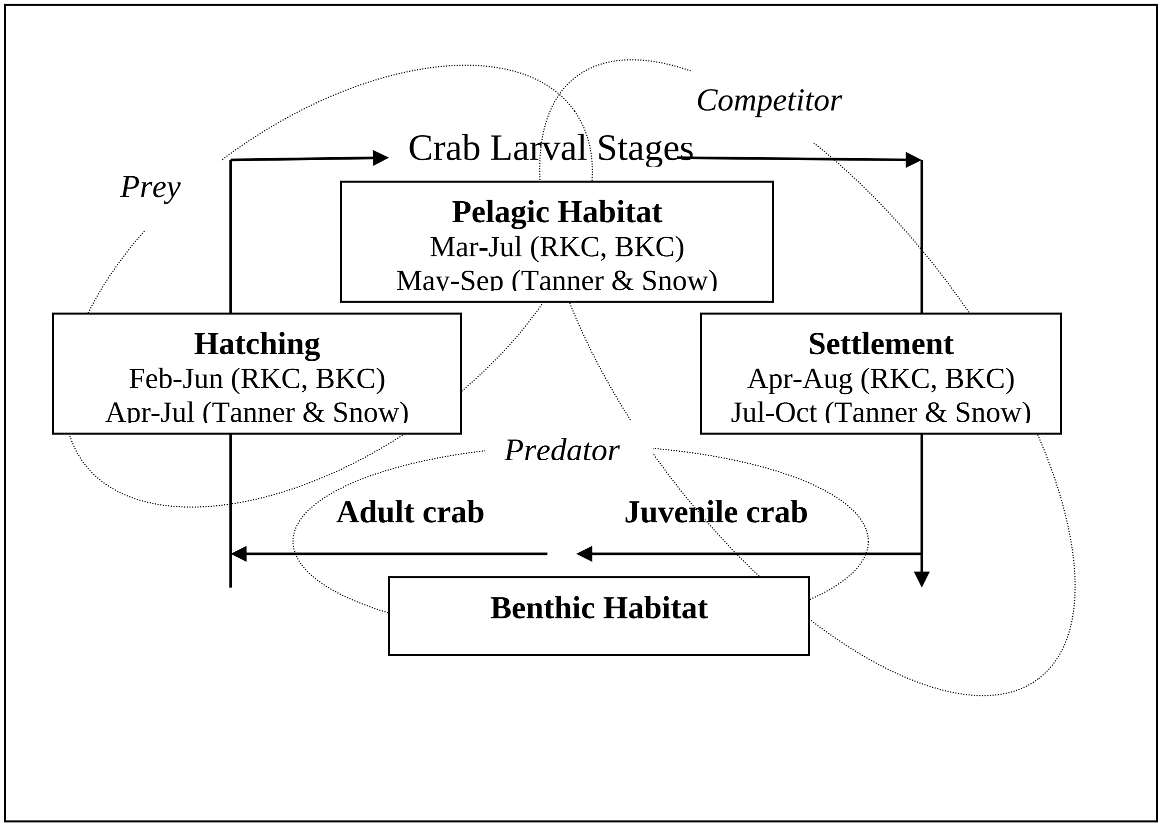

Figure 1. Seasonal timing and duration of crab life history stages in relation to the physical and biological components of the Bering Sea/Aleutian Island ecosystem, red king crab (RKC) and blue king crab (BKC).

