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

2008 BSAI Crab SAFE

Compiled by

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of the Bering Sea and Aleutian Islands

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September 2008

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Fisheries of the Bering Sea and Aleutian Islands Regions

Table of Contents

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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), 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 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*,(Bristol Bay, Pribilof Islands, Norton Sound and Adak), 2 blue king crab, *Paralithodes platypus* (Pribilof District and St Matthew Island) 2 golden (or brown) king crab *Lithodes aequispinus* stocks (Aleutian Island and Pribilof Islands), EBSTanner crab *Chionoecetes bairdi*, and EBS snow crab *C. opilio*. All other BSAI crab stocks are exclusively managed by the State of Alaska.

The report is assembled by the Crab Plan Team (CPT) with contributions from the Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS), and is available to the public and presented to the North Pacific Fishery Management Council (NPFMC) on an annual basis. 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 16-18, 2008 at the Alaska Fisheries Science Center in Seattle WA to review the status of stocks and stock assessments in order to provide the recommendations and status determinations contained in this report. 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, Josh Greenburg, Herman Savikko, Gretchen Harrington, Doug Pengilly, Bob Foy, Lou Rugolo, Wayne Donaldson, and Diana Stram. This report builds upon recommendations contained in the May 2008 report.

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.

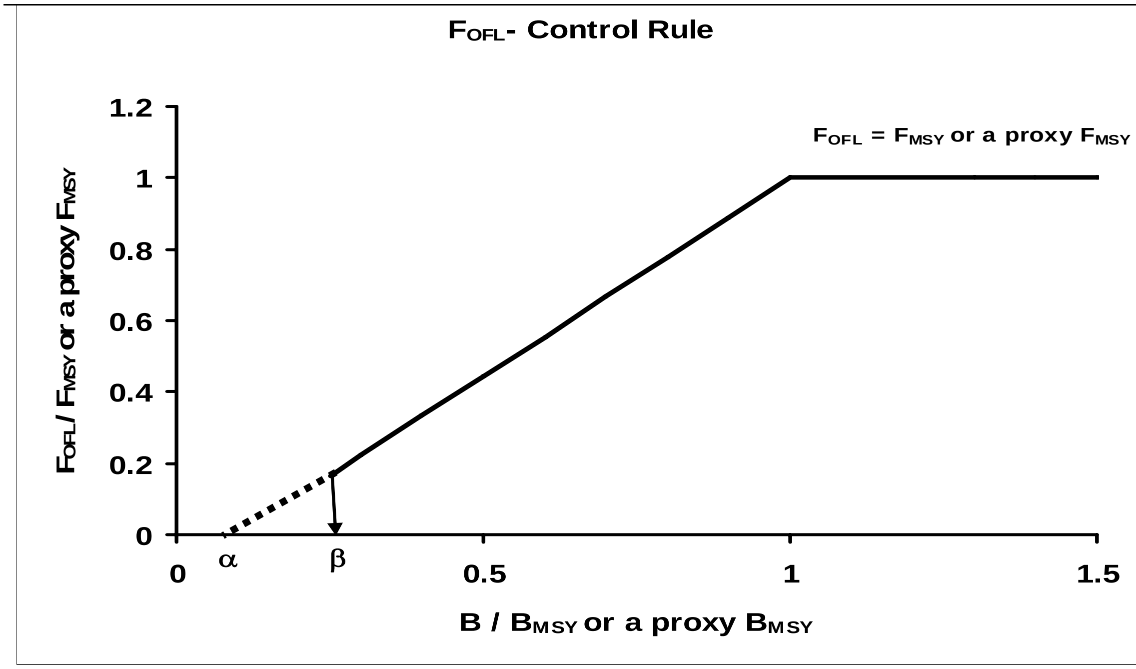

Table 1. Five-Tier System for setting overfishing limits for crab stocks. The tiers are listed in descending order of information availability. Table 6-2 contains a guide for understanding the five-tier system.

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

This was the first year of implementation of the new process for annual stock assessment and OFL determination for all ten BSAI crab stocks. The Crab Plan Team commends all of the stock assessment authors on the assessments produced (Chapters 1-10) under a limited time frame and with great attention to providing comprehensive details on a stock by stock basis.

The team's final recommendations on Tier levels, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs and whether an OFL is applied to retained catch only or to all catch are all listed in Table 3. 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 District 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 Islands golden king crab and Adak red king crab).

The team understands that under this new process, the CPT has the ability to provide recommendations for consideration in the following assessment cycle on an annual basis. The team has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2009 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 2008 CPT Report).

General recommendations for all assessments

- The assessments should provide complete documentation on model formulation, assumptions, data sources and all calculations used in the stock assessment for computing the OFL.
- For stocks where biomass estimates for OFL setting are based on survey estimates, consideration should be given to averaging recent abundance to obtain a more reliable estimate of current stock size.
- Future 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 this default value.
- All three rebuilding plans (EBS snow crab, Saint Matthew blue king crab and Pribilof District blue king crab) need to be revised given new estimates of stock status parameters.
- Research on handling mortality rates needs to be performed to better specify handling mortality rates used in the analysis.
- The assessments must include consistent key management-related stock status information
- The assessments should include model-predictions from April models on fits to the data for September assessments to allow the impact of adding new data to be determined.
- The Plan Team encourages the authors to work closely with NMFS survey staff to ensure consistency between ADF&G and NMFS survey estimates.
- Estimates of precision with the survey values should be included in all assessments.
- 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.
- 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.

Stock Status Summaries

1 Eastern Bering Sea Snow Crab (*C. opilio*)

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} established in 1998 (921.6 million lbs of total mature biomass).

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 1978-2008 seasons and estimates abundance from 25-29mm to 130-135mm using 5mm size bins. The results of the annual Bering Sea bottom trawl survey are analyzed in three periods: before 1982, 1982-88, and 1989 onwards, with different selectivity and catchability parameters for each period. The model is based on the assumption of a terminal molt at maturity. Unlike previous assessments, the 2008 assessment pre-specified rather than estimated the parameters determining growth. Two variants of the assessment were presented to the CPT in May 2008, which selected the base model (in which maturity is not estimated within the assessment, but is rather pre-specified based on auxiliary analysis).

The assessment was modified for 2008 in response to an external industry review and a review by the CIE. Specifically, the model is no longer fitted to length data by shell condition, but rather to data combined over shell condition, and it now assumes that females and males grow at the same rate at 25mm. The treatment of the size distribution of recruits has been revised to improve the residual patterns for the length-frequency data. The assessment may be refined again in the next year based on further consideration of the comments from the CIE review and the CPT.

Compared with the assessment presented to the CPT in May 2008, the final assessment uses catch and fishery length-frequency data for the 2007/08 season as well as survey abundance and length-frequency data for 2008.

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 increase in mature male biomass has been greater than in mature female biomass. Recruitment has varied considerably over the period 1979-2008, with the recruitment (at 25mm) in 1986 the highest on record. Recruitment between 2003 and 2006 is estimated to be near or above average, while the estimated recruitments for 2007 and 2008 are below average.

Tier determination/Plan Team discussion and resulting OFL determination

The CPT recommends that snow crab be a Tier 3 stock 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} is 317.7 million lbs. The MSST is defined as half of the proxy for B_{MSY} (158.9 million lbs).

Status and catch specifications (millions lbs.) of snow crab

Year	Biomass (MMB)	OFL	TAC	Retained Catch	Total Catch
2005/06	188		37.2	37.0	46.9
2006/07	218		36.6	36.4	49.4
2007/08	218		63.0	63.0	78.6
2008/09	251.1	77.3	TBD	TBD	TBD

The 2008/09 MMB exceeds the proxy for MSST so the stock is not currently overfished. This stock is in Tier 3b stock status. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

The CPT notes 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.

Additional Plan Team recommendations

The next assessment should: (a) include retrospective analyses, (b) update the reference list, (c) include a full description of the model, including its forecast component and the weights assigned to the penalties and likelihood components, (d) expand the description of the way in which discards are treated in the model, (d) include past GHLs in the table of catches, and (e) further justify the values chosen for the weighting factors (the lambdas) and explore sensitivity to alternative values. The next assessment should also consider: (i) imposing a penalty to prevent the probability of maturity declining with increasing size if maturity is estimated within the model, (ii) set the effective sample sizes for the length-frequency data based on the effective sample sizes estimated from the fit of the model, (iii) explore whether it is possible to improve the residual patterns for the length-frequency data by modifying how maturity, growth and natural mortality are modeled and the implications of the change in distribution of the population over time, (iv) reduce the number of size classes for females, and (v) include measures of uncertainty for estimated quantities such as recruitment, and mature male biomass. 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.

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

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

2 Bristol Bay red king crab (BBRKC)

Fishery information relative to OFL setting.

The commercial harvest of 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 the 1970s. The fishery is managed for a TAC coupled with restrictions for size (≥ 6.5-in CW), sex (male only), and season (no fishing during mating/molting periods). Prior to 1990, the harvest rate was based on population size, and prerecruit and postrecruit abundances, and varied from 20% to 60% of legal males. In 1990, the harvest strategy became 20% of 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 of 15% of mature males but also incorporates a cap 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. A TAC of 18.3 million lbs was established for the 2005 season, reduced to 15.5 million lbs for the 2006 season, and increased to 20.4 million lb for the 2007 season. Average retained catch for the period 2005 to 2007 was 18.0 million lbs. Catch abundance of legal males per pot lift was relatively high in the 1970s, low in the 1980s to mid-1990's, and has gradually increased since 2000 to an average of 29.7 crab/pot lift over the last three years; CPUE increased markedly with the implementation of crab rationalization in 2005. Annual non-retained catch of female and sublegal male RKC during the fishery averaged 1.7 million lbs since data collection began in 1990. Estimates of fishing mortality have ranged from 0.28 to 0.38 following implementation of crab rationalization. Total catch (retained and bycatch mortality) was 22.7 million lbs in 2005, declined to 17.2 million lbs in 2006 and increased to 23.3 million lbs in 2007.

Data and assessment methodology

The stock assessment model involves a length-based model incorporating data from the eastern Bering Sea trawl survey, commercial catch, and at-sea observer data. Stock abundance is estimated for male and female crabs ≥ 65-mm CL during 1985 to 2008. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date from the fishery which targets males ≥6.5-in CW) were obtained from ADF&G fish tickets and reports, fishery bycatch data from the ADF&G observer database, and groundfish trawl bycatch data from the NMFS trawl observer database.

Stock biomass and recruitment trends

Estimates of stock biomass have generally increased since 1985, but remain well below historic levels of the 1970s. Recent above-average year classes have largely recruited into the fished population with no evidence of new strong recruitment. Mature male biomass increased from 72.3 million lbs in 2005 to 95.6 million lbs in 2008.

Tier determination/Plan Team discussion and resulting OFL determination

The authors are commended for updating the assessment per May CPT and June SSC recommendations. However, the team made several recommendations for improvements to the assessment. For example, to the extent possible, the model should incorporate data prior to 1985. It was also suggested that future assessments include some analysis of model sensitivity to different weightings (lambdas). The magnitude of lambdas has a direct effect on projected biomass and catch likelihood profiles because increasing lambdas artificially decreases the width of the profiles. It was also recommended that the author consider parameter estimation in a Bayesian context. The authors noted that patterns seem to exist in the trawl survey residuals for female crab; the female maturity curve is currently knife-edged. It is requested that the authors examine scenarios which attempt to address the female trawl survey residual patterns. In addition, it is requested that when key parameters are fixed in the model, more justification, such as a sensitivity analysis, should be included for estimating parameters external to the model. The CPT specifically recommended investigating the sensitivity of the survey q which is fixed in the model. The team recommends that these additional analyses be incorporated into the assessment for the Spring 2009 review.

The Plan Team concurs with the author in recommending 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 75.11 million lb in 2008. Total catch OFL includes discard and retained male catch and male trawl bycatch, but not female pot or trawl bycatch.

Status and catch specifications (million lbs.) of BBRKC in recent years.

Year	Biomass (MMB)	OFL	TAC	Retained Catch	Total catch
2005/06	79.92		18.3	18.3	22.72
2006/07	82.03		15.5	15.4	17.22
2007/08	85.94		20.4	20.4	23.22
2008/09	95.6	24.2	TBD	TBD	TBD

The 2008/09 MMB exceeds the proxy for MSST so the stock is not currently overfished. This stock is in Tier 3a stock status. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

The Plan Team encourages the authors to work closely with NMFS survey staff to ensure consistency between ADF&G and NMFS survey estimates. A follow-up to this process would also be the inclusion of estimates of precision with the survey values. Survey abundances should be tabulated in the assessment.

Ecosystem Considerations summary

A variety of ecological factors likely affect BBRKC recruitment and growth, although the mechanisms are unclear. For example, previous research suggested BBRKC recruitment trends may partly relate to decadal shifts in physical oceanography. Recruitment may also relate to spatial and temporal patterns in groundfish distributions. Finally, spatial distributions of RKC females have likely shifted in response to changes in near bottom temperatures.

3 Eastern Bering Sea Tanner Crab (*C. bairdi*)

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 IFQ for these two fisheries. However, NMFS will set one OFL for the eastern Bering Sea Tanner crab because evidence indicates that the EBS Tanner crab is 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˚ W. longitude. ADF&G opened both fisheries for the 2006/07 and 2007/08 crab fishing years. In 2007, NMFS determined the stock was rebuilt.

Tanner crab are caught as bycatch in the groundfish fisheries, in the directed Tanner crab fishery itself (principally as non-retained females and sublegal males), and in crab fisheries directed on other species (notably, eastern Bering Sea snow crab and 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, that model is not employed to assess the stock as 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. Fish ticket data are used for computing retained catch and observer data from the crab and groundfish data 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

Mature male biomass (MMB) and legal male biomass (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 to its current level of 143.1 million pounds in 2008.

In the 2008 survey, estimated abundance of legal males increased over the 2007 abundance estimate by 9%; however, the 2008 survey showed a marked decline in estimated abundance across all other size classes of males and females.

Tier determination/Plan Team discussion and resulting OFL determination

The team recommends this stock as a Tier 4 stock because no stock assessment model has been developed for the entire EBS stock.

B_{MSY} proxy is estimated at 189.76 million pounds MMB at the time of mating, based on the SSC's recommendation that B_{MSY} proxy be calculated as 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 the time of mating. This sequence of years extends those included in the May CPT recommendation (1975-1980). However the team notes that adding data from surveys prior to 1975 adds to existing data quality and availability issues including that the surveyed area expanded through the 1970s to 1980, when the area surveyed is roughly what it remains to date; and data retrieval is an issue (data from 1969 through the 1970s generally must be gleaned from various published summaries and is generally not retrievable from databases). The SSC in June 2008 also asked that results be examined for 1969-2007 data. The authors noted that the post-1980 data may not be appropriate: post 1980-data had a history of stock collapse, closures, and imposition of a rebuilding plan.

The recommended OFL is based on γ=1.0. An alternative analysis, based on $F_{35\%}$/M, was presented to the CPT in response to an SSC recommendation. $F_{35\%}$/M was re-estimated by the assessment authors rather than being set to 2.1 because the fishery selectivity appears to have changed since the EA was conducted. However, this analysis remains preliminary and the CPT look forward to seeing an updated analysis based on a stock assessment model in May 2009.

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

Year	**Biomass (MMB)**	**OFL**	**TAC (east + west)**	**Retained Catch**	**Total Catch**
2005/06	86.24		1.6	0.95	4.19
2006/07	126.58		2.97	2.12	11.95
2007/08	150.74		5.62	2.11	8.80
2008/09	108.28	15.52	TBD	TBD	TBD

The 2008/09 MMB exceeds the proxy for MSST so the stock is not currently overfished. The stock is in Tier 4b stock status. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

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

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

Ecosystem Considerations summary

Although studies are limited, the EBS Tanner crab fisheries do not appear to negatively impact any ecosystem components. Climate change may negatively impact Tanner crab abundance through increasing predator abundance, decreasing benthic production, and the potential for decalcification in a more acidic ocean.

4 Pribilof Islands red king crab

Fishery information relative to OFL setting.

There is no harvest strategy for this fishery in State regulation. The fishery began as bycatch in 1973 during the blue king crab fishery. A red king crab fishery opened with specified GHL for the first time in September 1993. The 1993 fishery yielded 2.6 million lbs under a 3.4 million lb GHL, with highest catches occurred east of St. Paul Island, but harvests also south, southwest, west and northeast of St. Paul Island. The 1994 fishery was also prosecuted with a specified red king crab GHL. Since 1995, a combined GHL for red and blue king crabs was set and ranged from 1.3 to 2.5 million lbs. The fishery has remained closed since 1999 because of uncertainty with estimated red king crab survey abundance and concerns for incidental catch of blue king crab that are in a depressed state. The non-retained catches from pot and groundfish bycatch estimates of red king crab ranged from 0.01 to 0.19 million lbs during 1992-2008.

Data and assessment methodology

Although a catch survey analysis has been used for assessing the stock in the past, which incorporated data from the eastern Bering Sea trawl survey, commercial catch, pot survey, and at-sea observer data; for this assessment trends in MMB at mating are based on NMFS annual trawl survey estimates for the period 1980-2008 and incorporated commercial catch and observer data. For 2008 reference points' estimation, an F_{OFL} was determined using a mean mature male biomass (MMB) at the time of mating, 2008 MMB (projected to mating time), a default λ value of 1, and an M value of 0.18. This F_{OFL} was used on the legal male biomass at the time of the fishery to determine the catch OFL. Total legal crab removal (retained and bycatch losses) with legal biomass and MMB were used to estimate the exploitation rate at the time of the fishery.

Stock biomass and recruitment trends

The stock exhibited widely varying mature male and female abundances during 1980-2008. The 2007 survey time estimate of MMB was 16.58 million pounds and dropped to 12.49 million pounds in 2008. The recruitment trend appeared to be highly variable. However, survey estimates are highly influenced by the results of a limited number of tows with non-zero catches. 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

Two sets of data series, 1991-2007 and 1980-2007, were considered to determine mean MMB at mating as proxy B_{MSY}. The first series produced a mean estimate of 8.66 million pounds and is recommended by the CPT and SSC. The second series produced a mean estimate of 5.91 million pounds which was requested by the SSC for comparison purposes. The 2008 MMB at mating exceeded both proxy B_{MSY} values.

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

Year	Biomass (MMB)*	OFL	TAC	Retained Catch	Total catch
2005/06	2.59		closed	0	0.064
2006/07	13.87		closed	0	0.024
2007/08	14.70		closed	0	0.008
2008/09	9.26	3.32	TBD	TBD	TBD

*Note this biomass is at the time of mating. The value for 2008/09 is projected.

The 2008/09 MMB exceeds the proxy for MSST so the stock is not currently overfished. This stock is in Tier 4a stock status. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

There are concerns about the unreliability of biomass estimates and blue king crab bycatch mortality would occur in a directed red king crab fishery.

Ecosystem Considerations summary

There have been no direct studies of the prey of Pribilof Islands red king crab. Studies in other areas indicate that red king crab diet varies with life stage and that red king crabs are opportunistic omnivorous feeders, eating a wide variety of microscopic and macroscopic plants and animals. Pacific cod is the major predator of red king crab in the eastern Bering Sea. Recruitment trends for red king crab in the eastern Bering Sea may be partly related to decadal shifts in climate and physical oceanography. Strong year classes were observed when temperatures were low and weak year classes were occurred when temperatures were high, but temperature alone cannot explain year class strength trend. 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 seasonal ice cover has an effect on primary productivity and hence crab recruitment, but the changes in the ice cover on benthic communities of the Pribilof Islands are not well known. The trawl fishery ban around the Pribilof Islands protects the critical habitat of the red king crab in this area. The extent that pot gear impacts benthic habitat is not well known and most likely depends on the substrate.

5 Pribilof District blue king crab

Fishery information relative to OFL setting.

The Pribilof blue king crab fishery began in 1973, with peak landing of 11.0 million lbs in the 1980/81 season. A steep decline in landings occurred after the 1980/81 season. Directed fishery harvest from 1983 until 1987 was annually less than 1.0 million lbs with low CPUE. The fishery was closed in 1988 until 1995. The fishery reopened from 1995 to 1998. Fishery harvests during this period ranged from 1.3 to 0.5 million lbs. The fishery closed again in 1999 due to declining stock abundance and has remained closed through the 2007/08 season.

Estimated total mature biomass, based on the ADF&G catch-survey model decreased from 7.0 million lbs in 2001 to 4.5 million lbs in 2002, a level below MSST and resulting in the stock being designated as overfished in 2002.

Data and assessment methodology

The NMFS conducts an annual trawl survey that produces area-swept abundance estimates, and ADF&G is developing a catch-survey analysis model. In addition ADF&G is conducting a triennial pot survey of Pribilof king crab in September 2008. Those results will be available later this winter. However, because the model was not reviewed, the OFL determination is based on area-swept abundance estimates at the time of mating.

The CPT discussed the history of the fishery and the rapid decline in landings. It is clear that the stock has collapsed, although there is imprecision in the annual area-swept abundance estimates. The CPT discussed averaging recent biomass estimated to account for annual fluctuations to reduce noise in the data. For stocks where biomass estimates for OFL setting are based on survey estimates consideration should be given to averaging recent abundance estimate to obtain a more reliable estimate of current stock size.

Stock biomass and recruitment trends

Based on 2008 NMFS bottom-trawl survey, the estimated total mature-male biomass of 0.29 million pounds is higher than the 2007 estimate of 0.17 million pounds. However, the 2008 estimate is only 0.03 of B_{MSY}. The Pribilof blue king crab stock continues to show no indications of recovery. From recent surveys there is no indication of recruitment, and no sustainable yield

Tier determination/Plan Team discussion and resulting OFL determination

This stock is placed into Tier 4, stock status level c. The time period for B_{MSY} is 1980-84 plus 1990-97, excluding the 1985-1989 period. This was chosen as it eliminates periods of extremely low abundance. B_{MSY} is estimated as 9.28 million pounds. MSST is one half of the B_{MSY}. The retained catch OFL is 0 because the 2008 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 rebuilding plan needs to be revised to be consistent with amendment 24. However in the absence of a revised rebuilding strategy, the CPT recommends an OFL equal to the average catch since the directed fishery was closed (1999) through to 2006/07. Since this time period bycatch in the Pacific cod pot fishery has increased dramatically and is not representative of a sustainable yield. The total catch OFL (after discounting for mortality) for 2008/09 is 0.004 million pounds.

The CPT recommended gamma = 1, given the absence of information presented to establish an alternate value at this time. Natural mortality was M=0.18

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

Year	Biomass MMB*	OFL	TAC	Retained Catch	Total Catch
2005/06	0.68		closed	0	0.002
2006/07	0.33		closed	0	0.004
2007/08	0.66		closed	0	0.060
2008/09	0.25	0.004	closed	0	TBD

*Note this biomass is at the time of mating. The value for 2008/09 is projected.

The 2008/09 MMB is below the proxy for MSST so the stock is currently overfished. This stock is in Tier 4c stock status. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

The rebuilding plan needs to be revised given new estimates of stock status parameters Management options for revising the rebuilding plan are contained in the Crab Plan Team minutes (September 2008)

6 St. Matthew blue king crab (St. Matthew BKC)

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. The stock was declared overfished and closed in 1999, and has been under a rebuilding plan since 2000.

Data and assessment methodology

A four-stage catch survey analysis incorporates annual trawl survey data from 1978 to 2008, triennial pot survey data from 1995 to 2007, and commercial catch data from 1978 to 2007, and 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 include 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). The model was developed for five scenarios in which either one or both parameters of natural mortality (M) or survey catchability (q) were fixed (M = 0.18 and Q = 1). The first three scenarios include estimated M for one year (1999), while the other two assume that M was constant over time. The scenario with q and M fixed (with estimating M in 1999) was selected by the CPT because of the uncertainty in parameter estimation.

Stock biomass and recruitment trends

Mature male biomass has fluctuated greatly in three waves. The first pulse increased from 7.6 to over 17.6 million lbs from 1978 to 1981, followed by a steady decrease to 2.9 million lbs. in 1985. The second pulse 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 pulse had a steady increase from the low in 1999 to it present high of over 10.7 million lbs. in 2008.

Tier determination/Plan Team discussion and resulting OFL determination

St. Matthew BKC is recommended as a Tier 4 stock in 2008. The B_{MSY}^{proxy} varies as a function of years used to calculate average mature male biomass. The time period selected by CPT for estimating B_{MSY}^{proxy} was 1989 to 2008 because before 1986, the fishery was harvested at extremely high rates and this time period incorporates stock rebuilding several years after the stock crash. B_{MSY}^{proxy} during this time period is 7.39 million lbs. Gamma was recommended to be 1. OFL was set for this year using the Tier 4 control rule. A retained catch OFL was used because bycatch data was not included in this year's assessment.

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

Year	Biomass* (MMB)	OFL	TAC	Retained Catch	Total Catch
2005	5.291		closed	closed	TBD
2006	7.069		closed	closed	TBD
2007	9.682		closed	closed	TBD
2008	10.74	1.63 [retained]	TBD	TBD	TBD

*Note this biomass is at the time of mating. The value for 2008/09 is projected.

The 2008/09 MMB is above the proxy for MSST so the stock is not currently overfished. This stock is in Tier 4a stock status. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

The model should continue to be refined for review at the May 2009 CPT meeting to allow this stock to be considered for Tier 3 Further analyses are needed to explore scenarios of constant M over the whole time period, including runs tests and justifications of lambda with log-likelihood analyses. Bycatch data in all fisheries must be compiled to generate a total catch OFL for the May 2009 assessment. The CVs of the survey data should be used in the assessment next year. The assessment needs to include figures showing data and fits to these data for both pot and trawl surveys including confidence intervals on data and model results. The assessment should also examine the sensitivity of the weighting choices employed in the model to examine relative influence on results [e.g. conducting the assessment using each of the two indices of abundance in turn (pot and trawl survey)].

Ecosystem Considerations summary
Information on habitat, prey availability and predator trends are needed with greater spatial and temporal resolution in order to better understand how they may vary with St. Matthew BKC abundance.

7 Norton Sound Red King Crab

Fishery information relative to OFL-setting
Norton Sound red king crab harvest occurs in three fisheries: summer commercial, winter commercial, and winter subsistence fishery. The summer commercial fishery is the major fishery. Commercial fishing started in 1977 and, since 1994, commercial vessels were restricted harvesting Norton Sound red king crab only. In 1998, Community Development Quota groups were allocated a portion of the summer fishery quota. The winter commercial fishery is relatively small averaging 2,400 crabs annually during 1997-2007. The subsistence fishery, which averaged 5,300 crabs during 1978-2007, occurs mainly during the winter via hand lines and pots deployed through the near shore ice.

The management strategy for Norton Sound red king crab involves a stepped harvest rate (HR). The guideline harvest level for the summer fishery is established at three levels based on estimated legal biomass (ELB): (1) HR = 0% for ELB < 1.5 million lbs; (2) HR ≤ 5% for ELB from 1.5 to 2.5 million lbs; and (3) HR ≤ 10% for ELB > 2.5 million pounds.

Data and assessment methodology
Fishery-dependent data are available for the three fisheries. Fishery-independent data are available through four surveys: summer trawl, summer pot, winter pot, and a preseason pot survey. Surveys are conducted periodically with no survey being conducted on an annual basis. No bycatch or discard data is available for the fisheries. A length based stock model was developed to estimate annual stock abundance for the period 1976-2007. Summer commercial fishery data are available from 1977.

Stock biomass and recruitment trends
Estimated legal stock abundance was high during the 1970s, low in the early 1980s and mid 1990s, and has gradually trended upward since 1996. Estimated recruitment was low in the late 1970s and early and late 1990s, and higher in the early 1980s, mid 1990s, and early 2000s, with a generally upward trend in the most recent seasons.

Tier determination, Plan Team discussion and OFL determination
The Crab Plan Team discussed the current status of the stock abundance model and had several concerns. The team notes that most model parameters are fixed and recommends that the justification for this be provided as well as a sensitivity analysis conducted to evaluate alternative values. Selectively is currently pre-specified to increase with size. Model results appear to indicate that something is mis-specified in the way that the model

reaches each selectivity. The assessment should include greater sensitivity tests, particularly a range of weights on various parameters considered. Model specification should be investigated and alternative configuration sought as an improvement over the current model.

The team discussed alternative OFL setting approaches for this stock given concerns expressed about the model. Three alternative approaches are put forward: (1) use of the model estimate (understanding the issues inherent in the model estimate and suggestions for the following year); (2) use of the survey biomass estimate to calculate a Tier 4 OFL; and (3) placing this stock in to Tier 5 and basing an OFL on average catch. While the team expressed concerns as noted previously with the model and assessment as currently formulated, the team concluded that use of survey biomass estimates not presented was not sufficient, and that use of a Tier 5 formulation when biomass estimates are available is inappropriate.

The team chose to go forward with a Tier 4 recommendation for this stock and the use of the model biomass estimates to determine an appropriate OFL. The team discussed the author's recommendation of the use of the years 1983-2008 in order to exclude the 1976-1982 period. The start date of 1983 was chosen over 1980 due to representing the first appearance of post-regime shift recruitment. Gamma was recommended at 1.0 due to issues with the model and assumptions regarding selectivity in the model.

The team agreed with the assessment author's recommendation for the years under consideration for the BMSY proxy, and resulting OFL. For 2008, the B_{MSY} proxy is 3.57 million lbs, F_{MSY} proxy = 0.18, B = 5.24 million lbs, and LMB = 4.1162 million lbs. The 2008 *OFL* for retained catch is 0.246 million crabs or 0.68 million lbs. This OFL was established in June 2008 in order to allow for the summer fishery.

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

Year	Biomass (MMB)	OFL	TAC	Retained Catch	Total Catch
2005	3.89		0.37	0.40	
2006	3.62		0.45	0.45	
2007	4.40		0.32	0.31*	TBD
2008	5.24	0.68 [retained]	0.41	0.39*	TBD

*summer fishery only. Small winter and subsistence fisheries not included.

The 2008/09 MMB is above the proxy for MSST so the stock is not currently overfished. This stock is in Tier 4a stock status. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

The team requested that additional information be included in future assessment reports on asymptotic standard errors and selectivity parameters (to indicate which are fixed not estimated). The team discussed the rationale for using the M value of 0.18 and its basis on laboratory studies. Some team members did not agree with this estimate usage for this stock noting that model information could be used to inform the best estimate. The team recommends that alternative M values be examined in the next assessment. The team recommends exploration of a broader range of models and sensitivity analyses for this stock for the May 2009 assessment. The team further recommends the authors include a clear explanation of the gamma value chosen for future models. The assessment authors should also provide a more complete rationale for choice of range of years.

The SSC requested a presentation on this model at the October meeting.

8 Aleutian Islands golden king crab (AIGKC)

Fishery information relative to OFL setting

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 catch of 11.9 million lbs), but average harvests dropped sharply from the 1989/90 to 1990/91 season and average harvests for the period 1990/91–1995/96 was 6.9 million lbs. Management for a formally established GHL was first introduced with a 5.9-million lb GHL in the 1996/97 season, subsequently reduced to 5.7-million lbs beginning with the 1998/99 season. The GHL (or TAC, since the 2005/06 season) has remained at 5.7 million lbs through the current season. Average retained catch for the period 1996/97–2006/07 was 5.6 million lbs, including 5.3 million lbs in the 2006/07 season. This fishery is rationalized under the Crab Rationalization Program.

Data and assessment methodology

There is no assessment model in use for this stock. Available data are from fish tickets (retained catch numbers, retained catch weight, and pot lifts by 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 2006/07 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.

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.

Tier determination/Plan Team discussion and resulting OFL determination

AIGKC is recommended as a Tier 5 stock in 2008/2009. B_{MSY} and MSST are not estimated for this stock. OFL was set for this year using a retained catch OFL. The SSC differed with the Plan Team's recommended OFL in June 2008 (to use the time period for calculating average catch between 1990/1991 to 1995/1996 as prior to 1990, there were indications that harvest was not sustainable) and instead selected a longer time period over which to average catch. The time period recommended by the SSC is 1985/1986 to 1995/1996. This resulted in a retained catch OFL of 9.18 million pounds. This OFL was established in June 2008 due to the timing of the summer fishery.

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

Year	Biomass (MMB)	OFL	TAC	Retained Catch	Total Catch*
2005/06	NA		5.70	5.52	8.08
2006/07	NA		5.70	5.22	8.01
2007/08	NA		5.70	5.51	TBD
2008/09	NA	9.18 [retained]	5.99	TBD	TBD

*catch listed here has not been discounted for mortality

No overfished determination is possible for this stock given the lack of biomass information. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

The plan team reviewed a new stock assessment model for Aleutian Islands golden king crab (Chapter 8b). The plan team recommends continued development of the stock assessment model and presentation to the SSC in October. The team recommends incorporation of plan team and SSC comments into the model for the May 2009 plan team meeting. Use of an assessment model will allow for this stock to be moved to Tier 4 and would provide focus for establishing research and data collection priorities.

Sufficient bycatch data exists to generate a total catch OFL and needs to be synthesized with an analysis for future assessments.

Ecosystem Considerations summary

The assessment author should reference the Aleutian Islands Fishery Ecosystem Plan in future assessment reports. No ecosystem considerations were considered at this time.

9 Pribilof Islands golden king crab

Fishery information relative to OFL setting

The domestic fishery around the Pribilof Islands for male golden king crab ≥5.5 in. CW (≥124 in. CL) developed in 1982. Since then, fishery participation has been sporadic and retained catches variable. The fishery has been managed for a GHL of 0.15 million lbs since 2000. Non-retained bycatch occurs in the directed fishery as well as the Bering Sea snow crab fishery and Bering Sea grooved Tanner crab fishery. No vessels participated in the fishery in 2006 or 2007. This fishery was not included in the Crab Rationalization Program. This fishery opens on January 1 and is open year round operating under a commissioners permit. No permits have been issued since 2005 for this fishery.

Data and assessment methodology

There is no survey and no assessment model in use for this stock. Available data are from fish tickets (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 numbers of participating vessels or processors.

Stock biomass and recruitment trends

Estimates of stock biomass are not available. Between 2002 and 2005, the average size of legal male golden king crab taken in the commercial fishery decreased while CPUE increased, which may suggest some recruitment to the legal male portion of the stock during that period.

Tier determination/Plan Team discussion and resulting OFL determination

The team recommends that this stock be assigned to Tier 5 due to the lack of available biomass information. Catch history from 1993-1999 is proposed for OFL determination resulting in an OFL of 0.17 million lbs. This OFL is proposed for retained catch only.

Status and catch specifications (million lbs.) of Pribilof Islands golden king crab

Year	Biomass (MMB)	OFL	GHL	Retained Catch	Catch (non retained all fisheries)
2005/06	NA		0.15	Confidential*	0.019
2006/07	NA		0.15	0	(not available)
2007/08	NA		0.15	0	(not available)
2008/09	NA	0.17 [retained]	TBD	TBD	TBD

* Confidential data not available due to a total of less than three vessels or processors participating in the fishery

No overfished determination is possible for this stock given the lack of biomass information. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

All sources of mortality should be included in the assessment next year. The team recommends that additional information from the NMFS slope survey be included in the assessment for 2009.

10 Adak red king crab, Aleutian Islands

Fishery information relative to OFL setting

The domestic fishery has been prosecuted since 1961 and was opened every season through the 1995/96 season. Non-retained catch of red king crabs occurs in both the directed red king crab fishery and in the Aleutian Islands golden king crab fishery. Estimated non-retained catch during the 1996/97-2007/08 seasons has been low (less than 50,000 lbs) and was less than 10 percent of the retained catch in 2002/03 and 2003/04 seasons.

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 943,000 lbs, but the retained catch during the 1995/96 season was only 39,000 lbs. Since the 1995/96 seasons, the fishery was opened only occasionally. There was an exploratory fishery with a low GHL in 1998/99; three Commissioner’s permit fisheries in limited areas during 2001 and 2002 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 500,000 lbs 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 (2002/03 and 2003/04) were opened only in the Petrel Bank area. Retained catch in the last two commercial fishery seasons was 506,000 lbs (2002/03) and 479,000 lbs (2003/04). The fishery has been closed since the end of the 2003/04 season. Non-retained catch of red king crabs occurs in both the directed red king crab fishery, in the Aleutian Islands golden king crab fishery, and groundfish fisheries. Estimated non-retained catch during the 1996/97-2006/07 seasons averaged 26,000 lbs per year. This fishery is rationalized under the Crab Rationalization Program only for the area west of 179° W longitude.

Data and assessment methodology

There is no assessment model in use for this stock. The department conducts periodic pot surveys in the area. Prior to the 2006 survey, the last one conducted was in 2001, performed with industry participation under provisions of a commissioner's permit. In 2006 the department also conducted "niche" fishing in addition to their regular survey design. Pots were fished at locations between the survey stations, in strings similar to commercial fishing, utilizing the expertise of the vessel captain to provide location and pot spacing. Niche fishing was conducted to the northwest portion of the Petrel Bank, the area that produced the highest catch of red king crabs during the 2006 survey. Comparisons with the November 2001 industry survey were made for both the 2006 survey and niche fishing. Due to differences in fishing practices, direct comparisons cannot be made between the CPUE of legal males obtained during this survey with that obtained during the 2001 industry survey. Recognizing the limitations in making direct comparisons of the CPUE of legal males between the 2006 survey and the November 2001 survey, the following observations on CPUE of legal males during the 2006 survey and niche fishing relative to results of the November industry survey provide strong evidence that the abundance of legal red king crabs in the Petrel Bank area was substantially lower in November 2006 than in November 2001. The department attempted to do another systematic pot survey in 2007, but did not receive any bids for the charter. Future pot surveys will be dependent upon the department's ability to secure bids for charter work. The department has also been in discussion with industry representatives concerning their desire for departmental review of future, detailed proposals for survey work in this area.

The red king crab survey is too limited in geographic scope and too infrequent to provide a reliable index of abundance for the Aleutian Islands area.

Stock biomass and recruitment trends

Estimates of stock biomass are not available for this stock. No stock assessment model has been developed for this stock. Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. However, preliminary evidence indicates that red king crab stocks in the Adak area remain at low levels of abundance.

Tier determination/Plan Team discussion and resulting OFL determination

The team recommends this as a Tier 5 stock in 2008. B_{MSY} and MSST are not estimated. In May 2008 the CPT recommended that the OFL for 2008/09 be set at 26,287 pounds of bycatch only (representing the estimated average annual bycatch for the period 1996-2007). In June 2008 the SSC recommended that the 2008/09 OFL be set at 464,762 pounds of retained catch, computed as the average retained catch over the time period 1985/86-2007/08. Although the CPT disagree with the SSC recommendation for the 2008/09, this will form the basis for the OFL for this year.

The CPT note that the SSC recommendation relates to long-term productivity of the resource, but reiterates its concerns regarding the current status of this stock. The CPT will further analyze existing information and provide an updated rationale for an appropriate OFL for this stock given its current state in May 2009.

The SSC recommended exploring the possibility of using biomass dynamics (production) model to assess this stock, if the large observed changes in the distribution of the fishery can be adequately addressed. Information on bycatch estimates for the crab and groundfish fisheries during the 2007/08 season are included in the document. The CPT recommends the assessment better integrate the available bycatch information provided and anticipates computation of a total catch OFL for this stock in the May 2009 assessment.

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

Year	Biomass (MMB)	OFL	TAC	Retained Catch	Total Catch
2005/06	NA		Closed	0	0.004
2006/07	NA		Closed	0	0.010
2007/08	NA		Closed	0	0.011
2008/09	NA	0.46 [retained]	Closed	0	TBD

*catch listed here has not been discounted for mortality

No overfished determination is possible for this stock given the lack of biomass information. The CPT will evaluate whether overfishing occurred during 2008 when the catches for 2008/09 become available.

Additional Plan Team recommendations

For the May 2009 meeting, the Plan Team will discuss long-term plans for the assessment of this stock. While this fishery has a long history, with the domestic fishery dating back to 1961, much of the data on the stock prior to the early-to-mid 1980s is difficult to retrieve and analyze. Changes in definitions of fishery statistical areas over the history of the fishery also make it difficult to assess geographic trends in effort and catch over much of the fishery's history. Efforts to compile metadata would be very valuable.

Ecosystem Considerations summary

This stock is unsurveyed, remote, and data-poor. As information on predator/prey relationships becomes available, it will be included.

Table 3. Crab Plan Team final recommendations September 2008

Chap #	Stock	Tier (1-5) level	Stock Status level (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2008[2],[3] MMB	2008 MMB / MMB_{MSY}	Gamma γ.	Mortality (M)	2008/09 OFL mill lbs [note if retained only]
1	EBS snow crab	3	b	0.55	317.70	1979-2008 [recruitment]	251.10[2]	0.79	NA	0.23 0.29(mature females only)	77.30
2	BB red king crab	3	b	0.33	75.11	1995-2008 [recruitment]	95.58[2]	1.27	NA	0.18	24.20[4]
3	EBS Tanner crab	4	b	0.12	189.76	1969-1980 [survey]	108.28[2]	0.57	1.0	0.23	15.52
4	Pribilof Islands red king crab	4	a	0.18	8.66	1991-2007 [survey]	9.26[2]	1.07	1.0	0.18	3.32
5	Pribilof Islands blue king crab	4	c	0	9.28	1980-1984; 1990-1997 [survey]	0.25[2]	0.03	NA	NA	0.004
6	St. Matthew Island blue king crab	4	a	0.18	7.39	1989-2008 [model estimate]	10.74[2]	1.45	1.0	0.18	1.63 [retained]
7	Norton Sound red king crab	4	a	0.18	3.57	1983-2008 [model estimate]	5.24[3]	1.47	1.0	$0.18(M_1-M_5)$ $0.216(M_6)$	0.68 [retained]
8	AI golden king crab	5	NA	NA	NA	1985/86-1995/96 [retained catch]	NA	NA	NA	NA	9.18 [retained]
9	Pribilof Island golden king crab	5	NA	NA	NA	1993-1999 [retained catch]	NA	NA	NA	NA	0.17 [retained]
10	Adak red king crab	5	NA	NA	NA	1985/86-2007/08 [retained catch]	NA	NA	NA	NA	0.46 [retained]

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 2/15/2009 at time of mating.
3 Model mature biomass on 7/1/2008
4 Does not include female bycatch

Stock Assessment of eastern Bering Sea snow crab

Benjamin J. Turnock and Louis J. Rugolo
National Marine Fisheries Service
September 18, 2008

SSC Comments October 2007

Regarding the stock assessments for snow crab and Bristol Bay red king crab, a number of concerns were raised by the stock assessment authors and by the plan team that should be addressed by the authors in future assessments. Specifically, there are serious concerns about high fishing mortalities on the southern portion of the snow crab stock, which may exacerbate observed northward shifts in their distribution. The SSC recommends an analysis of the potential consequences of this high fishing mortality and of options for apportioning catch spatially. A second issue of concern is the presence of disturbing trends in the residuals of the fit to size frequency data, which may be a result of uncertainty in the practice of using shell condition as a proxy for shell age. We anticipate that these and other issues will be addressed in a requested CIE review of the snow crab assessment and the SSC looks forward to receiving a report on the review.

Changes to the Model and response to CIE review and SSC Comments

A CIE review on the Bering sea snow crab assessment model was conducted in March 2008. The reviewers suggested simplifying the model by not using shell condition in the estimation of fishery selectivities due to uncertainty in shell age and shell condition. The CIE review and SSC noted residual patterns in the first few bins of the length frequency fit.

To address these issues, the model was reconfigured to fit the pot fishery length frequencies for combined shell condition, equal to the procedure for survey data. One fishery selectivity curve was estimated for the total catch and one curve estimated for the retained catch for combined shell condition males in the directed fishery. To address the residual pattern, the recruitment distribution was shifted toward smaller size crab to better fit survey length data in the first length bin.

The CIE review also suggested that the mean growth of male and female crab should be equal at some small size.
The mean growth of males and females was changed so that both sexes had the same intercept in the linear growth equation. The slopes were adjusted so that growth at larger sizes was similar to growth observations, given the change in the intercepts.

The CIE review, the SSC and CPT have noted patterns in the residuals of the fit to the survey length frequency data.

A model that estimates a smooth function for the maturity probability for male and female crab was presented in the draft May 2008 assessment. The estimated maturity provided some improvement in residual patterns, however, projected catches and biomass values were very similar to the base model and are not presented in this assessment. Spatial differences in growth and maturity may occur and require development of a spatial model. Plots and tables presented here are for the base model

The CIE reviewers suggested investigating a simpler model fitting to total biomass and survey length frequency by sex only, with a simple knife-edge maturity function.

This will be investigated in future assessments, however, knife-edge maturity may not be a reasonable assumption, due to the link between maturity and growth for snow crab. Data on maturity status is collected each year for both males and females as part of the survey data, a knife-edge maturity schedule is unlikely to adequately represent growth with an animal with terminal molt.

CIE reviewers recommended not changing growth or maturity over time simply to fit the length frequency data.

Growth and maturity are constant over time in the model as in previous assessments.

Changes to the Data

Catch and fishery length frequency data were also updated through the 2007/8 season.
Survey abundance and length frequency data from 2008 were added to the model.

SUMMARY

A size based model was developed for eastern Bering Sea snow crab (*Chionoecetes opilio*) to estimate population biomass and harvest levels. Model estimates of total mature biomass of snow crab increased from the early 1980's to a peak in 1990 of about 1,580 million lbs. The total mature biomass includes all sizes of mature females and morphometrically mature males. Total mature biomass declined in the late 1990's to about 489 million lbs in 1999. The stock was declared overfished in 1999 because the survey estimate of mature biomass (330 million lbs) was below the minimum stock size threshold (MSST = 460 million lbs). A rebuilding plan was implemented in 2000. Model estimates of total mature biomass continued to decline to 348 million lbs in 2002, then increased to 556 million lbs in 2008. The 2007 observed survey total mature biomass increased to 607.8 million lbs, about 66% of Bmsy. However, in 2008 observed survey total mature biomass declined to 509.4 million lbs (55% of Bmsy). The observed survey estimate of males greater than 101 mm increased from about 135 million in 2006 to 151 million in 2007, then declined to 117 million in 2008. In 2006 there was a high degree of uncertainty in the estimated large male (>101mm) numbers. The 2007 survey estimate of 151 million crab had lower uncertainty than in 2006 estimate, with an estimated 95% confidence interval +/-40%. Two large tows in 2007 accounted for about 46 million of the 151 million large males. In the 2008 survey the largest tow accounted for about 8 million of the 117 million large males. Model estimates of large males (>101mm) were about 96 million crab in 2006, 132 million in 2007 and 155 million in 2008.

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 6.7 million lbs at the beginning of the directed fishery in 1973 to a peak of 328 million lbs in 1991, declined thereafter, then increased to another peak of 243 million lbs in 1998. Retained catch in the 2000 fishery was reduced to 33.5 million lbs 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 most recent GHL's. Retained catch in the 2006 fishery was 37 million lbs, 36.4 million lbs in 2007 and 63 million lbs in the 2008 fishery.

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. Discard mortality was assumed to be 50%.

Projected catch and biomass for 2008/9-2013/14 was estimated using mature male biomass at the time of mating (February) and fishing at the F35% and F40% control rules. Due to the decline in observed survey biomass in 2008, the trend in model estimated biomass is lower than estimated in the 2007 assessment. The 2008/9 mature male biomass at mating time is projected to be at 79% of B35% fishing at the F35% control rule and 84% of B35% fishing at the F40% control rule. Using a harvest control rule with B40% and F40%, the 2008/9 total catch was estimated at 59.7 million lbs (F = 0.40), with a retained catch of 49.7 million lbs. Using a harvest control rule with B35% and F35%, the 2008/9 total catch OFL was estimated at 77.3 million lbs (F = 0.55) with a retained catch of 64.7 million lbs.

F35%	OFL Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass
Year								
2008/9	77.3	60.2	93.4	64.7	0.55	251.1	175.2	555.5

The rebuilding plan developed for snow crab projected a 50% probability of rebuilding by 2010. The probability of rebuilding to the total survey mature biomass Bmsy of 921.6 million lbs in 2010 is 0% fishing at either the F35% or F40% control rules. The year of rebuilding to total survey biomass with fishing at the F40% control rule was estimated at 2020.

If snow crab are managed as a Tier 3 stock, then B35% would serve as a proxy for Bmsy, and mature male biomass at the time of mating would be used to assess the stock. Under tier 3 management, the probability of rebuilding to B35% in 2010 is 0.2%, fishing at F35%, and 5.3% fishing at F40%. Rebuilding to B35% using mature male biomass at mating time and fishing at F40% was estimated at 50% for the year 2015/16.

There is a high degree of uncertainty in future biomass and catch projections, and the projected OFLs and biomass may change when the next survey biomass is added to the model. The probability of rebuilding by 2010 is dependent on recruits estimated by the model and the trend in biomass in the last few years of the survey, while projections in later years will depend on the method of generating future recruitments. Biomass is expected to be slightly higher in 2009/10 to 2010/11, then decrease due to recent lower recruitment estimates and using autocorrelation to generate future recruitments in the projections. The use of random recruitment will result in a higher probability of rebuilding the stock relative to using a spawner recruit curve and autocorrelated recruitment as used in the projections presented here. The trends in future biomass will depend on realized catches and future recruitment and may change in future assessments as more data on the strength of the recent recruitments is obtained.

Exploitation rates in the southern portion of the range of snow crab have been higher than target rates estimated using abundances in the geographic distribution of the stock due to the majority of catch occurring in the southern portion of the snow crab range. This prominent feature of the fishery for Bering Sea snow crab has possibly contributed to the shift in distribution to less productive waters in the north. Computing the catch based on the complete survey biomass, then extracting that catch from only the southern component of the stock results in exploitation rates higher than the target rate on crabs in the southern area of the distribution. A biologically meaningful solution would be to split the catch into two regions, north and south, according to the percent distribution of the survey estimate of exploitable males from those regions or the distribution at the time of the fishery if known. In 2003 and 2004, 26% and 24% respectively of male biomass greater than 101 mm measure in the survey was south of 58.5 deg N. The distribution of catch in the 2006/7 fishery is similar to recent fisheries. Synchronizing the population distribution and catch distribution would result in realized exploitation rate at or close to the target rate in all areas.

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.

CATCH HISTORY

Snow crab were harvested in the Bering Sea by the Japanese from the 1960s until 1980 when the Magnuson Act prohibited foreign fishing. Retained catch in the domestic fishery increased in the late 1980’s to a high of about 328 million lbs in 1991, declined to 65 million lbs in 1996, increased to 243 million lbs in 1998 then declined to 33.5 million lbs in the 2000 fishery (Table 1, Figure 1). Due to low abundance and a reduced harvest rate, retained catches remained low and were 32.7 million lbs in the 2002 fishery (40.0 million lbs total catch (with 50% discard mortality), 28.3 million lbs of retained catch in 2003 (35.1 million lbs total catch). Retained catch in the 2005/6 fishery was 37.0 million lbs and in 2006/7 fishery, 36.4 million lbs. The retained catch for the 2007/8 fishery was 63 million lbs.

Discard from the directed pot fishery was estimated from observer data since 1992 and ranged from 11% to 64% (averaged about 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 9 million lbs, then declined to about 2 to 3 million lbs until 1998, when it declined to below 1 million lbs (except 2005, 1.4 million lbs). Discard in groundfish fisheries from highest to lowest catch is the yellowfin sole trawl fishery, flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery and the Pacific cod hook and line and pot fisheries.

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

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

101 mm CW. The average weight of retained crab has varied between 1.1 lbs (1983-1984) and 1.6 lbs(1979), and 1.3 lbs in the recent fisheries.

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

Harvest rates

The Harvest rate used to set the GHL (Guideline harvest level of retained crab only) previous to 2000 was 58% of the number of male crab over 101 mm carapace width estimated from the survey (Anonymous, 2000). 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 harvest strategy was developed based on simulations by Zheng (2002).

The actual 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 4). The exploitation fraction is calculated using the abundance for male crab over 101 mm estimated from the survey data reduced by the natural mortality from the time of the survey until the fishery occurs, approximately 7 months later, since the late 1980's. The historical GHL calculation did not include the correction for time lapsed between the survey and the fishery. In 1986 and 1987 the exploitation rate exceeded 1.0 because some crabs are retained that are less than 102 mm, discard mortality of small crabs is also included, and survey catchability may be less than 1.0. The exploitation fraction using the total catch divided by the mature male biomass estimated from the model, ranged from 10% to 50% (Figure 5). The exploitation fraction estimated by dividing the total catch by the model estimate of the crabs over 101 mm ranged from about 15% to 80% (Figure 5). The total exploitation rate on males > 101 mm was 50% to 75% for 1986 to 1994 and near 70% for 1998 and 1999 (year when fishery occurred).

Prior to adoption of Amendment 24, Bmsy (921.6 million lbs) was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (BSAI crab FMP 1998). MSST was defined as 50% of the Bmsy value (MSST=460 million lbs of total mature biomass). The harvest strategy since 2000/1 used a retained crab harvest rate on the mature male biomass of 0.10 on levels of total mature biomass greater than ½ MSST (230 million lbs), increasing linearly to 0.225 when biomass is equal to or greater than Bmsy (921.6 million lbs) (Zheng 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.

ABUNDANCE TRENDS

Survey Biomass

Abundance is estimated from the annual Bering Sea 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 deg 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 degrees N) and mature crabs deeper areas to the south of the juveniles (Zheng et al. 2001).

The total mature biomass (all sizes of morphometrically mature males and females) estimated from the survey declined to a low of 188 million lbs in 1985, increased to a high of 1,775 million lbs in 1991 (includes northern stations after 1989), then declined to 330 million lbs in 1999, when the stock was declared overfished (Table 2 and Figure 2). The mature biomass increased in 2000 and 2001, mainly due to a few large catches of mature females. Survey estimates of total mature biomass increased from 519 million lbs in 2006 to 607.8 million lbs in 2007, then decreased in 2008 to 509.4 million lbs.

The observed survey estimate of males greater than 101 mm increased from about 69 million in 2005 to 135 million in 2006, 151 million in 2007, then declined to 117 million in 2008. In 2006 there was a high degree of uncertainty in the estimated large male (>101mm) numbers, with the majority being caught in one tow. The 2007 survey estimate of 151 million crab has lower uncertainty than in 2006, with an estimated 95% confidence interval +/-40%. Two large tows in 2007 accounted for about 46 million of the 151 million large males. In the 2008 survey the largest tow accounted for about 8 million of the 117 million large males. Model estimates of large males (>101mm) were about 96 million crab in 2006 and 132 million in 2007 and 155 million in 2008.

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 and Orensanz unpub. Data).

Survey abundance by size for males and females indicate a moderate recruitment of small crab in 2004, 2005 and 2006 (Figures 6 through 9). High numbers of small crab in the late 1970’s 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 deg 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 2003, 66% of the catch was south of 58.5 deg N. (Figure 10), and in 2004 78% of the catch was south of 58.5 deg N. (Figure 11). In 2003 and 2004 the ice edge was farther north than past years, allowing some fishing to occur as far north as 60-61 deg N. Catch in the 2007 fishery was similar to recent years (Figure 12) with most catch south of 58 degrees N. and west of the Pribilof Islands between about 171 deg. W and 173 deg W.

Summer survey data from 2003 to 2007 show approximately 75% of the mature male snow crab population resides in a region outside of the fishery zone (north of 58.5 deg N Latitude). The 2003 survey estimated about 24% of the male snow crab >101mm were south of 58.5 deg N. About 48% of those males were estimated to be new shell. In 2004 and 2005, about 26 % of the survey abundance of male snow crab > 101 mm and the mature male biomass were south of 58.5 deg N. latitude (Figures 13 through 17). About 53% of those males south of 58.5 deg N. were estimated to be new shell (which are preferred by the fishery). The 2004 fishery retained about 19 million crab of which about 14.8 million were caught south of 58.5 deg south (about 78%). Although these new shell males are morphometrically mature (i.e., large clawed), at the time of the fishery, they are subject to exploitation prior to recruiting to the reproductive stock. The 2003 survey estimate of new shell male crab > 101 mm was about 7.6 million south of 58.5 deg N. which would have been fished on in the 2004 fishery. In the 2004 survey about 9.5 million new shell males >101mm were estimated south of 58.5 deg N.

The spatial distribution of large male snow crab in the 2007 survey was similar to 2005 (Figures 17 and 18), however, 2007 had fewer crab in the area to the south and west of St. Matthew Island. Female crab > 49 mm occurred in higher concentration in generally three areas, just north of the Pribilof Islands, just south and west of St. Matthews Island, and to the north and west of St. Matthew Island. Males > 78 mm were distributed in similar areas to females, except the highest concentrations were between the Pribilof Islands and St. Matthews Island.

The spatial distribution of large male snow crab in the 2008 survey was farther south and east than in 2007 (Figures 18 and 18b). The 2008 summer survey estimated about 56% of large males below 58.5 deg N, higher than in previous years. About 53% of large new shell males were estimated to be south of 58.5 deg N. New shell crab were 66% of the large crab south of 58.5 deg N. There was one large tow of large males that occurred at 168 W 57N, farther east than has been observed in recent years. Also in 2008 the largest tows resulted in estimates of abundance of about 8 million crab (in a 20nm by 20nm square), while in 2007 the largest tows were about 20-25 million crab.

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 deg N exceeds the target rate, possibly resulting in a depletion of males from the southern part of their range. Snow crab larvae probably drift north and east after hatching in spring. Snow crab appear to move south and west as they age, however, no tagging studies have been conducted to fully characterize the ontogenetic or annual migration patterns of this stock. High exploitation rates in the southern area may have resulted in a northward shift in snow crab distribution. Lower egg production in the south from lower clutch fullness and higher percent barren females possibly due to insufficient males for mating may drive a change in distribution to the north. The northward shift in mature females is particularly problematic in terms of annual reproductive output due to lowered productivity from the shift to biennial spawning of animals in waters < 1.5 deg C in the north. The lack of males in the southern areas at mating time (after the fishery occurs) may result in insufficient males for mating.

Armstrong and Ernst (in press) found the centroids of survey summer distributions have moved to the north over time (Figures 19 and 20). In the early 1980's the centroids of mature female distribution were near 58.5 deg N, in the 1990's the centroids were about 59.5 deg N. The centroids of old shell male distribution was south of 58 deg 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 (Figure 20). The distribution of males>101 mm was about at 58 deg N in the early 1980's, then was farther north (58.5 to 59 deg 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 deg N.(Figure 20). The centroids of the catch are generally south of 58 deg N, except in 1987 (Figure 20). 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 deg N in 1997 and 1998, then moved north to above 58.5 deg in 2002.

ANALYTIC APPROACH

Data Sources

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from 1978 to the 2008 season were used in this analysis. Observers were placed on directed crab fishery vessels starting in 1990. Size frequency data on the total catch (retained plus discarded) in the directed crab fishery were available from 1992 to 2008. Total discarded catch was estimated from observer data from 1992 to 2008(Table 1). The discarded male catch was estimated for 1978 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period 1992 to 2008. 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 ADF&G harvest strategy used since 2001, which assumes a discard mortality of 25% (Zheng 2002). The discard mortality assumptions will be discussed in a later section. The estimated discards previous to 1992 may be underestimates due to the lack of escape mechanisms for undersized crab in the pots prior to 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	1978-2008 (Year when fishery actually occurred)
Discarded male and female crab pot fishery size frequency	1992-2008
Trawl fishery bycatch size frequencies by sex	1991-2007
Survey size frequencies by sex and shell condition	1978-2008
Retained catch estimates	1978-2008
Discard catch estimates from snow crab pot fishery	1992-2008 from observer data
Trawl bycatch estimates	1973-2007
Total survey biomass estimates and coefficients of variation	1978-2008

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.

Details of the population dynamics and estimation equations, description of variables and likelihood equations are presented in Appendix A (Tables A.1, A.2 and A.3). The population dynamics equations, incorporating the growth transition matrix and molting probabilities are similar to other size based crab models (Zheng et al. 1995 and 1998). There were a total of 234 parameters estimated in the model (Table A.4) for the 30 year range of data (1978-2007). The 90 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 31 recruitment parameters estimated in the model, one for the mean recruitment, 30 for each year from 1979 to 2008 (male and female recruitment were fixed to be equal). There were 12 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 estimated. One parameter was estimated to fit the pot fishery CPUE time series.

Molting probabilities for mature males and females were fixed at 0, i.e., growth ceases at maturity which is consistent with the terminal molt paradigm (Rugolo et al. 2005 and Tamone et al. 2005). Molting probabilities were fixed at 1.0 for immature females and males. The intercept and slope of the linear growth function of postmolt relative to premolt size were fixed in the model using parameters estimated from growth measurements for Bering Sea snow crab (4 parameters, Table A.5). 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 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. Eighty-eight 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.

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 21).

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 (Lou Rugolo et al. 2005).

The probability of a new shell crab maturing was estimated outside the model to move crab from immature to mature in the model. The probability of maturing was estimated to match the observed fraction mature for all mature males and females observed in the survey data. While the fraction of all animals that are mature is fit well, the fraction of crab that are old shell is greater than in the survey data. The probability of maturing by size for female crab was about 50% at about 50 mm and increased to 100% at 80mm (Figure 22). The probability of maturing for male crab was 20% at 80 mm, increased to 50% at 100mm, about 905 at 120mm and 100% at 135 mm.

Selectivity

Selectivity curves for the retained and total catch were estimated as two-parameter ascending logistic curves (Figure 23). 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 the retention curve by the selectivities for the retained plus discarded size compositions.

The selectivities for the survey and trawl bycatch were estimated with two-parameter, ascending logistic functions (Survey selectivities in Figure 24). Survey selectivities were set equal for males and females. Separate survey selectivities were estimated for the period 1978 to 1981, 1982 to 1988, and 1989 to the present. The maximum selectivity was estimated in the model. The separate selectivities were used due to the change in catchability in 1982 from the survey net change, and the addition of more survey stations to the north of the survey area after 1988. Survey selectivities have been estimated for Bering Sea snow crab from underbag trawl experiments (Somerton and Otto 1999) (Figure 24). 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.

Growth

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

Growth data from 14 male crabs collected in March of 2003 that molted soon after being captured were used to estimate a linear function between premolt and postmolt width (Lou Rugolo unpublished data, Figure 25). 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 25),

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

The parameters a and b were estimated from the observed growth data for Bering Sea male snow crab. However, the intercept for both male and female crab was estimated as the average of the intercepts estimated for males from the Bering Sea data and the value assumed for females. Equal intercepts were used because growth of both sexes is probably equal at some small size.

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

$$Gr_{s,l\to l'} = \int_{l'-2.5}^{l'+2.5} Gamma(\alpha_{s,l}, \beta_s)$$

Where Gr is the growth transition matrix for sex, s and length bin l (premolt size). l’ is the postmolt size. The Gamma distribution is,

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

Where x is length and alpha and beta are parameters. Beta for both males and females was fixed in the model at 0.75.

Natural Mortality

A full discussion of natural mortality estimation for snow crab was presented in the 2007 assessment (Turnock and Rugolo 2007). 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 it may be correlated with other parameters, and therefore is usually fixed. However, a large portion of the uncertainty in model results (e.g. current biomass), will be attributed to uncertainty in natural mortality, when natural mortality is estimated in the model. 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).

We examined the empirical evidence for reliable estimates of oldest observed age for male snow crab. Radiometric aging of male snow crab carapaces sampled in the Bering Sea stock in 1992 and 1993, as well as the ongoing tag recovery evidence from eastern Canada reveal observed maximum ages in exploited populations of 17-19 years (Nevissi, et al 1995, St. Marie 2002). 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. M=0.23 was used for all immature crab and for mature male crab. M was set at 0.29 for mature female crab assuming that maturity occurs at a younger age and post–mature longevity is similar to mature male crab. Information of longevity of female crab is needed for estimation of M.

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).

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 have 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 (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 26 and 27). 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 faction of barren females was low in 2006, however, increased to high levels in 2007. Clutch fullness was high in 2006, then declined in 2007.

The fraction of barren females in the 2003 and 2004 survey south of 58.5 deg N latitude was generally higher than north of 58.5 deg N latitude (Figures 28 and 29). In 2004 the fraction barren females south of 58.5 deg 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 deg N latitude.

Laboratory analysis of female snow crab collected in waters less than 1.5 deg C and colder 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 deg C) were estimated from the summer survey data for 1982 to 2006 (Figure 30). The centroid is the average latitude and average longitude. In the 1980's the cold pool was farther south(about 58 to 59 deg N latitude) except for 1987 when the centroid shifted to north of 60 deg N latitude. The cold pool moved north from about 58 deg N latitude in 1999 to about 60.5 deg N latitude in 2003. The cold pool was farthest south in 1989, 1999 and 1982 and farthest north in 1987, 1998, 2002 and 2003. 2005 the cold pool was north, then in 2006 back to the south. Both 2007 and 2008 were 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.

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.

RESULTS

The total mature biomass increased from about 961 million lbs in 1978 to the peak biomass of 1,580 million lbs in 1990. Biomass declined sharply after 1997 to about 348 million lbs in 2002, then increased to 556 million lbs in 2008 (Table 3 and Figure 2). The model is constrained 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 animals 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 31). Parameter estimates for the 50% discard mortality model are in Table 7. During the last five years (2004 to 2008 fishery seasons) model estimates of discard mortality averaged 15% of the retained catch. Estimates of observed discard mortality ranged from 6% of the retained catch to 32% of the retained catch (assuming 50% discard mortality). In the 2007/8 observed fishery discard mortality was similar to past years at about 15% of the retained catch.

Mature male and female biomass show similar trends (Table 3, Figures 32 and 34). Mature male biomass increased from 263 million lbs in 2006 to 330 million lbs in 2007, then continued to increase to 369 million lbs in 2008 (adjusted by survey selectivity). Observed survey mature male biomass increased from 331 million lbs (2006) to 385 million lbs (2007), then declined to 306 million lbs in 2008. Model estimates of mature female biomass increased from 180 million lbs in 2006 to 192 million lbs in 2007, then declined to 187 million lbs in 2008. Mature female biomass observed from the survey increased from 189 million lbs in 2006 to 223 million lbs in 2007, then declined to 204 million lbs in 2008. Estimated biomass was lower in this assessment than in the 2007 assessment (Turnock and Rugolo 2007) due to the change in estimated survey selectivities, which resulted from the changes in fishery selectivity, growth and recruitment distribution (Figures 33 and 35).

Fishery selectivities and retention curves were estimated using ascending logistic curves (Figures 23 and 36). Selectivities for trawl bycatch were estimated as ascending logistic curves (Figure 37). Plots of model fits to the survey size frequency data are presented in Figures 38 and 40 by sex for shell conditions combined with residual plots in Figures 39 and 41. 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 the inconsistency in growth indicated by the observed survey length frequency data.

Survey selectivities for the period 1978 to 1981 were estimated at about 95% at 30 mm (Figure 24 and Table 9). Survey selectivities for the period 1982 to 1988 were estimated at 50% at about 43 mm and 95% at 69 mm. Survey selectivities for the period 1989 to the present were estimated at 50% at about 34 mm and 95% at 45 mm. These selectivities were the best fit determined by the model. An underbag experiment estimated survey selectivity of 50% at 78 mm and a maximum of about 89% at 135 mm (Somerton and Otto 1998) with the survey net in use since 1982. The survey selectivities are multiplied by the population numbers by length to estimate survey numbers for fitting to the survey data.

The estimated number of males > 101mm generally follows the observed survey abundance estimates (Figure 42). The observed survey estimate of males greater than 101 mm increased from about 69 million in 2005 to 135 million in 2006, 151 million in 2007, the decreased to 117 million in 2008. The estimated 95% confidence interval for the observed survey large males in 2007 was +/-40% of the estimate. Model estimates of large males were about 96 million crab in 2006, 132 million crab in 2007 and 155 million crab in 2008.

Two main periods of high recruitment were estimated by the model, in 1981 (fertilization year) and in 1987-1988 (Figure 43). Recruits are 25mm to about 40 mm and may be about 4 years from hatching, 5 years from fertilization (Figure 44, although age is approximated). Low recruitments were estimated from 1990 to 1996 and in 2000 to 2002. The 1998-1999 year classes appear to be about average recruitment that has resulted in an increase in biomass in recent years. The estimated recruitments lagged by 5 years (approximate fertilization year) from the model are close to the higher survey estimates of abundance of females with eggs and abundance of females with eggs multiplied by the fraction full clutch from 1975 to 1988 (Figure 45). Recruitment was low from 1990 to 1996, showing little relationship to the reproductive index. Exploitation rates were generally higher in 1986 to 1994, and in 1998-99 than prior to 1986 (Figure 4).

The size at 50% selected for the pot fishery for total catch (retained plus discarded) was 103.9 mm for males (shell condition combined, Figure 23). 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 46 through 48. Fits to the trawl fishery bycatch size frequency data are in Figures 49 and 50.

Fishing mortality rates ranged from about 0.19 to 1.85 (Figure 51). Fishing mortality rates were 0.53 to 1.85, for the 1986 to 2003 fishery seasons. Full selection fishing mortality was estimated at 0.32 for 2005, 0.53 for the 2006 and 0.49 for 2007, and 0.66 for 2008 (year fishery occurred).

Likelihood components included fits to the catch and survey length frequencies, catch and survey biomass values, recruitment constraint, constraint on fishing mortality values and fits and constraints on the estimation of the first year abundance by length (Table 8).

Harvest Strategy and Projected Catch

Current Harvest Strategy

Harvest strategy simulations are reported by Zheng et al. (2002) based on a model with structure and parameter values different than the model presented here. The harvest strategy by Zheng et al. (2002) was developed for use with survey biomass estimates and was applied to survey biomass estimates to calculate the 2007/2008 fishery season retained catch of 63 million lbs. Prior to the passage of Amendment 24, Bmsy was defined as the average total mature survey biomass for 1983 to 1997. MSST was defined as ½ Bmsy. The harvest strategy consists of a threshold for opening the fishery (230.4 million lbs of total mature biomass(TMB), 0.25*Bmsy), a minimum GHL of 15 million lbs for opening the fishery, and rules for computing the GHL.

In previous years, the MSY biomass (B_{MSY} = 921.6 million pounds TMB) and overfishing rate (F_{MSY} =M=0.3, the exploitation rate to apply to current mature male biomass (MMB)), was determined as a function of TMB as,

$$E = \frac{0.75 * Fmsy * \left[\frac{TMB}{Bmsy} - \alpha \right]}{(1-\alpha)}$$

for TMB ≥ 0.25*Bmsy and TMB<Bmsy, where α = -0.35, and,

- E = (Fmsy * 0.75) = 0.225, for TMB ≥ Bmsy, and E = 0 for TMB < 0.25*Bmsy.

The maximum for a GHL_{max} is determined by using the E determined from the control rule as an exploitation rate on mature male biomass at the time of the survey,

- GHL_{max} = E•MMB.

There is a 58% maximum harvest rate on exploited legal male abundance. Exploited legal male abundance is defined as the estimated abundance of all new shell legal males >=4.0-in (102 mm) CW plus a percentage of the estimated abundance of old shell legal males >=4.0-in CW. The percentage to be used is determined using fishery selectivities for old shell males.

Overfishing Control Rule

Amendment 24 to the FMP introduced revised the definitions for overfishing. The information provided in this assessment is sufficient to estimate overfishing based on Tier 3b. The overfishing control rule for tier 3b is based on spawning biomass per recruit reference points (EA 2007) (Figure 54).

$$F = \frac{F35\% * \left[\frac{MMB}{B35\%} - \alpha \right]}{(1-\alpha)}$$

α = 0.1. F on the directed fishery is set to zero when mature male biomass is below 25% of B35% (Figure 54). MMB is mature male biomass at the time of mating. Biomass and catch projections based on F35% and B35% were used to estimate the catch OFL (Table 6). Projections with F40% and B40% were used to evaluate the effect of a reduced catch on 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 0.707, lower than the value from the 2007 assessment (F35%=0.99, Turnock and Rugolo 2007) due to the change in fishery selectivities from combining shell condition. B35% was estimated at 317.7 million lbs, also lower than estimated in 2007 (355 million lbs) due to the changes in growth, recruitment distribution, fishery selectivities and the resulting change in estimated survey selectivity. F40% was estimated at 0.56 and B40% at 363.0 million lbs.

B40% and B35% were estimated using average recruitment from1978 to 2008 and spawning biomass per recruit for males fishing at F40% or F35% respectively.

A measure of productivity can be estimated from the natural log of the ratio of recruitment to mature male biomass (Figures 57 and 58). The period from 1978 to 1988(fertilization year) has the highest productivity and 1989 to 2002 the lowest. The most recent period since 1997 has an average productivity that is higher than 1989 -1996 and is near the average for the whole time period (1978-2002).

Estimated fishing mortality from 1979 fishing season to 2008 have been above the F35% control rule except for six years (1979, 1984-1985, 1996-97, 2005) (Figure 54). The target F historically (pre-2000 fishery season) was about 1.1 which was exceeded in many years. The last three fishery seasons (2006-2008) F was estimated at 0.52, 0.49 and 0.66 all above the F35% control rule. The F in 2008 was above the F35% control rule in part due to a lower estimated abundance of large males and mature male biomass than the observed survey and the 2007 model estimates of abundance and biomass.

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 2008 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 2008 mature male biomass projected forward to the time of mating time (spring 2009), and $w_{s,l}$ is weight at length by sex. $Sel_{s,l}$ are the fishery selectivities by length and sex for the total catch (retained plus discard) estimated from the population dynamics model (Figure 23).

Harvest recommendations

Fishing mortality, biomass values and total catches were projected for the 2008/9 to 2013/14 fishery seasons (Table 6). The MMB in spring 2009 was estimated to be 251 million lbs, about 79% of B35% if a retained catch of 64.7 million lb is taken. The MMB in spring 2009/10 is estimated to be 256 million lbs, about 81% of B35%. The OFL using F35% total catch for 2008/9 was estimated at 77.3 million lbs (with a retained catch of 64.7 million lbs). The 2008/9 F40% total catch was estimated at 59.7 million lbs, with a retained catch of 49.7 million lbs. Total catch includes retained directed pot fishery, discard pot fishery (with 50% mortality of discards) and trawl bycatch (80% mortality).
Catch and biomass projections using the model with maturity estimated were slightly lower, however, very similar to the base model (Table 8). Fishing mortality reference points were higher, however, fishery selectivities were estimated lower, due to the changes in sizes at terminal molt in the population.

Computing the catch based on the total survey area may result in exploitation rates higher than the target rate on crabs in the southern area of the distribution. One solution would be to split the catch into two regions, north and south, according to the percent distribution of the survey estimate of large males or mature males from those regions. This would require knowing the location of catch inseason. Two other approaches would not require knowledge on inseason catch location. One approach would be to compute the catch from that portion of the stock where most of the catch is extracted. Another approach would be to compute a catch that would result in the target harvest rate for the southern portion of the stock and increase that catch according to the percent catch in the north.

Projections and Rebuilding Scenarios

Projections and rebuilding trajectories were estimated using simulation with F35% and F40% harvest control rules and lognormally distributed, autocorrelated recruitment from a Beverton-Holt spawner recruit curve (steepness= 0.68, R0=2.0 billion, cv recruitment =0.86, autocorrelation = 0.6). The rebuilding plan developed for snow crab projected a 50% probability of rebuilding by 2010. The probability of rebuilding to the total survey biomass Bmsy of 921.6 million lbs is 0% in 2010, fishing at F35% or F40% (Table 6). The year of rebuilding to total survey biomass with fishing at the F40% control rule was estimated at 2020.

Under tier 3 management, the probability of rebuilding to B35% in 2010 is 0.2%, fishing at F35%, and 5.3% fishing at F40%. Rebuilding to B35% using mature male biomass at mating time and fishing at F40% was estimated at 50% for the year 2015/16.

Biomass is expected to be slightly higher in 2009/10 to 2010/11, then decrease due to recent lower recruitment estimates and using autocorrelation to generate future recruitments in the projections. There is a high degree of uncertainty in future biomass and catch projections, and the projected OFLs and biomass may change when the next survey biomass is added to the model. The probability of rebuilding by 2010 is dependent on recruits estimated by the model and the trend in biomass in the last few years of the survey, while projections in later years will depend on the method of generating future recruitments. The use of random recruitment will result in a higher probability of rebuilding the stock relative to using a spawner recruit curve and autocorrelated recruitment as used in the projections presented here. The trends in future biomass will depend on realized catches and future recruitment and may change in future assessments as more data on the strength of the recent recruitments is obtained

The probability of rebuilding in the first few years of the projection depends on the variance on biomass used in the projections (cv=0.15). In later years, as recruitments enter the mature stock, then most variability is due to variability in recruitment. The use of random recruitment will result in a higher probability of rebuilding the stock relative to using a spawner recruit curve and autocorrelated recruitment as used in the projections presented here.

The model and observed biomass estimates are below the expected trends in biomass from the snow crab rebuilding plan for 2002 to 2008, due partly to the decrease in observed survey biomass in 2008 (Figures 55 and 56). Catches in the early years of the rebuilding period (2001 to 2006) exceeded the expected catches due to higher realized biomass and to a change in the minimum GHL that kept the snow crab fishery open. Projected catches estimated from the F35% and F40% control rule are lower than the expected values from the rebuilding. Future survey data and realized catches will result in changes to projected values.

Conservation concerns

- The Bering Sea snow crab survey estimates of total mature biomass in 2008 were 55% of the survey Bmsy (921.6 million lbs), down from the 2007 survey biomass. The probability of rebuilding to total survey mature biomass Bmsy by 2010 is low under the F35% and F40% control rules.

- Moderate recruitment is estimated in 1998-1999 fertilization year, however, in general recruitment has been at low levels in the last 10 years (since 1994). The stock is projected to be relatively flat, then decline.

- 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.

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.

The experiment to estimate catchability of the survey trawl net needs to be repeated with larger sample sizes to allow the estimation of catchability by length, sex and shell condition for snow crab (and Tanner crab). This is needed to determine if the number of mature old shell crabs in the observed survey (which are lower than expected in the model) are due to mortality (fishery discard or natural mortality) or due to lower catchability in the trawl survey.

Female opilio in waters less than 1.5 deg 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 (1,000s of lbs) 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 2007/8 were estimated from observer data. Model estimates of male discard include a 50% mortality of discarded crab.

Year fishery occurred	Retained catch(1,000s of lbs)	Observed Discard male catch	Observed Retained + discard male catch	Model estimate of male discard	Discard female catch	Model estimate total directed catch	Year of trawl bycatch	trawl bycatch
1973	6,711						1973	30,046
1974	5,033						1974	41,582
1975	8,250						1975	16,096
1976	10,050						1976	6,975
1977	16,284						1977	4,722
1978-79	52,272			12,711	73	65,056	1978	5,422
1979-80	75,025			11,988	91	87,104	1979	4,357
1980-81	66,933			15,352	81	82,366	1980	3,170
1982	29,355			11,392	46	40,793	1981	1,323
1983	26,128			6,142	62	32,332	1982	538
1984	26,813			3,289	44	30,146	1983	693
1985	65,999			7,278	43	73,320	1984	737
1986	97,984			14,930	44	112,958	1985	632
1987	101,903			24,072	96	126,071	1986	2,716
1988	135,355			34,065	139	169,559	1987	8
1989	149,456			40,910	148	190,514	1988	974
1990	161,821			46,669	192	208,682	1989	1,131
1991	328,647			73,657	204	402,508	1990	865
1992	315,302	96,214	411,516	53,970	234	369,506	1991	9,578
1993	230,787	124,865	355,652	41,689	481	272,957	1992	4,669
1994	149,776	38,922	188,698	28,458	321	178,555	1993	3,010
1995	75,253	29,436	104,689	19,698	232	95,183	1994	3,393
1996	65,713	42,104	107,817	18,216	63	83,992	1995	1,844
1997	119,543	54,391	173,934	23,462	277	143,282	1996	2,074
1998	243,342	41,982	285,324	36,701	22	280,065	1997	2,906
1999	194,000	34,158	228,158	30,716	26	224,742	1998	2,159
2000	33,500	3,790	37,290	5,416	2	38,918	1999	796
2001	25,256	4,537	29,793	4,138	2	29,396	2000	889
2002	32,722	13,824	46,546	7,280	17	40,019	2001	635
2003	28,307	9,938	38,245	6,837	3	35,147	2002	384
2004	23,942	4,196	28,138	4,011	6	27,959	2003	289
2005	24,892	3,716	28,608	3,012	3	27,907	2004	740
2005/2006	36,974	9,965	46,939	5,311	12	42,297	2005	1,378
2006/2007	36,356	12,995	49,351	7,040	5	43,401	2006	385
2007/2008	63,000	18,560	78,560	13,408	66	76,364	2007	702

Table 2. Observed survey female, male and total spawning biomass(millions of lbs) 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	336.6	424.9	761.5	163.4
1979	712.2	528.7	1,240.9	169.1
1980	894.8	385.1	1,279.9	109.0
1981	480.2	262.1	742.3	45.4
1982	507.0	403.0	910.1	65.0
1983	316.6	355.3	671.9	71.5
1984	145.2	387.5	532.6	154.2
1985	21.2	167.2	188.4	78.2
1986	55.8	200.9	256.7	80.0
1987	448.4	462.2	910.6	141.9
1988	556.1	538.8	1,094.9	167.3
1989	1,006.2	712.3	1,718.4	175.4
1990	649.6	905.4	1,555.0	407.2
1991	793.0	981.8	1,774.8	466.6
1992	463.9	574.8	1,038.8	251.4
1993	505.0	545.3	1,050.3	140.8
1994	473.6	379.4	853.0	80.3
1995	622.0	507.8	1,129.8	69.0
1996	435.0	744.9	1,179.9	170.1
1997	387.6	663.5	1,051.2	308.5
1998	285.4	529.3	814.7	244.0
1999	113.5	216.6	330.1	92.2
2000	374.7	227.1	601.8	75.6
2001	318.4	339.2	657.5	79.4
2002	120.5	232.8	353.3	73.5
2003	130.2	197.8	328.0	64.6
2004	194.3	196.6	390.9	65.8
2005	256.7	294.8	551.4	68.9
2006	188.9	330.5	519.5	135.3
2007	222.6	385.2	607.8	150.8
2008	203.5	305.9	509.4	117

Table 3. Model estimates of population biomass, population numbers, male, female and total mature biomass(million lbs) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs.

Year	Biomass (million lbs 25mm+)	numbers (million crabs 25mm+)	female mature biomass	Male mature biomass	total mature biomass	Number of males >101mm (millions)	Recruitment (millions, 25 mm to 50 mm)	Male mature biomass at mating time(Feb of survey year+1)	Ratio mature females to mature males at mating time
1978	1,361	7,924	479	482	961	100	*	340	2.9
1979	1,324	6,764	567	458	1,025	121	640	289	4.1
1980	1,199	5,732	594	350	945	80	571	210	5.3
1981	1,076	4,863	541	281	822	51	529	197	5.1
1982	1,036	4,581	449	341	790	99	891	253	4.0
1983	1,063	5,364	378	408	786	153	1,863	309	3.2
1984	1,108	5,712	355	421	775	163	1,568	269	3.2
1985	1,174	6,435	356	384	740	138	2,047	219	3.5
1986	1,501	11,330	374	370	744	120	6,400	207	3.6
1987	1,824	11,307	501	441	943	149	2,511	242	3.9
1988	2,088	10,381	606	538	1,145	180	1,672	289	3.8
1989	2,246	8,692	629	703	1,332	236	779	416	3.1
1990	2,270	7,065	570	1,009	1,580	412	527	482	2.6
1991	1,920	6,551	483	978	1,461	415	1,467	458	2.4
1992	1,584	7,520	421	733	1,154	281	2,779	369	2.6
1993	1,416	7,652	422	522	944	172	2,018	288	3.0
1994	1,377	6,730	444	419	863	114	907	277	3.1
1995	1,412	5,311	434	487	921	148	165	350	2.8
1996	1,416	4,228	379	660	1,039	254	195	438	2.2
1997	1,255	3,340	307	728	1,036	310	202	362	2.1
1998	882	2,822	243	515	758	201	479	236	2.3
1999	601	2,709	201	288	489	86	710	213	2.2
2000	541	2,374	181	240	421	69	301	172	2.3
2001	508	2,095	164	212	376	60	279	145	2.4
2002	499	2,247	146	203	348	61	658	144	2.3
2003	536	2,847	136	221	358	79	1,128	166	2.1
2004	598	3,282	148	236	383	90	1,076	177	2.2
2005	655	3,161	170	240	410	89	612	167	2.5
2006	738	3,617	180	263	443	96	1,183	188	2.4
2007	792	3,067	192	330	522	132	275	218	2.3
2008	789	2,819	187	369	556	155	493	200	

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

Table 4. 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 5. Natural mortality estimates for Hoenig (1983) and the 5% rule given the oldest observed age.

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

Table 6. Projections using F35% and F40% rules for 2008/9 to 2013/2014 fishery seasons. Mature male biomass is at time of mating (millions of lbs). Large male biomass (>101mm) is at the beginning of the fishery. Survey total mature biomass is at the time of the survey (millions of lbs). Probability of rebuilding was estimated using total survey mature biomass with a target of 921.6 million lbs and for mature male biomass at the time of mating using B35% (317.7 million lbs). F35% = 0.707, F40%= 0.56, B40%= 363.0 million lbs. Total catch includes retained pot fishery catch (males), discard pot fishery catch (with 50% mortality)(males and females) and trawl bycatch (with 80% mortality) (males and females).

F35%	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	Prob. of rebuilding to Bmsy (921.6 mill lbs)	Prob. of rebuilding to B35%	Exp. Rate for total catch on MMB at time of fishery
Year											
2008/9	77.3	60.2	93.4	64.7	0.55	251.1	175.2	555.5	0.000	0.000	0.24
2009/10	81.9	54.6	116.6	69.1	0.57	255.9	183.0	553.4	0.000	0.000	0.24
2010/11	79.7	52.8	109.9	67.4	0.56	253.1	181.4	547.6	0.000	0.002	0.24
2011/12	67.5	44.6	96.0	57.6	0.52	239.3	166.2	533.8	0.001	0.002	0.22
2012/13	57.9	34.5	90.6	47.8	0.49	230.1	142.3	528.8	0.005	0.011	0.20
2013/14	71.2	31.9	151.6	58.0	0.52	251.1	159.2	578.9	0.041	0.104	0.22

F40%	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (Full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	Prob. of rebuilding to Bmsy (921.6 mill lbs)	Prob. of rebuilding to B35%	Exp. Rate for total catch on MMB at time of fishery
Year											
2008/9	59.7	45.3	73.6	49.7	0.40	266.9	175.2	555.5	0.000	0.000	0.18
2009/10	69.8	44.5	102.0	58.9	0.43	281.6	195.5	570.8	0.000	0.007	0.20
2010/11	70.9	46.3	99.6	60.2	0.43	283.3	199.9	573.7	0.000	0.053	0.20
2011/12	61.7	39.8	88.4	52.8	0.40	270.2	187.0	563.7	0.001	0.059	0.19
2012/13	53.3	31.8	84.4	44.4	0.38	259.5	162.7	558.5	0.007	0.091	0.17
2013/14	64.2	28.7	136.3	52.7	0.41	281.3	178.5	607.5	0.044	0.240	0.19

Table 7. Parameters values for the model, excluding recruitments and fishing mortality parameters.

Natural Mortality immature both sexes and mature males	0.23
Natural Mortality mature females	0.29
Female intercept (a) growth	6.773
Male intercept(a) growth	6.773
Female slope(b) growth	1.05
Male slope (b) growth	1.16
Alpha for gamma distribution of recruits	11.5
Beta for gamma distribution of recruits	4.0
Beta for gamma distribution female growth	0.75
Beta for gamma distribution male growth	0.75
Fishery selectivity total males slope	0.166
Fishery selectivity total males length at 50%	103.9
Fishery selectivity retention curve males slope	0.2535
Fishery selectivity retention curve males length at 50%	97.772
Pot Fishery discard selectivity female slope	0.305
Pot Fishery discard selectivity female length at 50%	70.619
Trawl Fishery selectivity slope	0.0676
Trawl Fishery selectivity length at 50%	120.0
Survey Q 1978-1981	1.0
Survey 1978-1981 length at 95% selected	48.35
Survey 1978-1981 length at 50% selected	28.25
Survey Q 1982-1988	0.953
Survey 1982-1988 length at 95% selected	68.02
Survey 1982-1988 length at 50% selected	43.15
Survey Q 1989-present	1.0
Survey 1989-present, length at 95% selected	43.67
Survey 1989-present length at 50% selected	33.14
Fishery cpue q	0.00104

Table 8. Likelihood values by component for the snow crab assessment model.

Likelihood Component	Likelihood value
recruitment	22.1
fishery length retained	-1795.4
fishery length total	761.4
fishery length female	122.3
length survey	4560.3
length trawl bycatch	216.7
Fishing mortality penalty	517.6
total catch biomass	41.7
retained catch biomass	37.5
female discard biomass	0.1
trawl bycatch	111.8
survey biomass	1467.8
initial year abundance by length	4.4
initial year abundance by length smooth constraint	71.0
total	6139.1

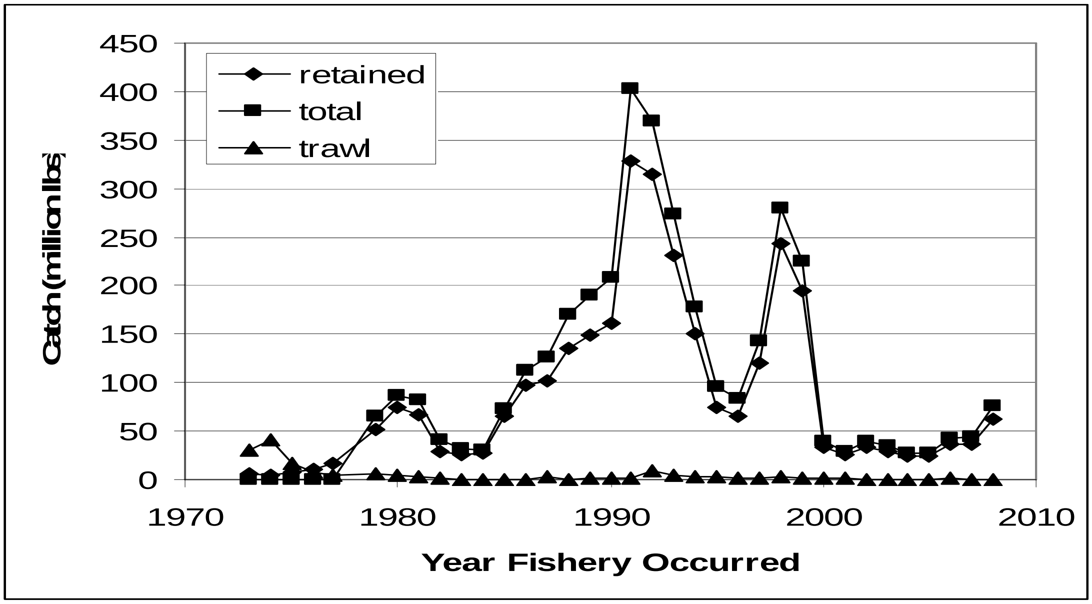

Figure 1. Catch (million lbs) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch is retained catch plus discarded catch after 50% discard mortality was applied. Trawl bycatch is male and female bycatch from groundfish trawl fisheries with 80% mortality applied.

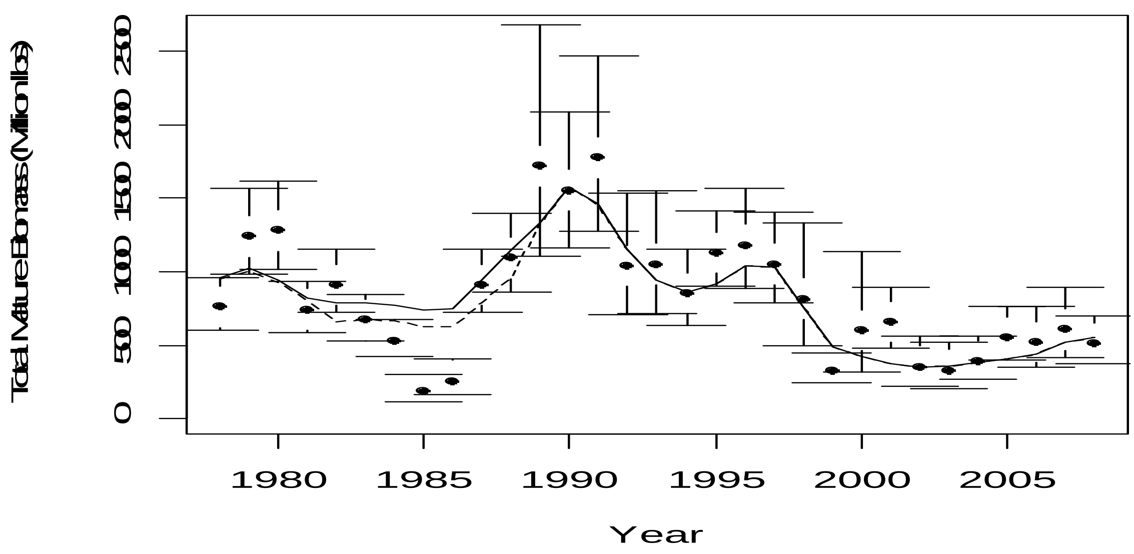

Figure 2. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

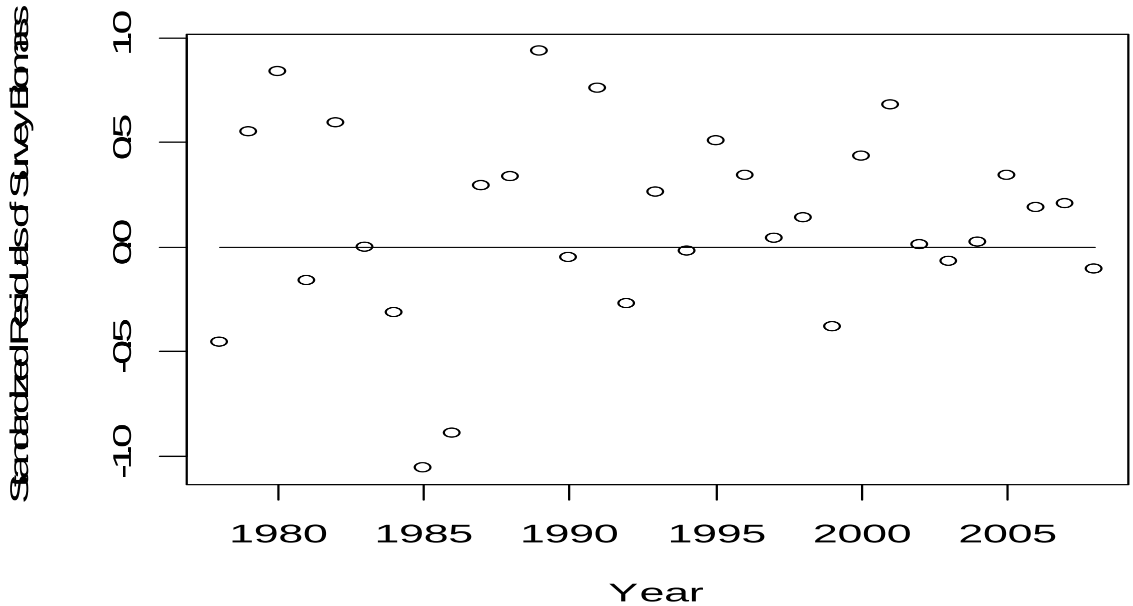

Figure 3. Standardized residuals for model fit to total mature biomass from Figure 2.

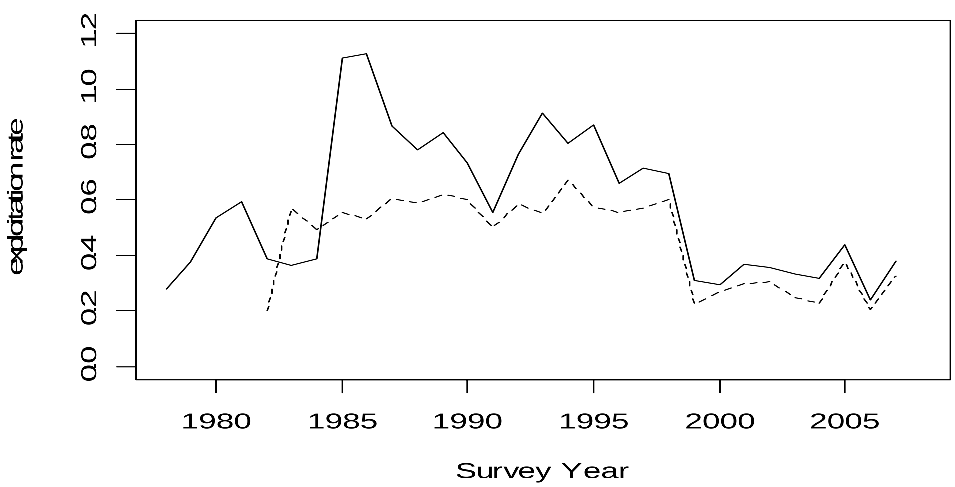

Figure 4. Exploitation rate estimated as the preseason GHL divided by the survey estimate of large male biomass (>101 mm) at the time the survey occurs (dotted line). The solid line is the retained catch divided by the survey estimate of large male biomass at the time the fishery occurs. Year is the survey year.

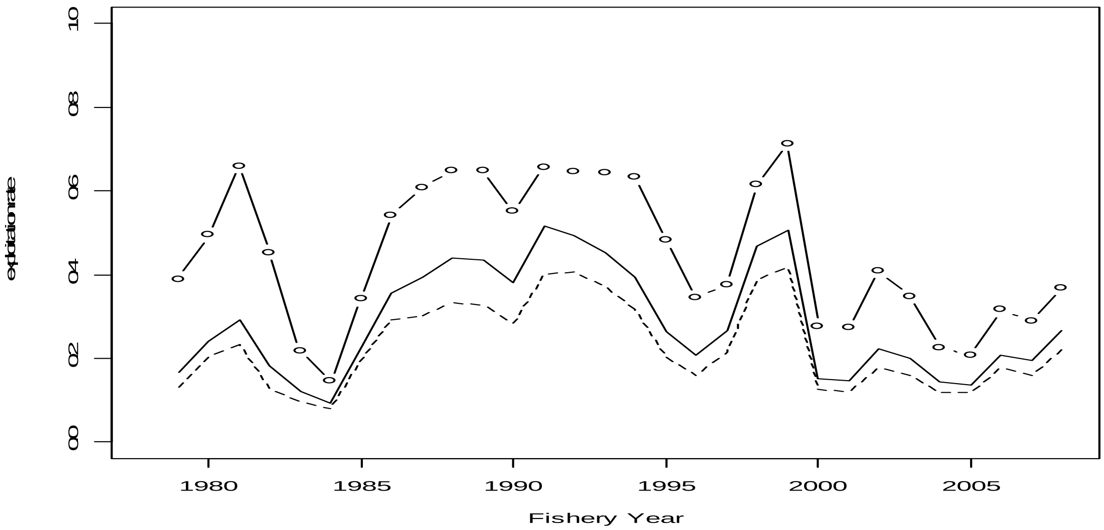

Figure 5. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line and dotted line). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the solid line with dots. Year is the year of the fishery.

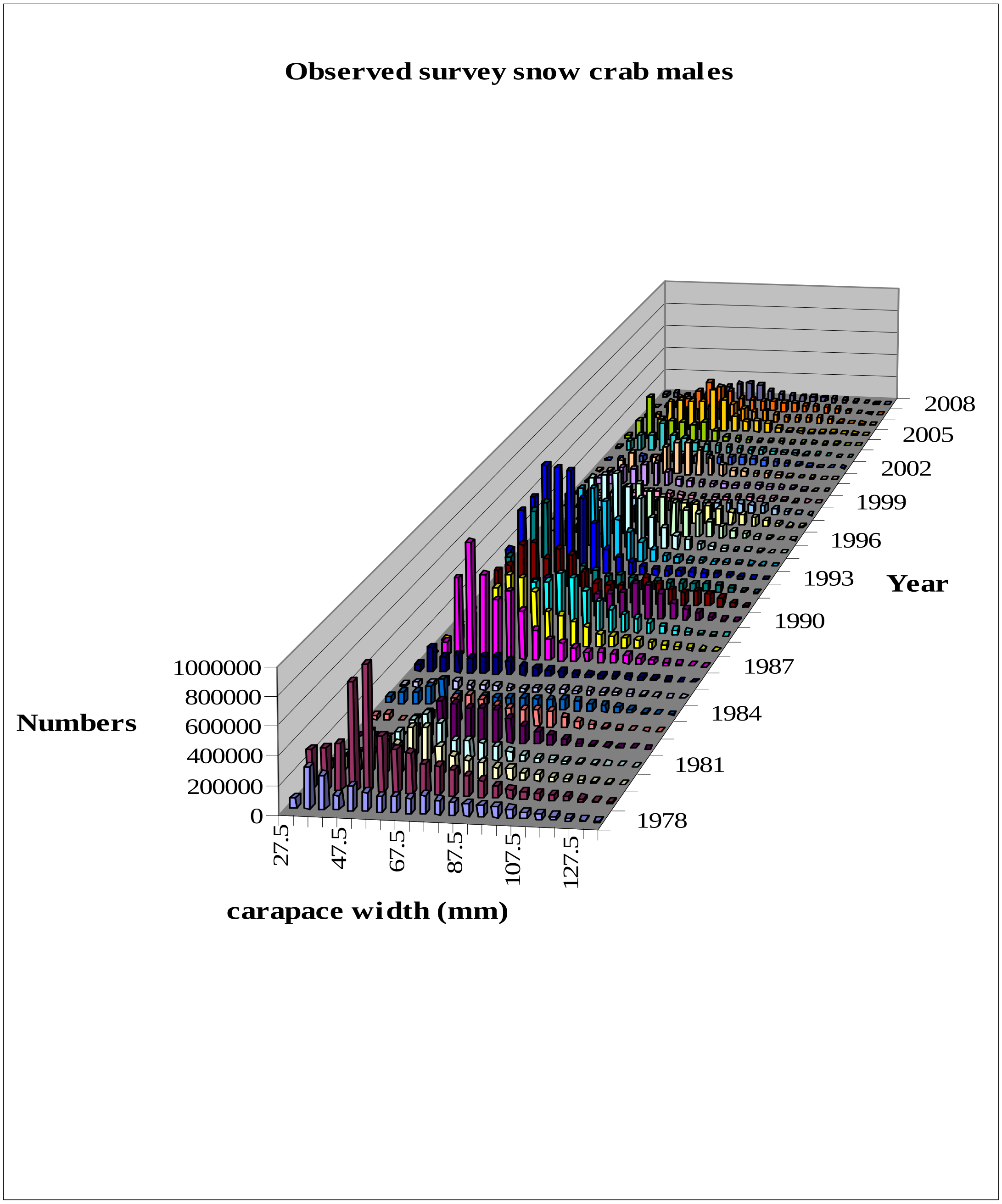

Figure 6. Observed survey numbers (1000's of crab) by carapace width and year for male snow crab.