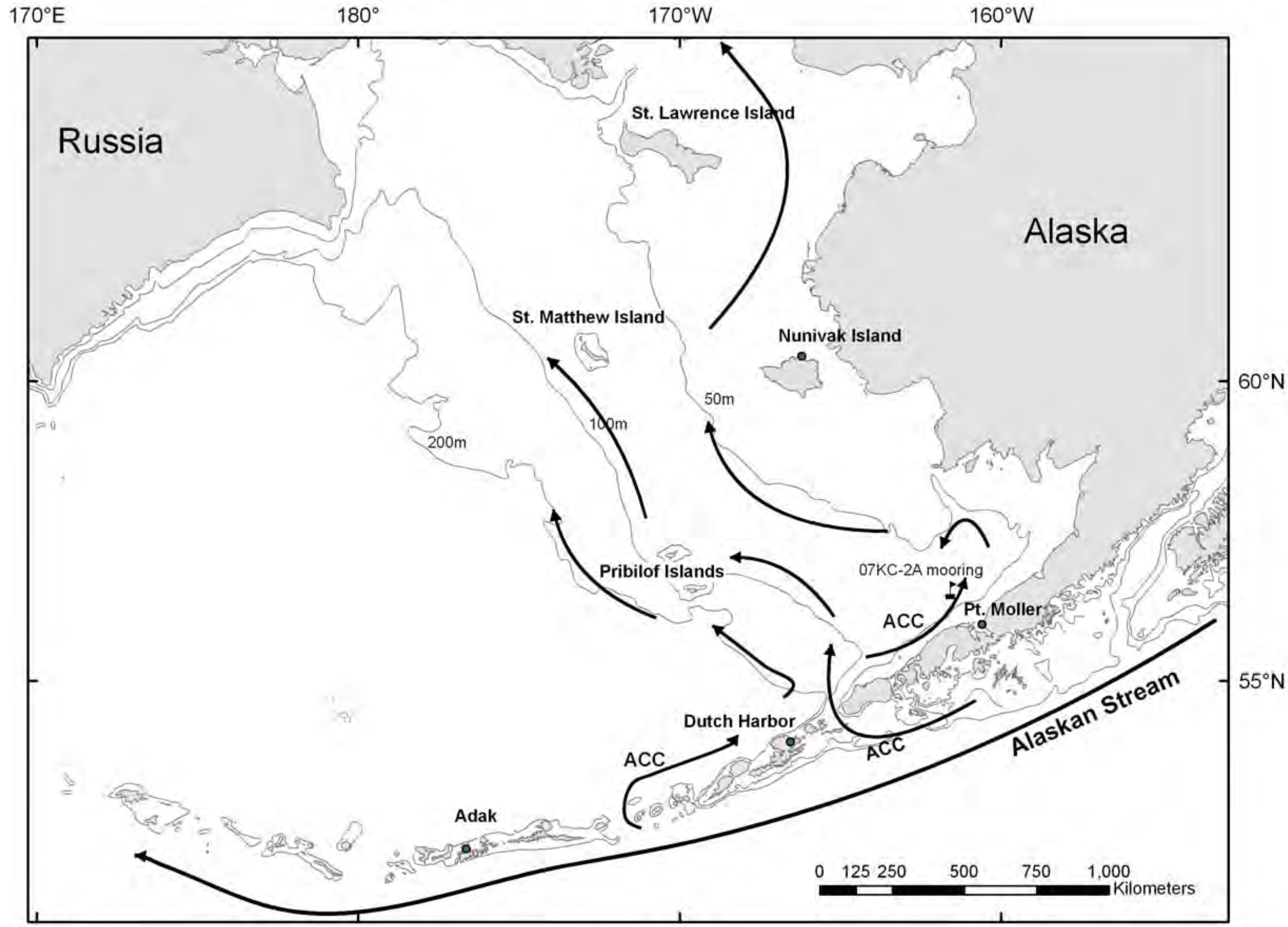

Figure 2. Inner, Middle, and Outer domains on the eastern Bering Sea shelf with King Crab mooring 2A (KC-2A) and major current flow depicted, including the Alaska Coastal Current (ACC) (Current flow adapted from Stabeno et al. 2001).

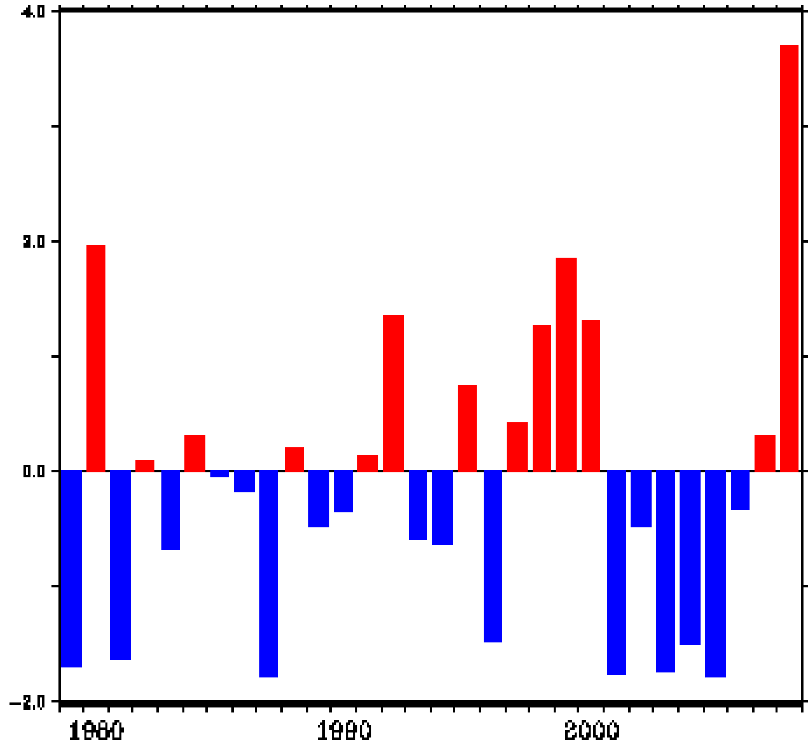

Figure 3. The Ice Cover Index in the eastern Bering Sea as the average ice concentration in a 2-deg x 2-deg box (56-58°N, 163-165°W) from Jan 1 to May 31st in 1978-2008 relative to the 1981-2000 mean of 7.15 (SD = 4.01). (Source: Overland 2008; Bering Climate 2008).

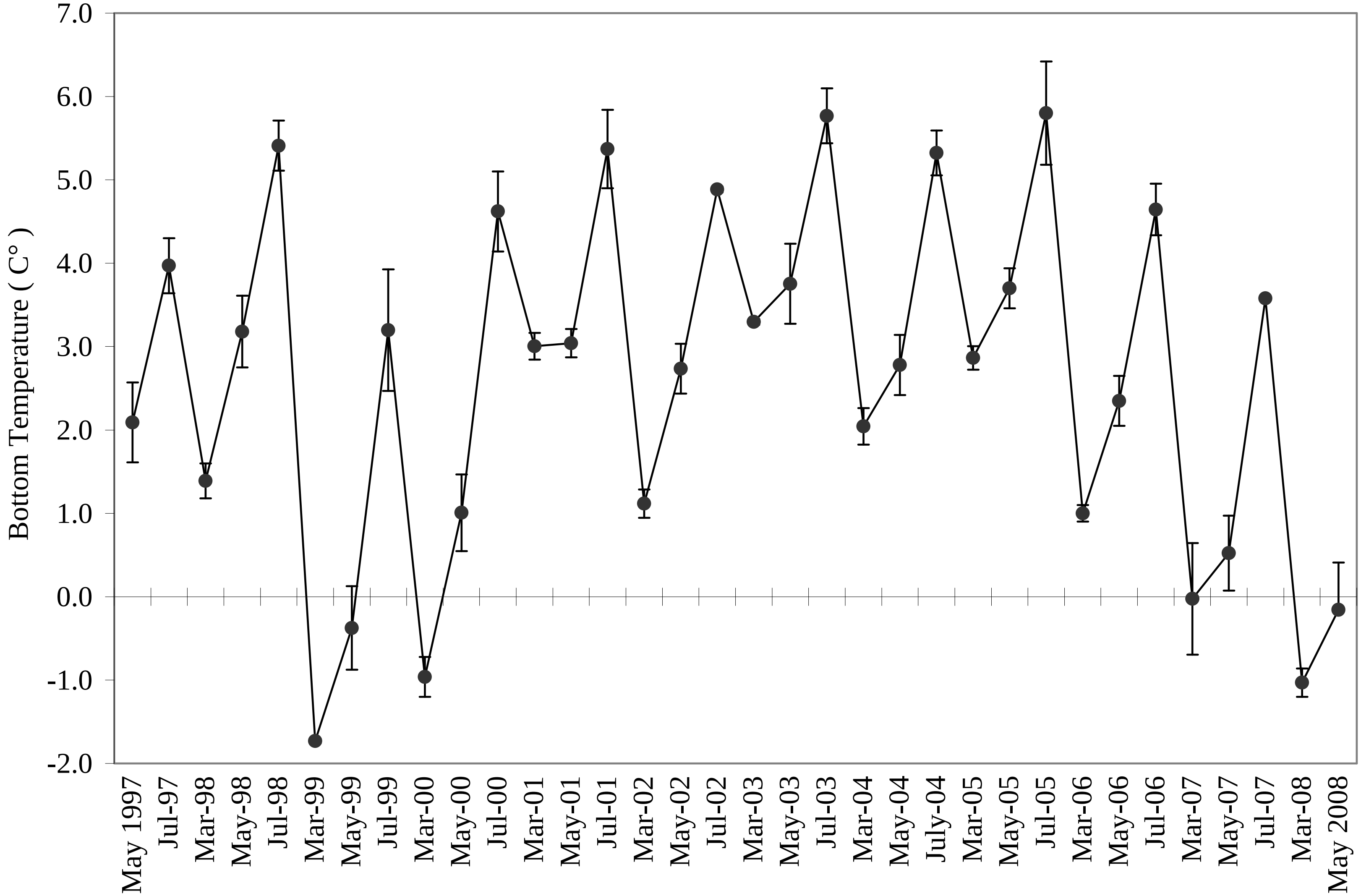

Figure 4. Monthly averaged water temperatures (± SD) at the Bristol Bay mooring M2 (KC-2A) in eastern Bering Sea from May 1997 to May 2008.

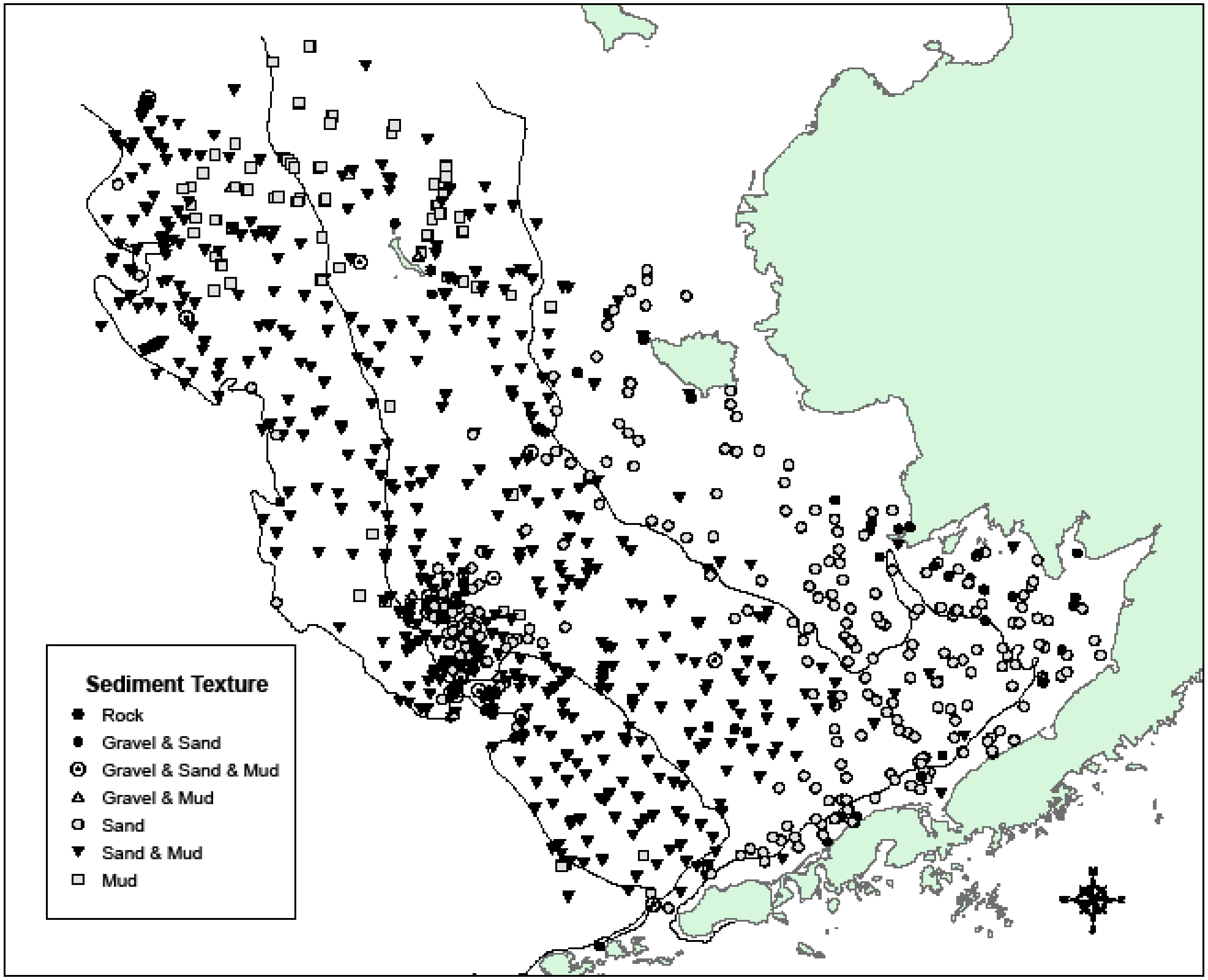

Figure 5. Distribution of benthic sediment types in the eastern Bering Sea (Source: Smith and McConnaughey 1999).