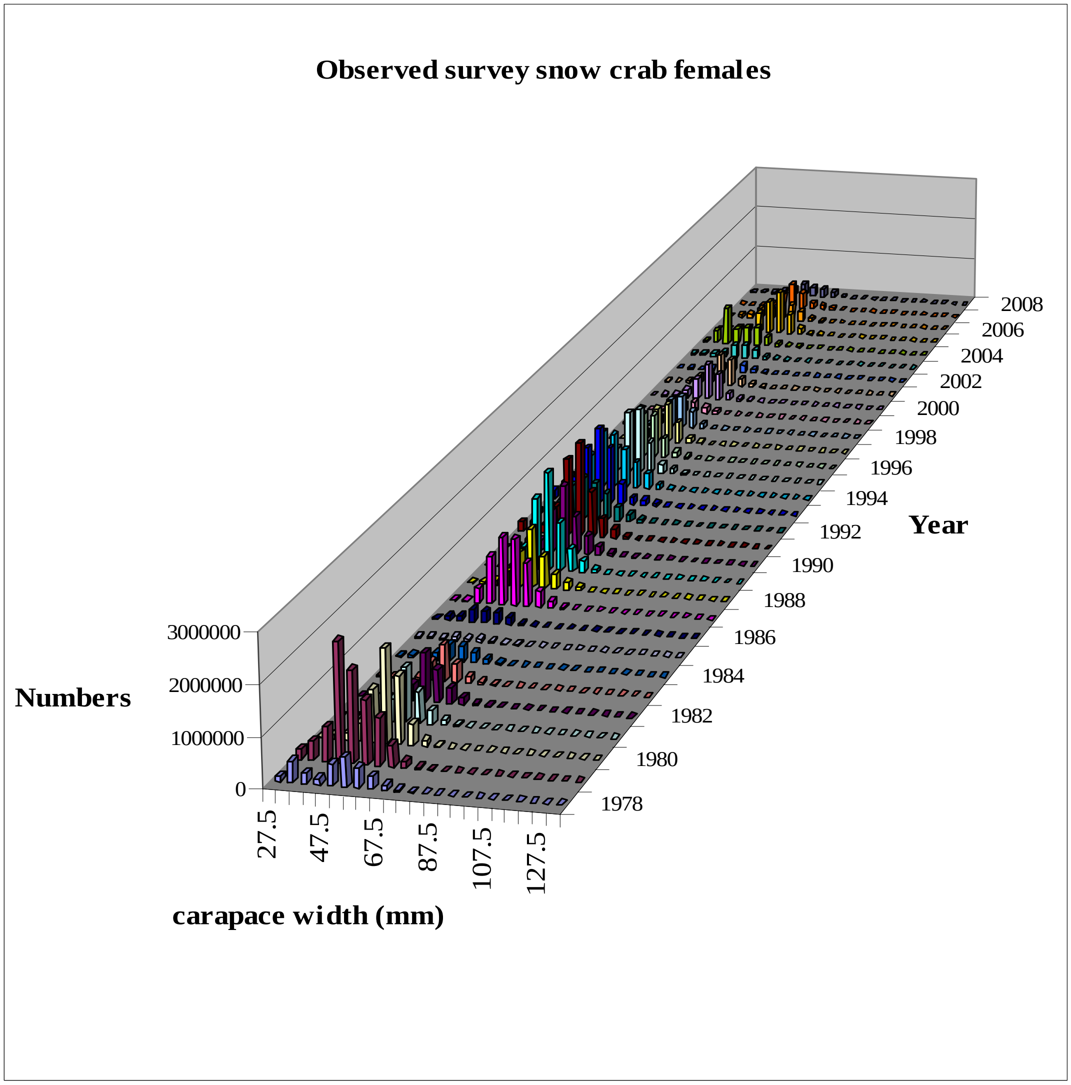

Figure 7. Observed survey numbers (1000's of crab) by carapace width and year for female snow crab.

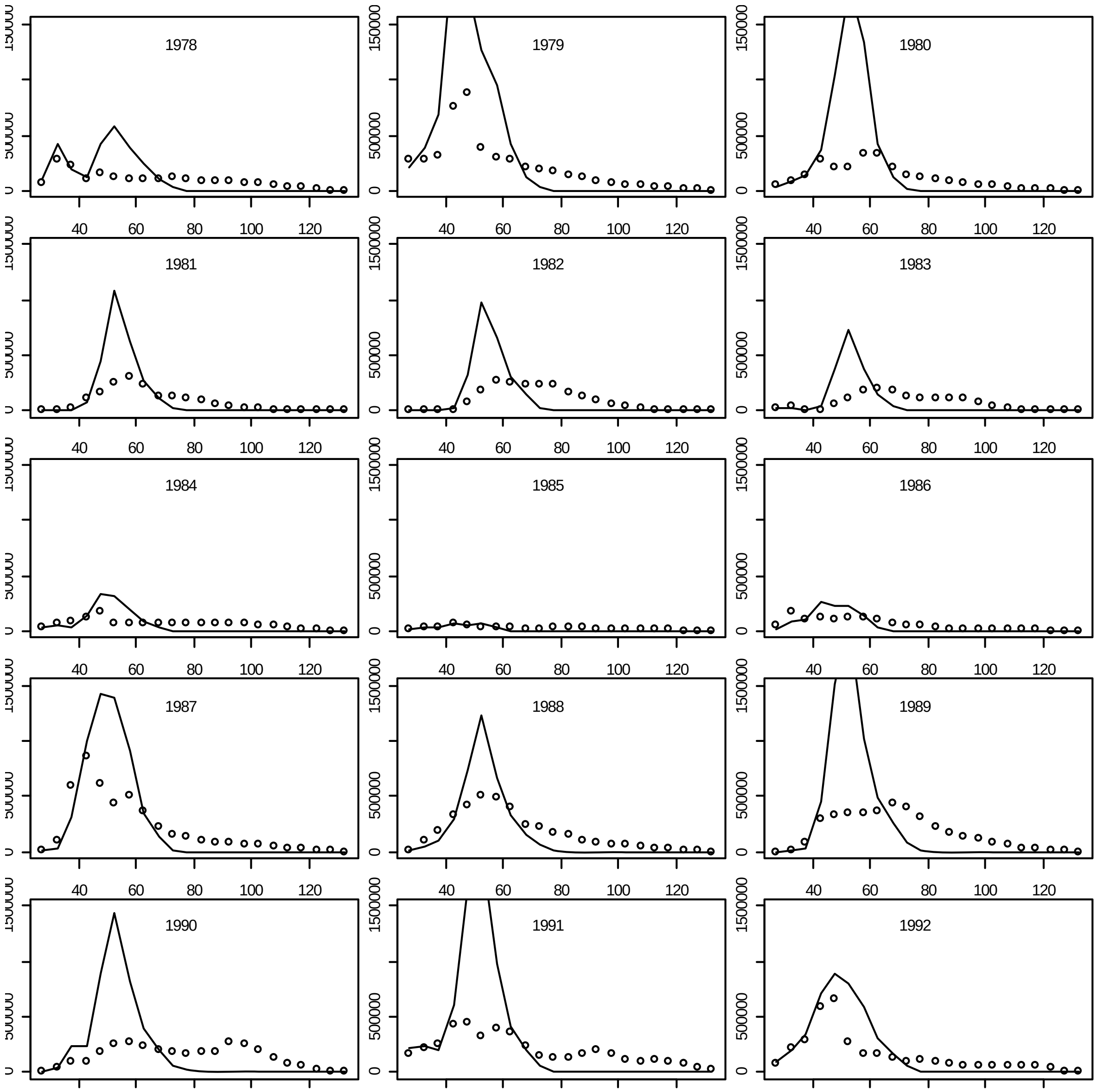

Figure 8. Observed survey numbers by length, males circles, females solid line.

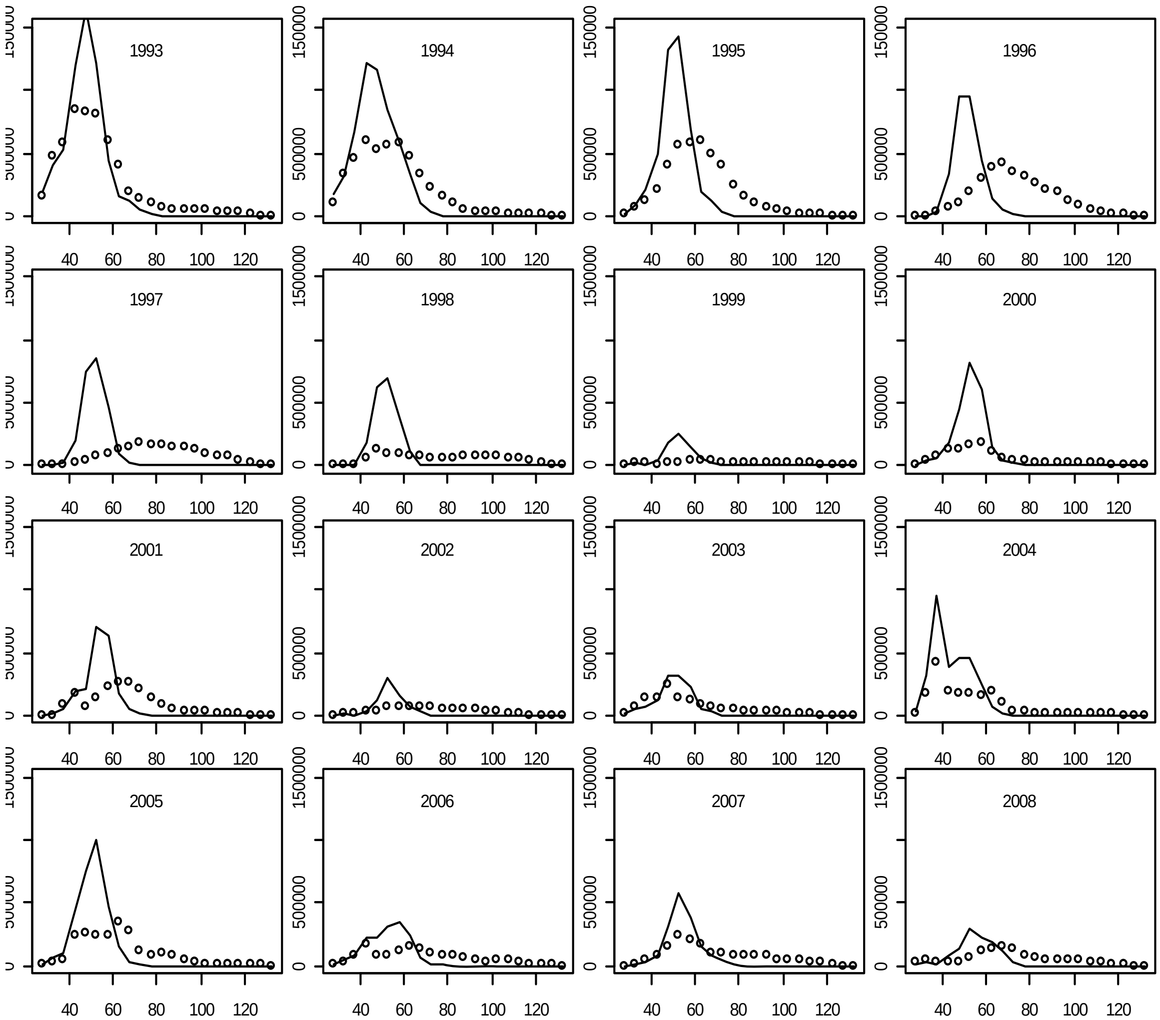

Figure 9. Observed survey numbers by length, males circles, females solid line.

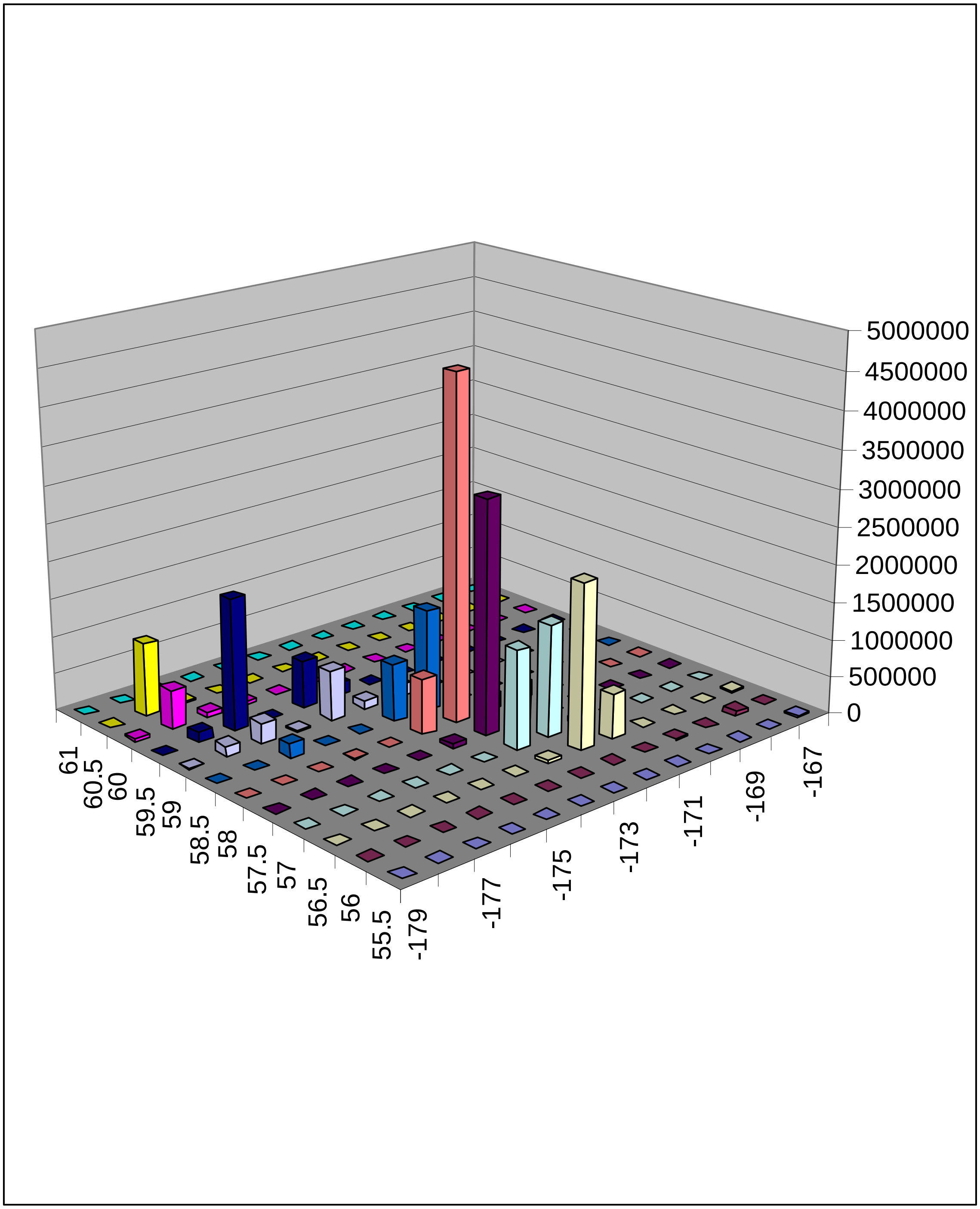

Figure 10. 2003 pot fishery retained catch in numbers by statistical area. Longitude in negative degrees. Areas are 1 degree longitude by 0.5 degree latitude.

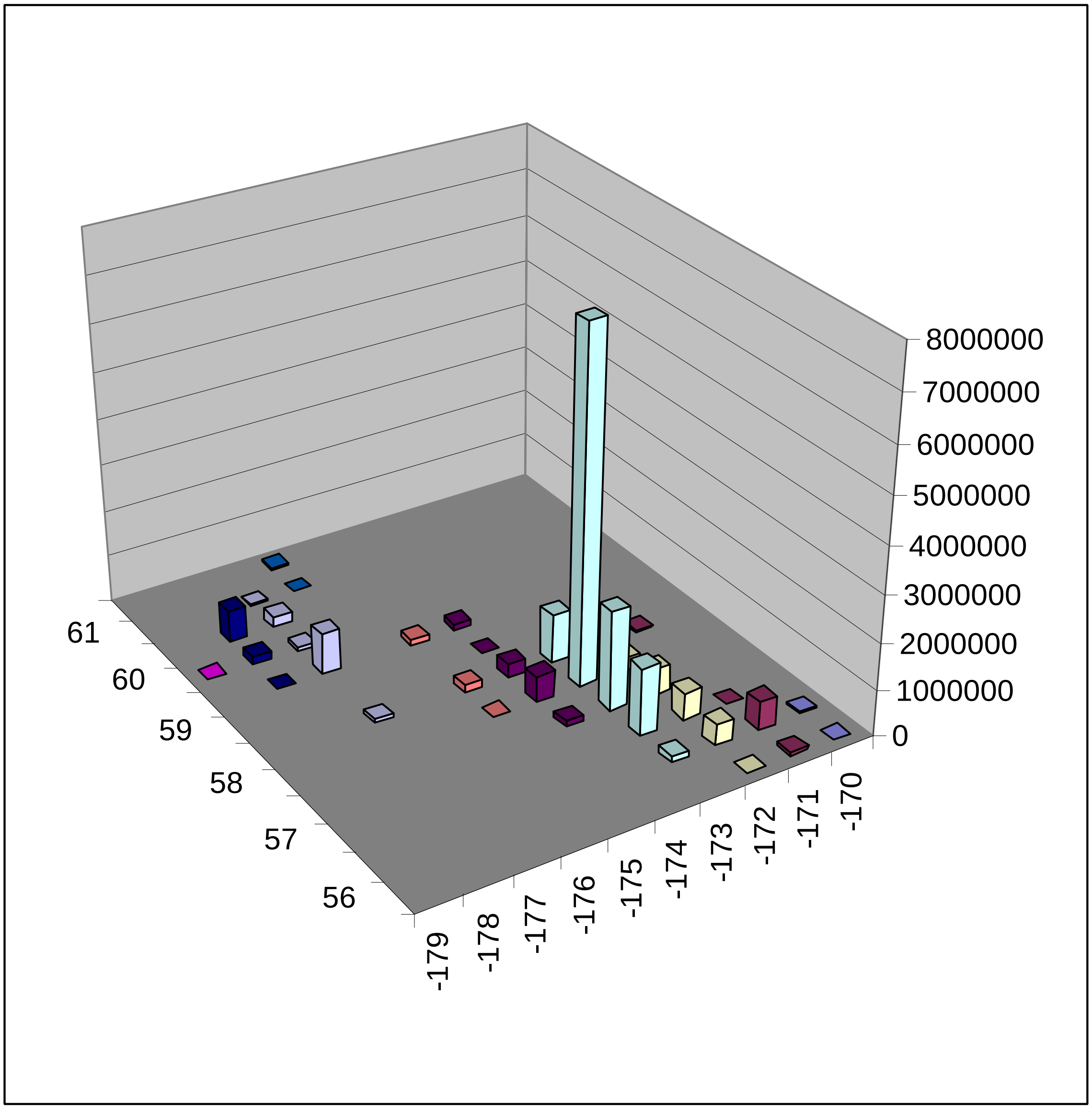

Figure 11. 2004 pot fishery retained catch in numbers by statistical area. Longitude in negative degrees. Areas are 1 degree longitude by 0.5 degree latitude.

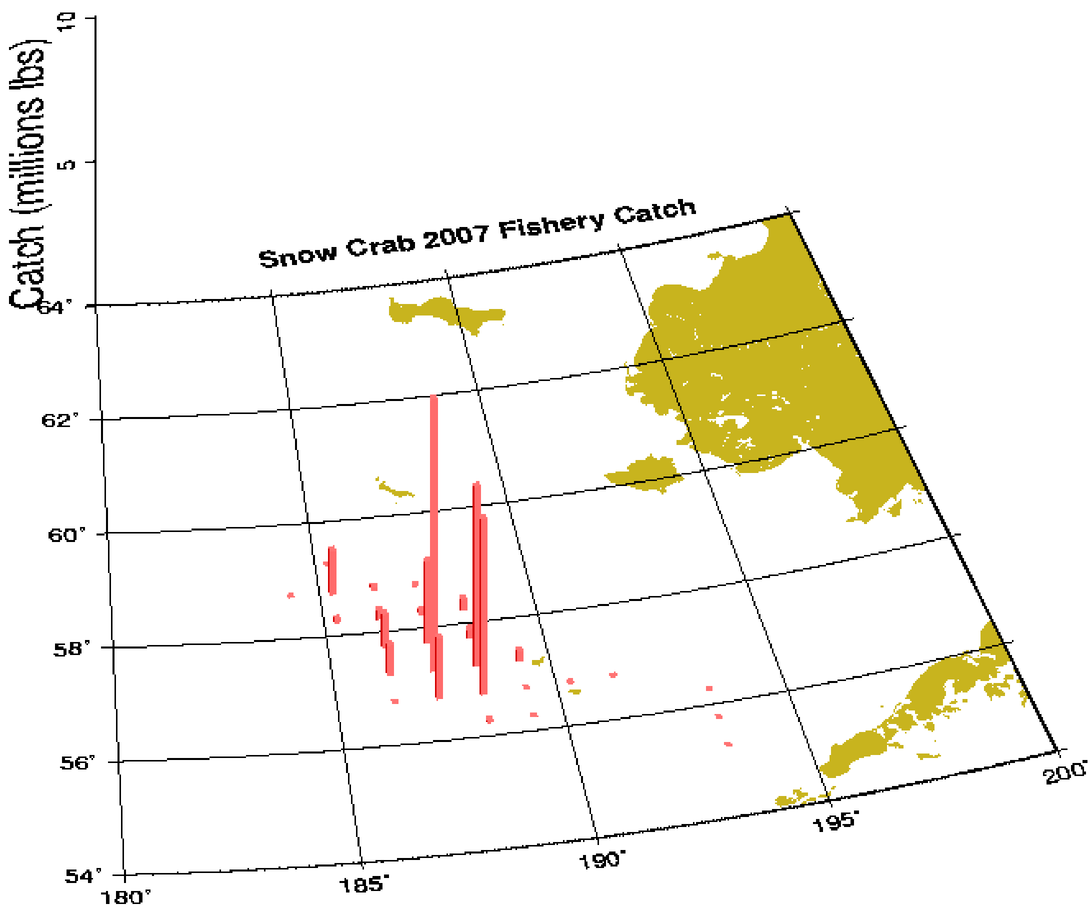

Figure 12. 2007 (2006 survey year) pot fishery retained catch(million lbs) by statistical area. Longitude increases from west to east (190 degrees = 170 degrees W longitude). Areas are 1 degree longitude by 0.5 degree latitude.

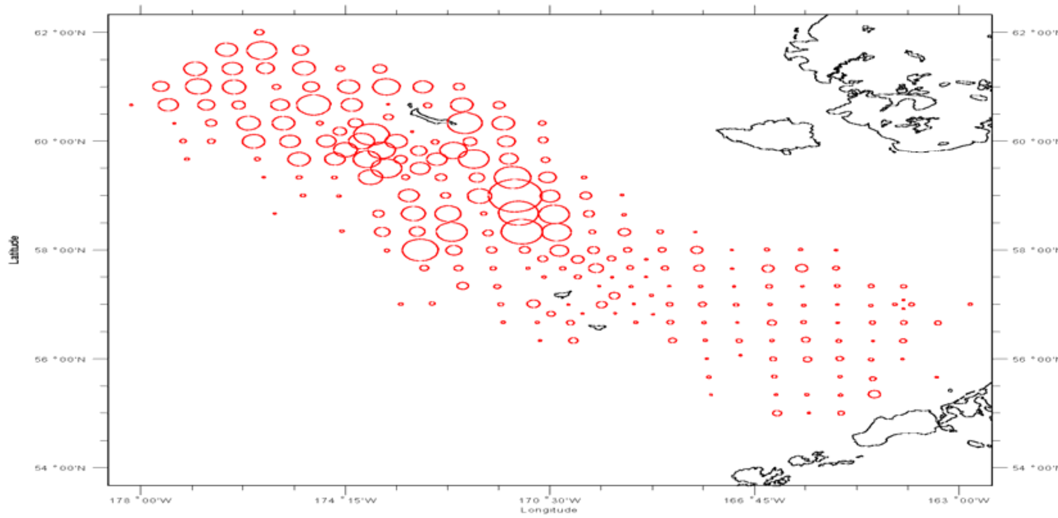

Figure 13. 2004 Survey abundance of males > 79 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle.

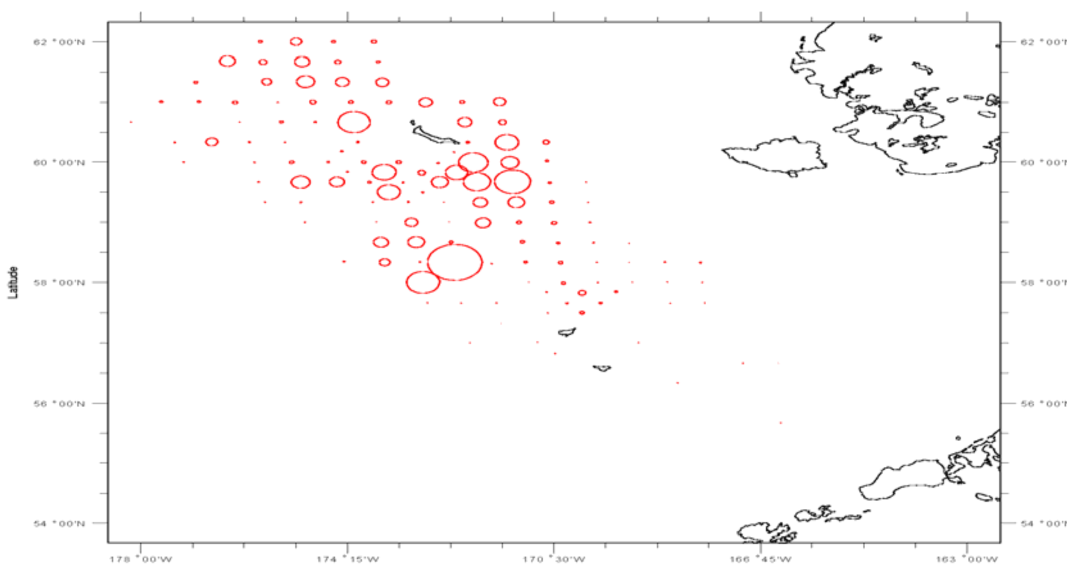

Figure 14. 2004 Survey abundance of females > 49 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle.

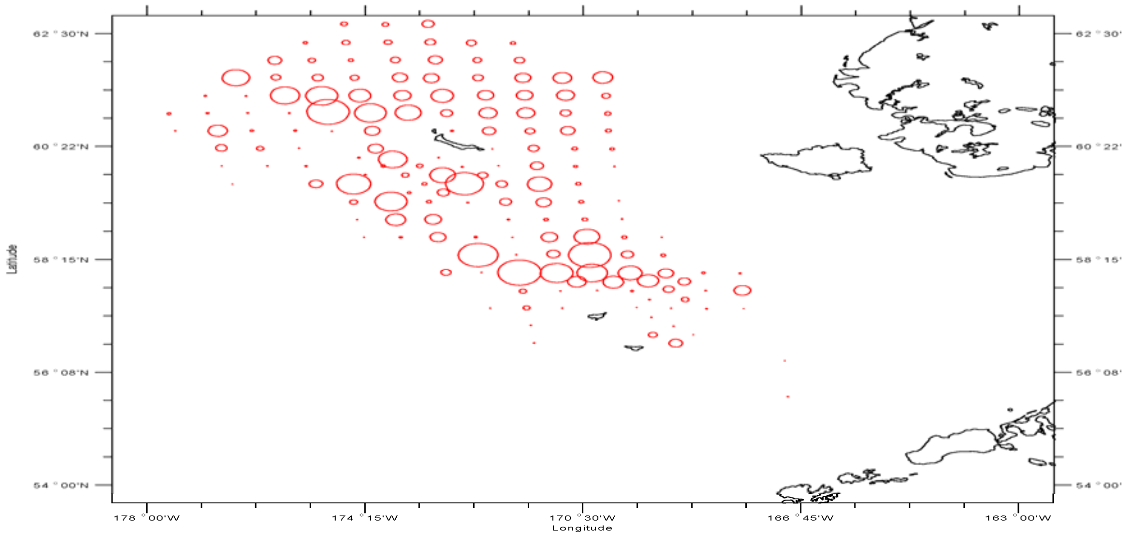

Figure 15. 2005 Survey abundance of females > 49 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle (not on the same scale as male abundance in Figure 54). Includes stations to the north of the standard survey area.

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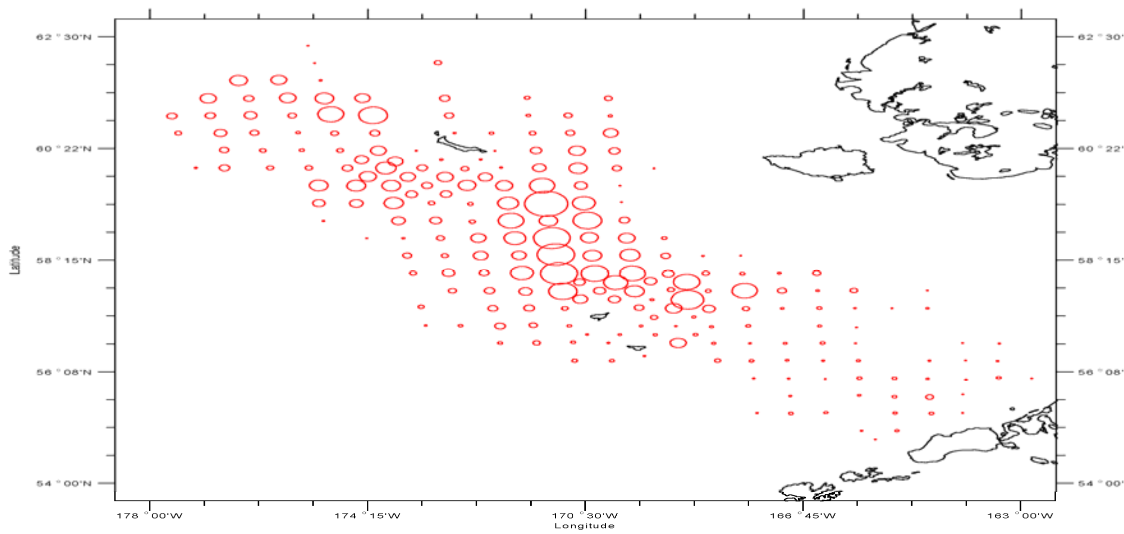

Figure 16. 2005 Survey abundance of males > 79 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle (not on same scale as female abundance in Figure 53).

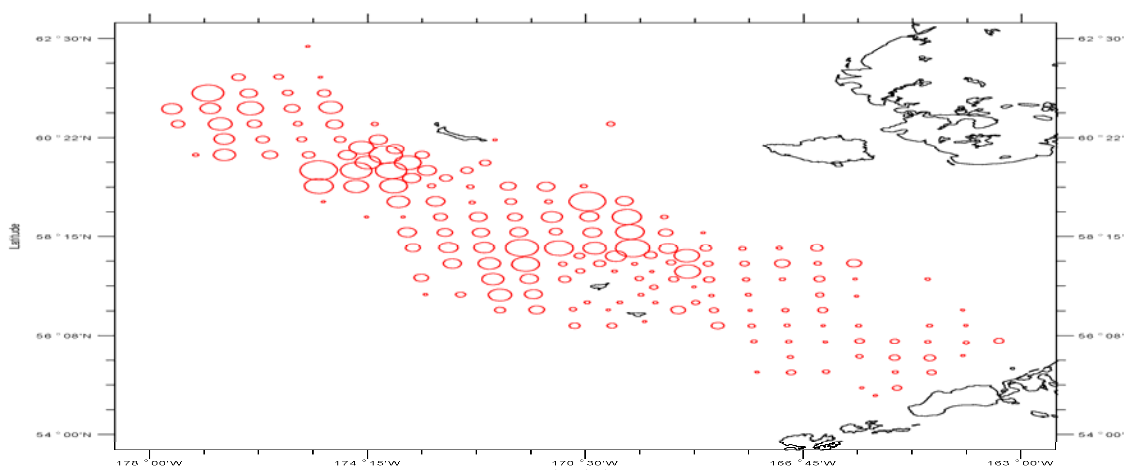

Figure 17. 2005 Survey abundance of males > 101 mm by tow. Abundance is proportional to the area of the circle.

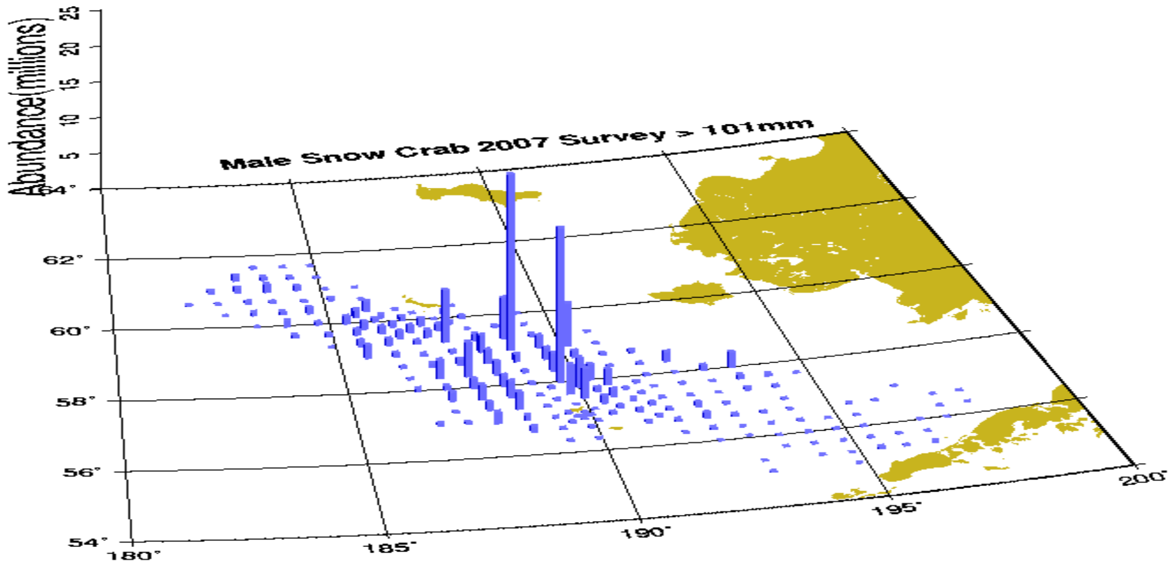

Figure 18. 2007 Survey abundance of males > 101 mm by tow. Abundance is in millions of crab.

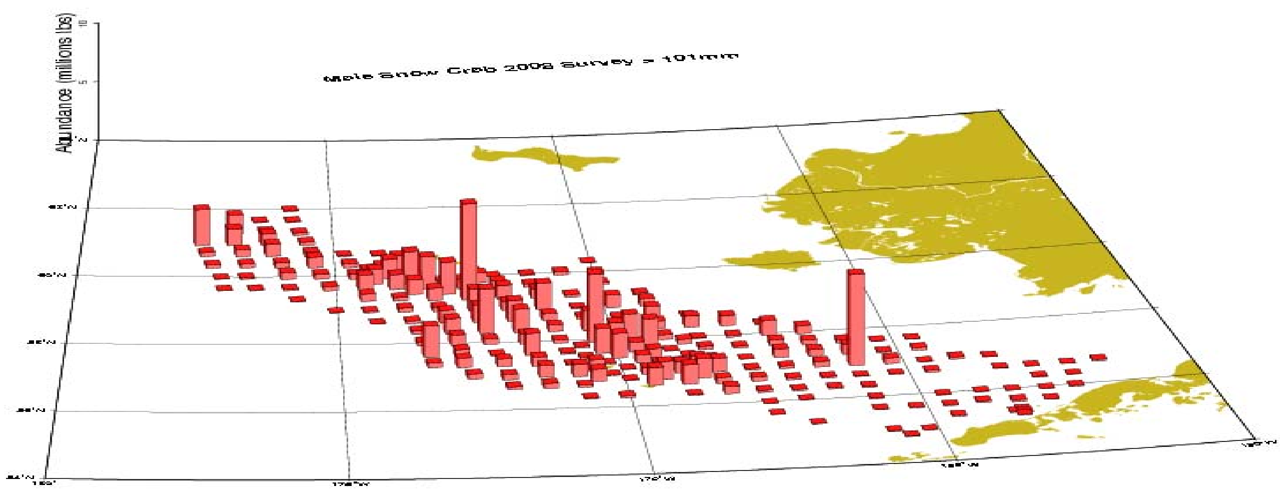

Figure 18b. 2008 Survey abundance of males > 101 mm by tow. Abundance is in millions of crab.

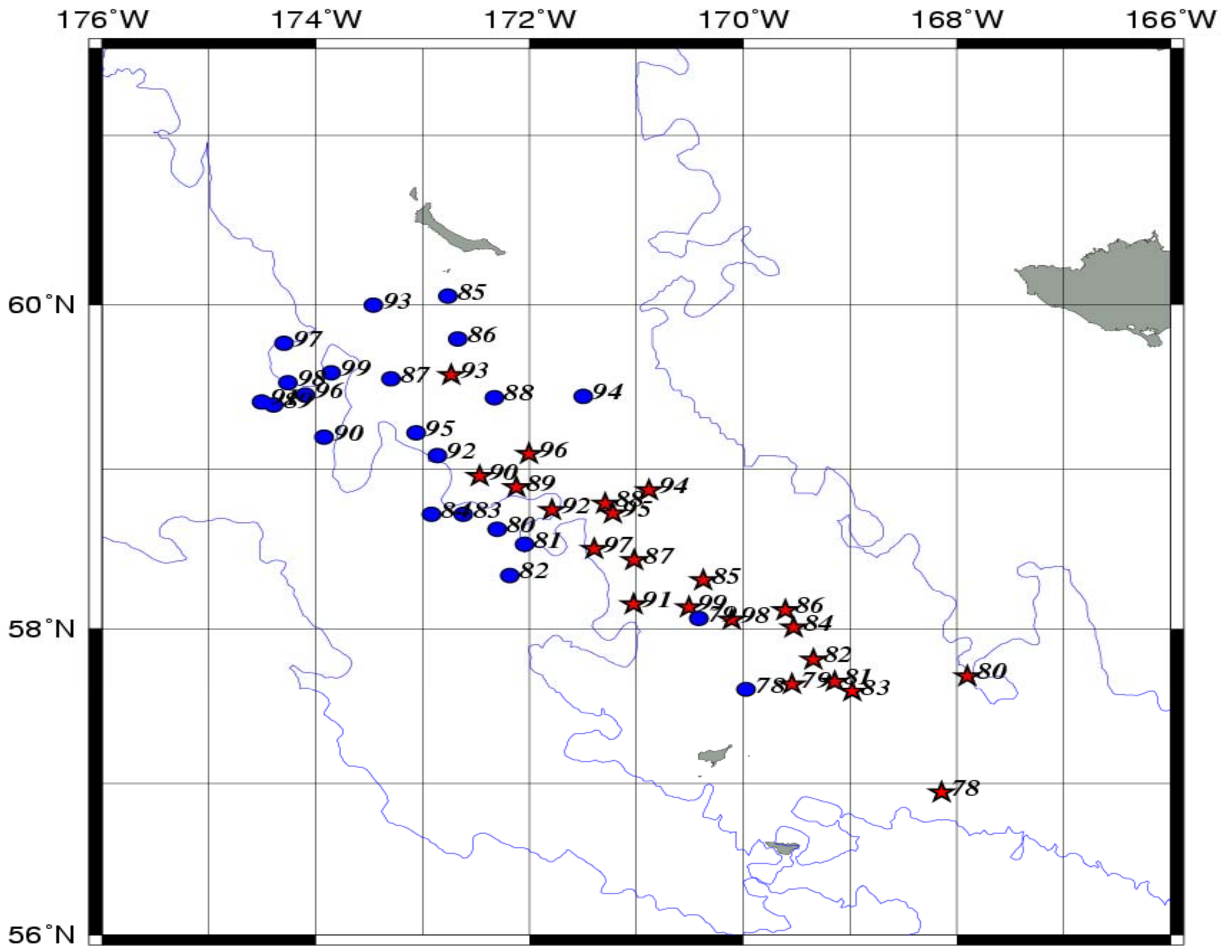

Figure 19. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars. Reprinted from Orensanz, Armstong and Ernst (in press).

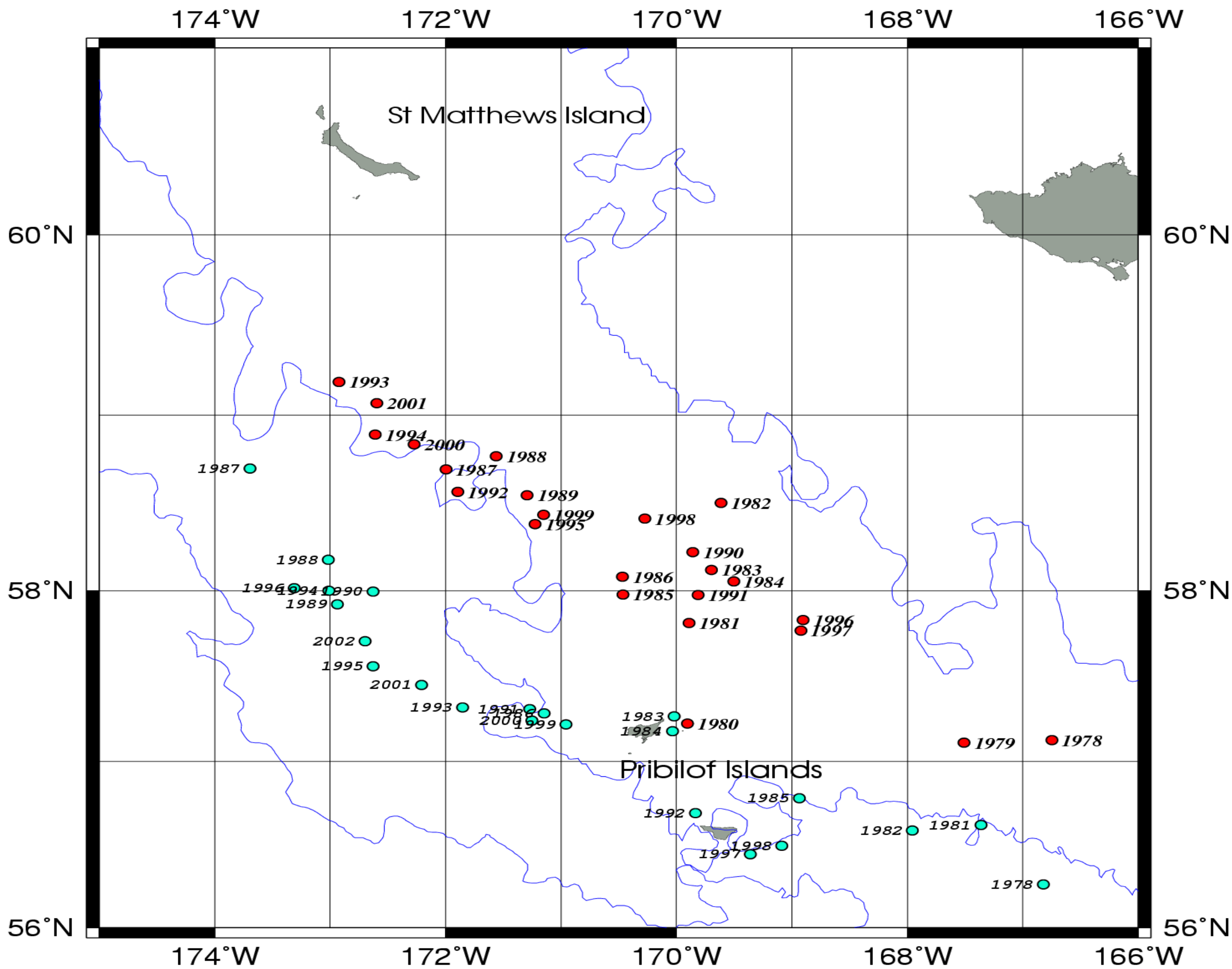

Figure 20. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green), from Orensanz, Armstong and Ernst (in press).

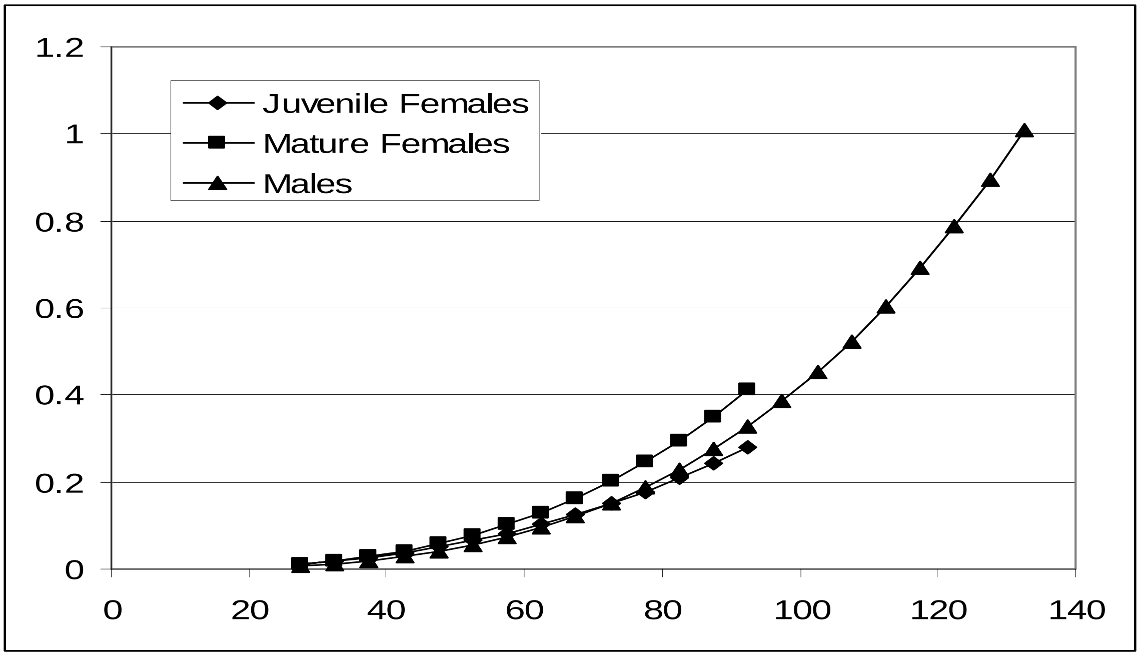

Figure 21. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

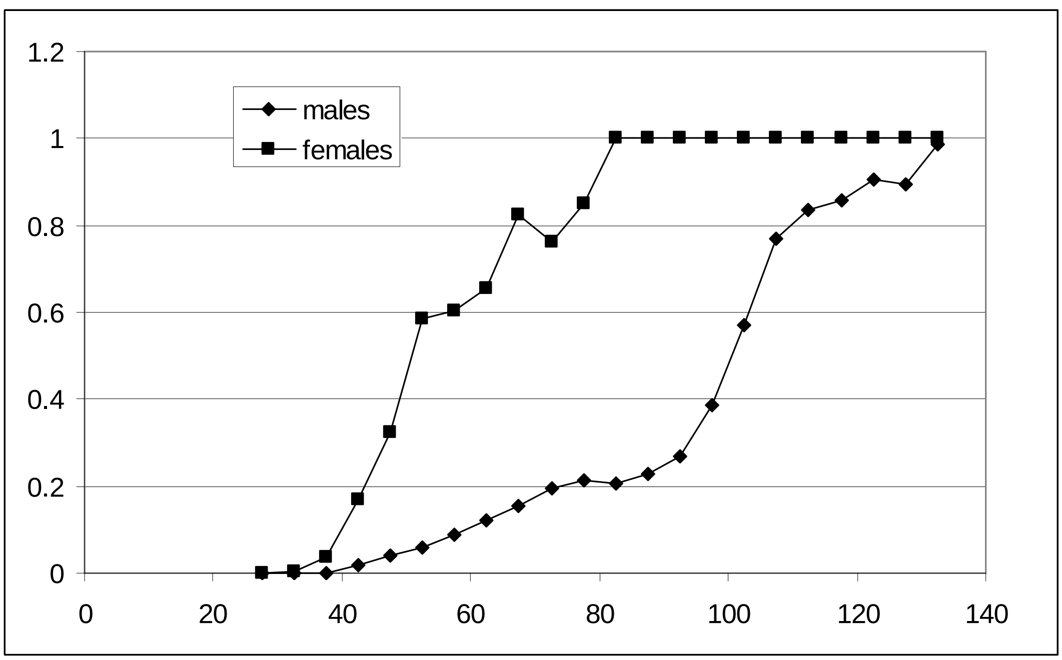

Figure 22. Probability of maturing by size for male and female snow crab (<u>not</u> the average fraction mature).

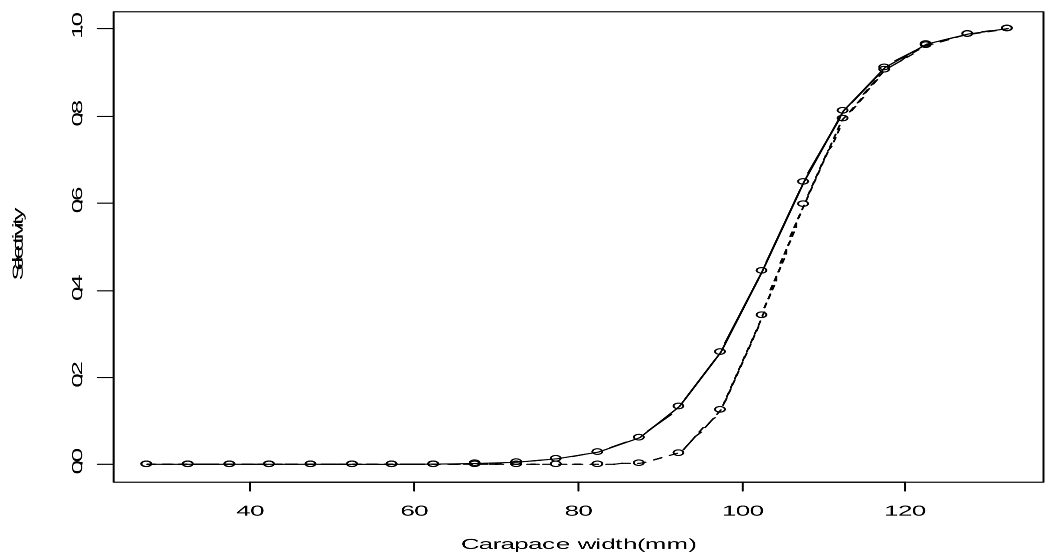

Figure 23. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

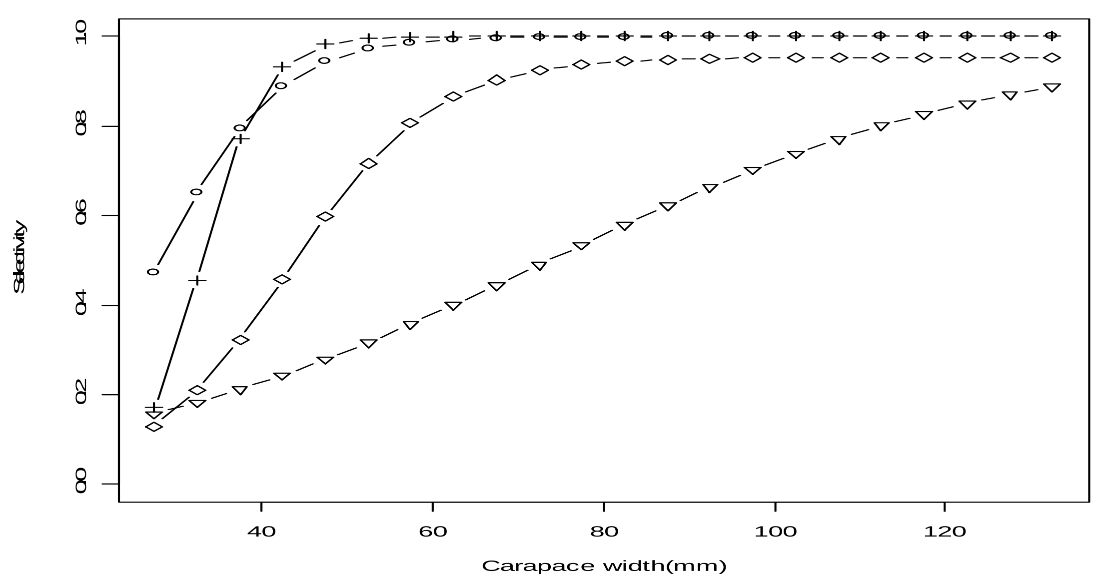

Figure 24. Survey selectivity curves for female and male snow crab estimated by the model for 1978-1981(solid line with circles), for 1982 to 1988 (solid line with diamonds), and 1989 to present (solid line with pluses). Survey selectivities estimated by Somerton and Otto (1998) are the solid line with triangles.