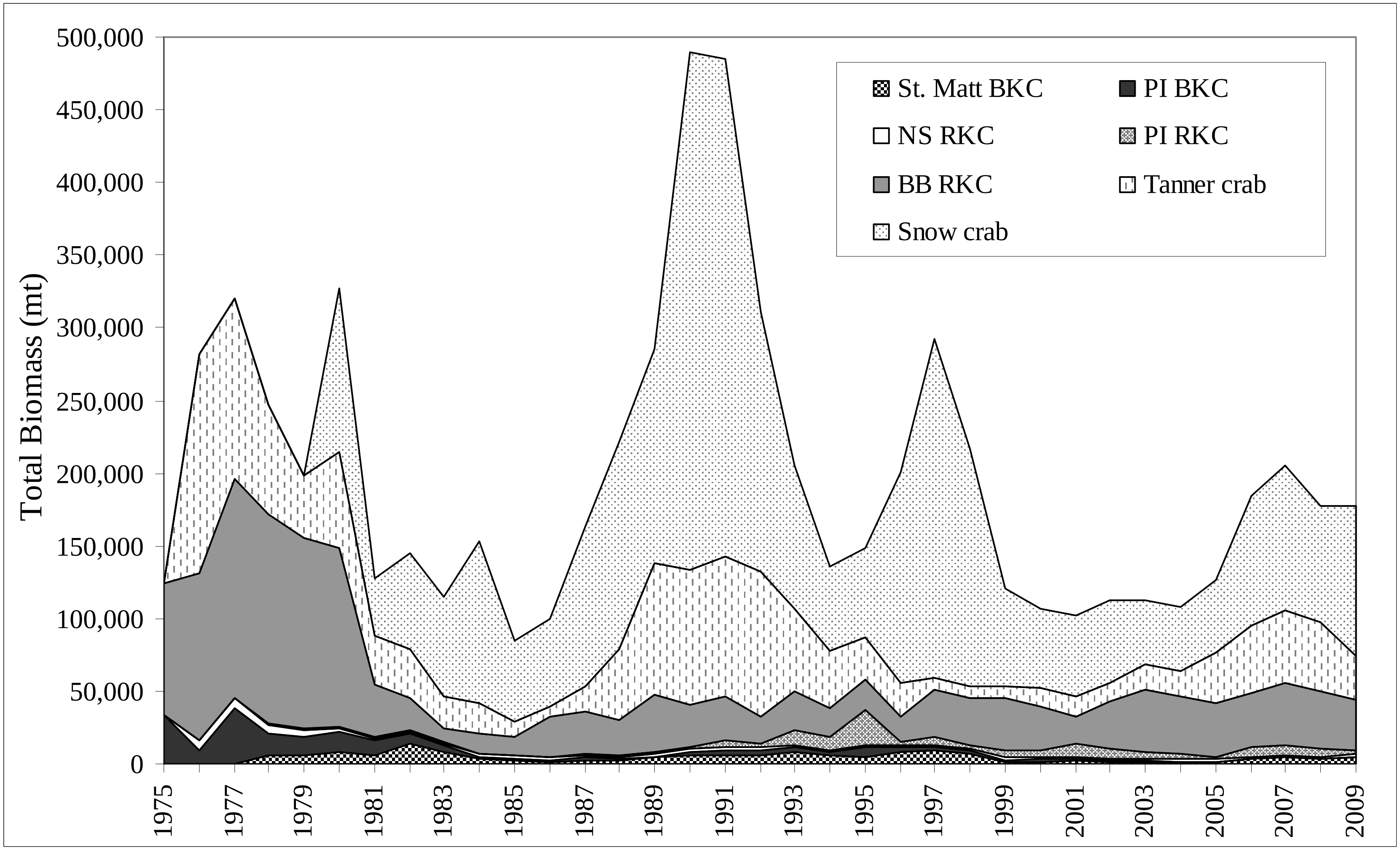

Figure 6. Trends in mature male biomass of seven eastern Bering Sea crab stocks: St. Matthew Island blue king crab (St. Matt BKC), Norton Sound red king crab (NS RKC), Bristol Bay red king crab (BB RKC), snow crab, Pribilof Islands blue king crab (PI BKC), Pribilof Islands red king crab (PI RKC), and Tanner crab.

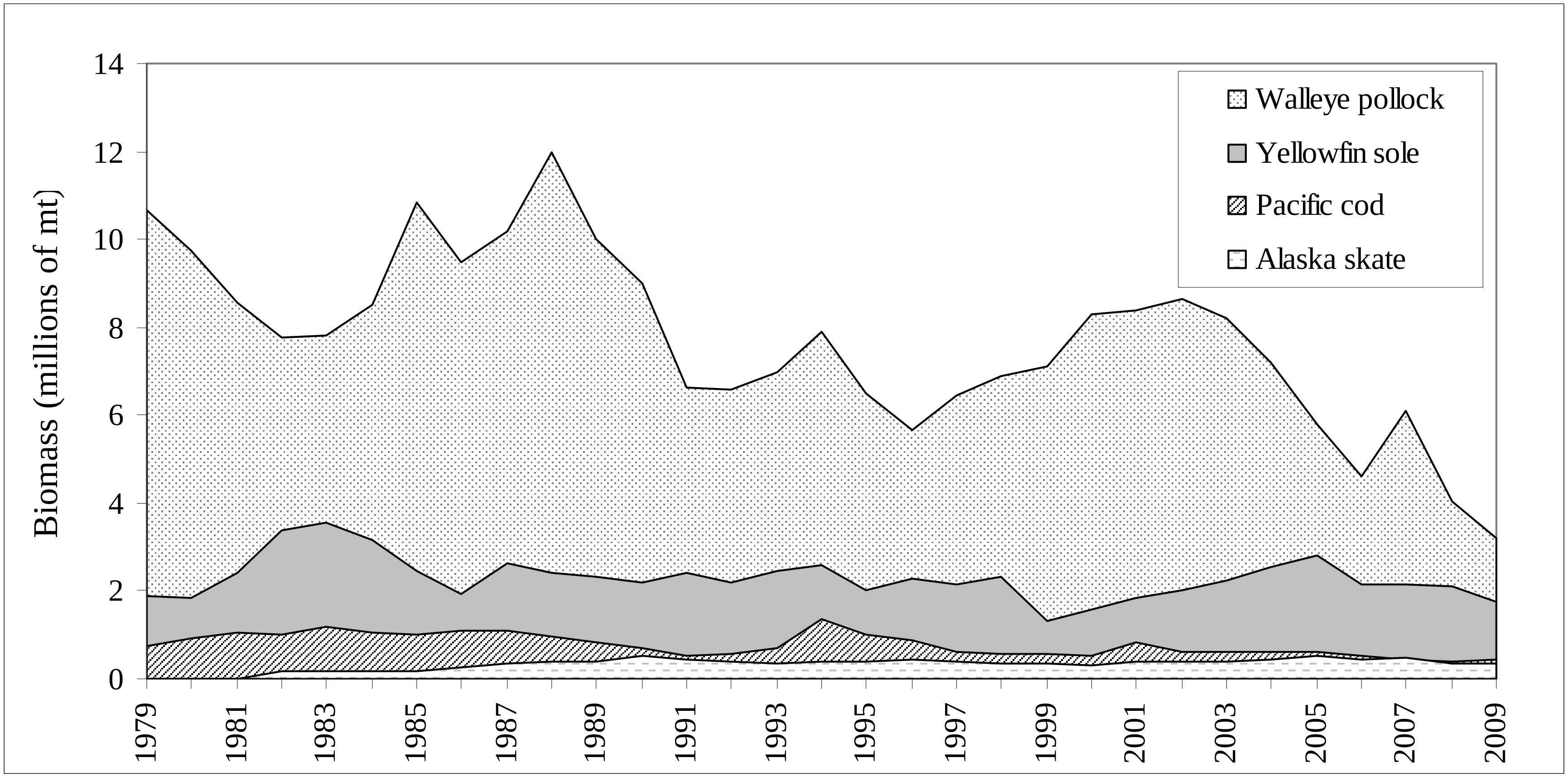

Figure 7. Trends in total biomass estimates of four major crab predators derived from the National Marine Fisheries Service eastern Bering Sea bottom trawl survey.