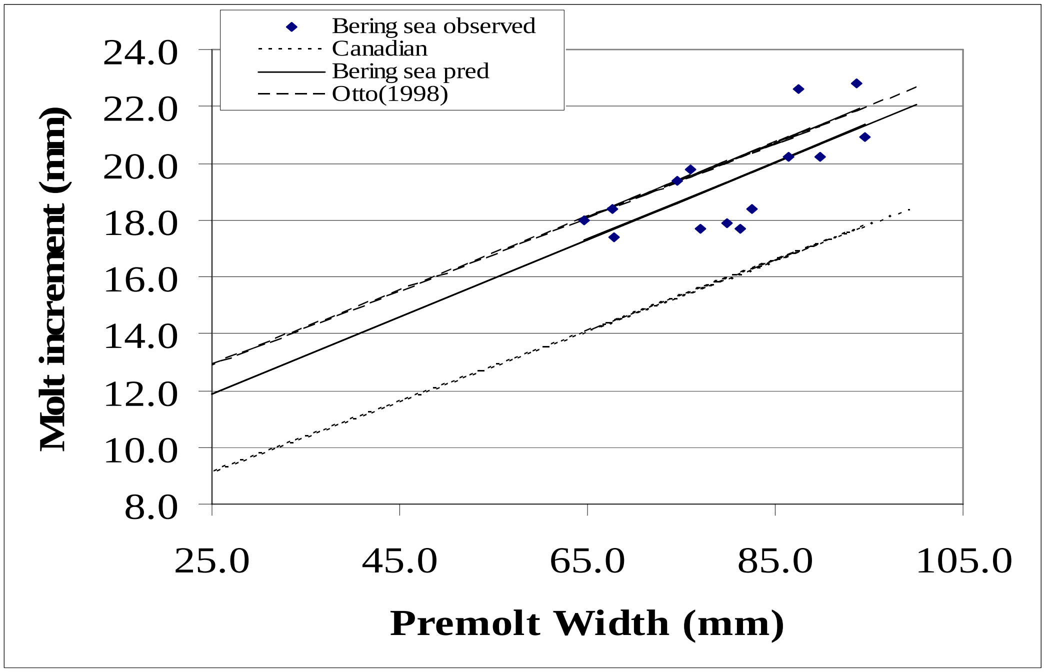

Figure 25. Growth increment as a function of premolt size for male snow crab. Points labeled Bering sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering sea pred is the predicted line from the Bering sea observed growth, which is used as a prior for the growth 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.

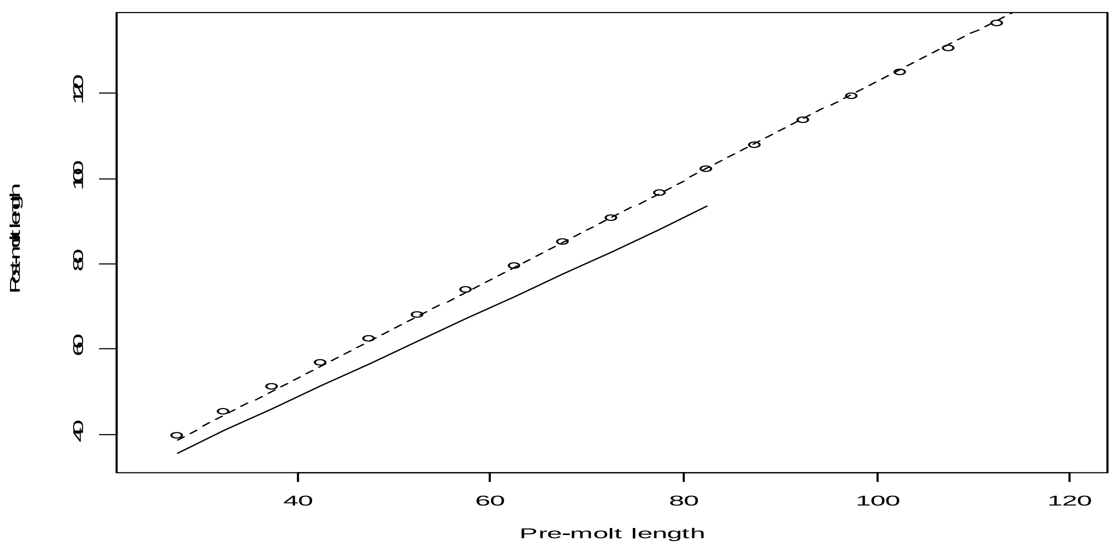

Figure 25. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the model. Circles are the observed growth curve.

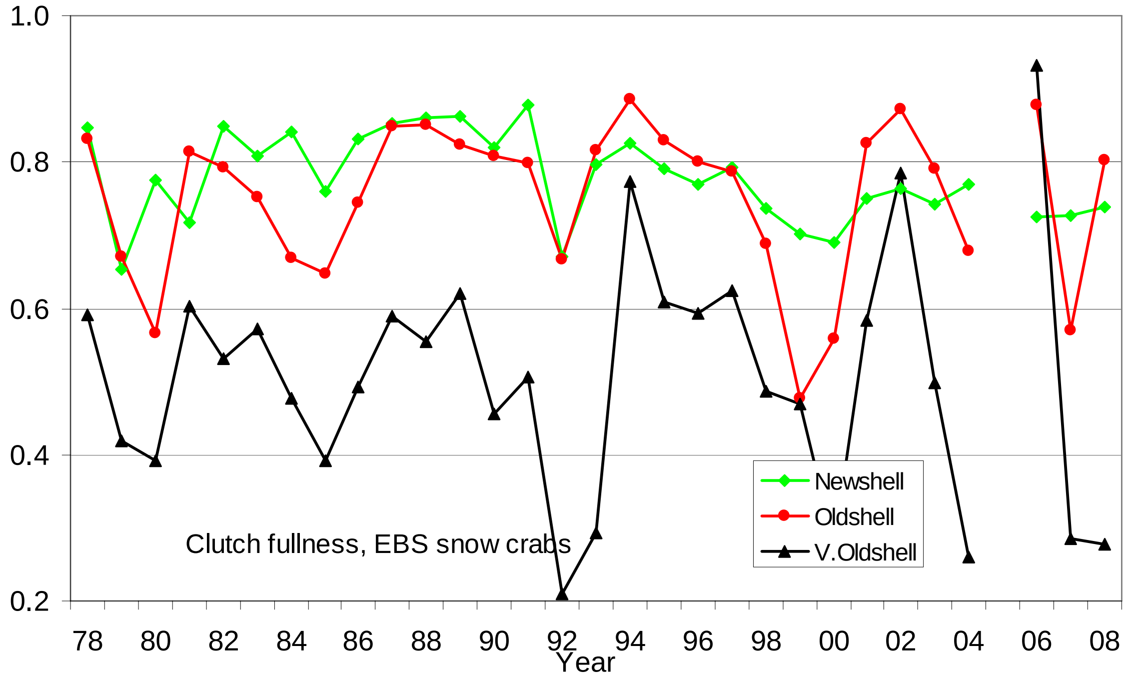

Figure 26. Clutch fullness for Bering sea snow crab survey data by shell condition for 1978 to 2008.

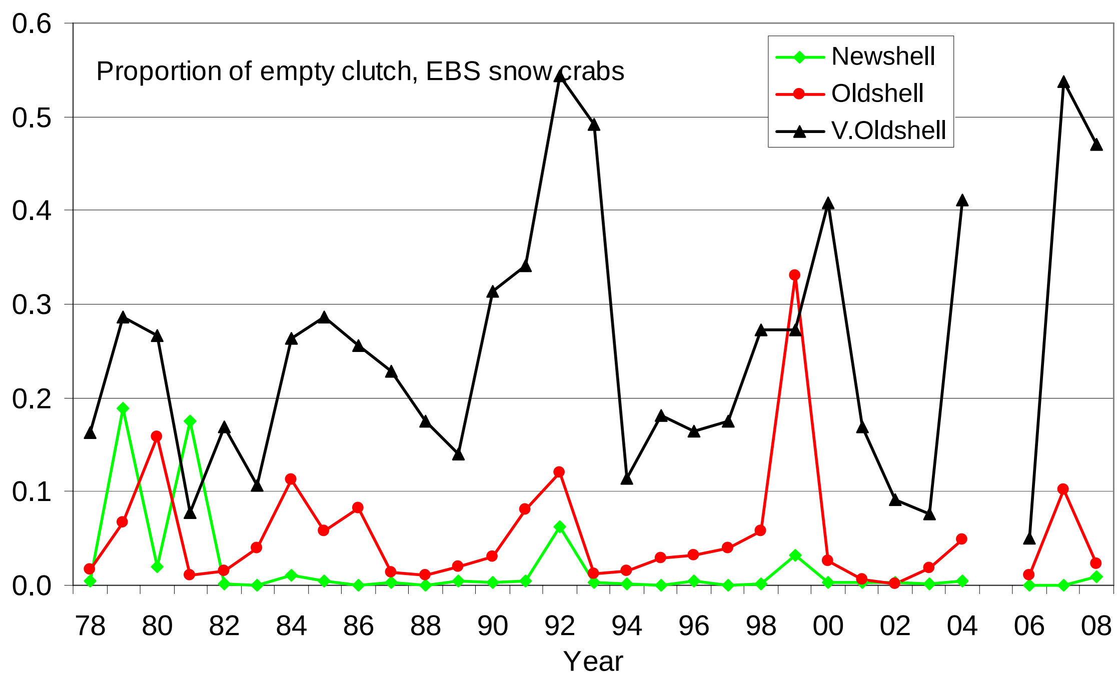

Figure 27. Proportion of barren females by shell condition from survey data 1978 to 2008.

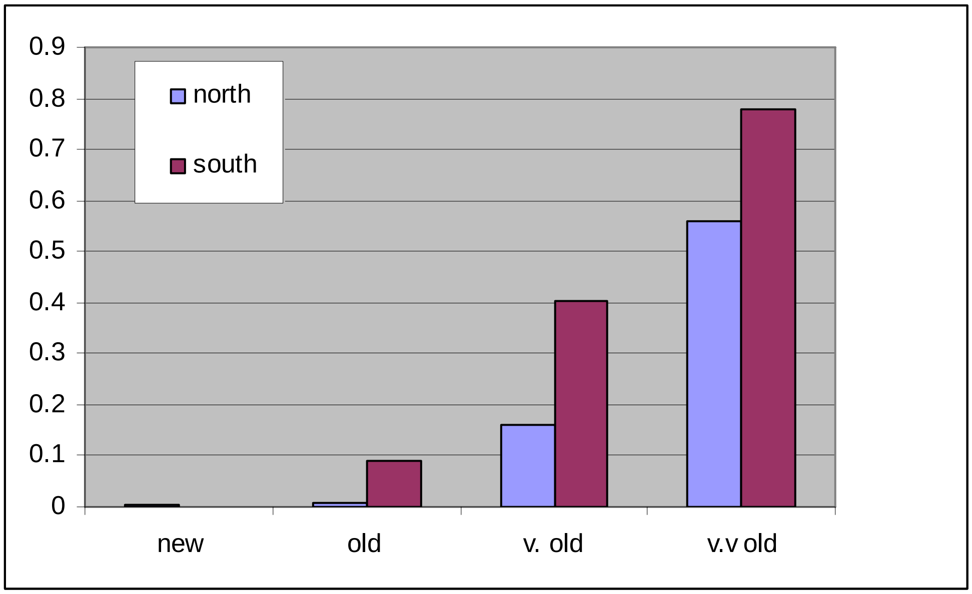

Figure 28. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

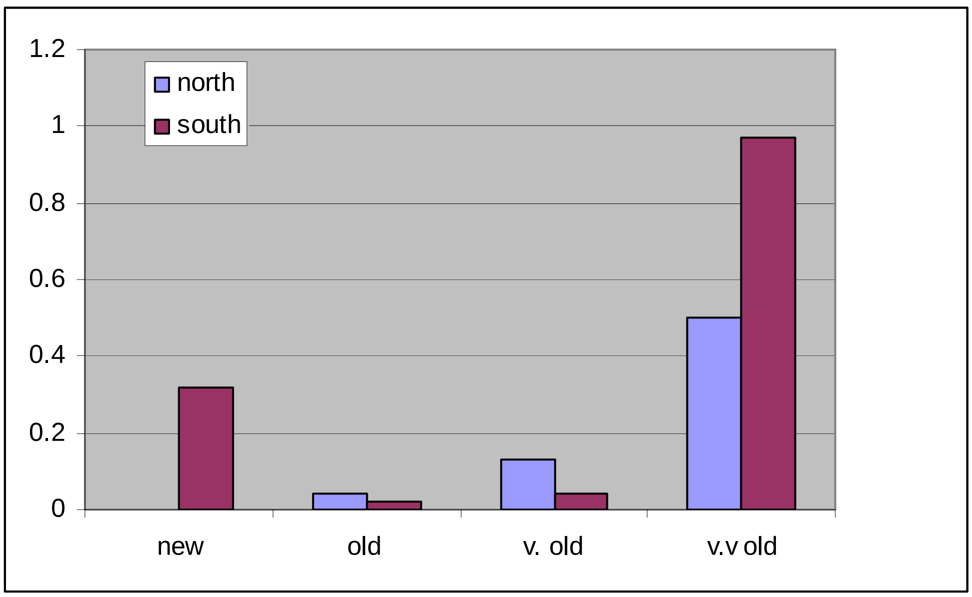

Figure 29. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

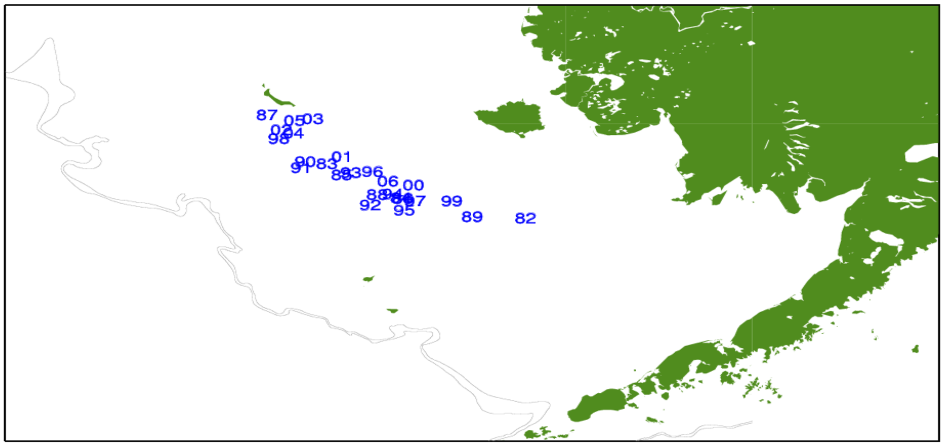

Figure 30. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

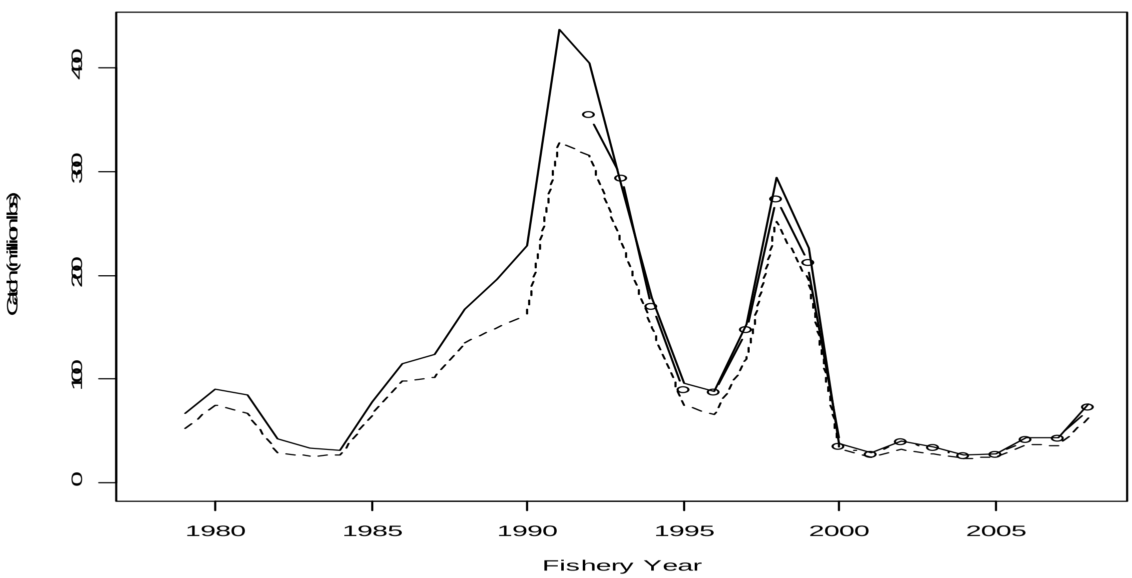

Figure 31. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 50% mortality of discarded crab) and observed retained catch (dotted line) for 1979 to 2008 fishery seasons.

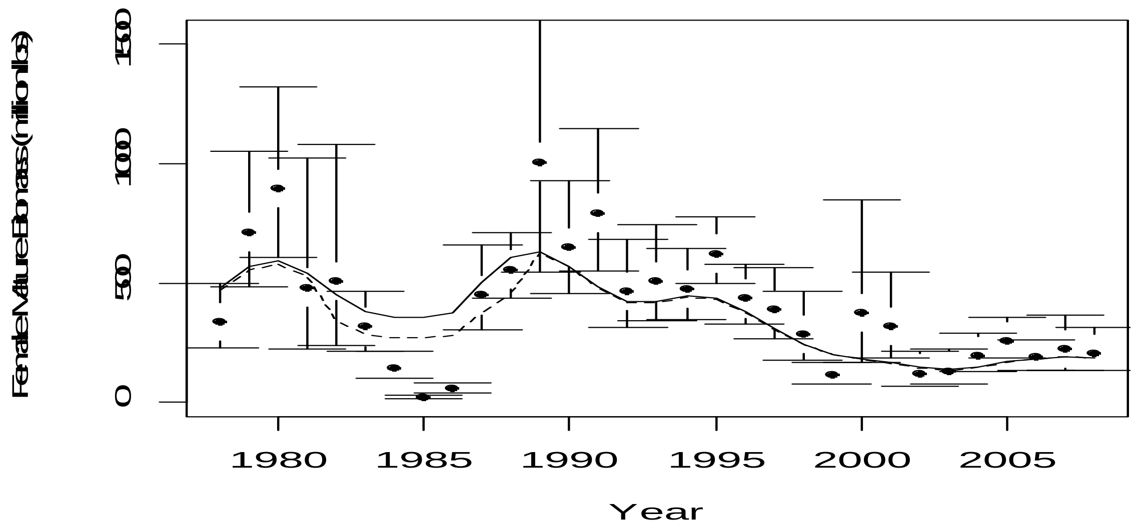

Figure 32. Population female mature biomass (millions of pounds, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

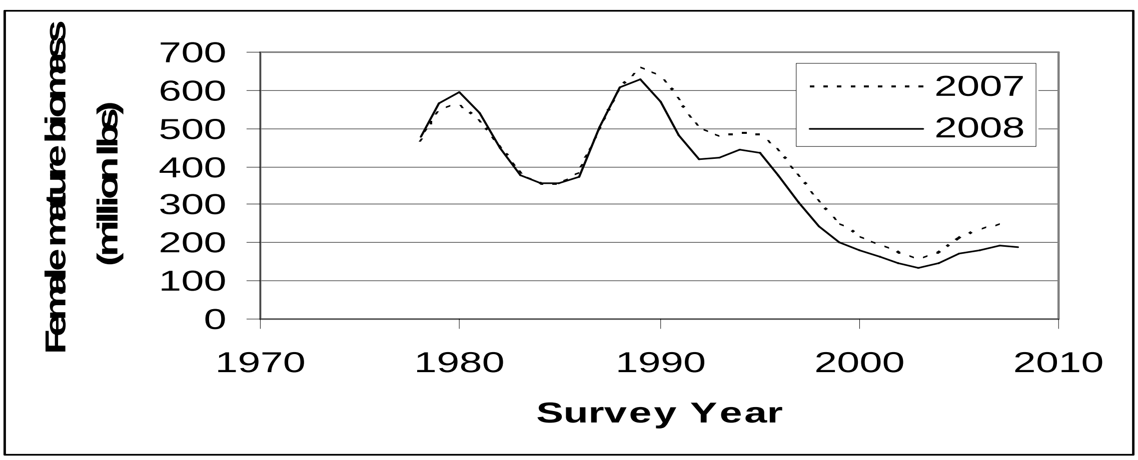

Figure 33. Population female mature biomass from the 2007 assessment and this assessment.

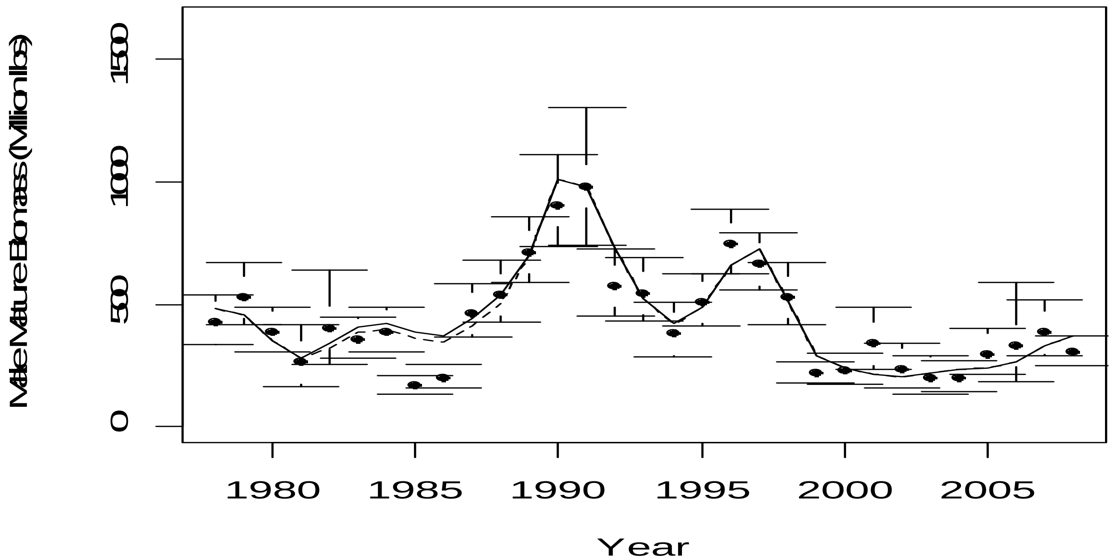

Figure 34. Population male mature biomass (millions of pounds, solid line), model estimate of survey male mature biomass (dotted line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

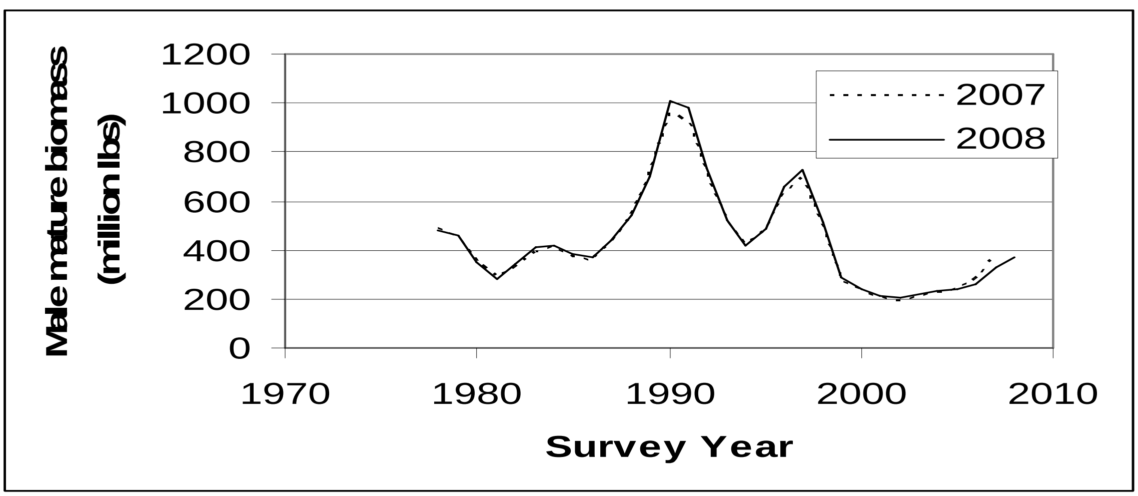

Figure 35. Population male mature biomass from the 2007 assessment and this assessment.

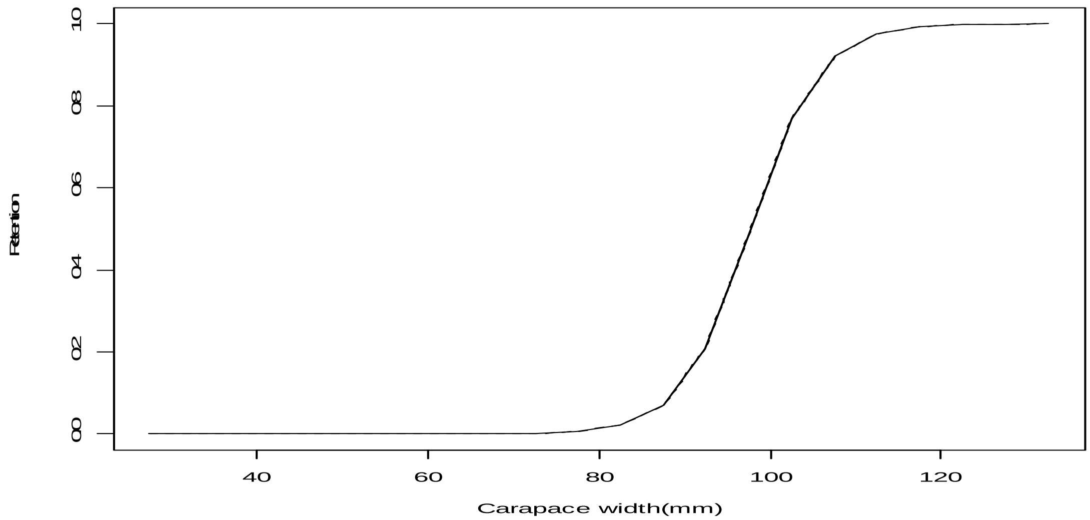

Figure 36. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

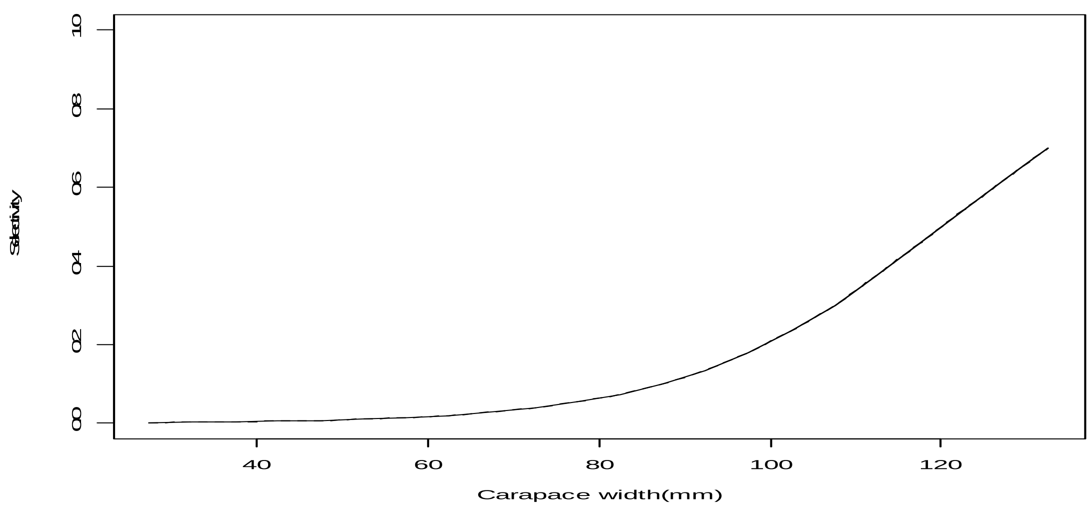

Figure 37. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

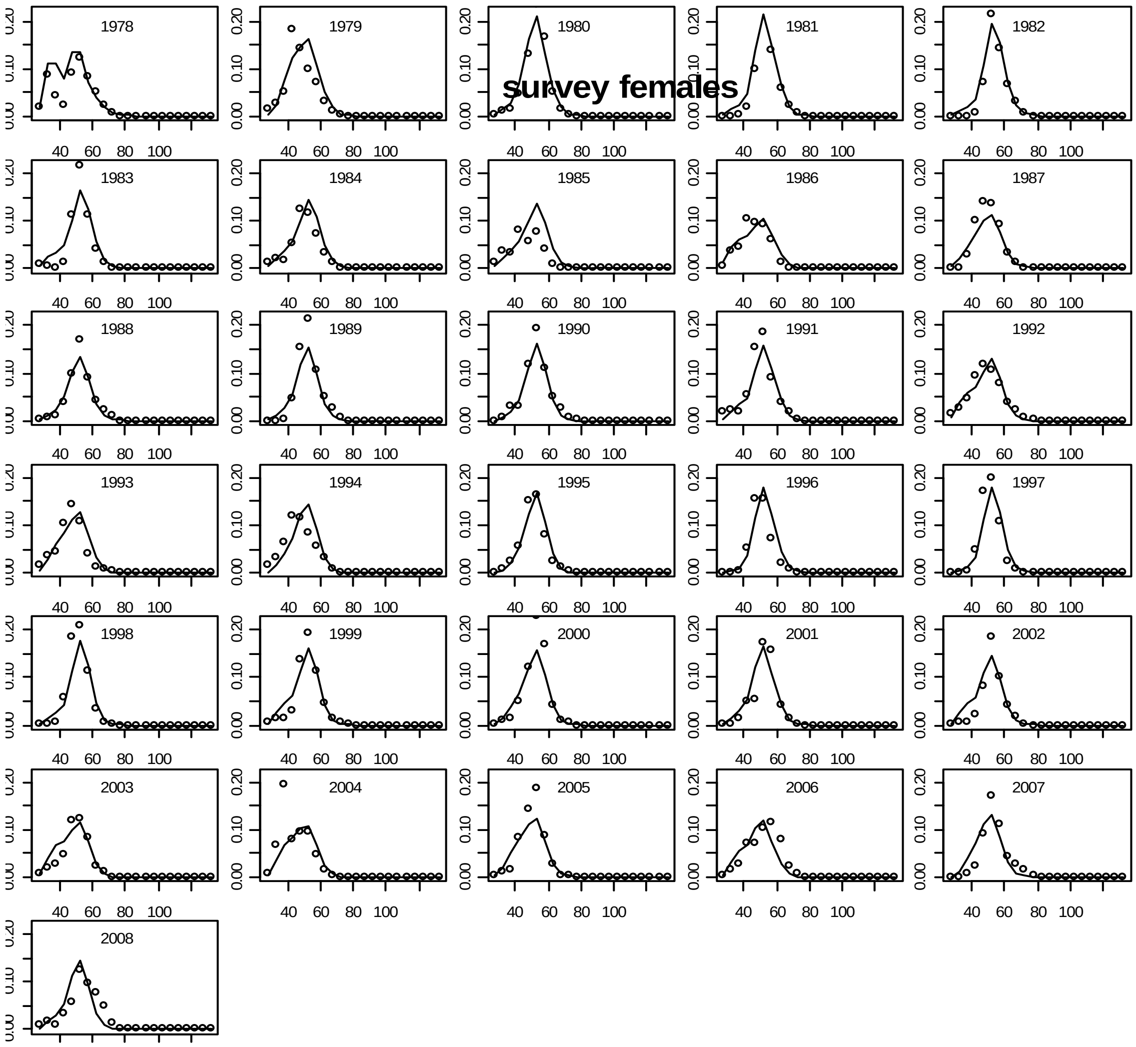

Figure 38. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

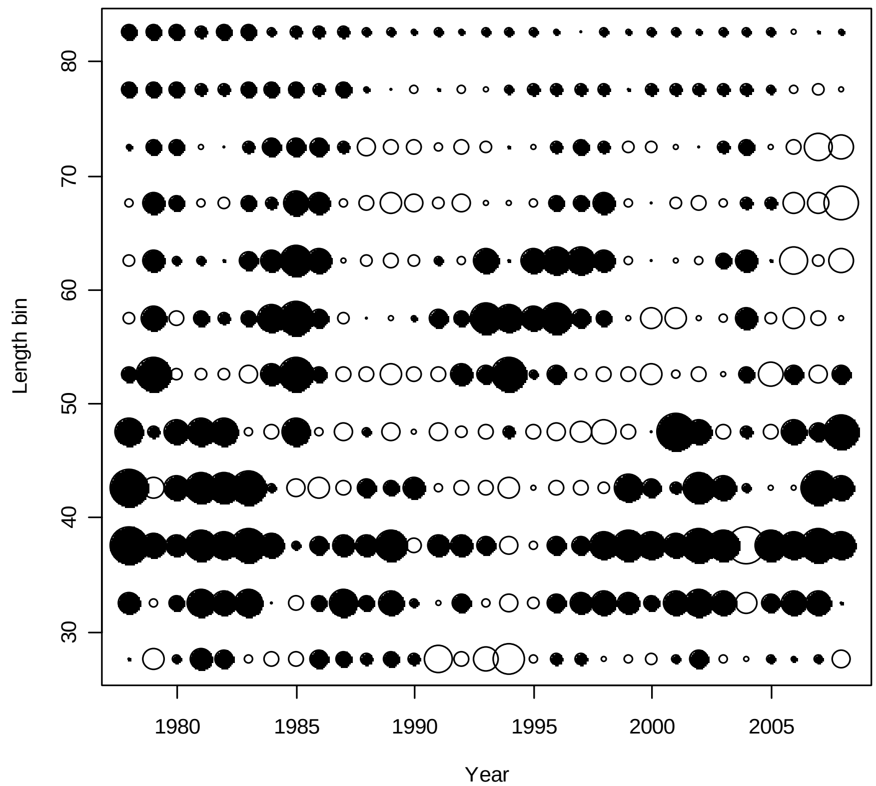

Figure 39. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

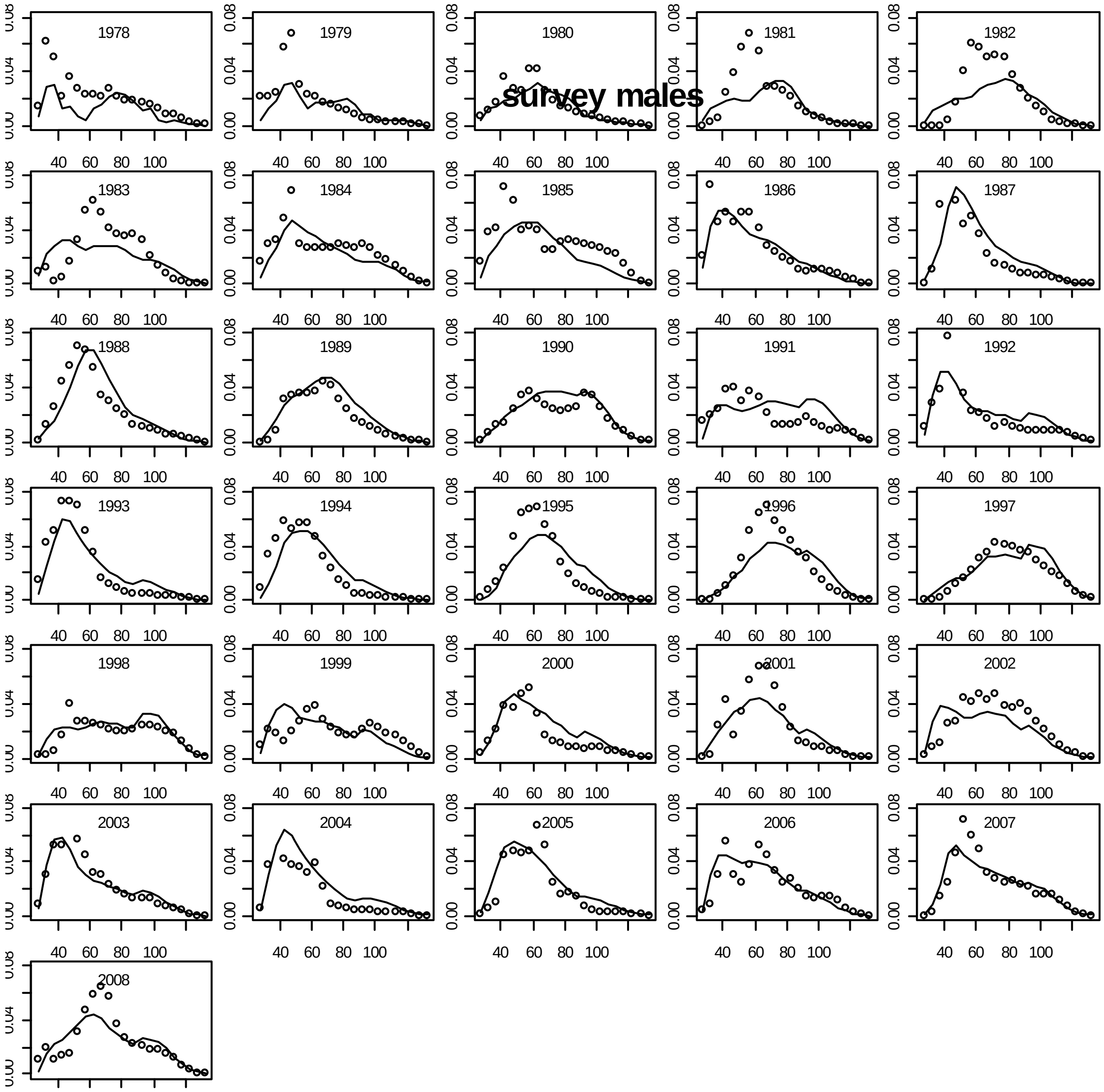

Figure 40. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

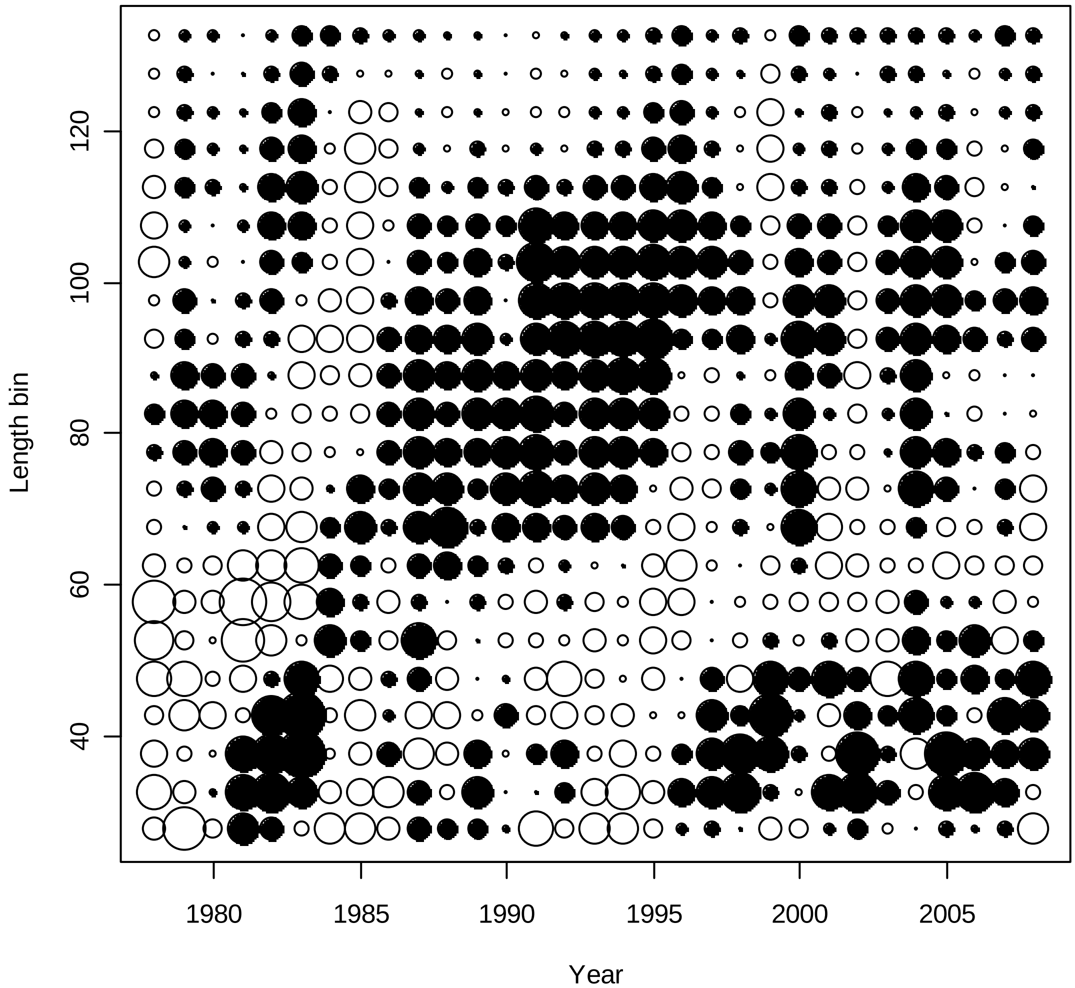

Figure 41. Residuals for fit to survey male size frequency. . Filled circles are negative residuals (predicted higher than observed).

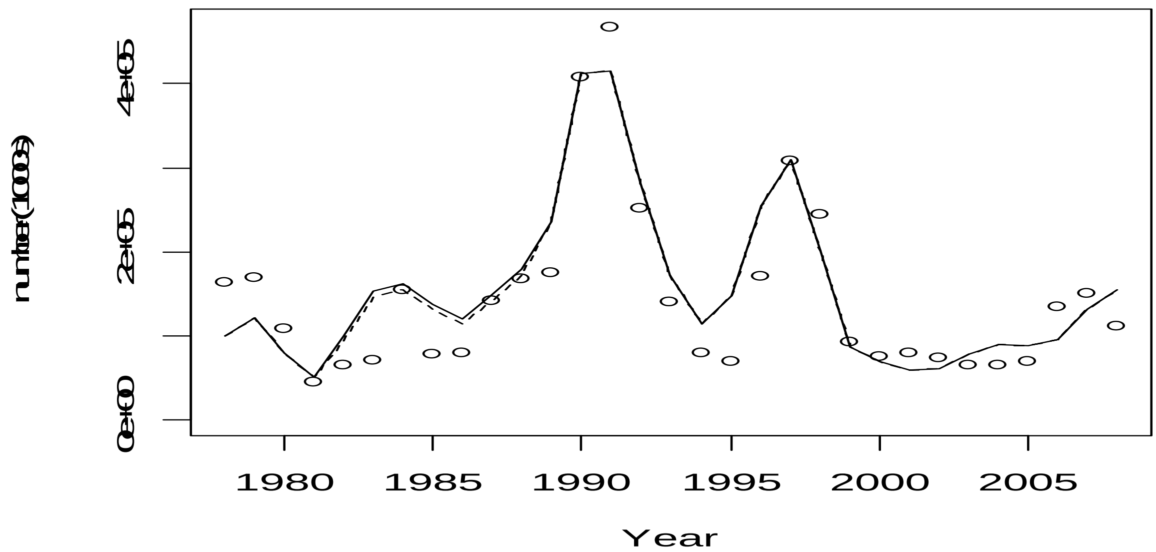

Figure 42. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

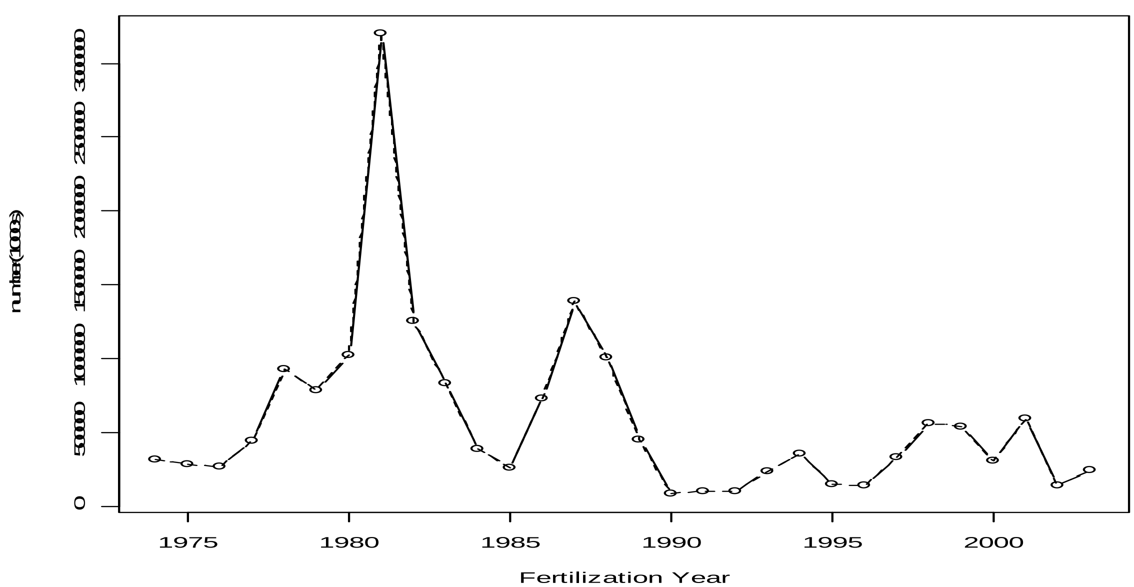

Figure 43. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment. Male and female recruitment fixed to be equal.

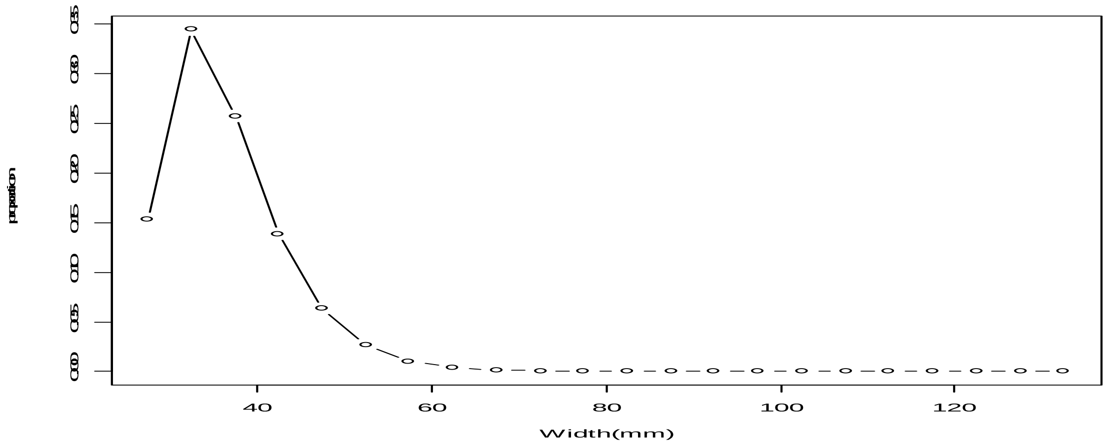

Figure 44. Distribution of recruits to length bins estimated by the model.

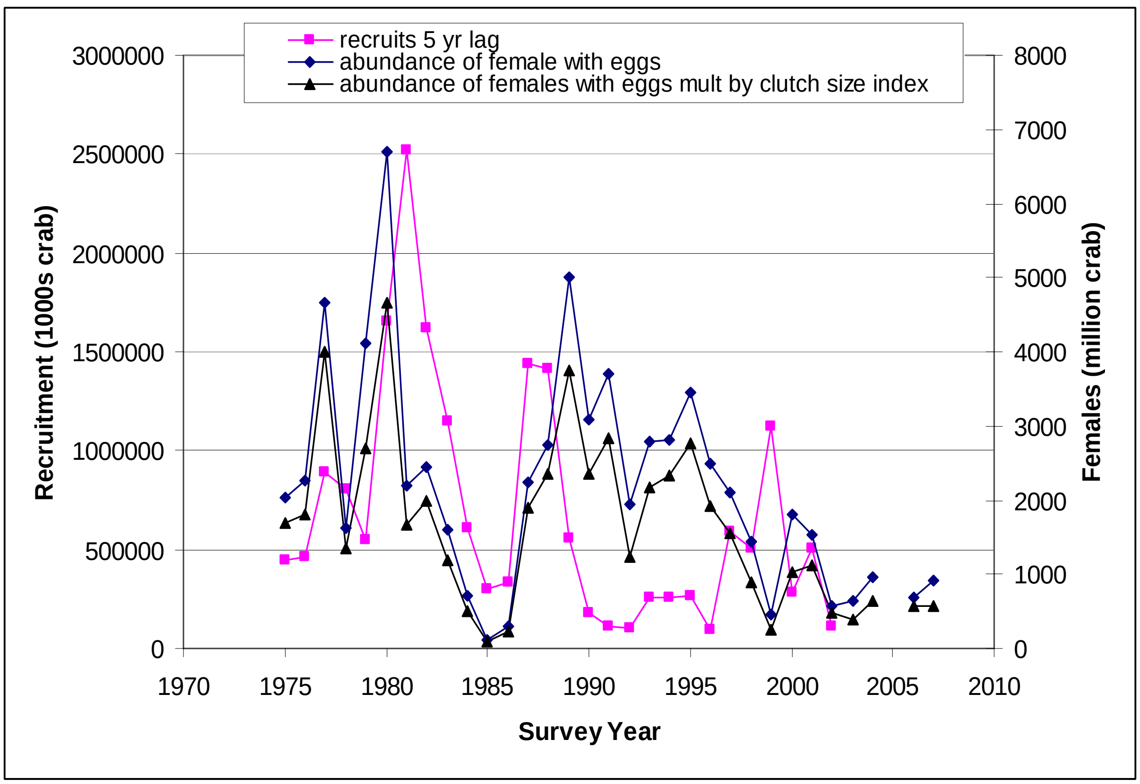

Figure 45. Model estimates of recruitment (fertilization year), survey abundance of females with eggs, and abundance of females with eggs multiplied by the fraction of full clutch from 1975 to 2007.