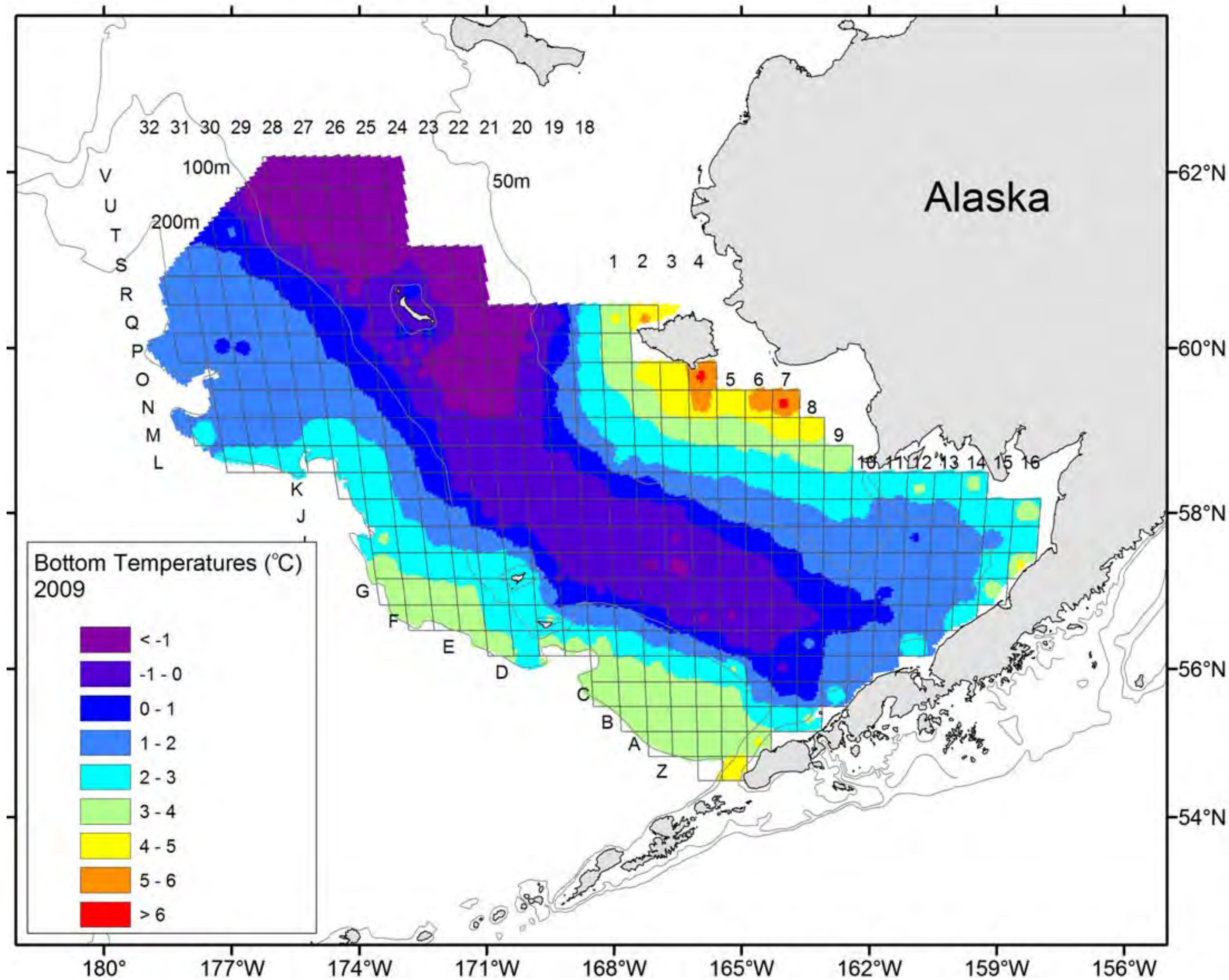

Figure 8a. Mean bottom temperatures (°C) measured at stations from the National Marine Fisheries Service eastern Bering Sea bottom trawl survey, beginning 2 June 2009 in Bristol Bay and ending on 19 July 2009 at station N28.

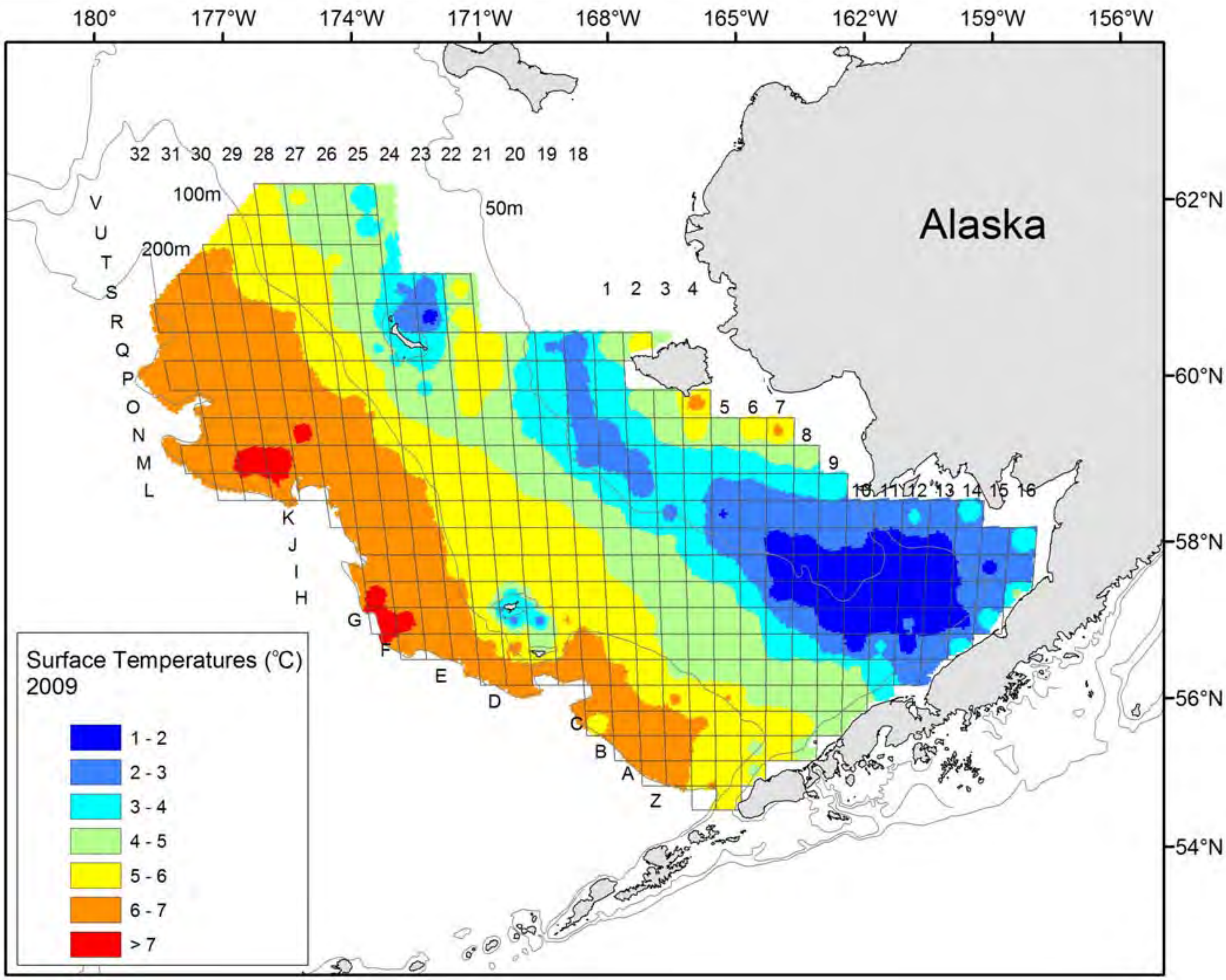

Figure 8b. Mean sea surface temperatures (°C) measured at stations from the National Marine Fisheries Service eastern Bering Sea bottom trawl survey, beginning 2 June 2009 in Bristol Bay and ending on 19 July 2009 at station N28.

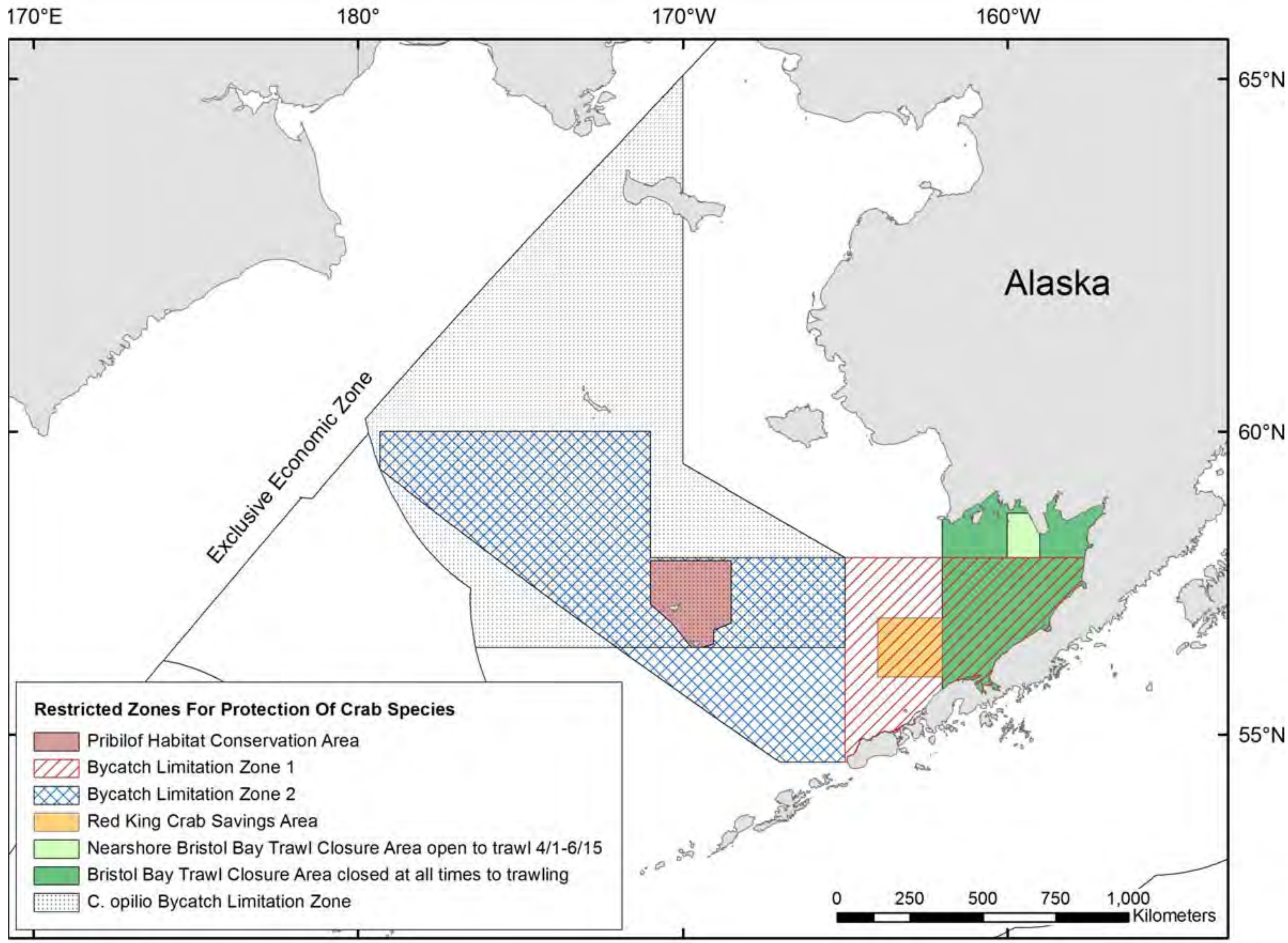

Figure 9. Restricted areas in the eastern Bering Sea enacted as protective management for commercial crab species.