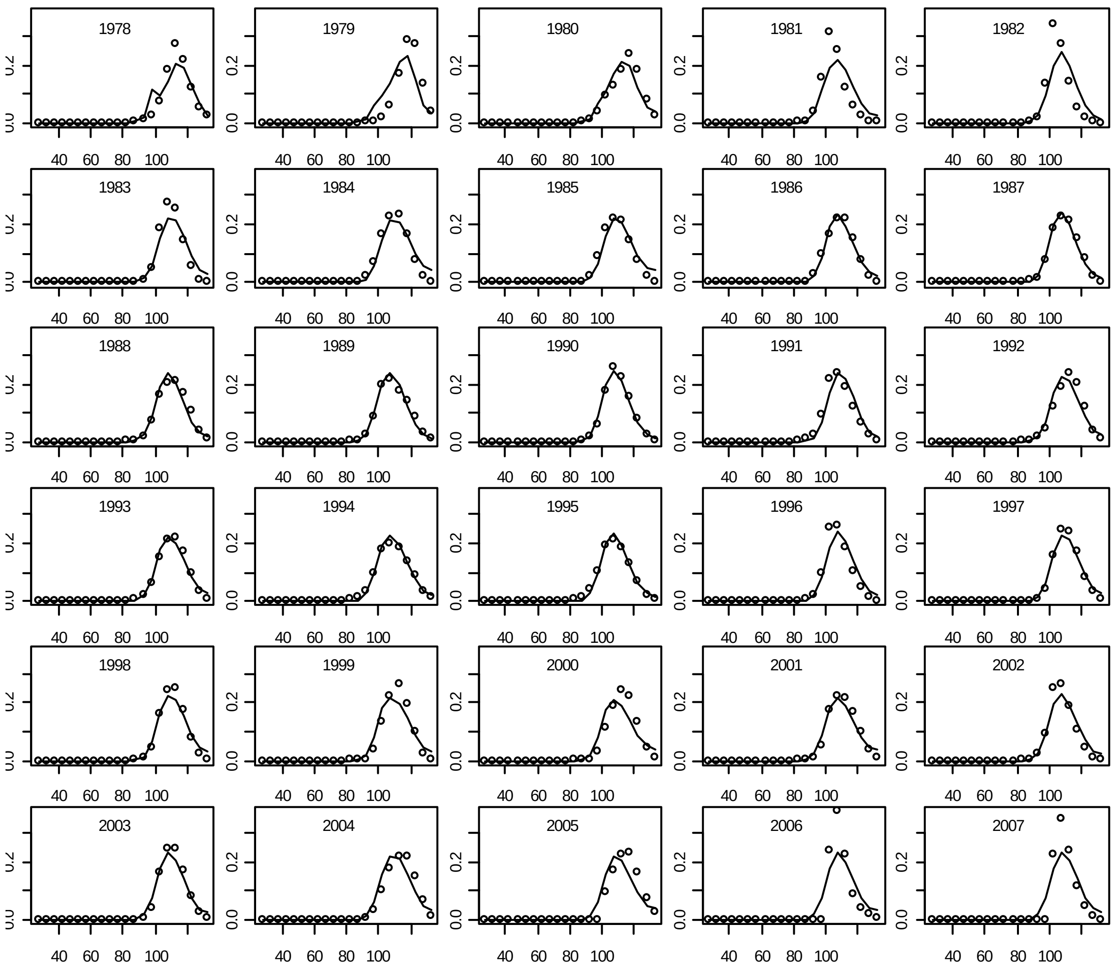

Figure 46. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

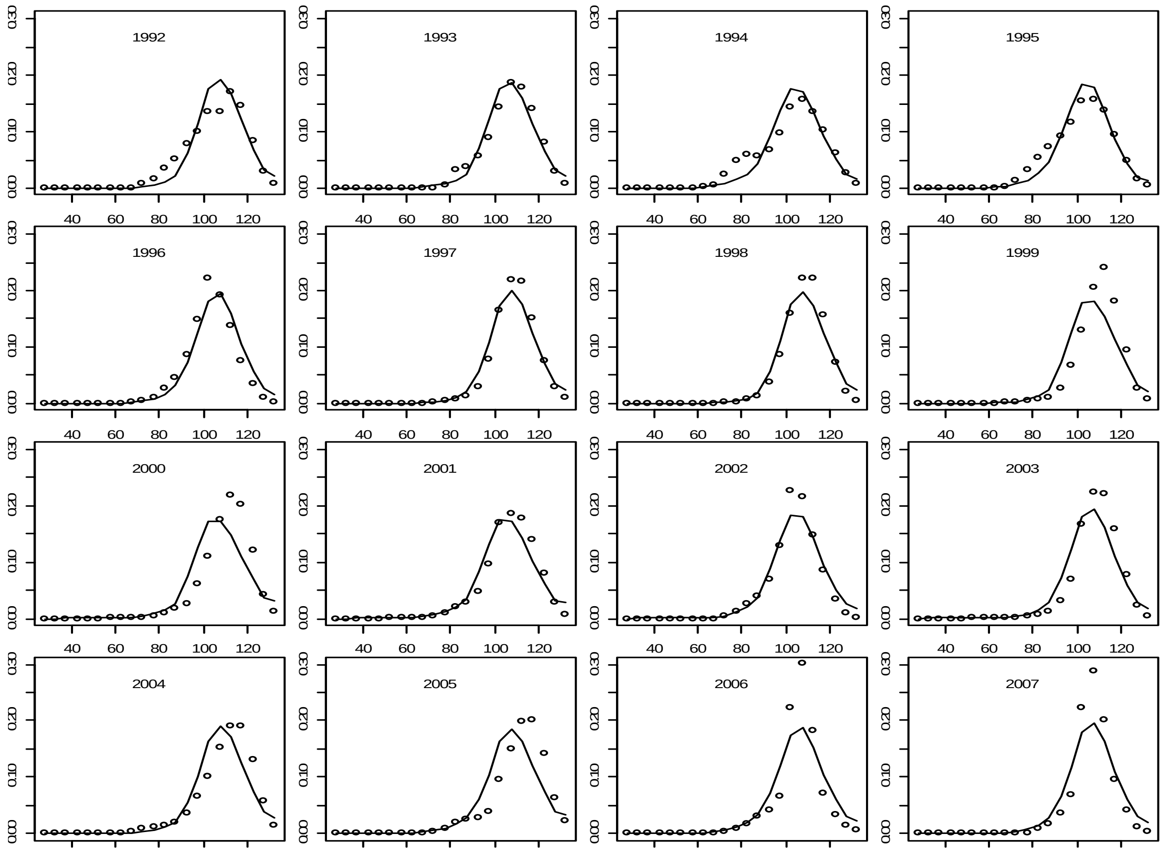

Figure 47. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

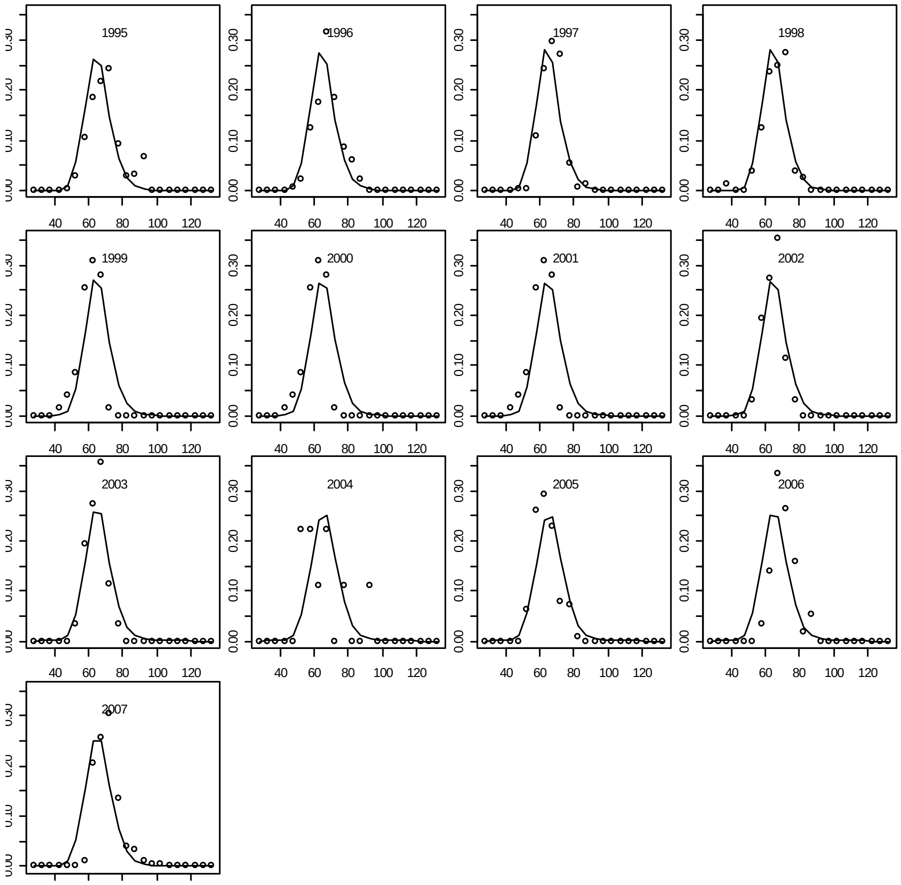

Figure 48. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

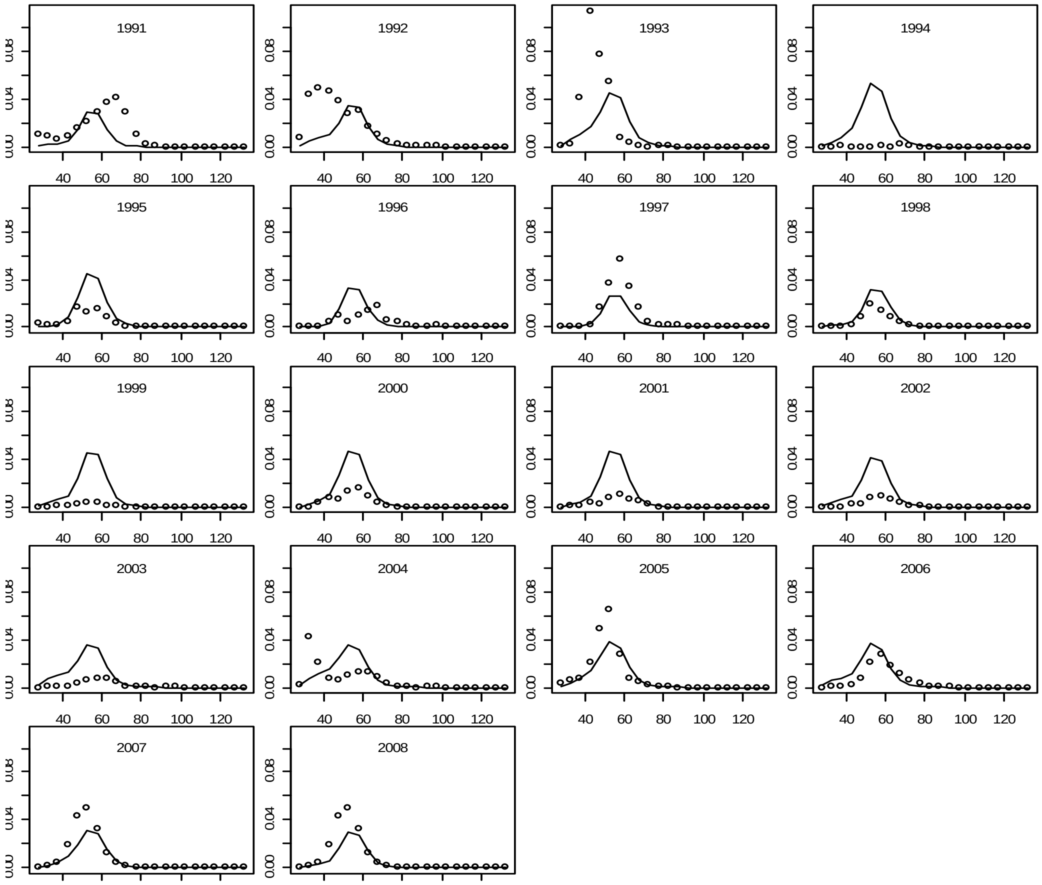

Figure 49. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

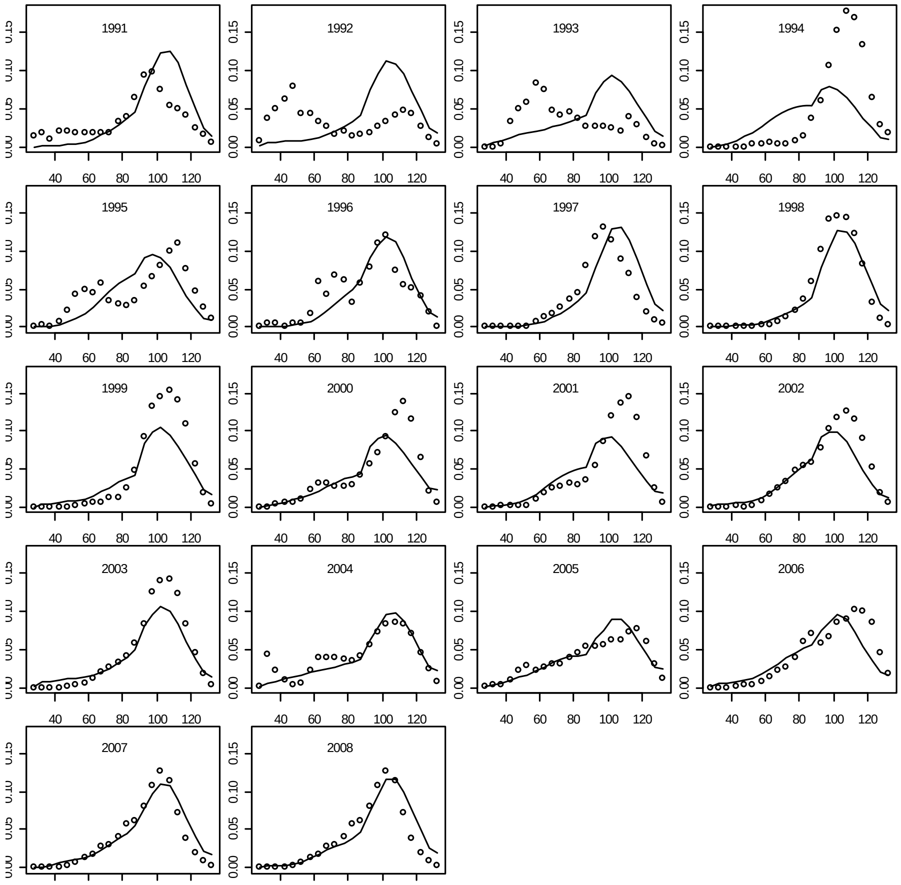

Figure 50. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

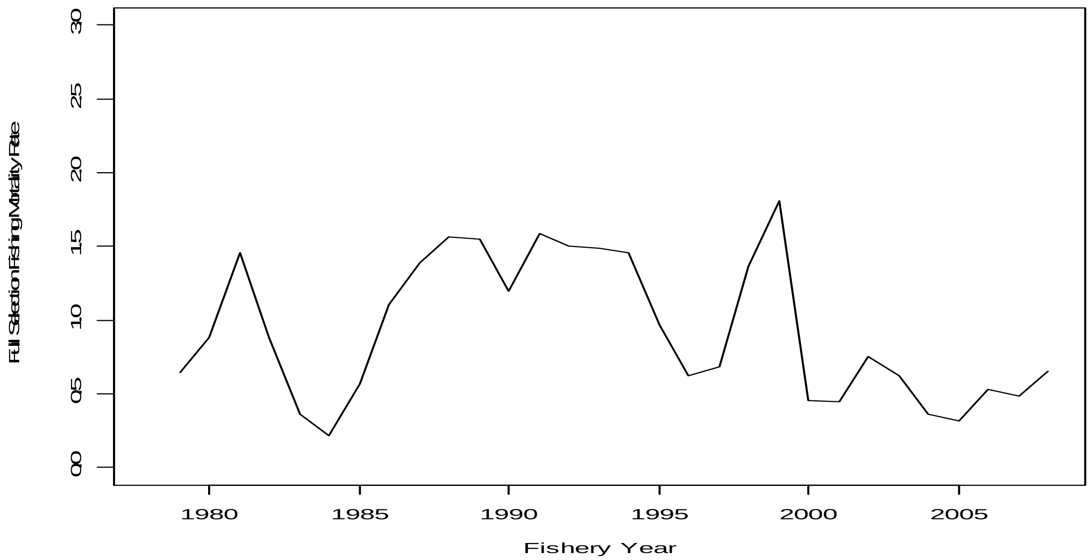

Figure 51. Full selection fishing mortality estimated in the model from 1979 to 2008 fishery seasons (1978 to 2007 survey years).

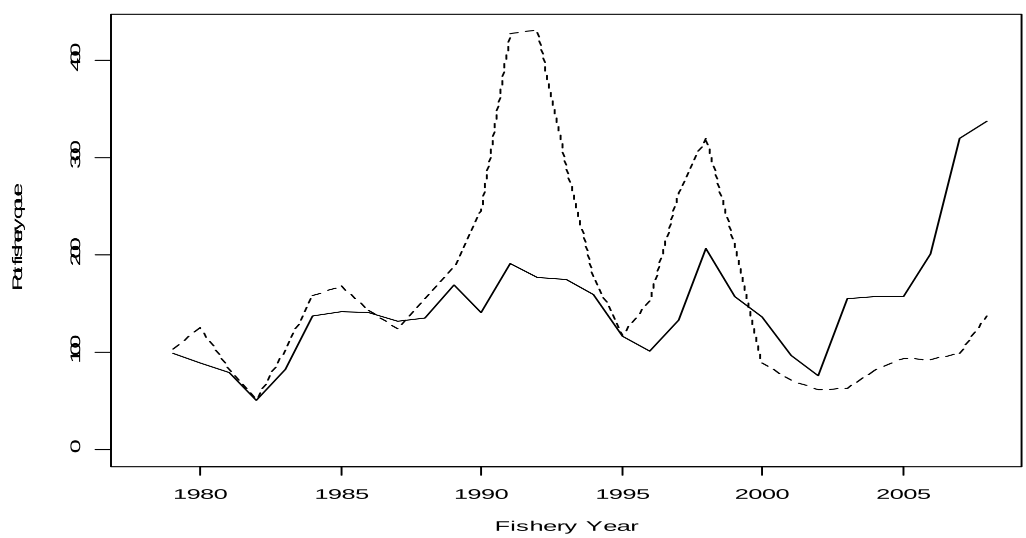

Figure 52. Fit to pot fishery cpue for retained males. Solid line is observed fishery cpue, dotted line model fit.

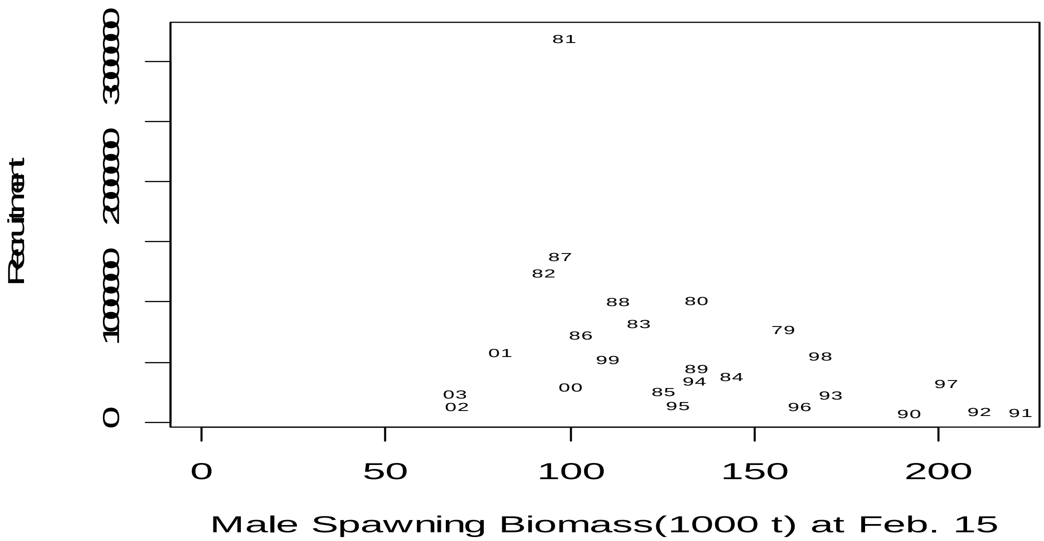

Figure 53. Spawner recruit estimates using male mature biomass at time of mating. Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

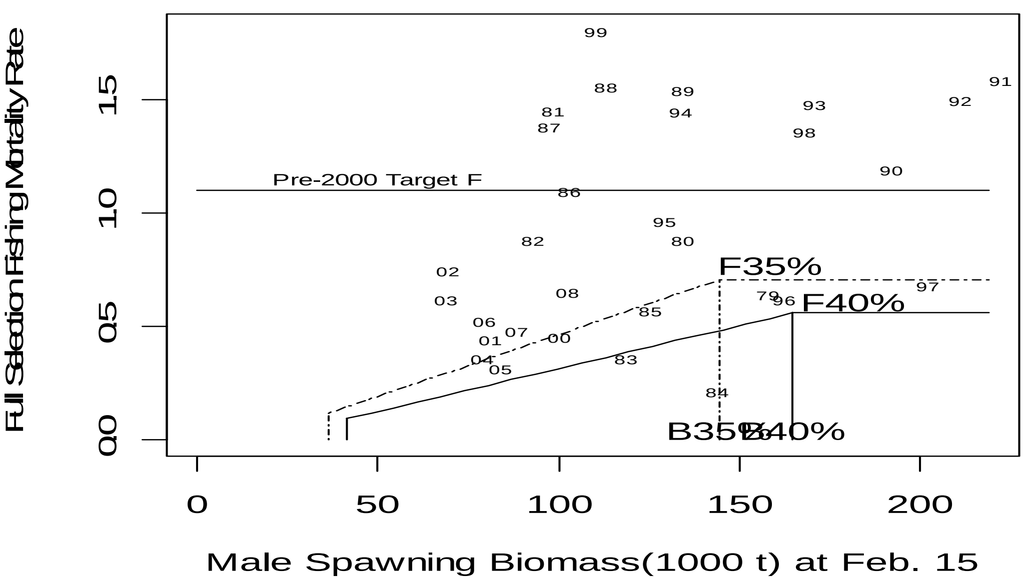

Figure 54. Harvest control rules. Two control rules are shown, one for F40% and one for F35% with alpha = 0.1. The pre-2000 target F of about 1.1 was the target F that resulted from the harvest strategy used before the 2000 fishery season. Vertical lines labeled B40% and B35% are estimated from the product of spawning biomass per recruit fishing at F40% or F35% respectively and mean recruitment from the stock assessment model.

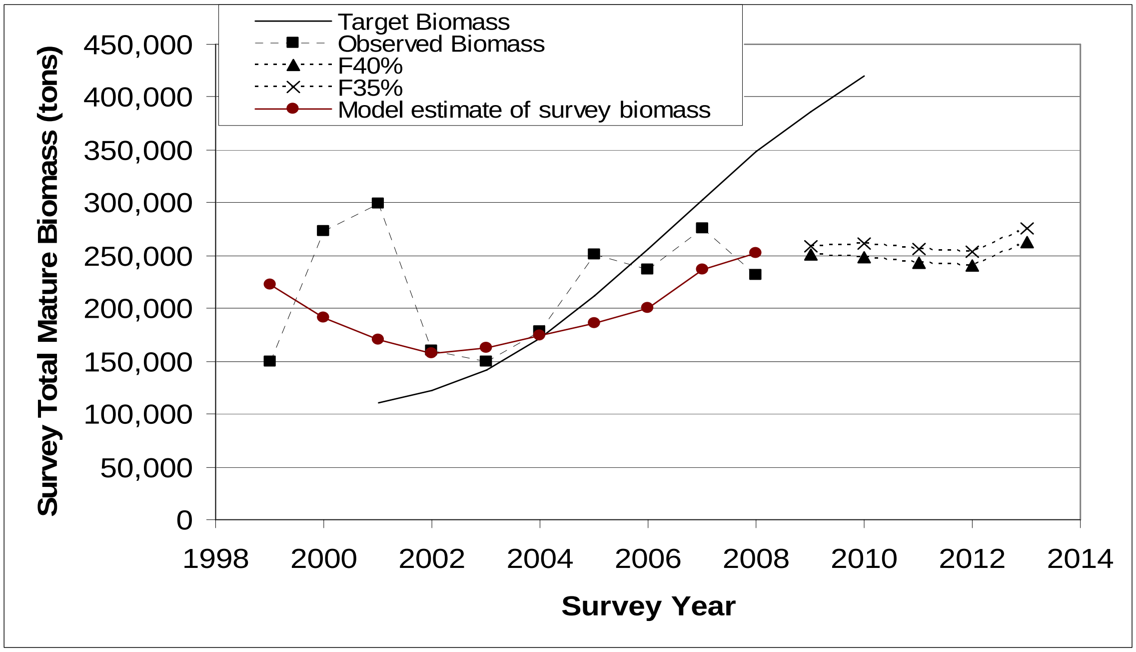

Figure 55. Target survey total mature biomass by year from rebuilding plan simulations, observed survey total mature biomass and model estimates of survey total mature biomass for the F40% and F35% harvest strategies. **2010 is 10 years from the start of the rebuilding plan**

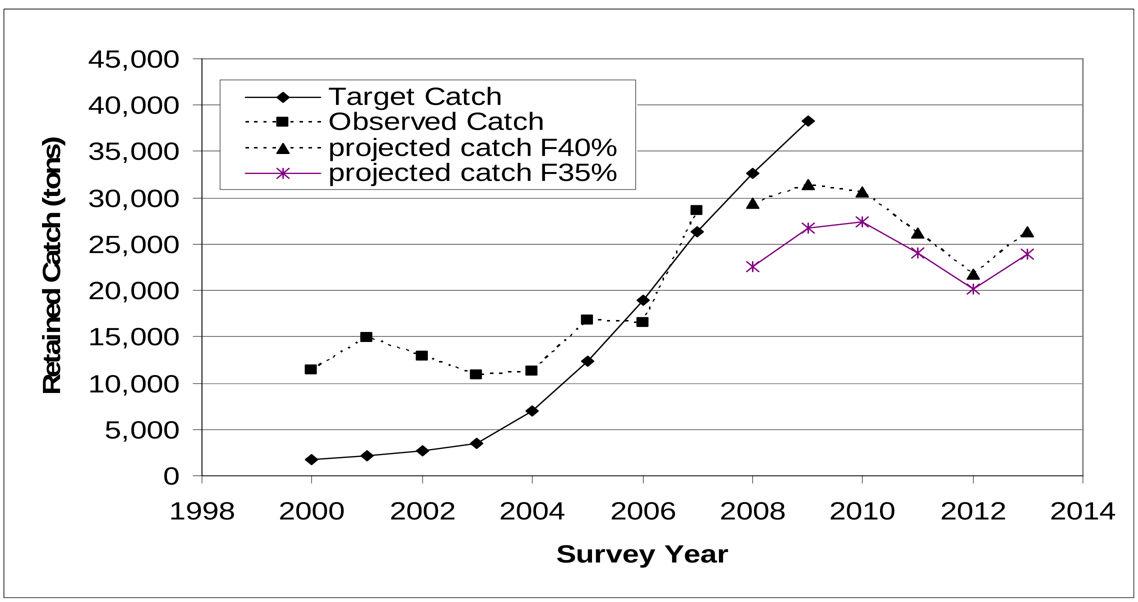

Figure 56. Target average retained catch by year from rebuilding plan simulations, observed retained catch for 2001 to 2007, and projected retained catch for 2008 to 2010 using the F40% and F35% harvest strategies.

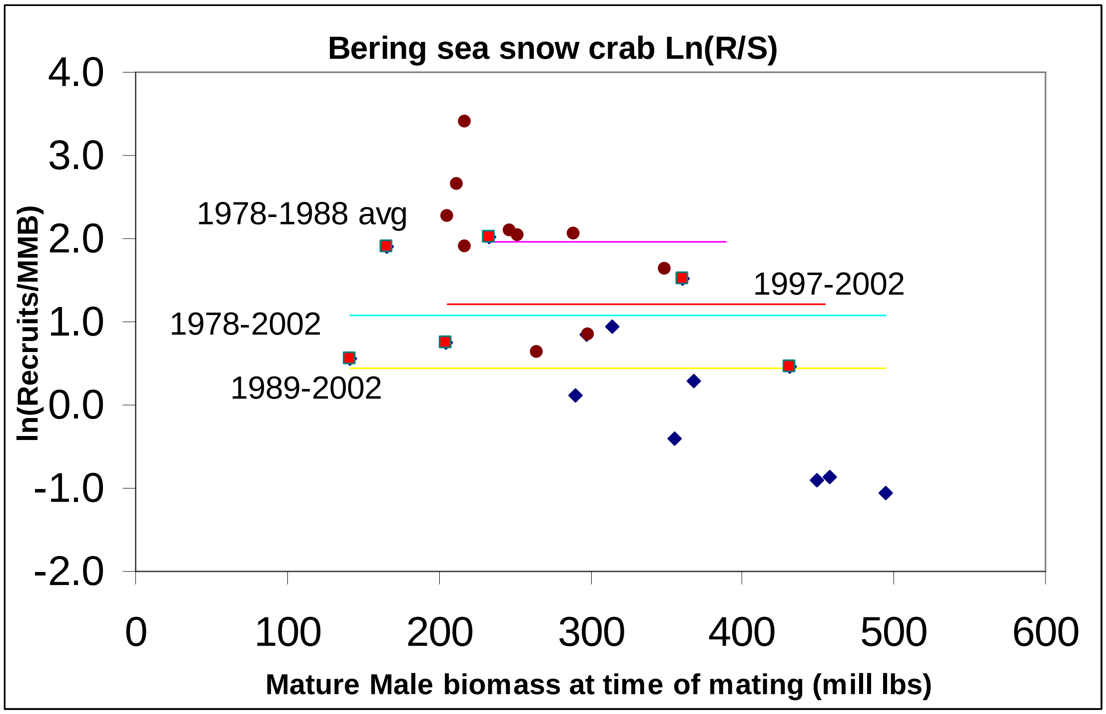

Figure 57. Productivity of snow crab (Ln(recruitment/mature male biomass at mating)) for different levels of mature male biomass at mating. Average values for various time periods are shown on the plot. Different symbols for MMB indicate which average they were included in.

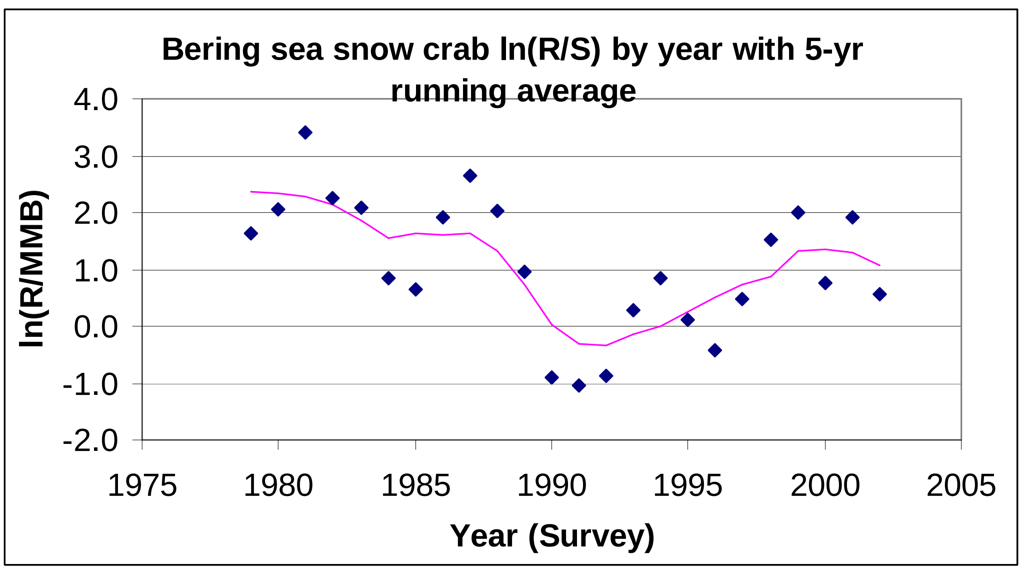

Figure 58. Productivity (ln(recruitment/Mature male biomass at mating)) from 1978 to 2002, with a 5-year running average.

Appendix A.

Table A.1. Model equations describing the population dynamics.

$N_{s,t,1} = pr_l\, R_{0,s} e^{\tau_{s,t}}$	$\tau_{s,t} \sim N(0,\sigma_R^2$	Recruitment
DIRECTED POT CATCH $C_{t,s,l} = \sum_{s,l} (1-e^{-F_{t,s,l} Sel_{t,s,l}}) e^{-M_s Cmid_t} N_{t,s,l}$ TRAWL BYCATCH $C_{t,s,l} = \sum_{s,l} (1-e^{-F^{trawl}_{t,s,l} Sel^{trawl}_{t,s,l}}) e^{-M_s Cmid_t} N_{t,s,l}$	$1 \le t \le$ $1 \le l \le$	Catch taken as a pulse fishery at midpoint of catch(survey is considered start of the year).
$Nimmature_{new,t+1,s,l+1} =$ $(Nimmature_{new,t,s,l} e^{-Zimmat_{new,t,s,l}}) Gr_{s,l} (1-\phi_{s,l})$ $Nmature_{new,t+1,s,l+1} =$ $(Nimmature_{new,t,s,l} e^{-Zimmat_{new,t,s,l}}) Gr_{s,l} (\phi_{s,l})$ $Nmature_{old,t+1,s,l+1} =$ $(Nmature_{new,t,s,l} e^{-Zmat_{new,t,s,l}}) + (Nmature_{old,t,s,l} e^{-Zmat_{old,t,s,l}})$	$1 \le t <$ $1 \le l \le$	Numbers at size. New is less than one year from terminal molt, old is > one year from terminal molt.
$SB_{t,s} = \sum_{l=1}^{L} w_{s,l} (Nmature_{new,t,s,l} + Nmature_{old,t,s,l})$		spawning biomass by sex

Table A.1. continued.

$Z_{t,s,l} = \sum_{fishery} F_{t,fishery,s,l} + M$			Total Mortality
$C_{t,fishery} = \sum_{s} \sum_{l} C_{t,fishery,s,l}$			Total Catch in numbers
$p_{t,l} = C_{t,l} / C_t$			proportion at size in the catch
$Y_t = \sum_{l=1}^{L} w_{t,l} C_{t,l}$			Catch biomass
$F_{t,fishery,s,l} = s_{t,s,l} F_{t,fishery}$			Fishing mortality by length using selecitivities and full selection F

$F_{t,s,l} = \sum_{fishery} F_{t,fishery,s,l}$			Total F over all fisheries (total pot and trawl fisheries)

Table A.1. continued.

$S_{s,l} = \frac{1}{1+e^{-a_s(l-b_s)}}$			Fishery selectivity for total catch by sex s, and size bin l.
$S_{male,l} = \frac{1}{1+e^{-a_{male}(l-b_{male})}} \frac{1}{1+e^{-c_{ret}(l-d_{ret})}}$			Fishery selectivity for male retained catch by size bin l is the selectivity for total catch (male) multiplied by the retention curve (ret)
$S_{surv,l} = q\frac{1}{1+e^{-a_{surv}(l-b_{surv})}}$			Survey selectivity by size – same for males and females
$S_{trawl,s,l} = \frac{1}{1+e^{-a_{s,trawl}(l-b_{s,trawl})}}$			Trawl bycatch selectivity by size and sex
$SB_{s,t} = \sum_{s} \sum_{l=1}^{L} w_{s,l} s_{surv,l} N_{s,t,l}$			Total Survey biomass
$Gr_{s,l\to l'} = \int_{l'-2.5}^{l'+2.5} Gamma(\alpha_{s,l}, \beta_s)$			Growth transition matrix using a Gamma distribution
$width_{t+1} = a_s + b_s width_t$			Mean post-molt width given pre-molt width

Table A.2. Negative log likelihood components.

$\lambda\sum_{t=1}^{T}\left[\log(C_{t,fishery,obs})-\log(C_{t,fishery.pred})\right]^2$	Catch using a lognormal distribution.
$-\sum_{t=1}^{T}\sum_{l=1}^{L} nsamp_t * p_{obs,t,l}\log(p_{pred,t,l})$ - offset	size compositions using a multinomial distribution. Nsamp is the observed sample size. Offset is a constant term based on the multinomial distribution.
offset = $\sum_{t=1}^{T}\sum_{a=1}^{A} nsamp_t * p_{obs,t,a}\log(p_{obs,t,a})$	the offset constant is calculated from the observed proportions and the sample sizes.
$\sum_{t=1}^{ts}\left[\frac{\log\left[\frac{SB_{obs,t}}{SB_{pred,t}}\right]}{sqrt(2)*s.d.(\log(SB_{obs,t}))}\right]^2$	Survey biomass using a lognormal distribution, ts is the number of years of surveys.
$s.d.(\log(SB_{obs,t})) = sqrt(\log((cv(SB_{obs,t}))^2+1))$	
$\lambda\sum_{s=1}^{2}\sum_{t=1}^{T}(e^{\tau_{s,t}})^2$	Recruitment, where $\tau_{s,t}\sim N(0,\sigma_R^2)$

Table A.3. List of variables and their definitions used in the model.

Variable	Definition
T	number of years in the model(t=1 is 1978 and t=T is end year
L	number of size classes (L =22)
W_l	mean body weight(kg) of crabs in size group l.
ϕ_l	Proportion of immature crab that become mature at size l.
R_t	Recruitment in year t
R_0	Geometric mean value of recruitment
τ_t	Recruitment deviation in year t
$N_{l,a}$	number of fish in size group l in year t
pr_l	Fraction of annual recruitment (Rt) distributed to length bin l
$C_{t,l}$	catch number of size group l in year t
$p_{t,l}$	proportion of the total catch in year t that is in size group l
C_t	Total catch in year t
Y_t	total yield in year t
$F_{t,s,l}$	Instantaneous fishing mortality rate for size group l, sex s, in year t
M	Instantananeous natural mortality rate
E_t	average fishing mortality in year t
ε_t	Deviations in fishing mortality rate in year t
$Z_{t,l}$	Instantantaneous total mortality for size group l in year t
GR	Growth transition matrix
$S_{s,l}$	selectivity for size group l, sex or shell condition s.

Table A.4. Estimated parameters for the model.

Parameter	Description
$\log(R_0)$	log of the geometric mean value of recruitment, one parameter
τ_t $1978 \le t \le 2008$, 31 parameters	Recruitment deviation in year t
Initial numbers by length for each sex and shell condition, 88 parameters.	Initial numbers by length
$\log(f_0)$	log of the geometric mean value of fishing mortality
ε_t $1978 \le t \le 2008$, 31 parameters, one set for retained catch, one set for female discard, and one set for trawl bycatch equals 97 total.	deviations in fishing mortality rate in year t
Slope and 50% selected parameters of the logistic curve	selectivity parameters for the total catch (retained plus discard) of new and old shell males.
Slope and 50% selected parameters of the logistic curve(shell condition combined)	Retention curve parameters for the retained males.
Slope and 50% selected parameters of the logistic curve (6 parameters)	Selectivity parameters for survey male and female crabs for three survey periods (1978-81, 82-88,89 to present).
Slope and 50% selected parameters of the logistic curve	Selectivity parameters for trawl bycatch male and female
Slope and 50% selected parameters of the logistic curve(2 parameters)	Selectivity parameters for crab fishery female bycatch

M	Natural mortality
Q for survey selectivity, 3 parameters	Survey catchability
Parameters for the linear growth function, intercept a and slope b (2 parameters male, 2 parameters female).	Growth parameters estimated from Bering sea snow crab data (14 observations).

Draft

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2008

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EXECUTIVE SUMMARY

A length-based model was applied to eastern Bering Sea trawl survey, catch sampling, and commercial catch data to estimate stock abundance of Bristol Bay red king crab (*Paralithodes camtschaticus*) during 1985-2008. The model assumes constant natural mortality (0.18) and estimates trawl survey selectivities. The model fit the data well, and its results were used to estimate biological reference points and federal overfishing levels for 2008. The biological reference points were estimated as follows:

$B_{35\%}$ = 75.11 million lbs, or 34,070 t,

$F_{35\%}$ = 0.33,

$F_{40\%}$ = 0.26.

Based on $B_{35\%}$ and $F_{35\%}$, the retained catch and total male catch limits for 2008 were estimated to be:

Retained catch: 20.587 million lbs, or 9,338.1 t,

Total male catch: 24.202 million lbs, or 10,978.0 t,

MMB on 2/15/2009: 95.58 million lbs, or 43,356.0 t.

Response to CPT Comments (from May 2008)

"The Plan Team identified the need for a table showing which parameters are model-estimated and which are fixed, as well as CVs or some other uncertainty measure. It was also suggested that future assessments include some analysis of model sensitivity to different weightings (lambda's). The magnitude of lambdas has a direct affect on projected biomass and catch likelihood profiles because increasing lambdas artificially decreases the width of the profiles. In

terms of evaluating uncertainty in some of the forcing parameters, the team recommended 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 Bayesian context. Figures of standardized residuals should be provided, along with providing clarification on whether the residual patterns reflect a cohort effect or a growth effect. The team also requested clarification of the effect of aging errors on molt probability. The team recommends that a column be added in the catch table for total catch (all sources of catch).”

1. Alternative weighting for likelihood values or a Bayesian approach can be evaluated for the SAFE report next year.
2. The model does not fix survey selectivities.
3. The previous report already has tables to indicate which parameters were estimated and which ones were fixed. The tables are reorganized so that all estimated parameters are in one table in this report. Standard deviations for individually estimated parameters are presented in this report.
4. The likelihood profile was presented for natural mortality in the previous report, and both likelihood profiles for natural mortality and survey catchabilities are presented in this report.
5. Residuals in Figures 24-26 are standardized in this report. Impacts of constant mortality for female residual patterns were discussed in both the previous and this report, including the effects of changes in growth over time.
6. The likely effects of shell-aging errors on estimates of male molting probabilities are mentioned in this report.
7. A column is added to the catch table for total catch.
8. Extending the model to the data before 1985 can be carried out for next year’s assessment. The estimated B35% could be affected by the high recruitment as well as the low recruitment before 1995, if a longer time series was used.

Response to SSC Comments specific to this assessment (from June 2008)

1. *“The model should be fit to the full time series, beginning in 1968, and to the more recent time series for evaluating and comparing both alternatives. We encourage the use of available historical data and, as necessary, modifications to the model structure to account for seeming discontinuities.”*

The work has been planned to extend the model to the data before 1985 and the results will be reported in the SAFE report in 2009.

2. *“The period of recruitment that was selected for estimating $B_{35\%}$ was based on a presumed oceanographic regime shift in 1989. However, little evidence for a shift in mean recruitment or for an effect of the regime shift on red king crab was provided. Future analyses should include a more thorough evaluation of recruitment trends based on a model fit to the full time series. Absent a strong rationale to the contrary, the reference time period should include periods of both high and low recruitment to better represent the average reproductive potential of the stock.”*

The mean recruitment is higher for brood period 1990-2003 than that during brood period 1985-1989. Brood year 1990 corresponds to recruitment in 1995 due to a time lag of 5 years (from hatching to recruitment). After extending the model to the data before 1985, different reference periods can be evaluated in 2009.

3. *"It is anticipated that a revised time series of CPUE estimates for the trawl survey will be available in time for the next assessment (Bob Foy, NMFS, pers. comm.). For consistency with other analyses and over the long term, the assessment should incorporate this revised time series."*

Current NMFS and ADFG estimates of area-swept abundance do not differ greatly. The assessment authors have not received any revised estimates from NMFS.

4. *"The analysis could benefit from a Bayesian framework for parameter estimation with prior distributions for natural mortality (M), catchability (Q), and other parameters. For example, a prior for Q could be based on results from trawl experiments, a likelihood profile for Q could be provided, or Q could be freely estimated."*

This can be evaluated for the SAFE report in 2009.

5. *"A better rationale for the chosen weights for different likelihood components should be provided or, wherever possible, estimated coefficients of variation should be used for time series of catch, CPUE, survey biomass, etc."*

Estimated CVs are available and used in the model for survey biomass, but estimated CVs are not available for catch and bycatch. Effective sample sizes for length composition can be evaluated in 2009.

6. *"A table of negative log-likelihoods for each likelihood component should be included for each candidate model."*

These are added in this report.

7. *"The apparent convergence problem in the likelihood profile (Fig. 31) should be addressed."*

This problem does not occur with the additional 2008 data in this report.

8. *"The analysis could benefit from inclusion of a figure showing male pot bycatch selectivity and should include a rationale for the chosen selectivity function."*

Pot bycatch selectivity was in the previous report. Additional curves showing highgrading selecitvities during 2005-2007 are added to the current report.

9. *"Estimates of uncertainty for biomass and recruitment should be reported."*

CVs of estimated recruitment are presented in this report. The likelihood profiles of estimated mature male biomass on 2/15/2009, estimated retained catch and total catch in 2008 are presented in this report.

10. *"If historical data are incorporated in future modeling, care should be taken to account for the major changes that have occurred in gear and fishing practices between the heyday of Russian and Japanese fisheries, the wild west days of the domestic derby fishery, and the current rationalized fishery."*

Agree.

11. *"Rationalization in the crab fishery has increased the soak time and may have resulted in increased escapement of smaller crab from pots and associated changes in selectivity. The SSC recommends that the authors evaluate the effects of soak time on CPUE and selectivity."*

No commercial CPUE data are used in the model. The time series during rationlization is too short to evaluate the relationship between soak time and bycatch selectivity. This can be examined in the future.

Response to SSC Comments in General (from June 2008)

"General recommendations to all assessment authors for future assessments:

1. *To the extent possible, a consistent format should be used for the assessments; sections that are not relevant to a particular stock should be omitted."*

Agree. Ecosystem Considerations section will be updated using the standard format next year.

2. *"Each assessment should provide a range of alternatives for the Plan Team and SSC to consider when setting OFLs, for example, alternative model configurations for Tier 1-3 stocks, alternative parameter values where these are highly uncertain and cannot be estimated, or alternative time periods used in Tier 4 and Tier 5 calculations."*

Due to time constraints, many alternatives are not provided in this report. Alternative models and parameter values will be provided in the report in 2009.

3. *"Model-based stock assessments should clearly document all data sources, model equations, the number of parameters, a list of which parameters are estimated in the model, and a list of fixed parameters, and a justification for the selected parameter values."*

Agree.

4. *"The rationale for selecting a specific time period for establishing B_{MSY} proxies based on time series of recruitment (Tier 1-3) or biomass (Tier 4) or for establishing an OFL based on catch histories (Tier 5) should be clearly articulated. Unless compelling reasons exist to choose a different period, the default should be the full time series for which data are available. When alternative time periods are considered, the rationale and the resulting reference points should be presented for consideration by the Plan Team and SSC."*

Agree.

5. *"The crab OFL definitions are designed to provide a guide for defining the best available proxy for MSY when data are insufficient to directly estimate MSY. The guidelines allow gamma in the formula for computing F_{OFL} under Tier 4 to be set at a value higher or lower than 1. A gamma less than 1 might be justifiable if the available biomass measure includes a large portion of small crab that has not recruited to the fishery. A gamma greater than 1 might be justifiable if the directed fishery can be expected to harvest male crab with carapace widths well above the size at 50% maturity. The SSC agrees with the Plan Team recommendation that* ***future stock assessments should provide analyses to support the choice of gamma****. These analyses could include an exploration of fishery selectivity and a comparison of minimum size limits and size at 50% maturity for male crab. The SSC does not recommend the use of an $F_{35\%}/M$ ratio derived from one stock as a default for gamma on an unrelated stock unless there is a strong rationale for concluding that the fishery is likely to be prosecuted in an identical manner and knowledge of stock status is sufficient to justify the harvest rate."*

Agree. This does not apply to this stock.

6. *"To the extent possible, bycatch information should be provided for all stocks included in the SAFE so that stock OFLs can be moved from "retained catch OFL" to "total catch OFL"".*

Total catch OFL is used in this report.

7. *"For stocks with an assessment model, the SSC requests that the authors include a table summarizing the fit to data (including number of parameters, likelihood for each data component, etc.)."*

These are included in this report.

8. *"The ecosystem considerations sections could be expanded to include information on prey and predator composition in a consistent format (e.g., pie charts similar to the groundfish assessments). A discussion of seabird predation on crab would be a useful addition. We note that seabirds feed on larval through juvenile crab, particularly in shallow or nearshore areas, such as the Pribilof Islands. Plankton-feeding birds eat larval crab and juveniles are consumed by seaducks and seabirds, particularly during winter months."*

Few prey and predator data are available for this stock.

9. *"Each assessment should include figures showing the available time series of catch and survey biomass, in addition to tables, to facilitate comparisons and the selection of appropriate time periods."*

Agree. These are in this report.

10. *"The presentation of recruitment time series should be standardized as to year (examples include year of recruitment to maturity for spawner/recruit data, or perhaps year of hatching; and year of recruitment to legal size for catch data) to clearly illustrate specific cohort strength."*

Recruitment is referred to year of recruiting or hatching and the time lag of five years from hatching to recruiting is consistently reported in this report.

11. *"Assessment authors should provide alternative options for setting OFLs to the Plan Team and the SSC, particularly where there are large uncertainties about correct model structure or parameter estimates."*

Agree. More alternatives will be provided in the report in 2009.

INTRODUCTION

Stock Structure

Red king crab (RKC), *Paralithodes camtschaticus*, are found in several areas of the Aleutian Islands and eastern Bering Sea. The State of Alaska divides the Aleutian Islands and eastern Bering Sea into three management registration areas to manage RKC fisheries: Aleutian Islands, Bristol Bay, and Bering Sea (Alaska Department of Fish and Game (ADF&G) 2005). The Aleutian Islands area covers two stocks, Adak and Dutch Harbor, and the Bering Sea area contains two other stocks, the Pribilof Islands and Norton Sound. The largest stock is found in the Bristol Bay area, which includes all waters north of the latitude of Cape Sarichef (54°36' N lat.), east of 168° W long., and south of the latitude of Cape Newenham (58°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.

Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States (Bowers et al. 2008). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974 (Bowers et al. 2008). The Russian fleet fished for RKC from 1959 through 1971. The Japanese fleet employed primarily tanglenets with a very small proportion of catch from trawls and pots. The Russian fleet used only tanglenets. United States trawlers started to fish for Bristol Bay RKC in 1947, and effort and catch declined in the 1950s (Bowers et al. 2008). The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t), worth an estimated $115.3 million ex-vessel value (Bowers et al. 2008). The catch declined dramatically in the early 1980s and has stayed at low levels during the last two decades (Table 1). After the stock collapse in the early 1980s, the Bristol Bay RKC fishery took place during a short period in the fall (usually lasting about a week), with the catch quota based on the stock assessment conducted in the previous summer (Zheng and Kruse 2002a). As a result of new regulations for crab rationalization, the fishery was open longer beginning with the 2005/2006 season from October 15, 2005 to January 15, 2006. With the implementation of crab rationalization, historical guideline harvest levels (GHL) were changed to a total allowable catch (TAC). The GHL/TAC and actual catch are compared in Table 2. The implementation errors are quite high for some years, and total actual catch from 1980 to 2007 is about 6% less than the sum of GHL/TAC over that period (Table 2).