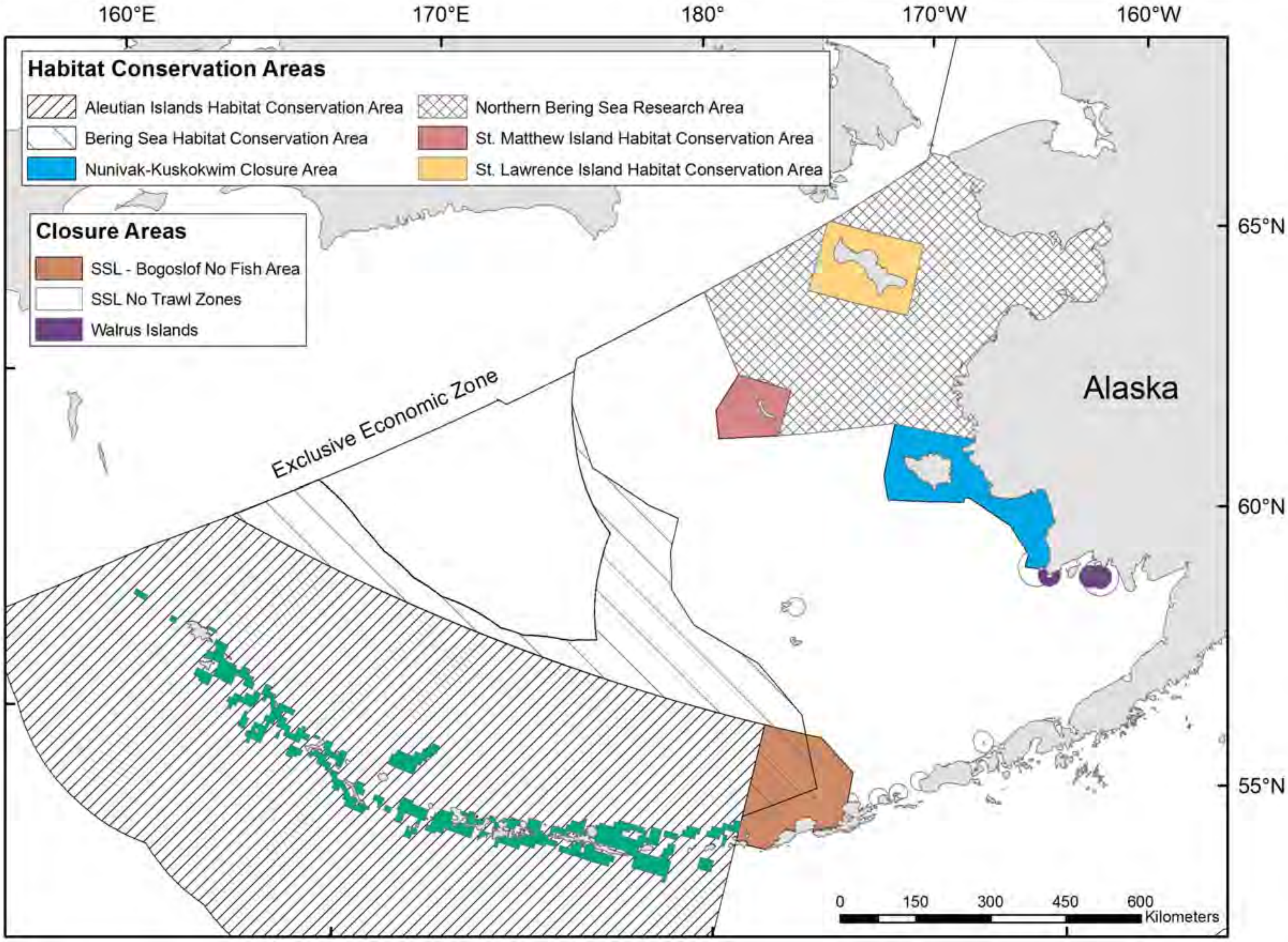

Figure 10. Habitat conservation areas and other locations closed to bottom trawling in the eastern Bering Sea and Aleutian Islands.

Table 1. Summary of ten commercial stocks managed under the Bering Sea and Aleutian Island (BSAI) king and Tanner crab Fishery Management Plan. Species listed in bold represents 2009/2010 commercial fisheries. TAC (Total Allowable Catch), GHL (Guideline Harvest Level), RKC (red king crab), BKC (blue king crab), GKC (golden king crab), CL (carapace length), CW (carapace width).

BSAI Crab Stock	TAC or GHL	Status of Fishery	Fishing season	Legal male size	Mean size retained males in 2008/2009
Bristol Bay RKC	16.01 million pounds legal males	Open in 2009	October 15, 2009-January 15, 2010	≥135 mm CL	153.2 mm CL
Pribilof Islands RKC	N/A	Closed in 1998			
Norton Sound RKC	3.75 million pounds legal males	Open in 2009	June 15 – September 20, 2009	≥121 mm CW	116 mm CW
Aleutian Islands (Adak) RKC	N/A	Closed in 2004			
Aleutian Islands GKC	5.985 million pounds legal males	Open in 2009	August through following spring	≥135 mm CL	151.6 mm CL east of 174°W, 151.2 mm CL west of 174°W
Pribilof Islands GKC	0.15 million pounds of legal males	Few vessels registered for 2009-2010	August through following spring	≥140 mm CW	No vessels registered 2006-2008
Pribilof Islands BKC	N/A	Closed in 2002			
St. Matthew Island BKC	1.167 million pounds legal males	Open 2009 after 10 yr rebuilding plan	October to February	≥120 mm CL	N/A
EBS Tanner crab	1.35 million pounds of legal males	Open in 2009/ 2010 season west of 166° W	October to March or April	≥138 mm CW	150 mm CW east of 166° W, 146.7 mm CW west of 166° W
EBS snow crab	58.55 million pounds of legal males	Open in 2009/2010	October to May	≥78 mm CW legal, ≥102mm CW preferred	110 mm CW

Table 2. Historical bycatch statistics from the Bering Sea (Registration Area Q) scallop fishery. Fishing was not opened during the 1995/96 season (Source: Rosenkranz and Spafard in review).

	Crab bycatch limits			Estimated bycatch (number animals)				Lbs meat per Tanner/snow*
Season	Tanner	King (red)	Snow	Tanner	King (red)	Snow	Halibut	
1993/94	260,000	17,000	NA	290,913	207	15,000	165	<1
1994/95	260,000	17,000	NA	220,710	22	34,867	3,513	2
1996/97	257,000	500	275,000	16,642	0	106,935	124	1
1997/98	238,000	500	172,000	28,446	0	195,345	98	<1
1998/99	215,000	500	130,000	39,363	146	232,911	98	<1
1999/2000	65,000	500	300,000	62,268	2	159,656	106	<1
2000/01	65,000	500	150,000	52,505	2	103,350	50	1
2001/02	65,000	500	300,000	48,718	2	68,458	76	1
2002/03	65,000	500	300,000	48,053	2	70,795	85	<1
2003/04	65,000	500	150,000	31,316	0	16,206	61	<1
2004/05	65,000	500	150,000	15,303	0	3,843	0	<1
2005/06	65,000	500	150,000	15,529	2	5,211	53	1
2006/07	260,000	24	300,000	45,204	10	8,543	82	<1
2007/08	260,000	500	300,000	35,288	1	19,367	11	<1
2008/09	260,000	500	300,000	60,373	1	17,205	0	<1

* Ratio of pounds scallop meat harvested for each incidentally caught Tanner crab or snow crab × Tanner crab hybrid.