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 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 threshold of 8.4 million mature-sized females (≥90-mm CL) was added to existing management measures to avoid recruitment overfishing (Pengilly and Schmidt 1995). Based on a new assessment model and research findings (Zheng et al. 1995a, 1995b, 1997a, 1997b), the Alaska Board of Fisheries adopted a new harvest strategy in 1996. That strategy had two mature male harvest rates: 10% when effective spawning biomass (ESB) is between 14.5 and 55.0 million lbs and 15% when ESB is at or above 55.0 million lbs (Zheng el al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. An additional threshold of 14.5 million lbs of ESB was also added. In 1997, a minimum threshold of 4.0 million lbs was established as the minimum GHL for opening the fishery and maintaining fishery manageability when the stock abundance is low. In 2003, the Board modified the current harvest strategy by adding a mature harvest rate of 12.5% when the ESB is between 34.75 and 55.0 million lbs. The current harvest strategy is illustrated in Figure 1.

The purpose of this report is to document the stock assessments for Bristol Bay RKC. This report includes (1) all data used to conduct the stock assessments, (2) details of the analytic approach, (3) an evaluation of the assessment results, (4) estimates of biological reference points and federal overfishing limits for 2008, and (5) future projections and the near future outlook.

DATA

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 2005 (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.

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.

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.

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).

Survey Data

The NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conduct this multispecies, crab-groundfish survey during the summer. Stations are sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972 the trawl survey has covered the full stock distribution. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2008 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 NMFS post-stratifications. A “hot spot” was not surveyed with multiple tows during the early years. Two such “hot spots” affected the survey abundance estimates greatly: station H13 in 1984 (mostly juvenile crabs 75-90 mm CL) and station F06 in 1991 (mostly newshell legal males). The tow at station F06 was discarded in the NMFS abundance estimates (Stevens et al. 1991). In this study, the average abundances from all tows in the nine stations (the station itself and the eight adjacent stations) were used as the estimates of abundance for station H13 in 1984 and station F06 in 1991.

The approach here results in estimates close to those made by NMFS with some exceptions (Figure 6). Two surveys were conducted for Bristol Bay RKC in 1999, 2000, 2006-2008: 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 2006-2008 and resurveys of 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), and 32 stations (2007 and 2008) 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 7). Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000 because most mature females had not molted prior to the standard surveys. As in 2006, area-swept estimates of males >89 mm CL, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different between the standard survey and resurvey (P=0.74, 0.74 and 0.95) based on *t*-tests of paired two sample for means. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 are significantly different between the standard survey and resurvey (P=0.03) based on the *t*-test. All survey tows were included in NMFS estimates in 1999, 2000, 2006-2008. 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 five 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).

ANALYTIC APPROACH

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 assumed a constant natural mortality over time. Sources of mortality during the early 1980s need to be quantified to include data before 1985 into the research model. In this report, we present only the research model that was fit to the data only from 1985 to 2008.

Model Scenarios

Three scenarios with different handling mortalities were run for the research model. The base handling mortality rate was assumed to be 0.2, and alternative handling mortality rates of 0.1 and 0.4 were used for comparison.

Main Assumptions for the Model

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

(1) Natural mortality is constant over time, sex, shell condition, and length and was estimated with a maximum age of 25 and the 1% rule (Zheng 2005).

(2) Survey and fisheries selectivities are a function of length and were constant over time and shell condition. Selectivities are a function of sex except for trawl bycatch selectivities, which are the same for both sexes.

(3) Growth is a function of length and did not change over time.

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

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

(6) Survey catchabilities were set to 0.774 for females and 0.896 for males based on a trawl experiment by Weinberg et al. (2004).

(7) Female crabs are mature at sizes ≥90 mm CL and males mature at sizes ≥120 mm CL.

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

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

Population Model

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

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

where

$N_{l,t}$ is newshell crab abundance in length class l and year t,

$O_{l,t}$ is oldshell crab abundances in length class l and year t,

M is the instantaneous natural mortality,

m_l 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 assessment survey and the mid 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 pot and trawl bycatch.

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:

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

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

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

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

where

β, L_{50} are parameters, and

ι is the mid-length of length class l.

Recruitment is defined as recruitment to the model and survey gear rather than recruitment to the fishery. Recruitment is separated into a time-dependent variable, R_t, and size-dependent variables, U_l, representing the proportion of recruits belonging to each length class. R_t was assumed to consist of crabs at the recruiting age with different lengths and thus represents year class strength for year t. $R_{l,t}$ is computed as

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

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

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

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

where

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

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

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 is set at 65 mm, and the last length class includes all crabs ≥140-mm CL, resulting in length groups 1-16.

Fisheries Selectivities

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

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

Different sets of parameters (β, L_{50}) are estimated for retained males, female pot bycatch, and male and female trawl bycatch.

Male pot bycatch selectivity is modeled by two linear functions:

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

Where

φ, κ, γ are parameters.

During 2005-2007, 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.

Trawl Survey Selectivities/Catchability

Trawl survey selectivities/catchability are estimated as

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

with different sets of parameters (β, L_{50}) estimated for males and females. 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. Parameter A was set to be 0.774 for females and 0.896 for males based on a trawl experiment by Weinberg et al. (2004, Figure 8).

Parameters Estimated Independently

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 and 0.0197 in 2007 based on the proportions of discarded legal males to total caught legal males. Handling mortality rates was set to 0.2 for the pot fishery and 0.8 for the trawl fisheries.

Natural Mortality

Based on an assumed maximum age of 25 years and the 1% rule (Zheng 2005), M was estimated to be 0.18 for both males and females.

Length-weight Relationship

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

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

Ovigerous Females: $W = 0.02286\ L^{2.234}$, (11)

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

where

W is weight in grams, and

L is CL in mm.

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 9). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females, and the data presented in Gray (1963) were used to estimate those for mature females (Figure 9). 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. These percentages are roughly close to the composition of maturity. 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).

Sizes at Maturity for Males

Sizes at functional maturity for Bristol Bay male RKC have been assumed to be 120 mm CL (Schmidt and Pengilly 1990). This is based on mating pair data collected off Kodiak Island (Figure 10). Sizes at maturity for Bristol Bay female RKC are about 90 mm CL, about 15 mm CL less than Kodiak female RKC (Pengilly et al. 2002). The size ratio of mature males to females is 1.3333 at sizes at maturity for Bristol Bay RKC, and since mature males grow at much larger increments than mature females, the mean size ratio of mature males to females is most likely larger than this ratio. Size ratios of the large majority of Kodiak mating pairs were less than 1.3333, and in some bays, only a small proportion of mating pairs had size ratios above 1.3333 (Figure 10).

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

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 = 1986 to 2008), total abundance in the first year (1985), 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 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. Annual fishing mortalities were also estimated for the directed pot fishery for males (1985-2007), pot-discarded females (1990-2007), and groundfish trawl discarded males and females (1985-2007). Total number of parameters to be estimated is 130. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

To increase the efficiency of the parameter-estimation algorithm, we assumed that the relative frequencies of length and shell classes from survey year 1985 approximate the true relative frequencies within sexes. Thus, only total abundances of males and females for the first year were estimated; 3n unknown parameters for the abundances in the first year, where n is the number of length-classes, were reduced to one under this assumption.

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

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

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

where

L is the number of length groups,

T is the number of years, and

n is the effective sample size, which was assumed to be 400 for retained males, 200 for trawl survey and 100 for bycatch length composition data.

The weighted negative log-likelihood functions are:

$$\begin{aligned}
&Length\,compositions: \quad -\sum \ln(Rf_i)\,, \\
&Biomasses\,other\,than\,survey: \quad \lambda_j \sum\left[\ln(B_t/\hat{B}_t)^2\right], \\
&Survey\,bimass: \quad \lambda\sum\left[\ln(B_t/\hat{B}_t)^2/(2cv_t^2)\right], \\
&R\ variation: \quad \lambda_R\sum[\ln(R_t/\overline{R})^2]\,, \\
&R\ sex\,ratio: \quad \lambda_s[\ln(\overline{R}_M/\overline{R}_F)^2]\,,
\end{aligned} \tag{13}$$

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.

Weighted λ_j are assumed to be 500 for retained catch biomass, 50 for survey biomass, and 20 for all other biomasses, 2 for recruitment variation, and 20 for recruitment sex ratio. These λ_j values represent prior assumptions about the accuracy of the observed biomass data and about the variances of these random variables.

RESULTS

Population Abundance

The model fit the fishery biomass data well and fit the survey biomass reasonably well (Figures 11 and 12). Because the model estimates annual fishing mortality for pot male catch, pot female bycatch, and trawl bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences. The model did not fit the mature crab abundance directly and depicted the trends of the mature abundance well (Figure 12). Estimated mature crab abundance has increased during the last 20 years with mature females being 6 times more abundant in 2008 than in 1985 and mature males being 2.5 times more abundant in 2008 than in 1985 (Figure 12).

The model also fit the length and shell composition data well (Figures 13-20). Model fit of length compositions in the trawl survey was better for newshell males and females than for oldshell males. The model predicted lower proportions of oldshell males in 1993, 1994 and 2002 and higher proportions of oldshell males in 1988, 1997, 2001, 2003, 2004 and 2006 than the area-swept estimates (Figure 14). In addition to size, molting probability may also be affected by age and environmental conditions. Tagging data show that molting probability changed over time (Basilger 1974). Therefore, the relatively poor fit to oldshell males may be due to use of a constant molting probability function as well as shell aging errors. It is surprising that the model fit the length proportions of the pot male bycatch well with two simple linear selectivity functions (Figure 17). We explored a logistic selectivity function, but due to the long left tail of the pot male bycatch selectivity, the logistic selectivity function did not fit the data well.

Modal progressions are tracked well in the trawl survey data, particularly beginning in the mid-1990s (Figures 13 and 15). Cohorts first seen in the trawl survey data in 1986, 1990, 1995, 1999, 2002, 2004 and 2005 can be tracked over time. Some cohorts can be tracked over time in the pot bycatch as well (Figure 17), but the bycatch data did not track the cohorts as well as the survey data. Groundfish trawl bycatch data provide little information to track modal progression (Figures 19 and 20).

The model can be extended to the data before 1985. However, due to a sharp decrease in population abundance in the early 1980s, it is difficult to fit the data with a constant natural mortality. The model can be used to investigate changes in natural mortality and impacts of observed and unobserved bycatch on the population in the late 1970s and early 1980s. These were the original objectives to develop the research model.

Parameter Estimates

Negative log-likelihood values and parameter estimates are summarized in Tables 5 and 6, respectively. Length-specific fishing mortality is equal to its selectivity times the full fishing mortality. Estimated full pot fishing mortalities for females and full fishing mortalities for trawl bycatch were very low due to low bycatches as well as handling mortality rates less than 1.0. Estimated recruits varied greatly from year to year (Table 6). Estimated low selectivities for male pot bycatch, relative to the retained catch, reflected the 20% handling mortality rate (Figure 21). Both selectivities were applied to the same level of full fishing mortality. Estimated selectivities for female pot bycatch were close to 1 for all mature females (Figure 21), and the estimated full fishing mortalities for female pot bycatch were much lower than for male retained catch and bycatch (Table 6).

One of the most important results is estimated trawl survey selectivity/catchability (Figure 21). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. Estimated survey selectivities in Figure 21 are generally smaller than the capture probabilities in Figure 8 because survey selectivities include capture probabilities and crab availability. 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 systematical 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 1985-2008 (Figure 22) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crabs, possibly due to changes in molting probabilities over time or shell aging errors. Overestimates or underestimates of oldshell crabs will result in lower or higher estimates of male molting probabilities.

Residual Patterns

Residuals of total survey biomass and proportions of length and shell condition, calculated as observed minus predicted, were plotted to examine their patterns. Residuals of total survey biomass were standardized by the estimated standard deviation. The residuals of total survey biomass did not show any consistent patterns (Figure 23). Standardized residuals of proportions of survey newshell males appear to be random over length and year (Figure 24). Residuals of proportions of survey oldshell males were mostly positive or negative for some years (Figure 25). This is expected since a constant molting probability function over time was used. Changes in molting probability over time or shell aging errors would create such residual patterns. There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females before 1995 and positive after 1994 (Figure 26). The pattern was opposite for small-sized mature females. Several factors could cause such a pattern: (1) a lower natural mortality after 1994, (2) changes in survey selectivities, (3) an unknown source of mortality before 1995, or (4) changes in growth over time. ADF&G stock assessment model estimates different levels of natural mortality for different periods of years and suggests a lower natural mortality after 1993. The inadequateness of the model can be corrected by adding parameters to address these factors. Even though the residuals for females were not random, the model appears to fit annual mature female abundance quite well (Figure 12).

Retrospective Analyses

Two kinds of retrospective analyses were conducted for this report: (1) historical results and (2) the 2008 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 2008 estimates as the baseline values, we can also evaluate how well the model had done in the past. The 2008 model results are based on sequentially excluding one-year of data to evaluate the current model performance with less data.

Historical Results

The model first fit the data from 1985 to 2004 in 2004. Thus, five historical assessment results are available. The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1000 for survey biomass, 2000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5, 2, and 1 were also applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 27).

In 2005, to improve the fit for retained catch data, the weight for retained catch biomass increased to 3000 and the weight for retained catch proportions 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 be 500 for retained catch, 200 for survey data, and 100 for bycatch data. Weights for biomasses were changed to 800 for retained catch, 300 for survey and 50 for bycatches. The weights in 2007 were the same as 2006. Generally, estimates of time series of abundance in 2005 were slightly lower than in 2006 and 2007, and there were few differences between estimates in 2006 and 2007 (Figure 27).

In 2008, estimated coefficients of variation for survey biomass were used to compute likelihood values as suggested by a Crab Plan Team member in 2007. Weights were re-configured because of this change: 500 for retained catch biomass, 50 for survey biomass, and 20 for bycatch biomasses. Effective sample size was lowered to 400 for the retained catch data. These changes were necessary for the estimation to converge and for a relatively good balanced fit to both biomasses and proportion data. Also, sizes at 50% selectivities for all fisheries data were allowed to change annually, subject to a random walk pattern, for all assessments before 2008. The 2008 model does not allow annual changes in any fishery selectivities. Except for higher estimates of abundance during the late 1980s and early 1990s, estimates of time series of abundance in 2008 were generally close to those in 2006 and 2007 (Figure 27).

2008 Model Results

The performance of the 2008 model includes sequentially excluding one-year of data. The model performed well except estimates for the early 2000s made with terminal year 2002 (Figure 28). Lower estimates in the early 2000s were primarily due to extremely low survey estimates in 2001.

Overall, both historical results and the 2008 model results performed reasonably well. No great overestimates or underestimates occurred as observed in Pacific halibut (*Hippoglossus stenolepis*) (Parma 1993) or some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002a; Ianelli et al. 2003). Since the model has not been used to set TAC or overfishing limits, historical implications for management from these assessment errors can not be evaluated at the current time. However, management implications of the ADF&G stock assessment model were evaluated by Zheng and Kruse (2002a).

Effects of Handling Mortality Rate on Abundance Estimates

The baseline handling mortality rate for the pot fishery was set at 0.2. A 50% reduction and 100% increase resulted in 0.1 and 0.4 as alternatives. Overall, a higher handling mortality rate resulted in slightly higher estimates of mature abundance, and a lower rate resulted in a minor reduction of estimated mature abundance (Figure 29). Differences of estimated legal abundance and mature male biomass were small among these handling mortality rates (Figure 30).

Effects of Natural Mortality

Changes in natural mortality resulted in changes in model fitting, abundance estimates and $F_{35\%}$ values (Figure 31). Estimated $F_{35\%}$ is highly sensitive to values of natural mortality, and a higher M resulted in a higher $F_{35\%}$. The M = 0.18 results in close to the best fit of the data and results in intermediate values of estimated legal male abundance (Figure 31). Higher M values generally result in lower estimates of legal male abundance in 2008.

Effects of Survey Catchabilities

Changes in trawl survey catchabilities resulted in changes in model fitting and abundance estimates (Figure 32). When fixing survey catchability for females to be 0.774, the likelihood value is maximized with a male survey catchability of 1.10, an unlikely value biologically. When fixing survey catchability for males to be 0.896, the likelihood value is maximized with a female survey catchability of 0.80, close to the estimated value from the double-bag experiment (Weinberg et al. 2004). When fixing the ratio of male to female catchabilities to be 1.1576 (0.896/0.774), the likelihood value is maximized with male and female catchabilities of 1.10 and 0.95, respectively. However, the likelihood values are very close for male survey catchabilities from 1.00 to 1.10 (Figure 32). Estimated legal male abundance in 2008 is highly sensitive to values of male survey catchability, and a higher male survey catchability resulted in a lower legal abundance. Changes in female catchability have little impacts on estimated legal male abundance (Figure 32).

Exploitation

Estimated full pot fishing mortalities ranged from 0.0 to 0.592 during 1985-2007 with estimated values over 0.4 during 1985-1987, 1990-1991, 1993, and 1998 (Table 6). Estimated fishing mortalities for pot female bycatch and trawl bycatch were less than 0.06.

The average of estimated male recruits from 1995 to 2008 (Figure 33) and mature male biomass per recruit was used to estimate $B_{35\%}$. The choice of this recruitment will be discussed in the “Biological Reference Points” section. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 34). Before the current harvest strategy was adopted in 1996, many fishing mortalities were above $F_{35\%}$ (Figure 34). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005 and 2007 but below the $F_{35\%}$ limits in other years.

Stock-Recruitment Relationships

Estimated mature male biomass and recruitment were plotted to illustrate their relationships (Figure 35). Neither the estimated Ricker nor the Beverton-Holt curve was statistically significant.

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 36). 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 36). The average clutch fullness was almost identical for these two periods (Figure 36).

BIOLOGICAL REFERENCE POINTS AND OVERFISHING LIMITS FOR 2008

Bristol Bay RKC is currently placed in Tier 3 (NPFMC 2007). For Tier 3 stocks, estimated biological reference points include $B_{35\%}$, $F_{35\%}$ and $F_{40\%}$. Estimated model parameters were used to conduct mature male biomass per recruit analysis. Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 1998 to 2007 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 1990-2007. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower in 2006 and 2007 than in 2005 after the fishing industry minimized discards of legal males. Thus, the average of retained selectivities and discard male selectivities in 2006 and 2007 were used to represent current trends for per recruit analysis and projections. Because of higher estimated recruitment after 1994 than during 1985-1994 and the potential regime shift after 1989 (Overland et al. 1999), which corresponded to recruitment in 1995 and later, we used average of estimated male recruitment during 1995-2008 (Figure 33) to develop $B_{35\%}$. The biological reference points were estimated as follow:

$B_{35\%}$ = 75.112 million lbs, or 34,070 t,

$F_{35\%}$ = 0.33,

$F_{40\%}$ = 0.26.

Based on $B_{35\%}$ and $F_{35\%}$, the retained catch and total catch limits for 2008 are estimated to be:

Retained catch: 20.587 million lbs, or 9,338.1 t,

Total catch: 24.202 million lbs, or 10,978.0 t,

MMB on 2/15/2009: 95.58 million lbs, or 43,356.0 t.

Likelihood profiles of mature male biomass on February 15, retained catch and total catch for 2008 are illustrated in Figure 37. The confidence intervals are quite narrow for all three values.

PROJECTIONS AND FUTURE OUTLOOK

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 1995-2008. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2008. The 2008 abundance was randomly selected from the estimated normal distribution of the assessment model for each replicate. Four scenarios of fishing mortality for the directed pot fishery were used in the projections:

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

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

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

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

Each scenario was replicated 1000 times and projections made over 10 years beginning in 2008 (Table 8).

As expected, projected mature male biomasses were much higher without the directed fishing mortality than under the other scenarios. Among three scenarios with directed fishing, the ADF&G harvest strategy produced the most stable mature male biomass and catch over time (Table 8, Figures 38 and 39). With its forward looking feature, the ADF&G harvest strategy reduced fishing mortality one year or two years earlier than the $F_{40\%}$ and $F_{35\%}$ scenarios when recruitment was poor. At the end of 10 years, projected mature male biomass was above $B_{35\%}$ for the $F_{40\%}$ scenario and the ADF&G harvest strategy and similar to $B_{35\%}$ for the $F_{35\%}$ scenario (Figure 38).

Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is stable. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had largely entered the legal population by 2006 (Figure 40). 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 will continue to enter the mature male population next year and start to recruit to the legal population next year (Figure 40). However, no strong cohorts have been observed in the survey data after this cohort (Figure 40). Due to these above average year classes, mature and legal crabs should remain at relatively high abundance levels compared to the previous 20 years if natural mortality does not increase greatly, as happened in the early 1980s for this stock and in 1999 for St. Matthew Island blue king crab (Zheng and Kruse 2002b). The mature and legal abundance may start to decline after 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.

ECOSYSTEM CONSIDERATIONS

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

Impacts of Changes in Oceanographic Conditions on RKC Recruitment

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

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

Predation by Groundfish

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

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

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

Spatial distributions of crabs and groundfish may also play an important role on groundfish predation on crabs. Like crab stocks, spatial distributions of groundfish stocks in the eastern Bering Sea changed over time (Figure 41). During recent years, biomass distribution centers of Pacific cod, flathead sole and arrowtooth flounder shifted to the northwest, those of rock sole, skates and Alaska plaice shifted to the northeast, whereas spatial distributions of yellowfin sole remained relatively stable (Figure 41). The northward expansion for some groundfish seems to relate to warmer bottom temperatures, perhaps due to a northward extension of suitable habitat. With warmer temperatures, the center of groundfish spatial distributions moved farther to the north (Zheng and Kruse 2006).

Changes in spatial distributions of groundfish in the eastern Bering Sea are best illustrated by distributions of Pacific cod biomass from 1982 to 2004 (Figure 42). In the early 1980s, Pacific cod mainly occurred in shallow waters <50 m in the Bristol Bay area and in deep waters >100 m in the northwest of the eastern Bering Sea. However, during 1985-1988 and 1991-1996 the distribution of Pacific cod biomass was widespread across the shelf. In recent years, cod abundance concentrated in the north, around St. Matthew Island, and stayed at a relatively low density in Bristol Bay.

Other striking examples of changes in spatial distributions are provided by rock sole and skates (Figure 43). Rock sole mainly occurred in Bristol Bay and the Pribilof Islands in the 1980s. During the last 15 years, rock sole have expanded to the north up to St. Matthew Island. The biomass of skates has also increased greatly during the last 20 years and expanded northward. Among other commercially important species, biomass of arrowtooth flounder and flathead sole has also increased during the 1980s.

Impacts of Shifts of Spatial Distribution on Crab Recruitment Success

Spatial distributions of Bristol Bay RKC changed profoundly during the last three decades (Hsu 1987; Loher 2001; Zheng and Kruse 2006; Figure 44). Generally speaking, RKC abundance in southern Bristol Bay was high during the 1970s, declined, and was extremely low after 1979 (Zheng and Kruse 2006). Female RKC were found primarily in central Bristol Bay during 1980-1987 and 1992-2006 (Zheng and Kruse 2006). The distribution centers of mature females moved south slightly during 1988-1991 but did not reach the southern locations previously occupied in the 1970s. Loher (2001) hypothesized that changes in near bottom temperatures associated with the 1976/77 regime shift are causes for spatial shifts of RKC female distributions. Because small juvenile RKC are generally located downstream of the mature females (Zheng and Kruse 2006), larval advection appears to be an important process for RKC.

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

RKC larval drifts were similar among three years (1975, 1987 and 2004) but very different among different hatching locations (Figure 45). At southern and middle locations, larvae generally drifted to the northeast, and at the northern location, larvae drifted to the north or northwest. Larvae hatched in the southern location were estimated to reach central Bristol Bay, whereas larvae hatched in central Bristol Bay were estimated to settle in the northernmost reaches of Bristol Bay. Owing to prevailing currents, larvae hatched in central and northern Bristol Bay are very unlikely to settle in the southern portions of Bristol Bay (Figure 45).

Settling locations appear to have an important impact on resultant year-class strength for Bristol Bay RKC (Figure 46). For years with strong year classes, crab larvae were generally estimated to have settled in the central portion of Bristol Bay (Zheng and Kruse 2008). Because the simulations started at the centers of the annual distribution of the brood stock, larval settling locations from these years likely also represent the centers of a broader distribution of settling larvae that are well dispersed from south to north along the shallow shelf of Bristol Bay. Larvae associated with weak year-classes generally settled farther downstream in northern Bristol Bay or to the northwest outside of Bristol Bay. Occasionally, larvae hatched in the southern Bristol Bay settled there. Larvae hatching in the middle or later portion of the hatching period may contribute disproportionately to subsequent recruitment; early hatching larvae had longer larval stages and were dispersed farther downstream from the hatching locations than those hatched late in a spawning season (Figure 46).

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

ACKNOWLEDGMENTS

We thank Doug Woodby and the Crab Plan Team for reviewing the earlier draft of this manuscript. This report is funded in part by a cooperative agreement from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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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

35

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

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

Table 3. Annual sample sizes for catch by length and shell condition for retained catch and bycatch of Bristol Bay red king crab.

Year	Trawl Survey Males	Trawl Survey Females	Retained Catch	Pot Bycatch Males	Pot Bycatch Females	Trawl Bycatch Males	Trawl Bycatch 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					

37

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	

Table 5. Summary of statistics for the model

Parameter counts

Fixed growth parameters	36
Fixed length-weight relationship parameters	6
Fixed mortality parameters	3
Fixed survey catchability parameters	2
Fixed highgrading parameters	3
Fixed initial (1985) length composition parameters	56
Total number of fixed parameters	106
Free growth parameters	4
Initial abundance (1985)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	23
Female recruitment deviations	23
Fishing mortality parameters	3
Pot male fishing mortality deviations	23
Pot female bycatch fishing mortality deviations	16
Trawl bycatch fishing mortality deviations	23
Free selectivity parameters	12
Total number of free parameters	131
Total number of fixed and free parameters	237

Negative likelihood components

Length compositions---retained catch	-623.922
Length compositions---pot male discard	-663.566
Length compositions---pot female discard	-1463.220
Length compositions---trawl discard	-1319.990
Length compositions---survey	-31361.600
Retained catch biomass	6.343
Pot discard male biomass	58.636
Pot discard female biomass	26.202
Trawl discard	0.572
Survey biomass	1713.440
Recruitment variation	94.707
Sex ratio of recruitment	0.026
Total	-33532.400

Table 6. Summary of model parameter estimates for Bristol Bay red king crab. CVs are for recruits. Values in parenthesis are standard deviation.

	F for Pot Fishery		F for Trawl	Recruits (million crabs)			
Year	Males	Female	Fishery Discard	Males	CV	Females	CV
1985	0.4340		0.0222	NA		NA	
1986	0.5921		0.0127	14.905	0.04	14.529	0.05
1987	0.4536		0.0074	6.922	0.08	6.783	0.09
1988	0.1885		0.0204	2.007	0.18	1.675	0.18
1989	0.2165		0.0048	4.734	0.10	2.097	0.18
1990	0.4326	0.0503	0.0091	11.478	0.06	9.124	0.05
1991	0.4084	0.0042	0.0095	6.891	0.06	3.722	0.09
1992	0.2104	0.0244	0.0148	0.605	0.27	0.661	0.25
1993	0.4697	0.0546	0.0175	6.515	0.05	3.730	0.08
1994	0.0000	0.0000	0.0023	0.486	0.27	0.668	0.29
1995	0.0000	0.0000	0.0069	32.175	0.02	33.532	0.03
1996	0.1743	0.0001	0.0024	8.080	0.06	8.289	0.08
1997	0.2049	0.0006	0.0023	0.472	0.28	0.555	0.29
1998	0.4070	0.0264	0.0047	6.762	0.06	7.419	0.09
1999	0.2758	0.0003	0.0059	18.763	0.04	19.421	0.05
2000	0.1559	0.0012	0.0029	5.786	0.10	5.847	0.14
2001	0.1411	0.0045	0.0042	2.313	0.15	6.415	0.12
2002	0.1585	0.0002	0.0031	32.550	0.03	41.118	0.03
2003	0.2609	0.0084	0.0036	5.531	0.12	5.749	0.13
2004	0.2658	0.0048	0.0023	16.461	0.09	18.420	0.06
2005	0.3902	0.0085	0.0029	30.063	0.04	35.930	0.04
2006	0.2849	0.0006	0.0025	11.334	0.08	7.299	0.12
2007	0.3478	0.0028	0.0021	4.799	0.14	4.126	0.17
2008				1.384	0.28	2.399	0.29

Growth β: males: 1.5323 (0.0815), females: 1.5915 (0.1314);
Recruits β: males: 0.6569 (0.0605), females: 0.7014 (0.0441);
Molting: *L50*: 137.890 (0.3904), β: 0.0841 (0.0029);
Total abundance in 1985: 68.7214 (0.9232) million crabs;
Retained selectivity: *L50*: 138.110 (0.2162), β: 0.4761 (0.0213);
Pot disc. female selectivity: *L50*: 81.776 (0.6846), β: 0.4343 (0.1255);
Pot disc. male selectivity parameters:
φ: -0.2337 (0.0136), κ: 0.0027 (0.0001), γ: -0.0115 (0.006);
Groundfish trawl disc. selectivity: *L50*: 145.960 (5.6542), β: 0.0587 (0.0036);
Trawl survey male selectivity: *L50*: 88.817 (1.4463);
Trawl survey female selectivity: *L50*: 79.602 (0.8110);
Trawl survey selectivity: β: 0.0551 (0.0027).

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 1985-2008. 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)	Mature (>89mm)	Model Est. (>64mm)	Area-swept (>64mm)
1985	9.580	2.970	29.062	11.278	74.242	78.508
1986	13.746	5.721	40.009	17.261	96.446	89.315
1987	15.931	7.537	49.821	21.362	108.208	159.118
1988	16.494	9.115	60.601	25.261	113.837	105.753
1989	17.798	10.679	66.962	25.243	119.570	134.613
1990	17.897	11.541	59.941	22.787	121.499	123.130
1991	14.210	10.049	49.298	21.192	109.510	122.278
1992	11.461	8.099	46.104	22.159	99.759	82.672
1993	12.256	7.592	40.420	20.351	98.036	113.721
1994	11.685	6.842	51.720	17.505	85.919	70.864
1995	11.985	8.513	56.786	16.272	103.482	83.599
1996	12.079	9.086	52.229	22.298	120.286	96.806
1997	11.642	8.204	48.693	33.576	128.623	179.703
1998	16.818	8.057	56.528	34.257	136.646	185.235
1999	19.430	9.970	69.261	30.685	140.408	134.722
2000	17.513	11.814	71.168	33.237	144.663	142.995
2001	16.338	11.783	69.760	37.230	149.316	108.835
2002	18.434	11.507	75.800	36.442	166.022	160.326
2003	19.237	12.485	74.213	43.458	177.963	214.796
2004	17.553	12.032	68.247	53.631	187.427	221.664
2005	21.103	11.411	72.329	54.813	206.665	224.195
2006	22.470	12.506	81.235	61.775	217.835	198.799
2007	23.789	13.901	83.100	68.724	229.062	225.780
2008	27.471	14.564	95.584	64.220	227.244	235.723

Table 8. Comparison of projected mature male biomass (million lbs) on Feb. 15, retained catch (million lbs), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, $F_{35\%}$, and ADF&G harvest strategy with $F_{35\%}$ constraint during 2008-2017.

Year	MMB	95% limits of MMB		Catch	95% limits of catch		Mean F
No directed fishery							
2008	116.202	112.204	120.406	0	0	0	0
2009	143.486	138.549	148.676	0	0	0	0
2010	153.376	148.101	158.919	0	0	0	0
2011	151.045	145.455	157.102	0	0	0	0
2012	150.017	136.958	171.109	0	0	0	0
2013	154.485	127.329	202.063	0	0	0	0
2014	161.403	118.720	220.974	0	0	0	0
2015	168.243	113.310	239.856	0	0	0	0
2016	173.957	111.725	254.114	0	0	0	0
2017	179.380	108.490	266.927	0	0	0	0
$F_{40\%}$							
2008	99.362	95.944	102.957	16.507	15.939	17.104	0.260
2009	107.966	104.251	111.871	19.403	18.736	20.105	0.260
2010	99.940	96.503	103.550	21.115	20.388	21.878	0.260
2011	83.671	80.170	87.774	19.968	19.284	20.697	0.260
2012	74.659	65.125	92.573	16.091	14.063	18.049	0.243
2013	74.590	54.391	114.145	13.850	9.605	18.559	0.232
2014	77.837	48.306	121.884	13.762	7.156	22.039	0.234
2015	80.965	47.160	131.341	14.409	6.180	23.812	0.236
2016	82.881	46.290	133.481	15.069	5.779	25.666	0.236
2017	84.565	46.198	138.211	15.547	5.685	26.375	0.237
$F_{35\%}$							
2008	95.434	92.150	98.886	20.328	19.629	21.064	0.330
2009	100.614	97.152	104.254	22.895	22.107	23.723	0.330
2010	90.080	86.983	93.334	24.115	23.286	24.988	0.330
2011	73.407	70.915	76.500	21.260	19.916	22.632	0.316
2012	65.684	57.272	81.145	15.790	13.410	19.307	0.276
2013	66.401	47.847	102.167	13.966	9.030	19.916	0.271
2014	69.908	43.003	109.457	14.310	6.815	24.173	0.278
2015	72.955	42.286	118.456	15.236	6.085	26.020	0.283
2016	74.608	41.936	120.746	16.059	5.757	28.229	0.286
2017	75.979	42.351	122.838	16.593	5.834	28.876	0.288
ADF&G harvest strategy							
2008	95.580	92.456	98.886	20.664	18.960	21.064	0.327
2009	102.379	99.399	105.266	22.195	19.915	22.852	0.303
2010	96.632	94.010	99.071	19.516	18.127	20.277	0.249
2011	84.318	81.955	87.172	16.584	15.313	17.349	0.215
2012	76.171	67.965	89.883	15.796	12.209	20.530	0.226
2013	74.583	57.140	108.066	15.853	8.853	22.126	0.253
2014	76.265	50.291	113.400	15.896	6.988	25.563	0.262
2015	78.410	47.550	121.062	16.029	5.389	27.014	0.260
2016	79.844	46.253	123.963	16.195	5.059	28.714	0.256
2017	81.313	47.453	126.263	16.386	4.833	29.367	0.254

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

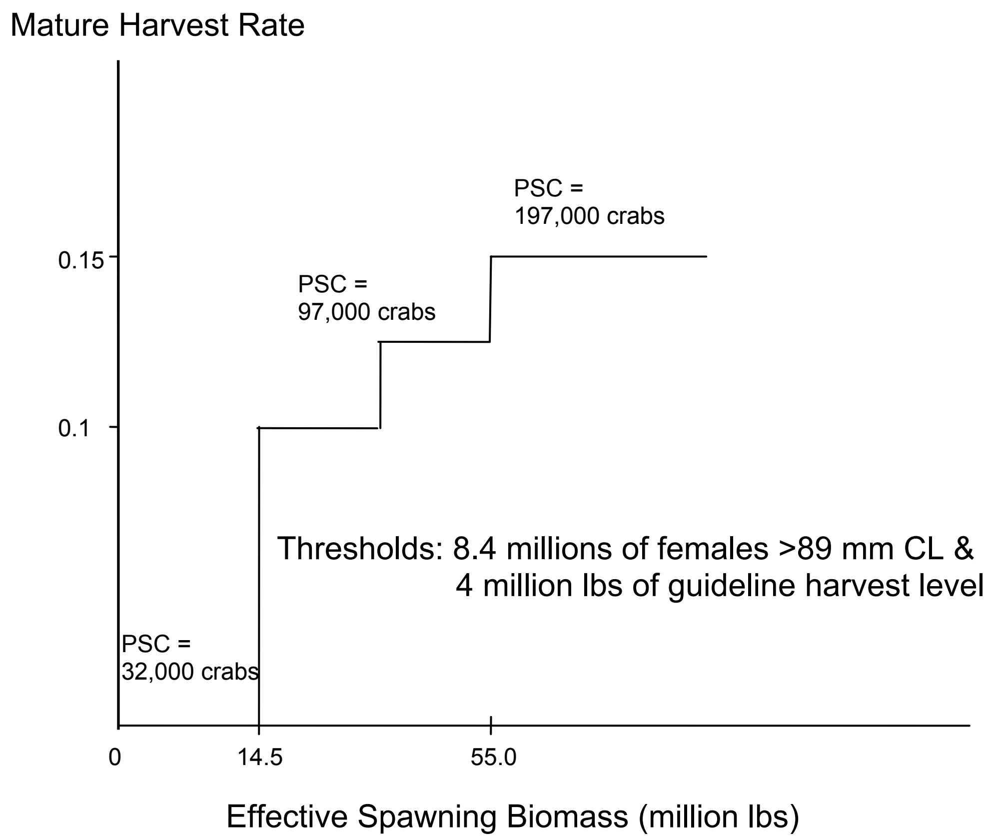


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crabs) of Bristol Bay red king crabs in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates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

45

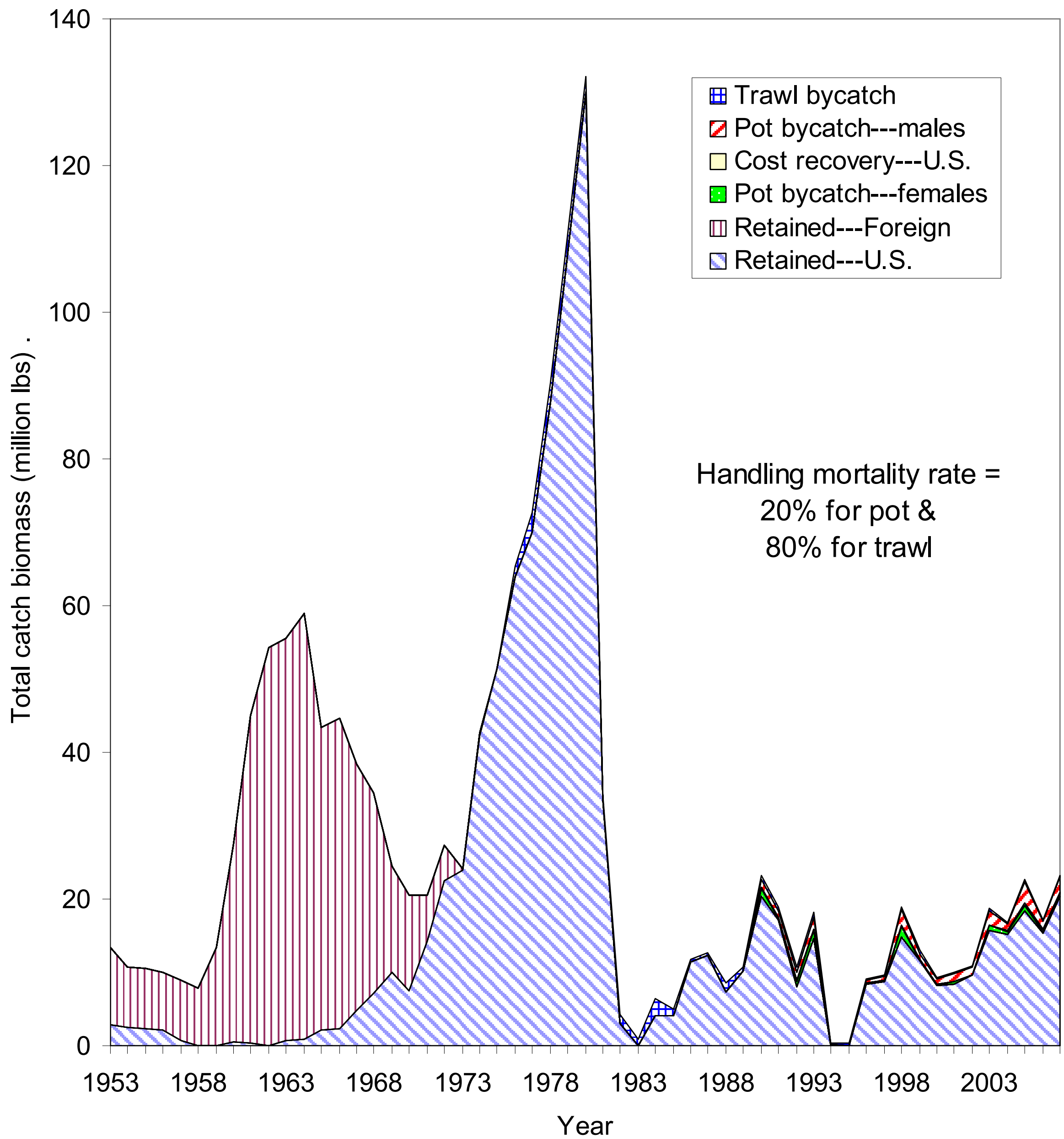


Figure 2. Retained catch biomass and bycatch mortality biomass (million lbs) for Bristol Bay red king crab from 1960 to 2007. Handling mortality rates were assumed to be 0.2 for the directed pot fishery and 0.8 for the trawl fisheries.

46

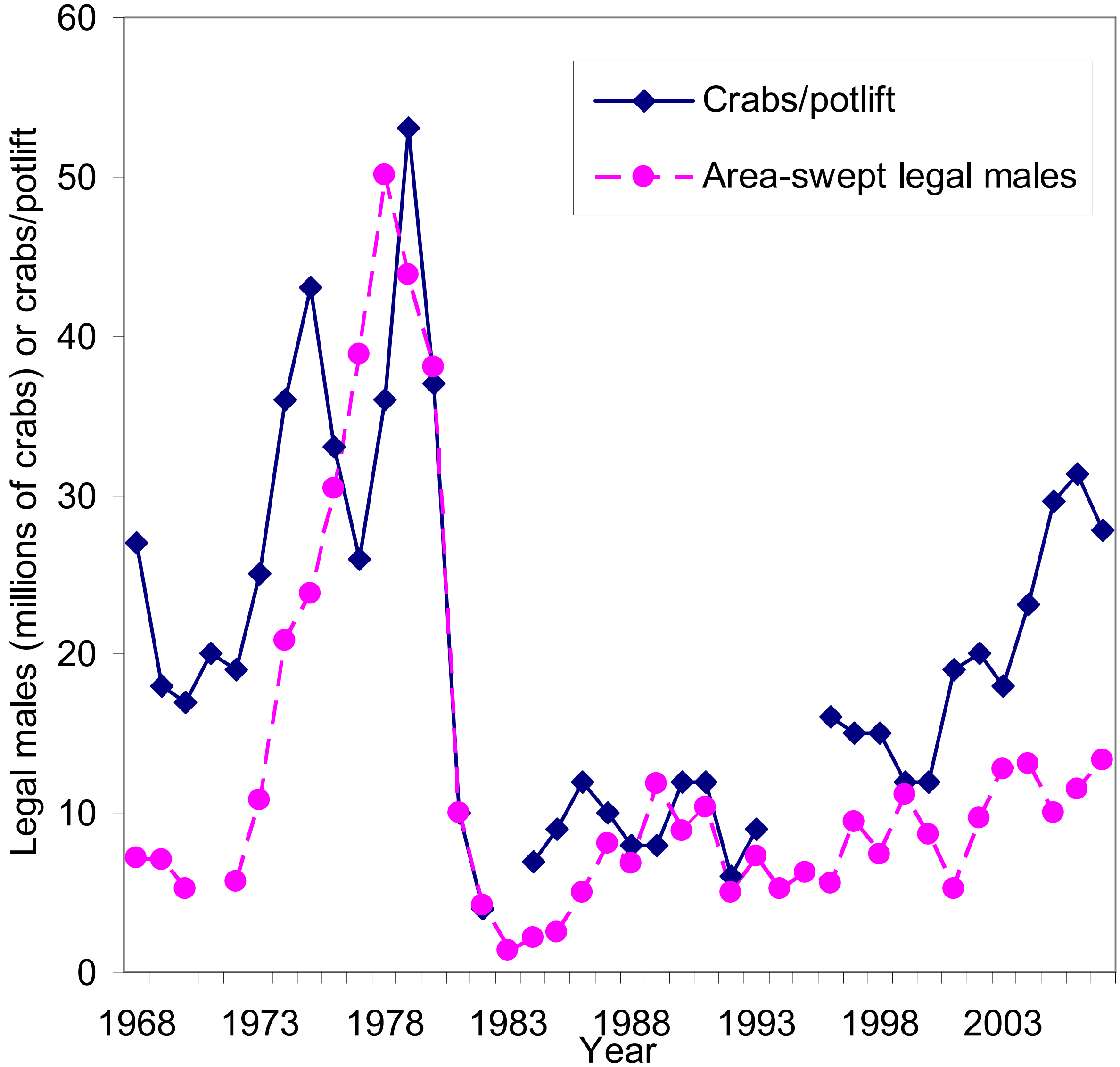


Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2007.

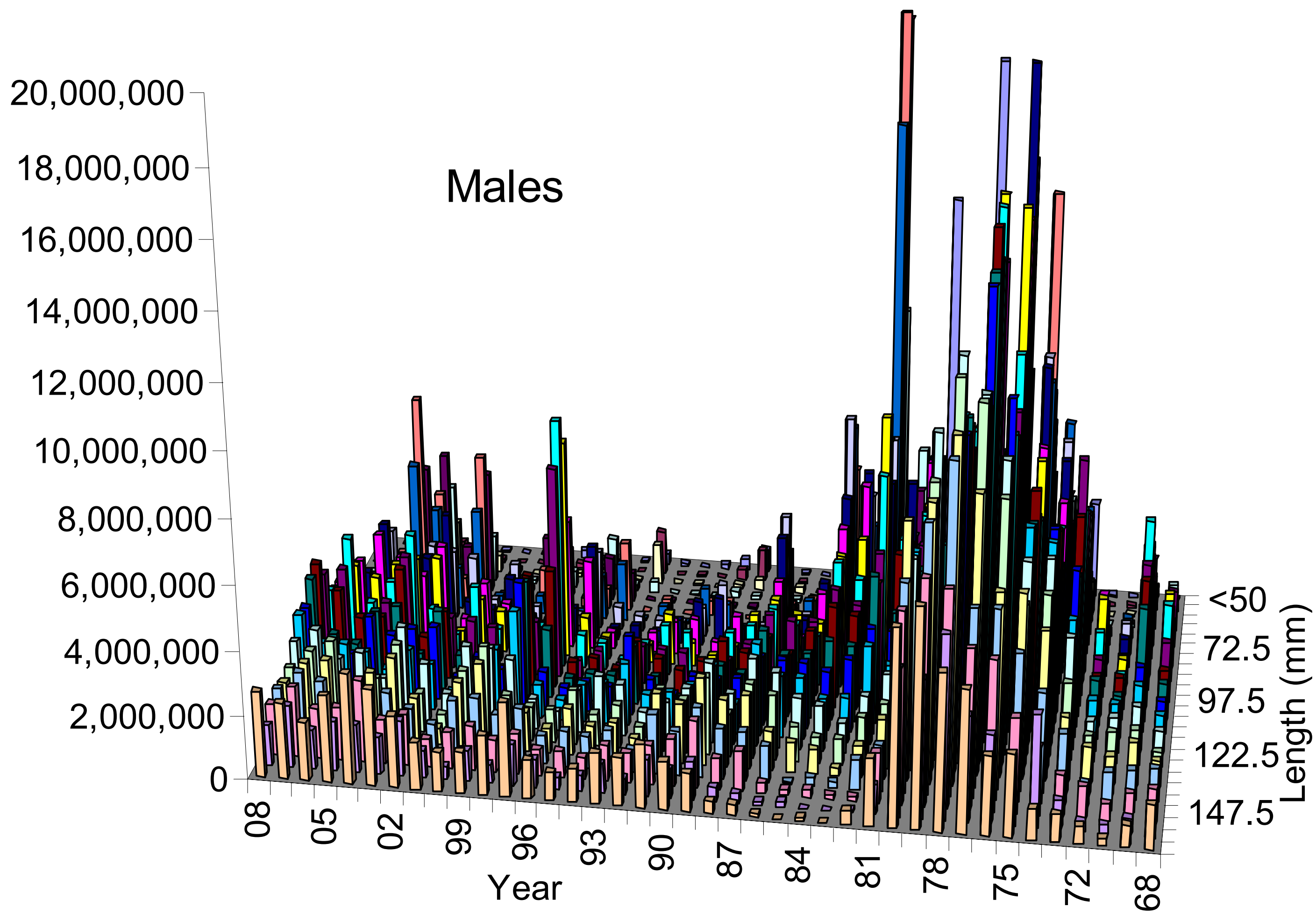


Figure 4. Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2008.

48

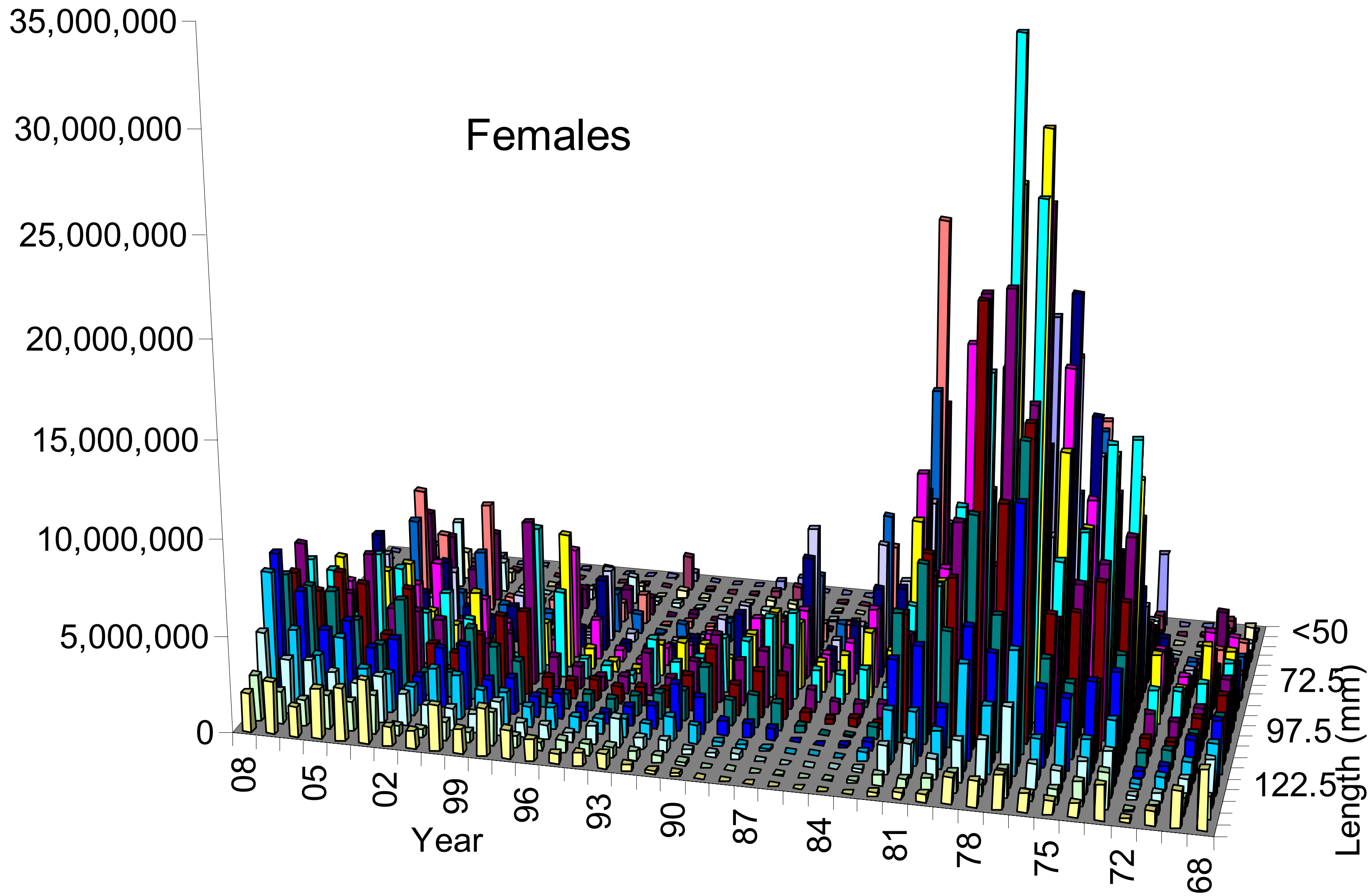


Figure 5. Survey abundances by length for female Bristol Bay red king crabs from 1968 to 2008.

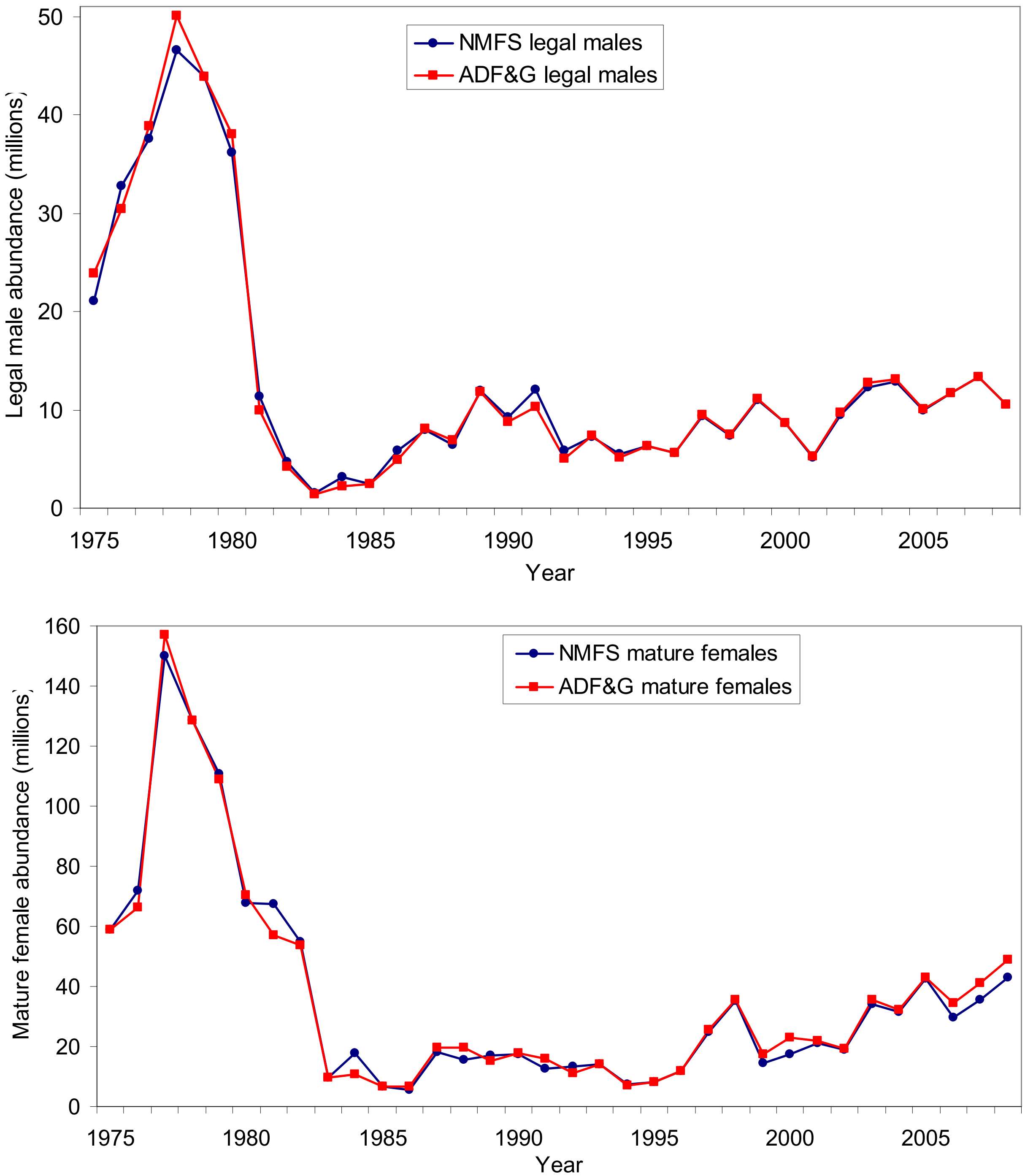


Figure 6. Comparison of survey abundance estimates by NMFS and ADF&G for Bristol Bay red king crab from 1975 to 2008.

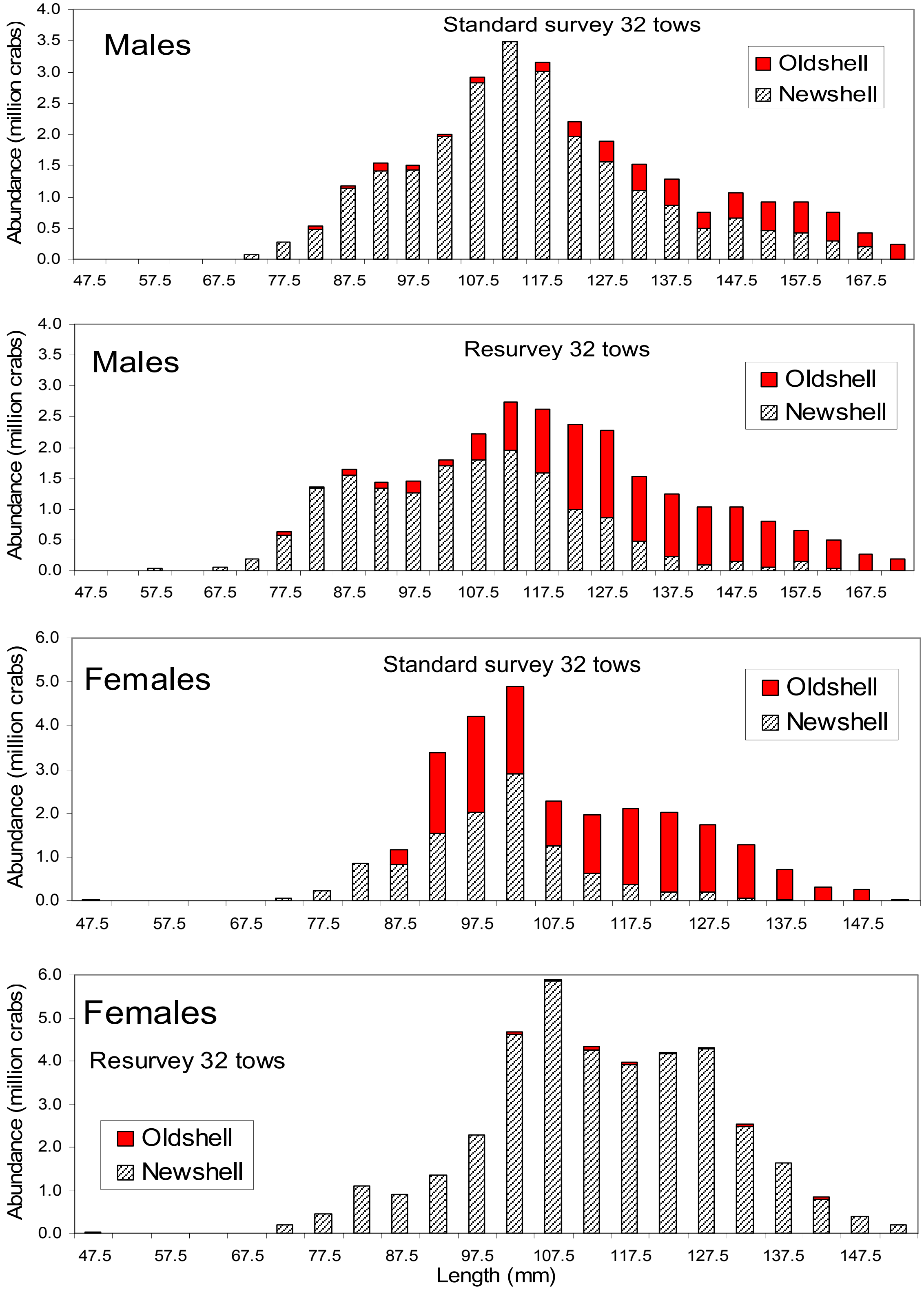


Figure 7. Comparison of area-swept estimates of abundance in 32 stations from the standard trawl survey and resurvey in 2008.

51

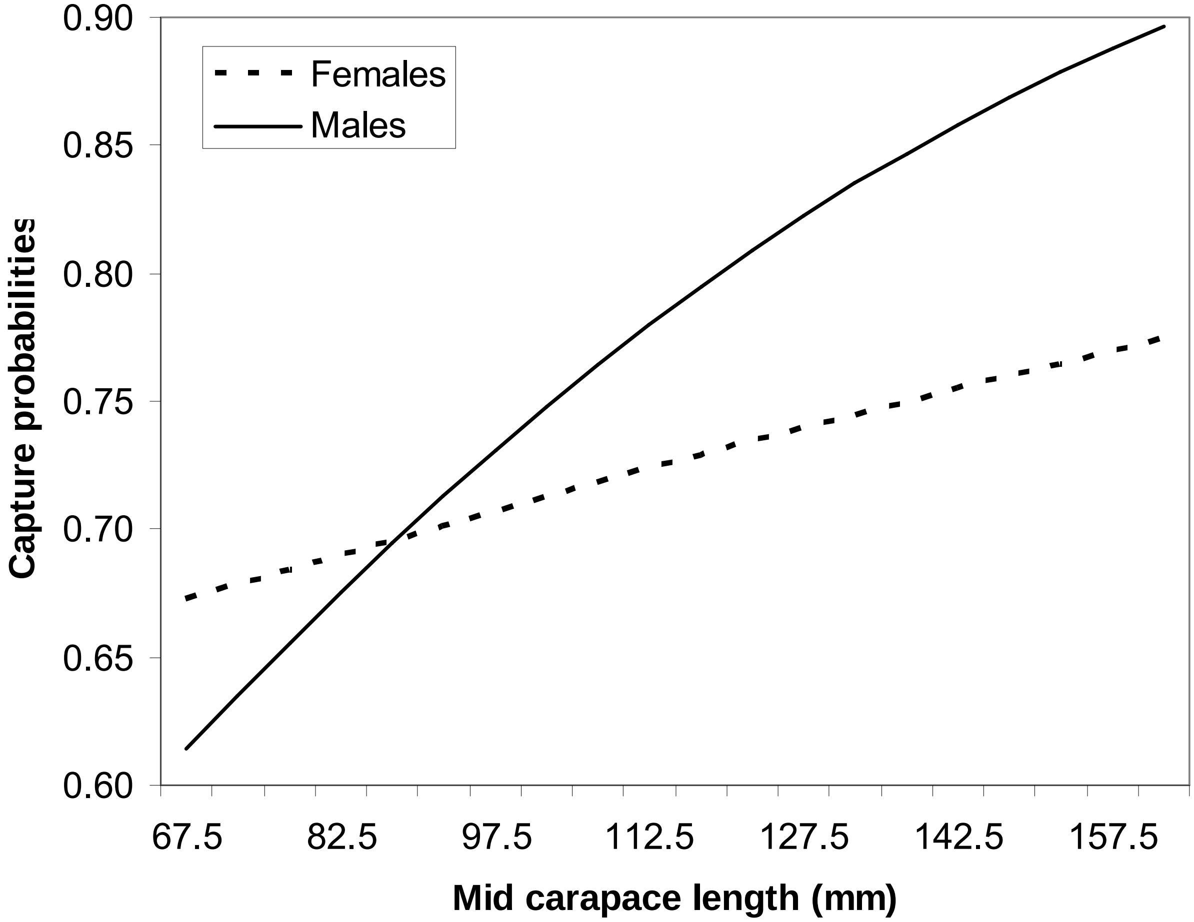


Figure 8. Estimated capture probabilities for Bristol Bay red king crab trawl survey by Weinberg et al. (2004).

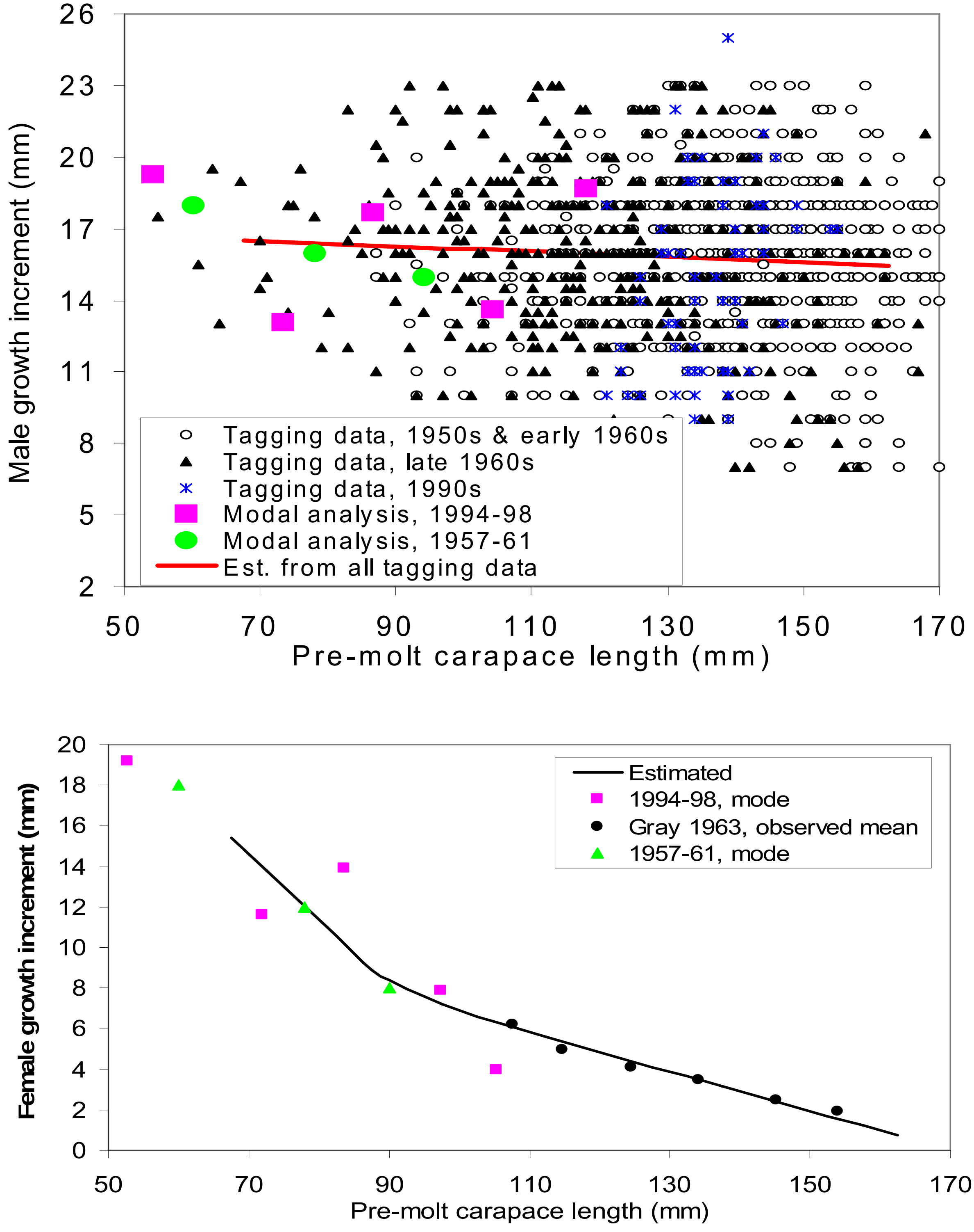


Figure 9. Mean growth increments per molt for Bristol Bay red king crab. Note: “tagging”---based on tagging data; “mode”---based on modal analysis.

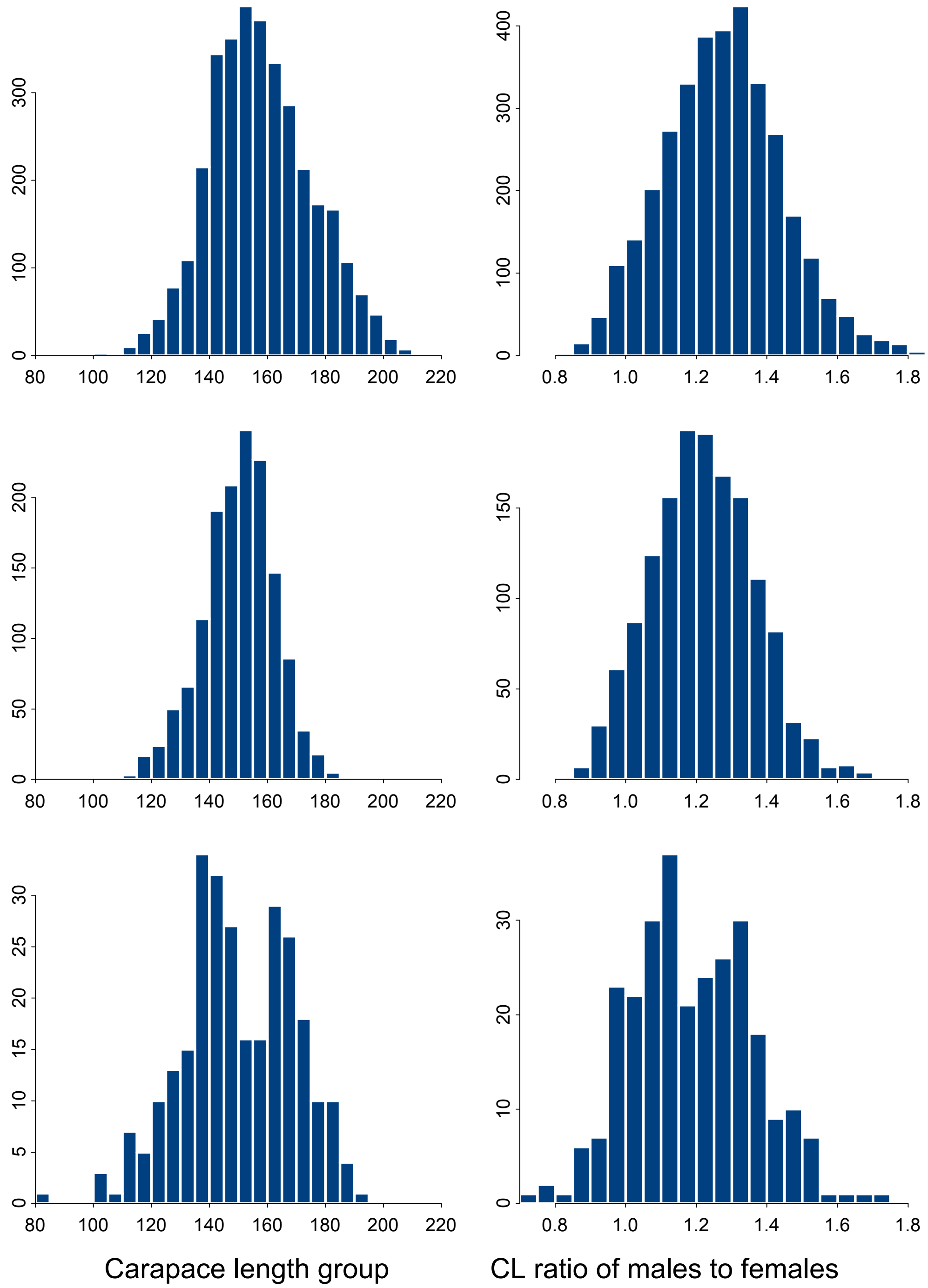


Figure 10. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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

54

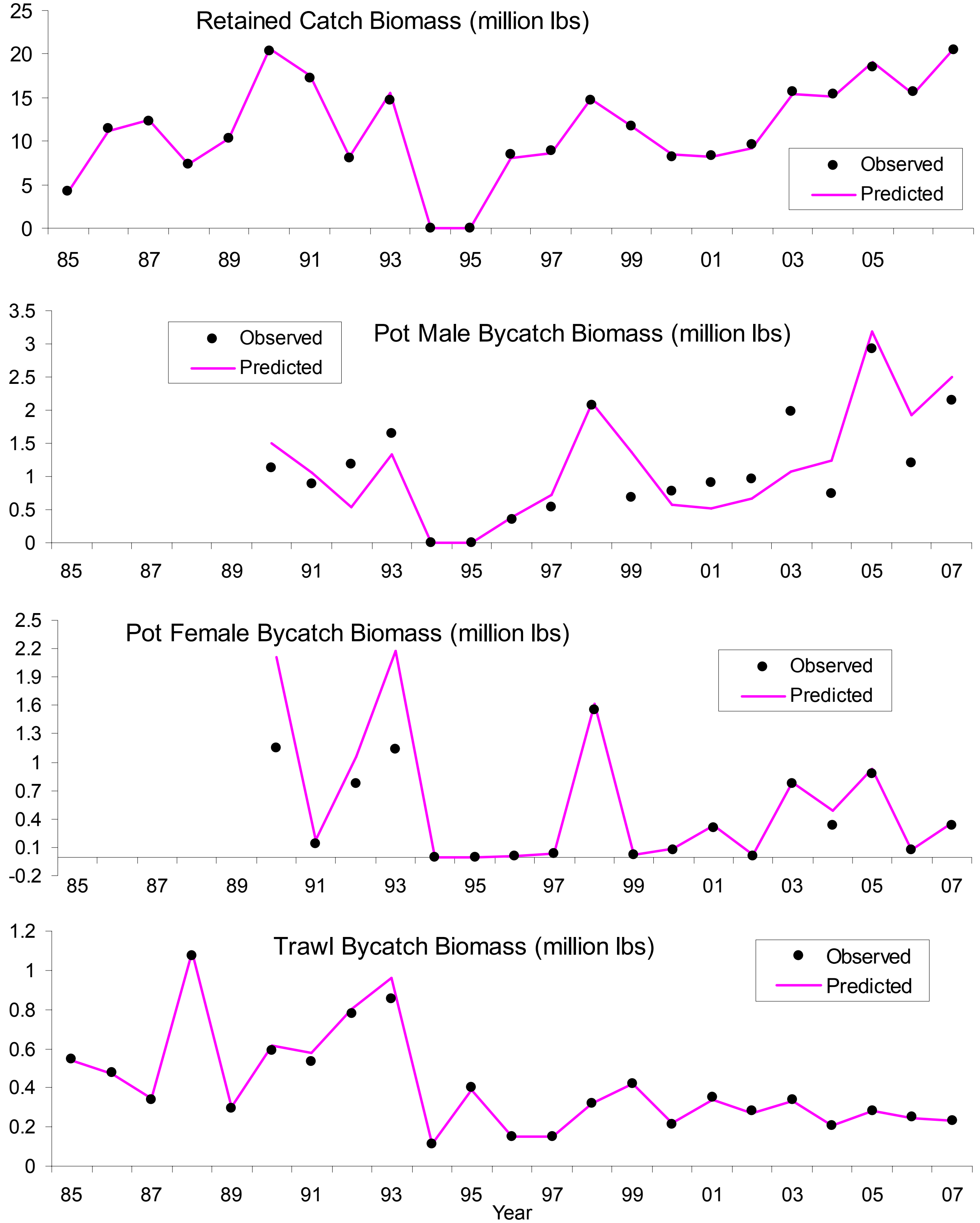


Figure 11. Observed and predicted catch mortality biomass. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

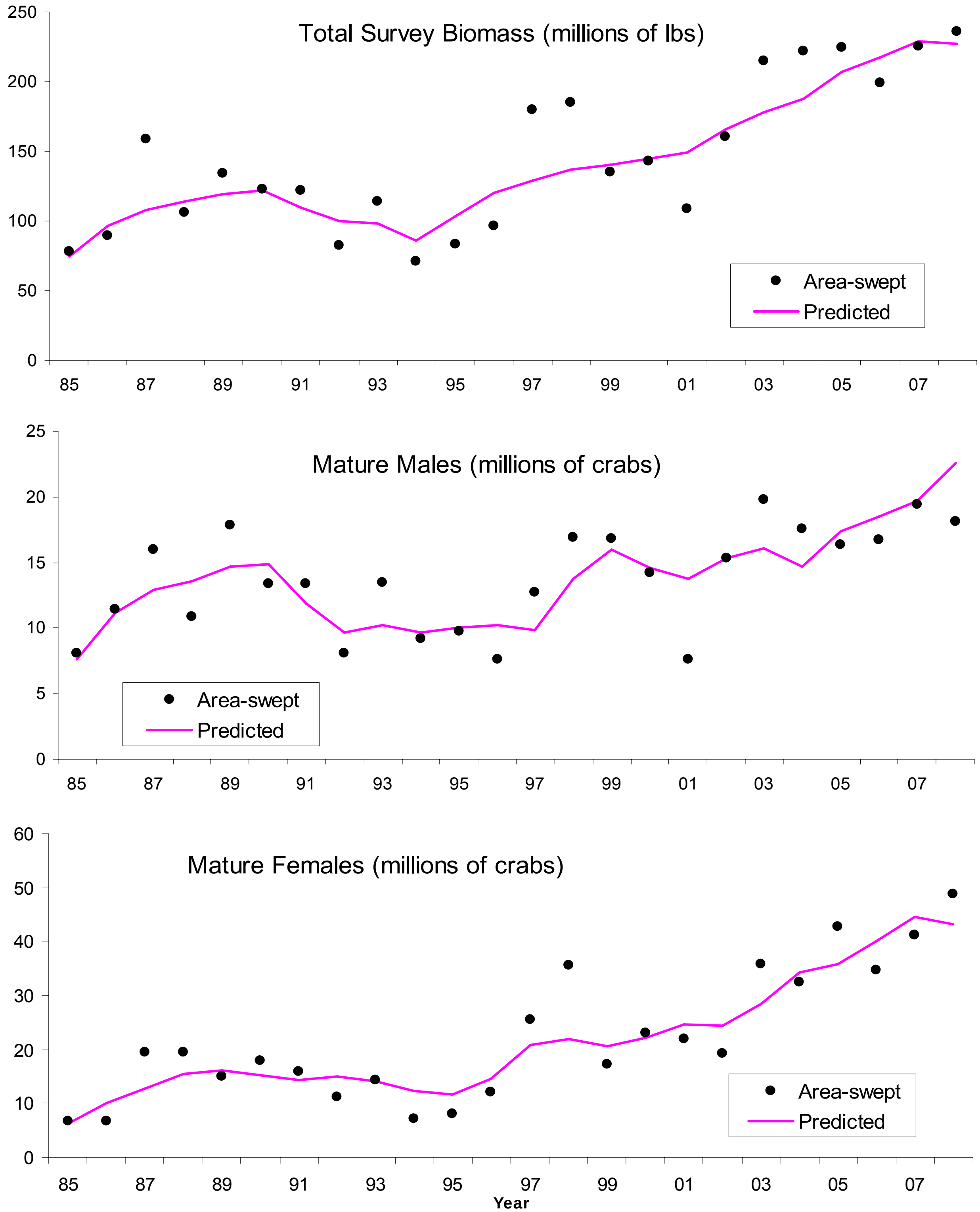


Figure 12. Comparisons of area-swept estimates of total survey biomass, mature male (>119 mm) and mature female (>89 mm) abundance and model prediction. Pot handling mortality rate is 0.2.

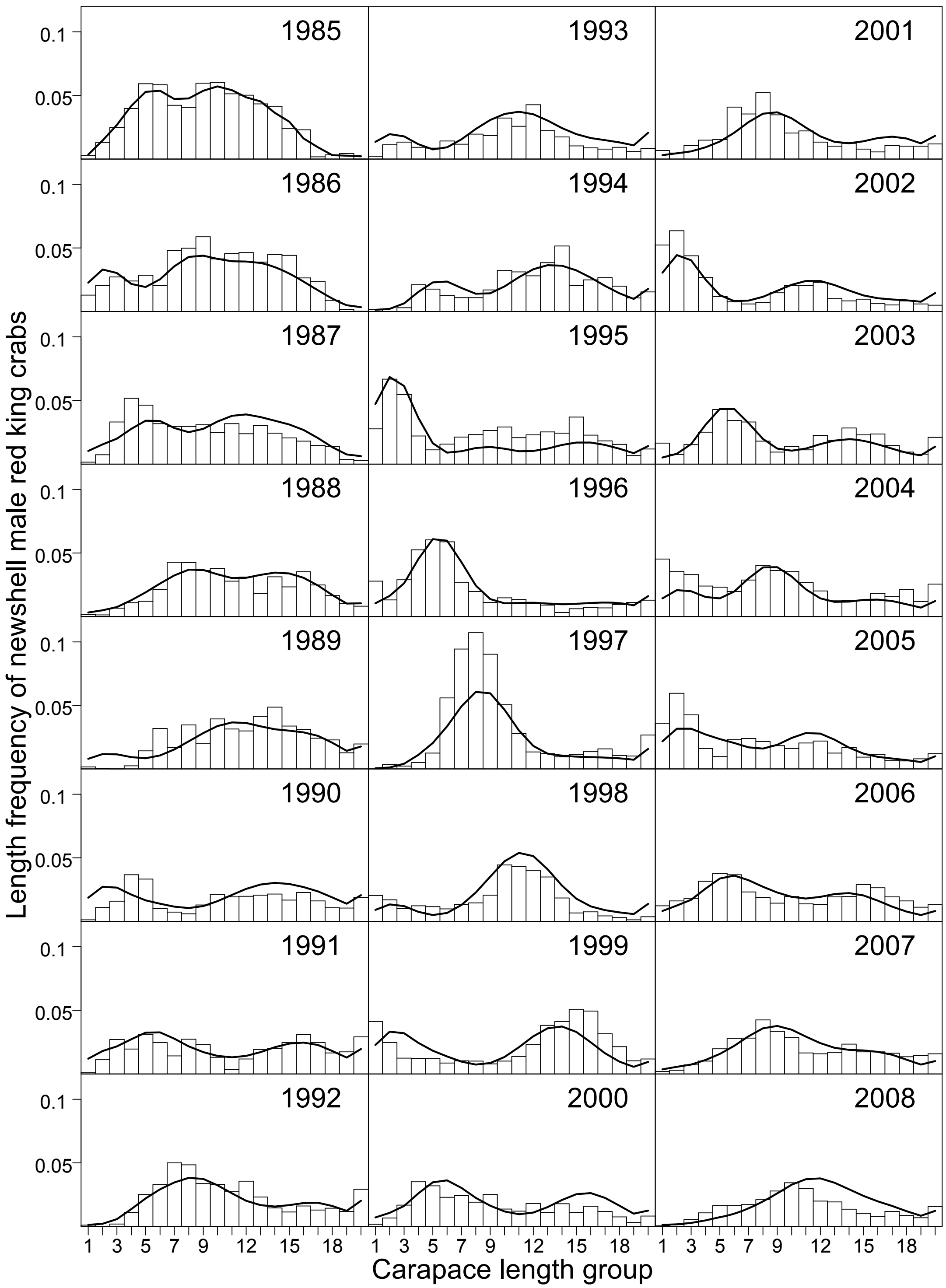


Figure 13. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay newshell male red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

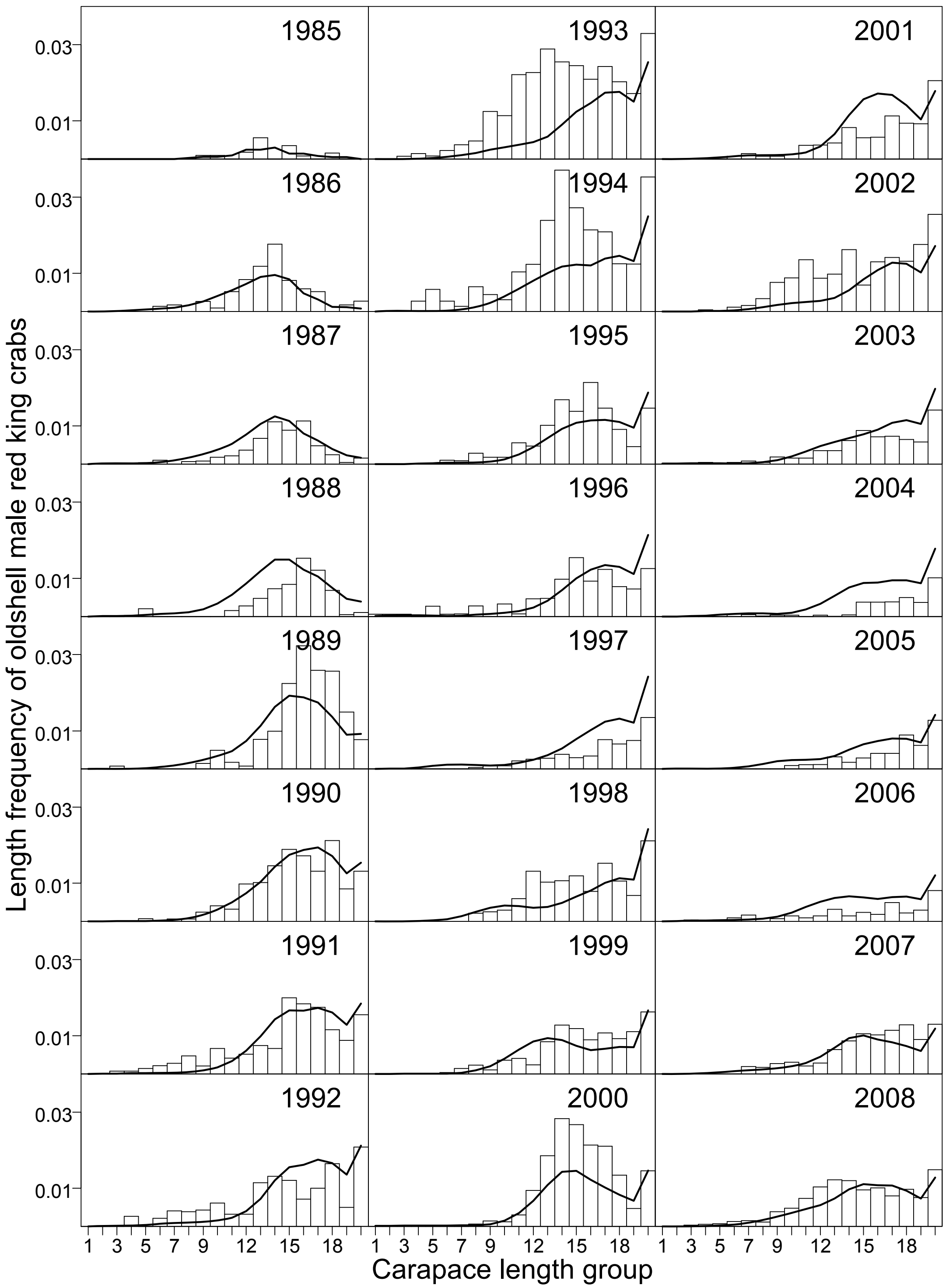


Figure 14. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay oldshell male red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

58

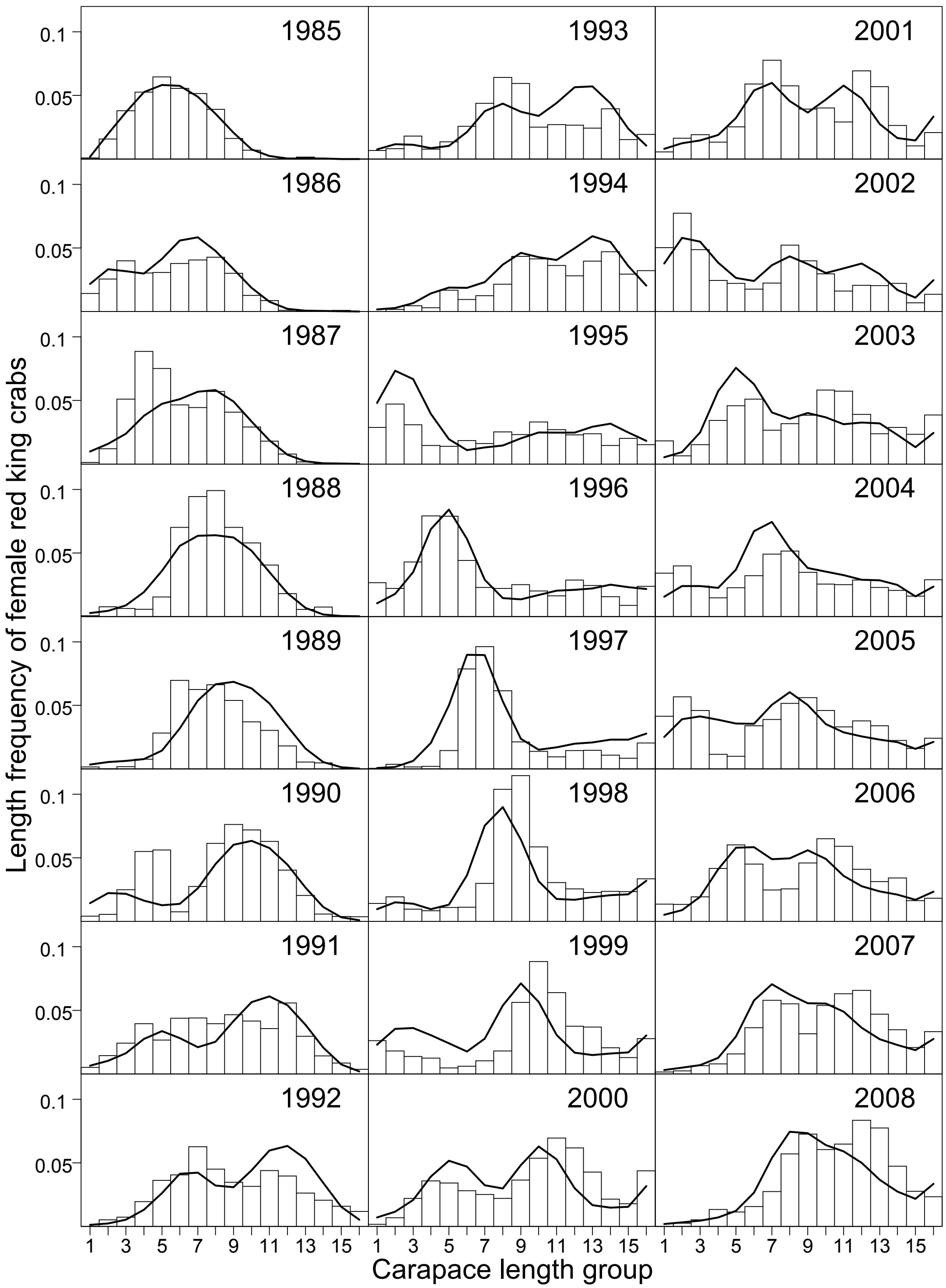


Figure 15. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

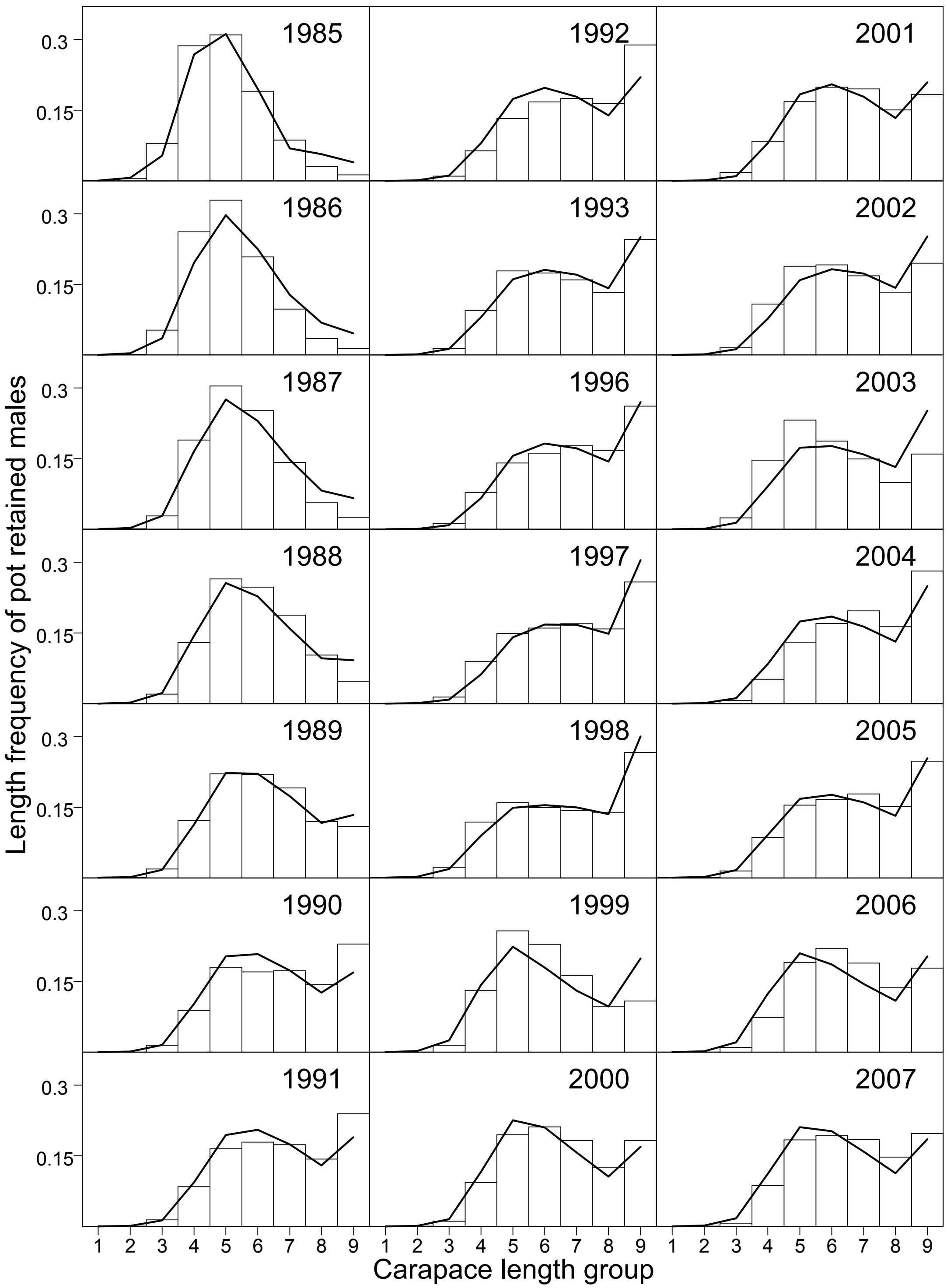


Figure 16. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 122.5 mm.

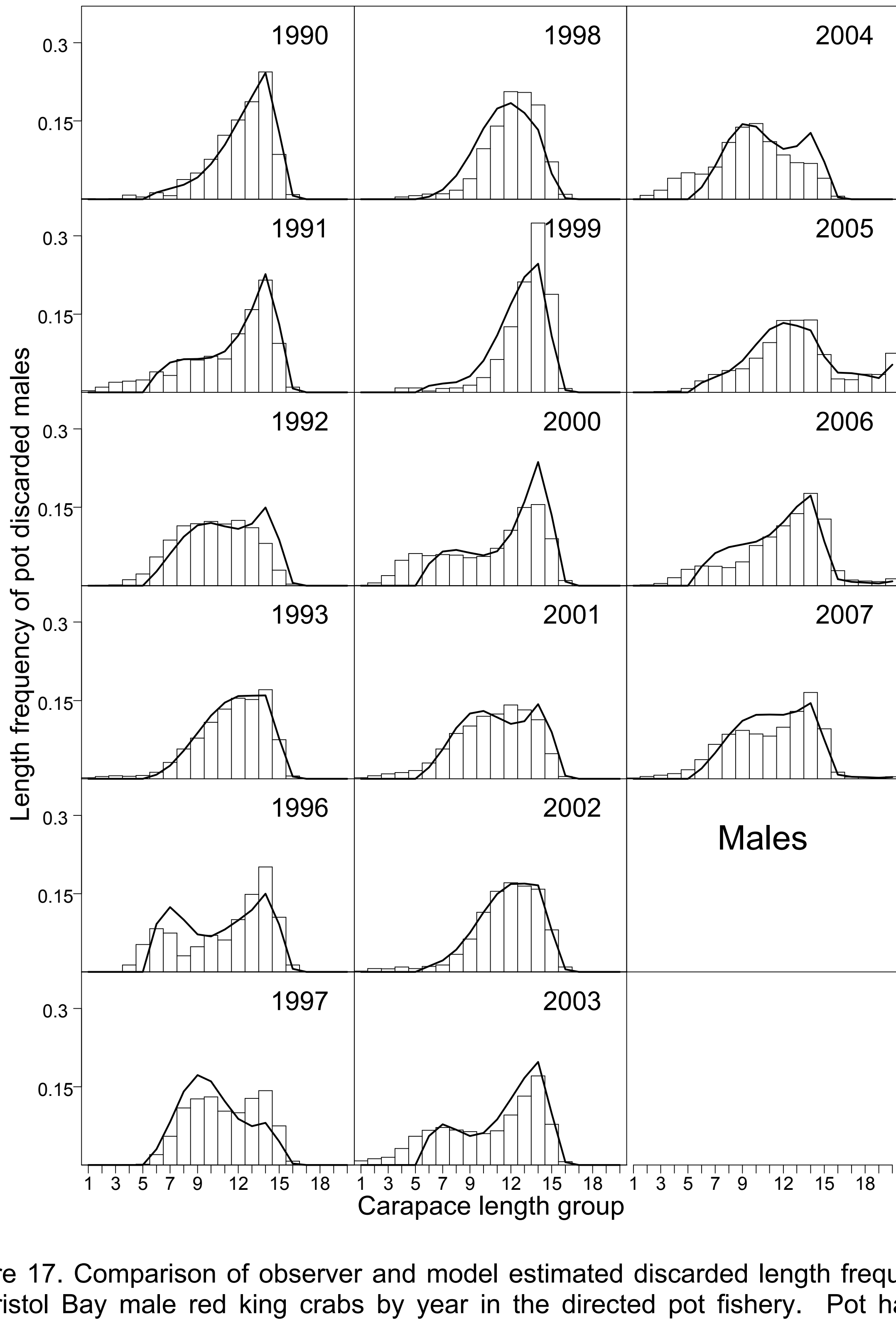


Figure 17. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

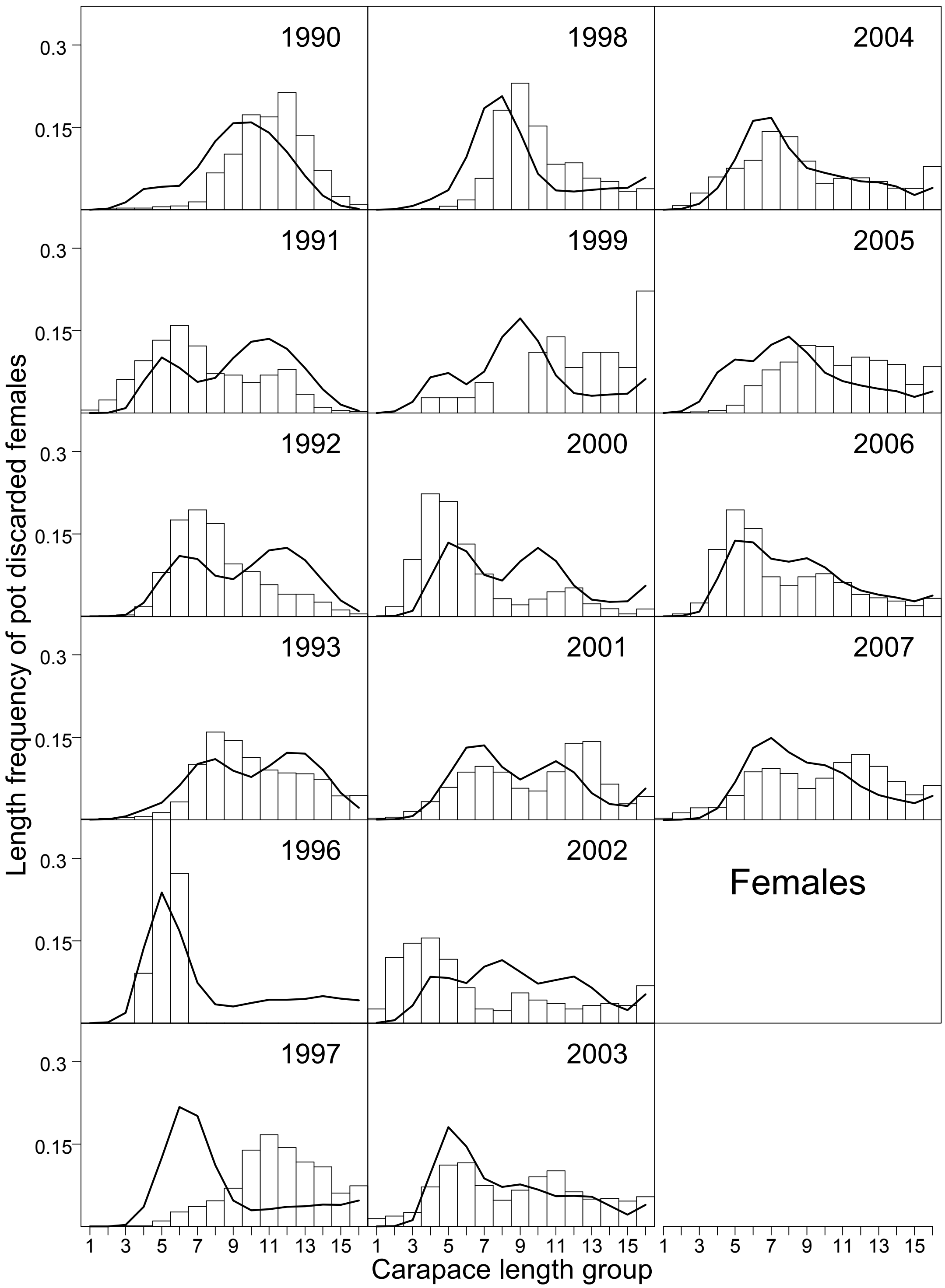


Figure 18. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

62

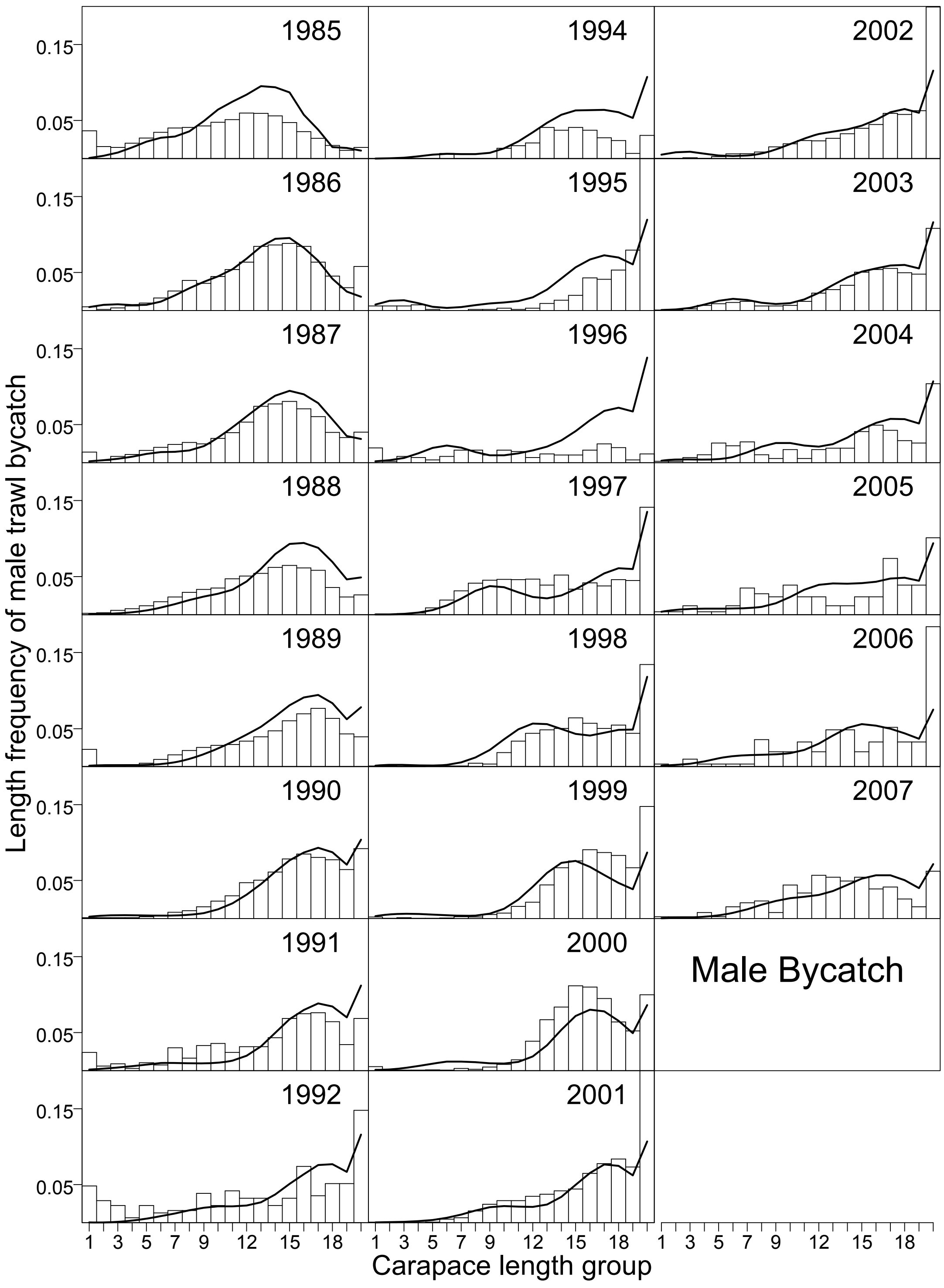


Figure 19. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

63

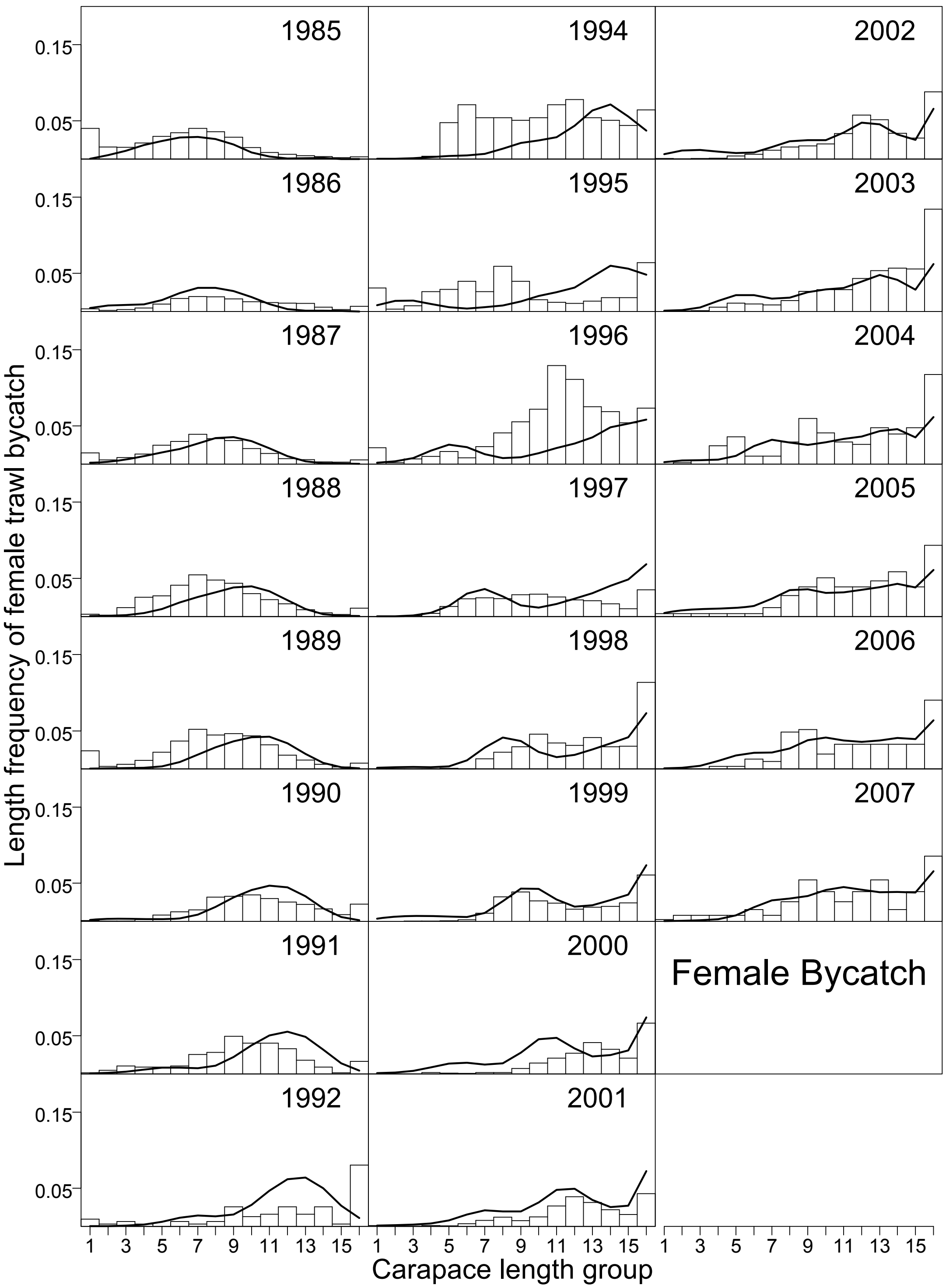


Figure 20. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

64

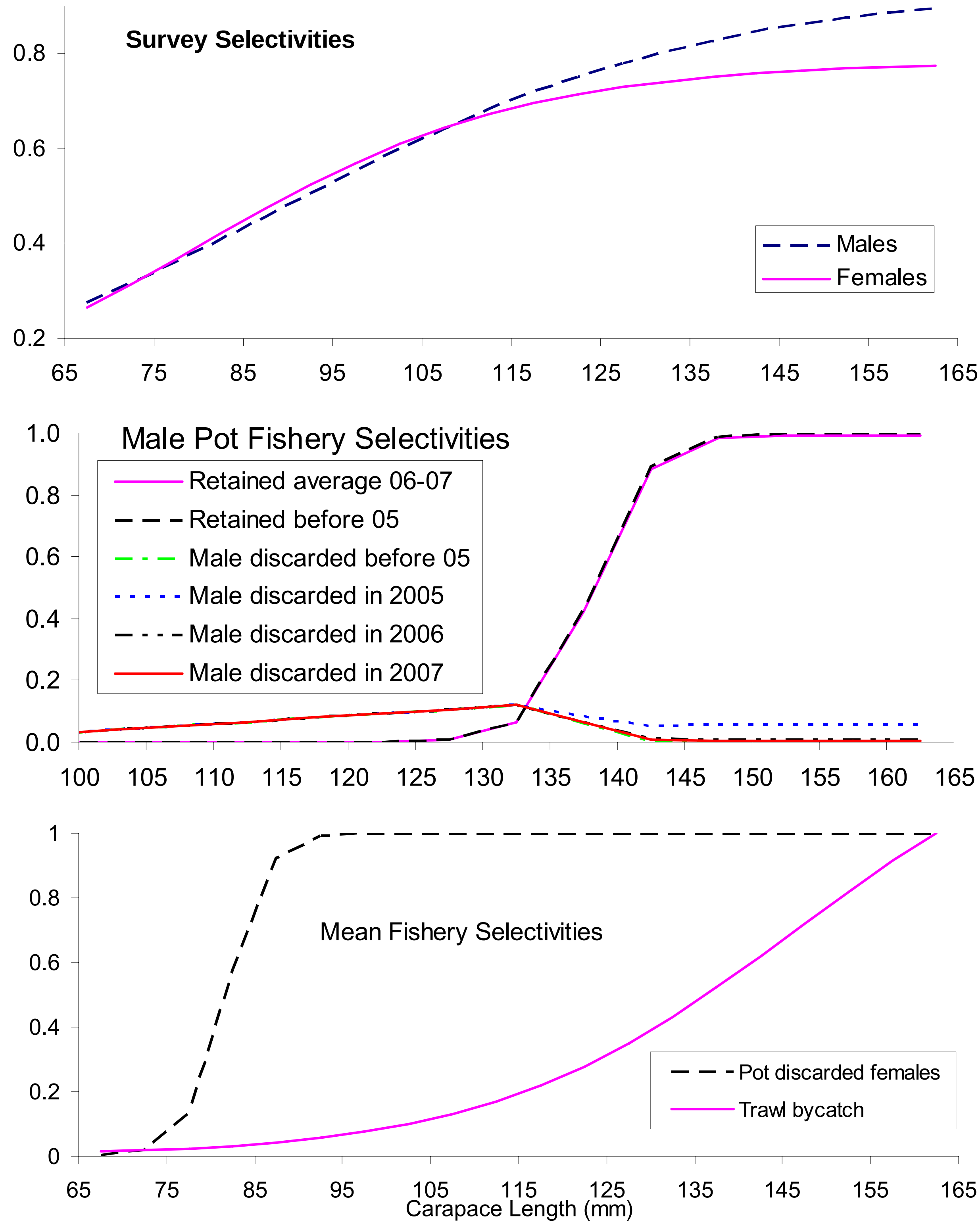


Figure 21. Estimated trawl survey selectivities, pot fishery selectivities, and groundfish trawl bycatch selectivities. Pot handling mortality rate is 0.2.

65

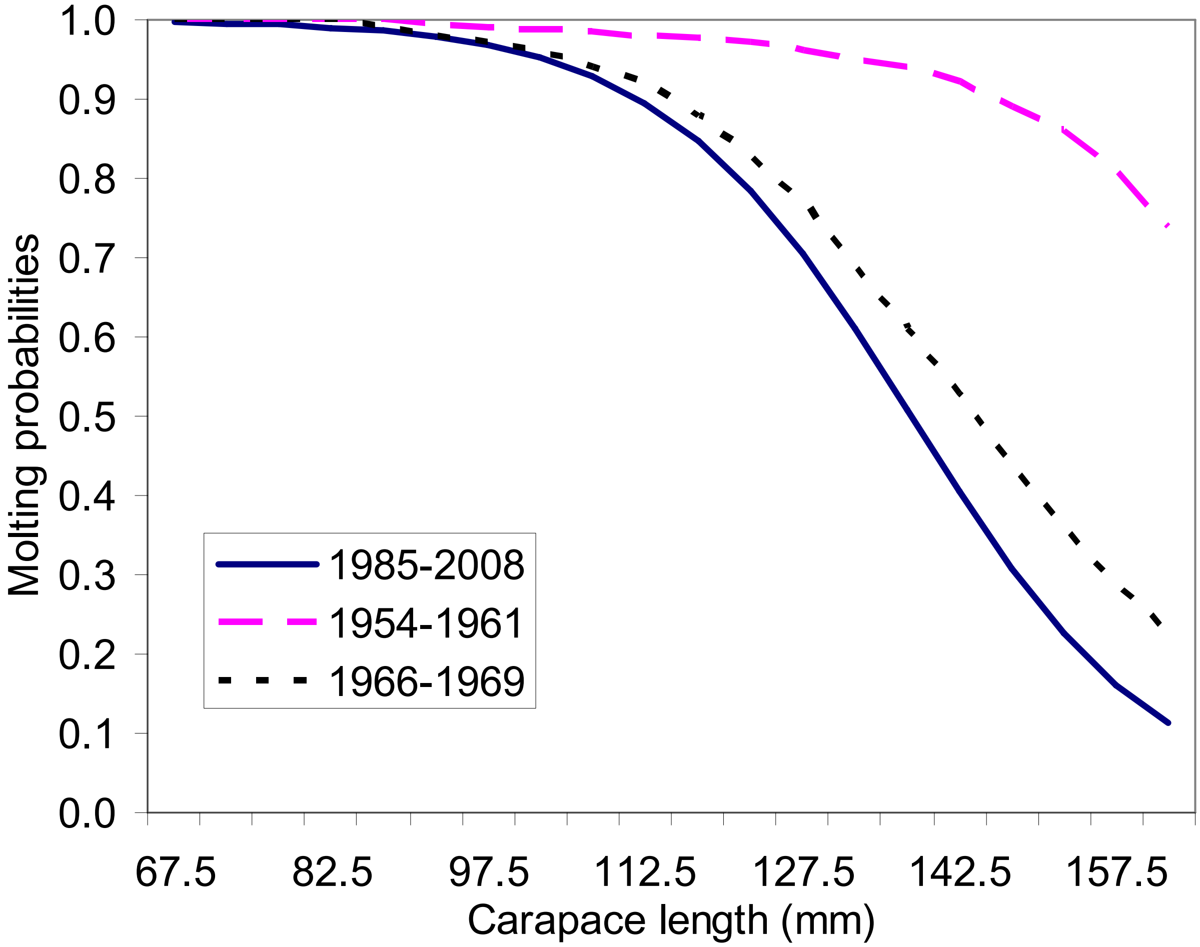


Figure 22. Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1985-2008 were estimated with a length-based model with pot handling mortality rate to be 0.2.

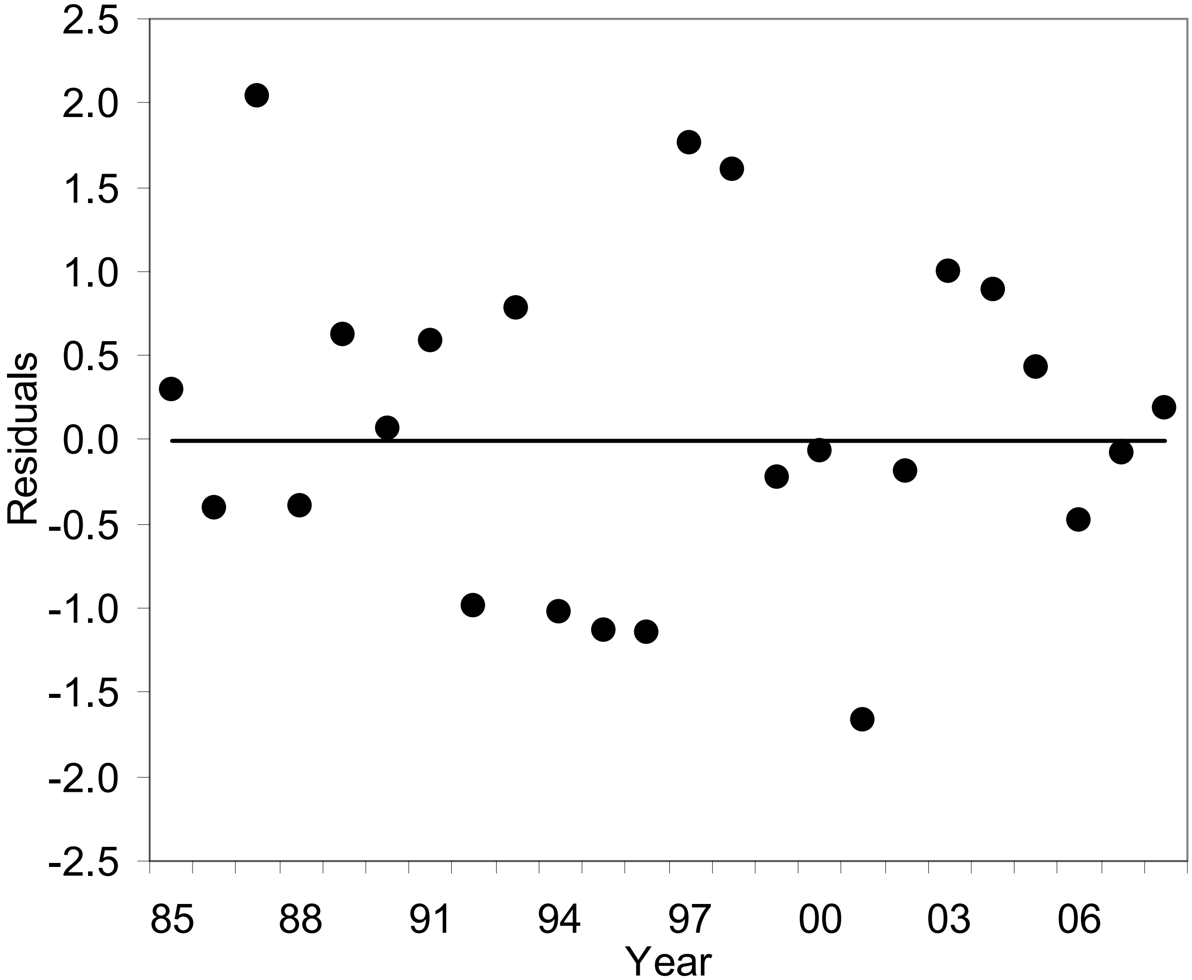


Figure 23. Standardized residuals of total survey biomass. Pot handling mortality rate is 0.2.

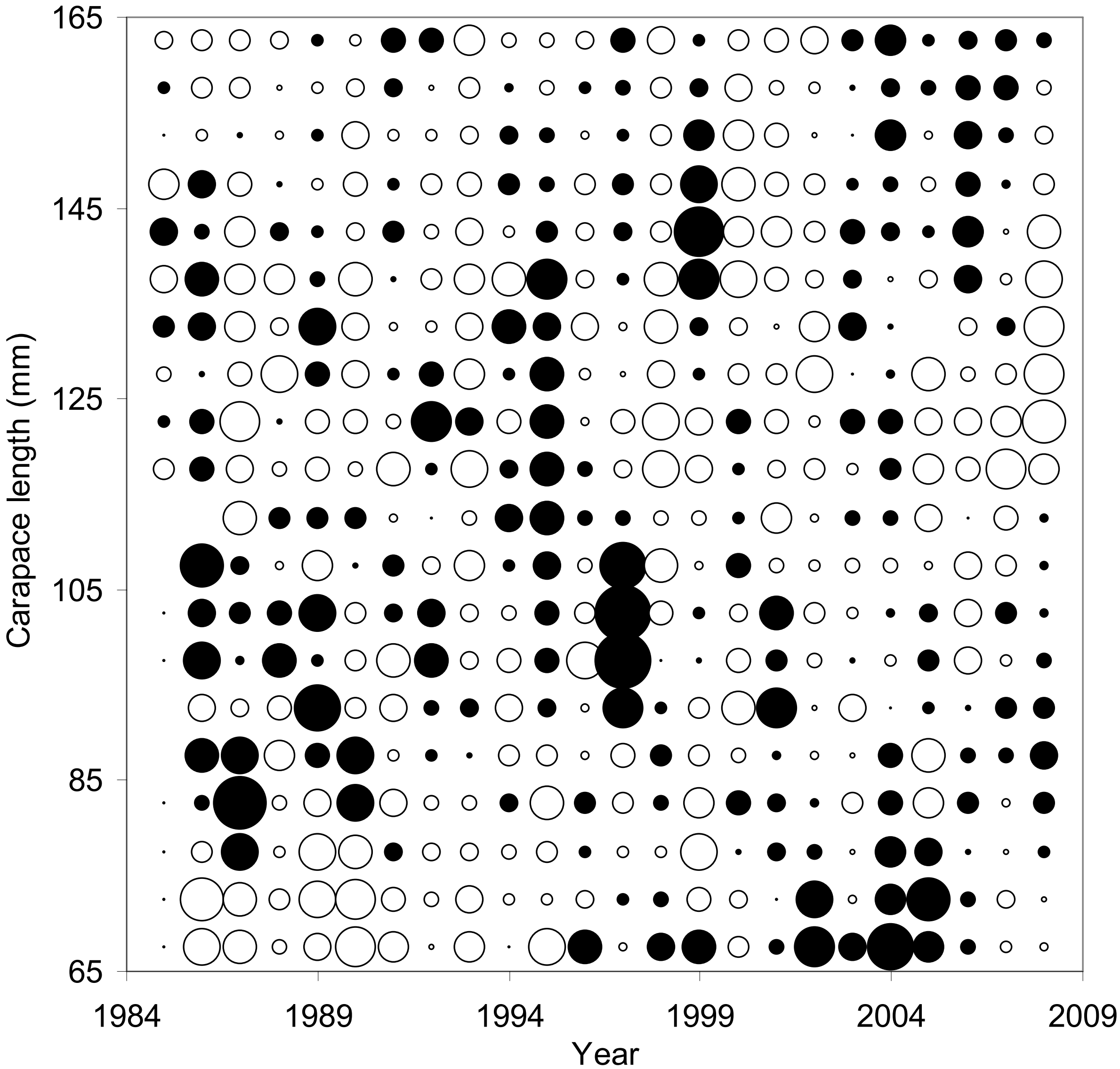


Figure 24. Standardized residuals of proportions of survey newshell male red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.

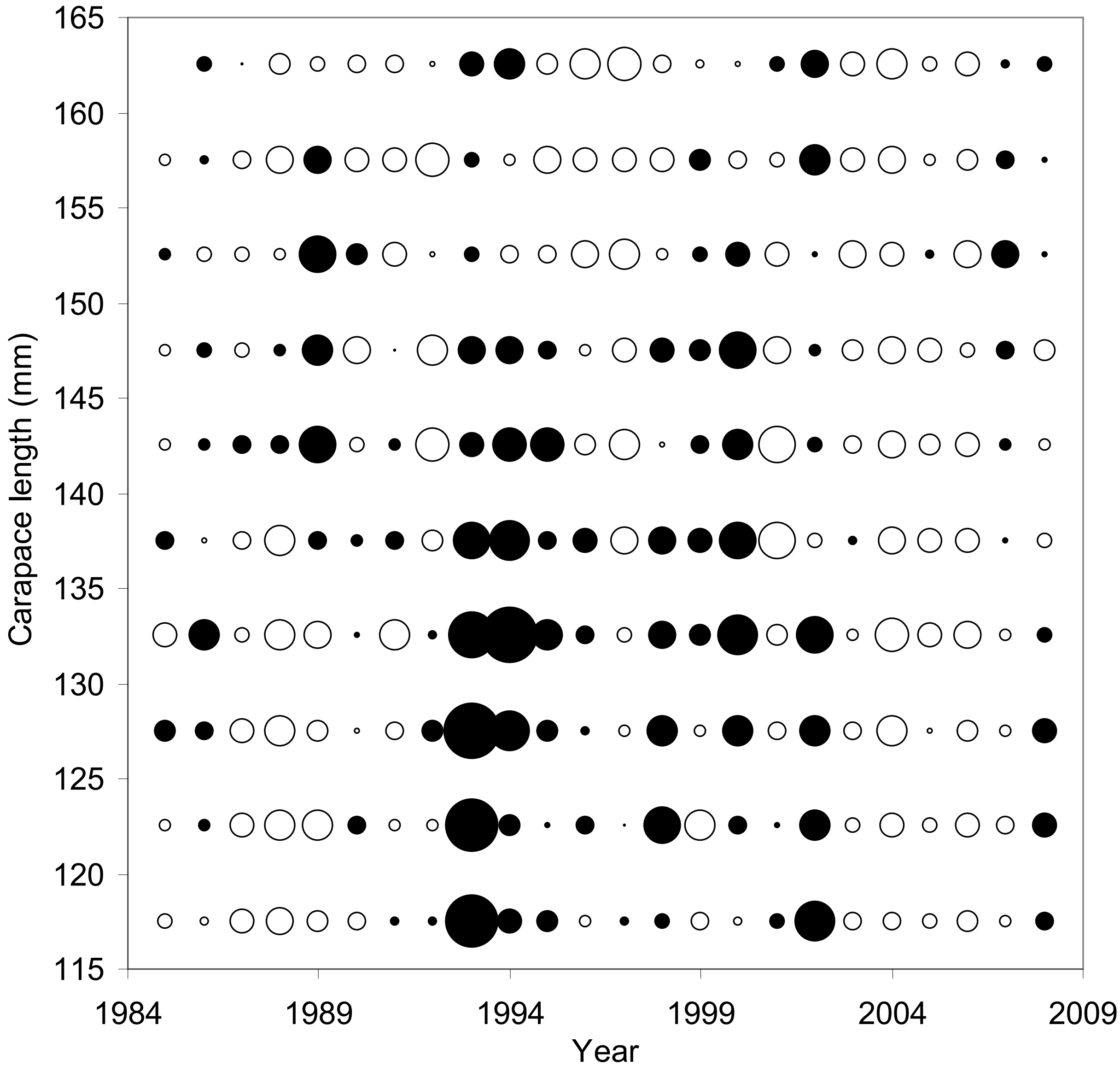


Figure 25. Standardized residuals of proportions of survey oldshell male red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.

69

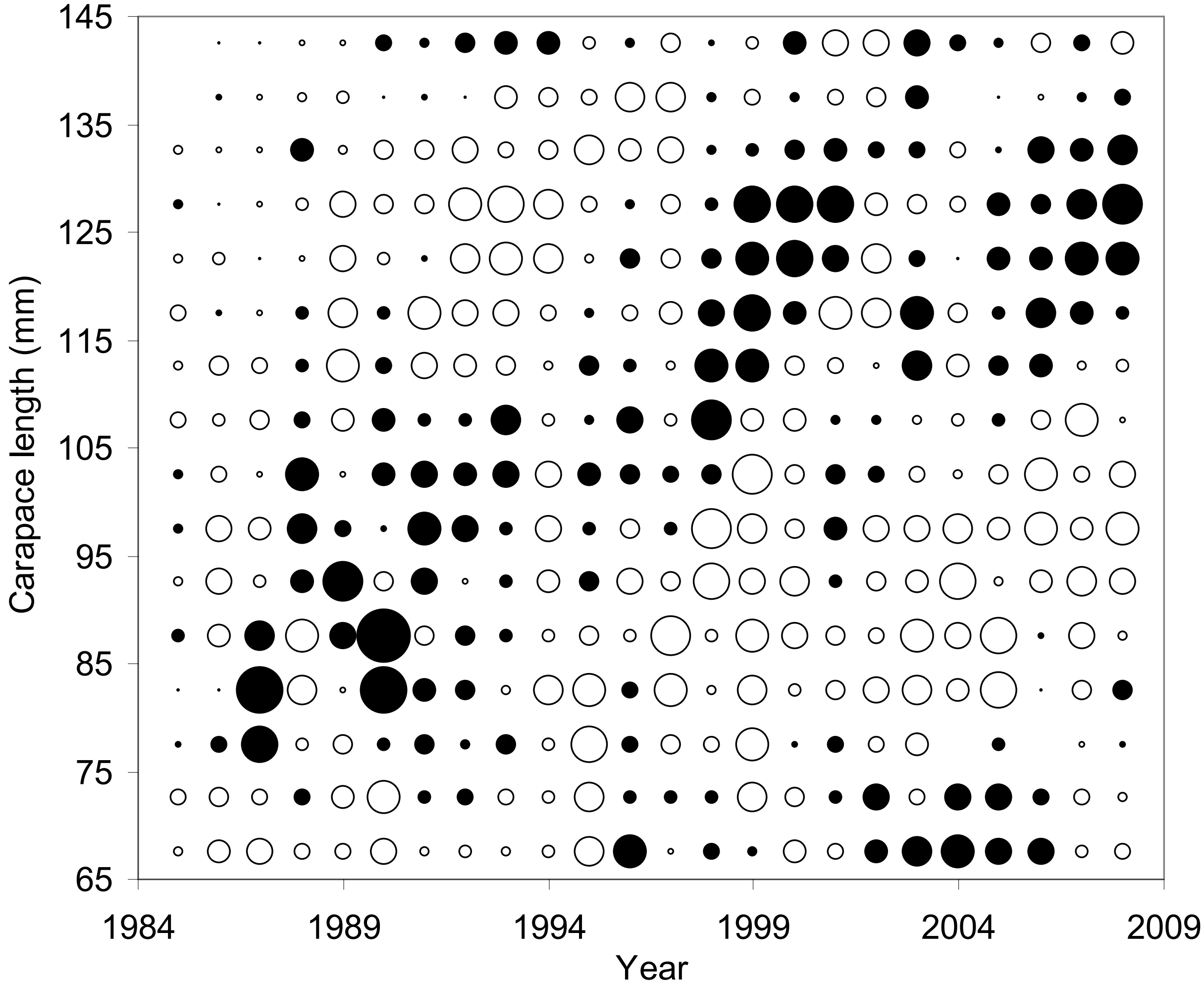
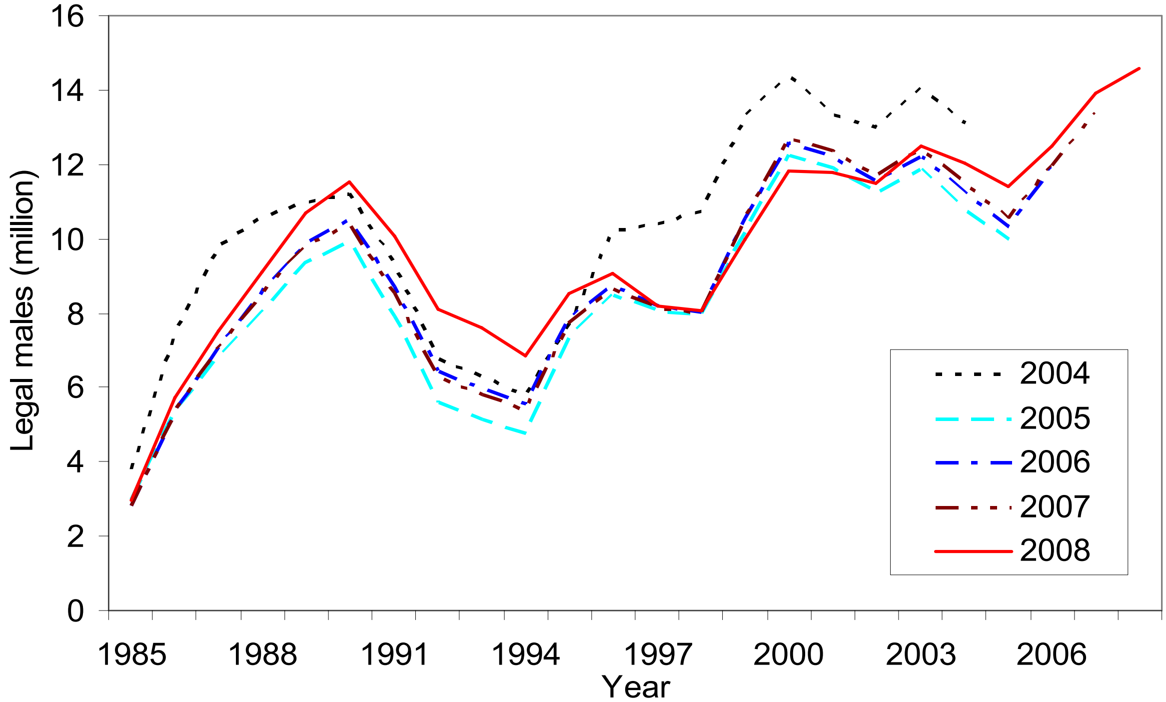


Figure 26. Standardized residuals of proportions of survey female red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.



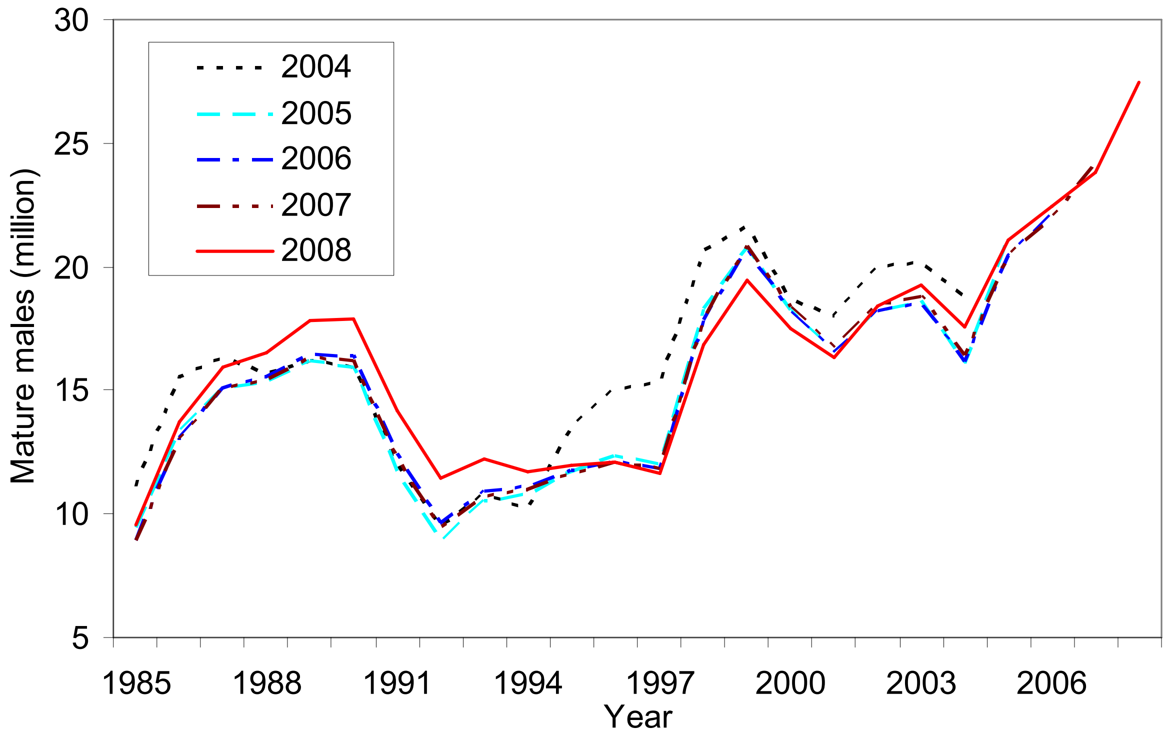
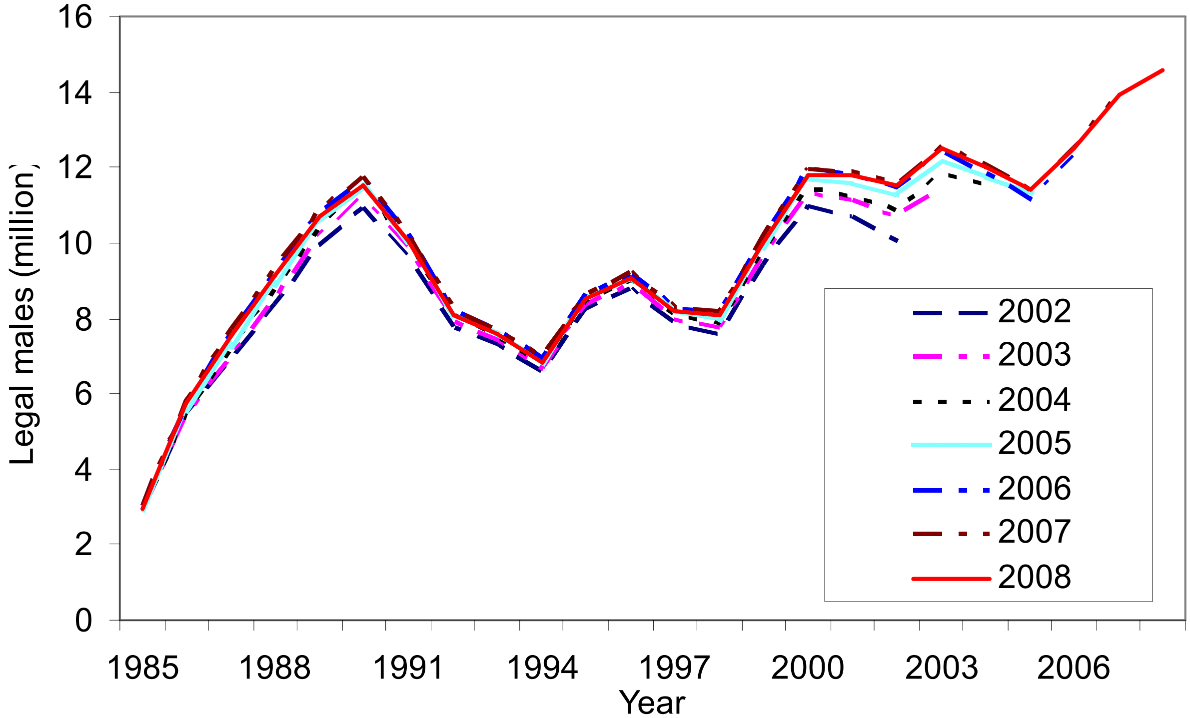


Figure 27. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1985 to 2008 made with terminal years 2004-2008. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot handling mortality rate is 0.2.

71



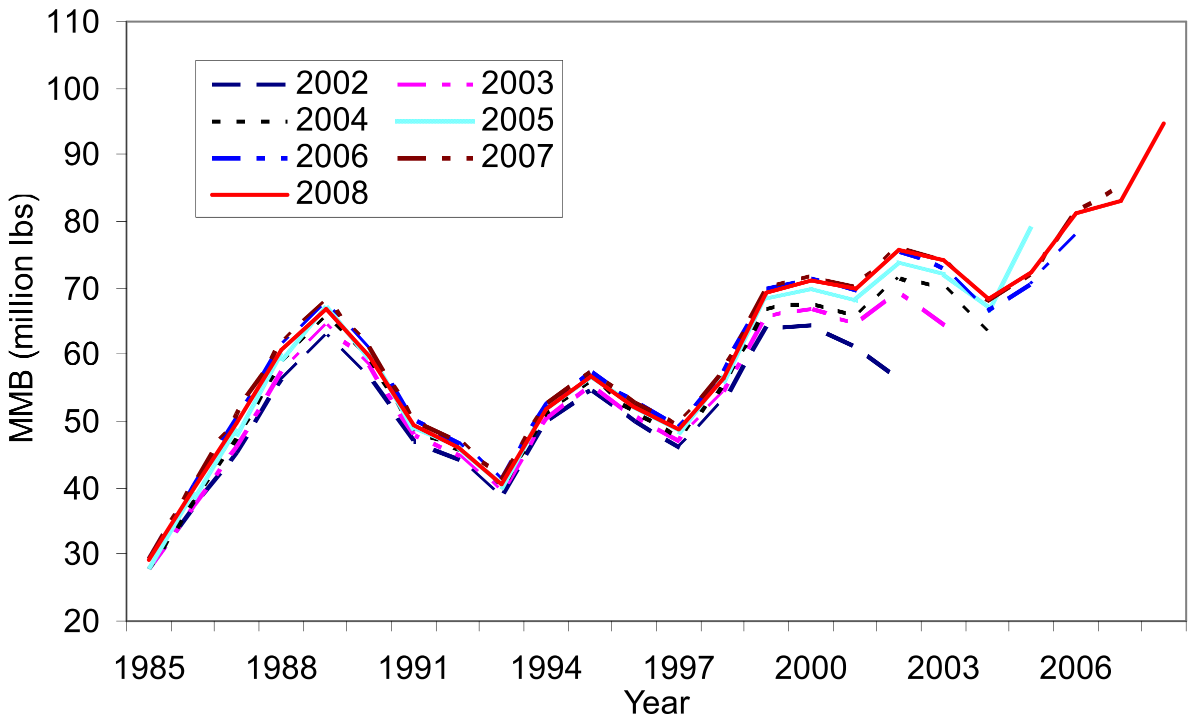
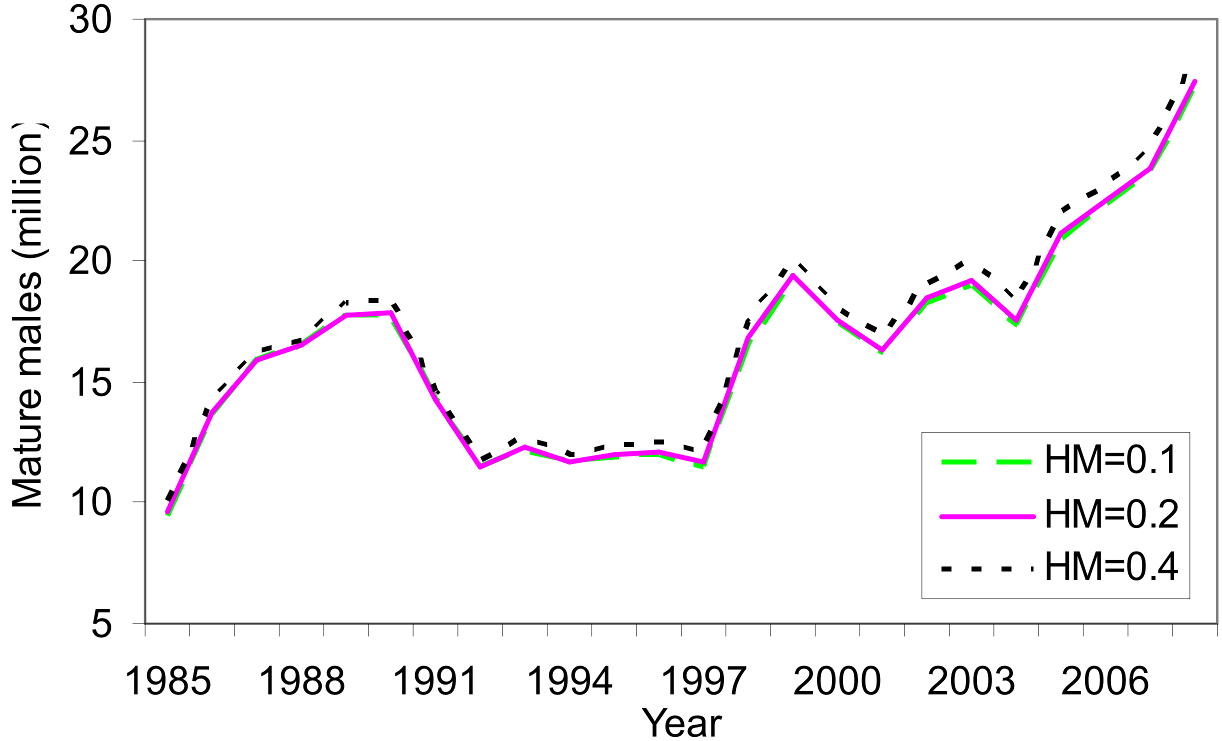


Figure 28. Comparison of estimates of legal male abundance (top) and mature male biomass (bottom) on Feb. 15 of Bristol Bay red king crab from 1985 to 2008 made with terminal years 2002-2008. These are results of the 2008 model. Legend shows the year in which the assessment was conducted. Pot handling mortality rate is 0.2.

72



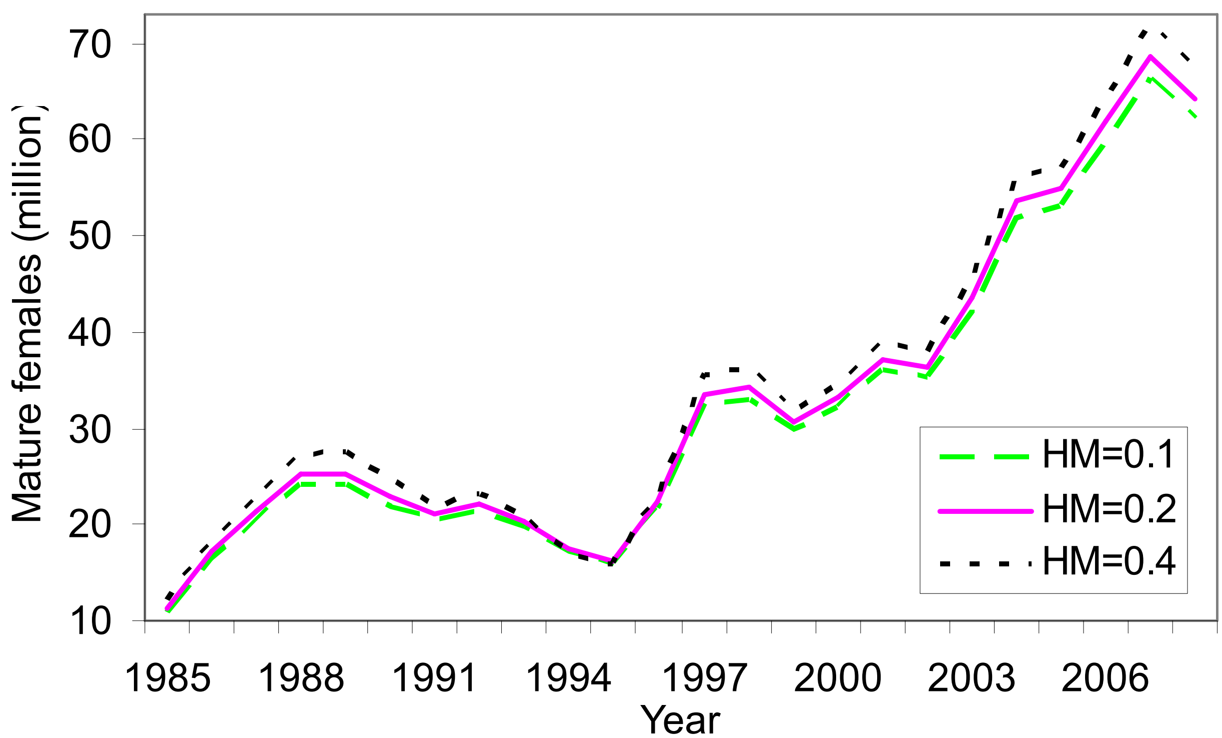
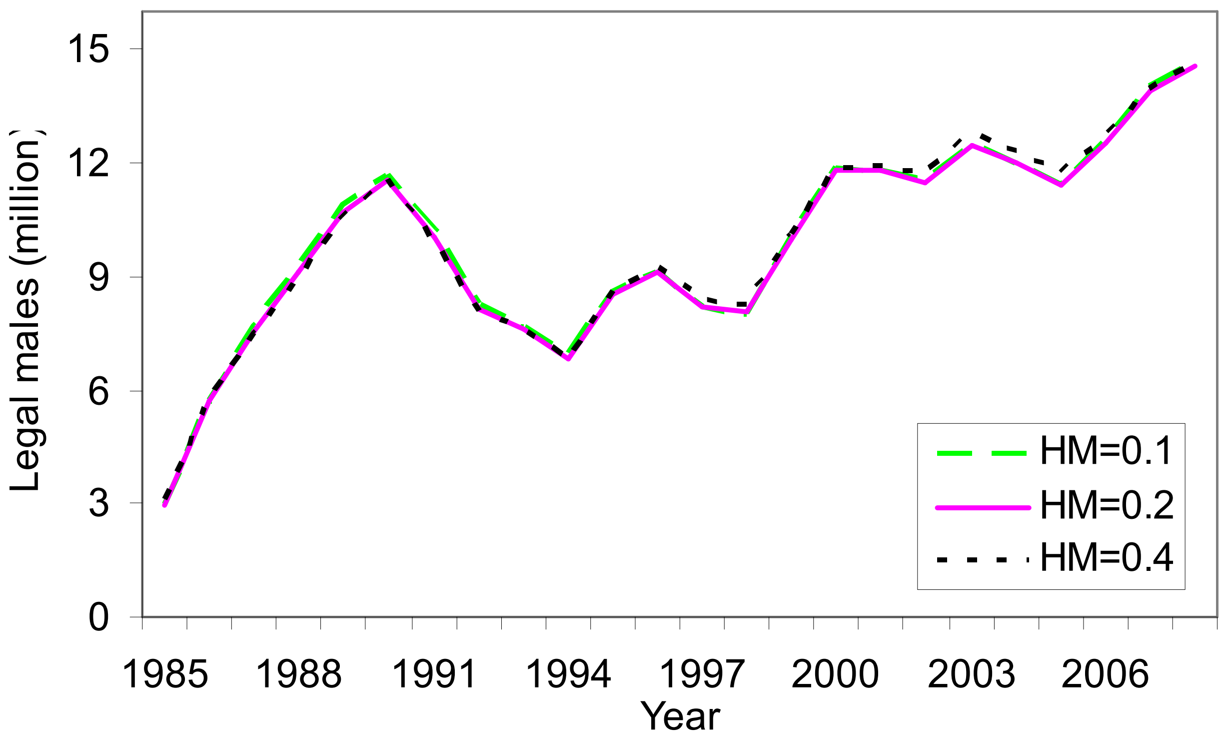


Figure 29. Comparison of mature abundance estimates for pot handling mortality rates of 0.1, 0.2 and 0.4.

73



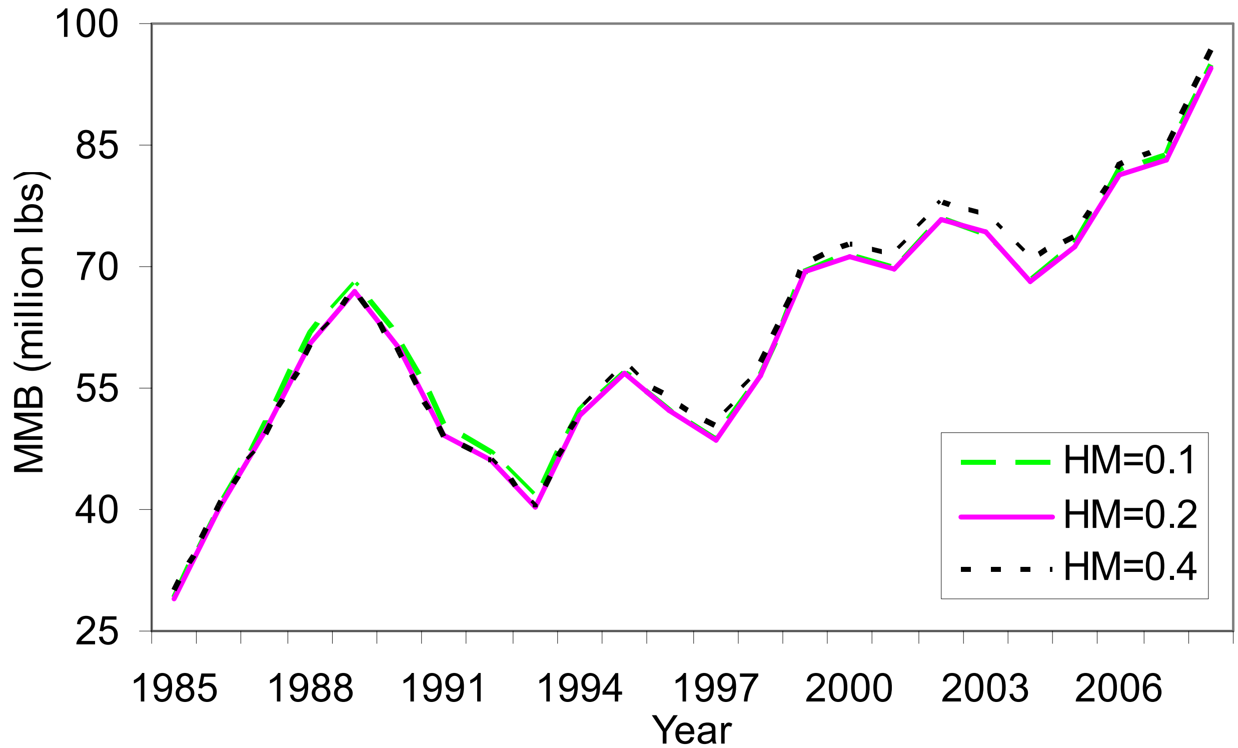
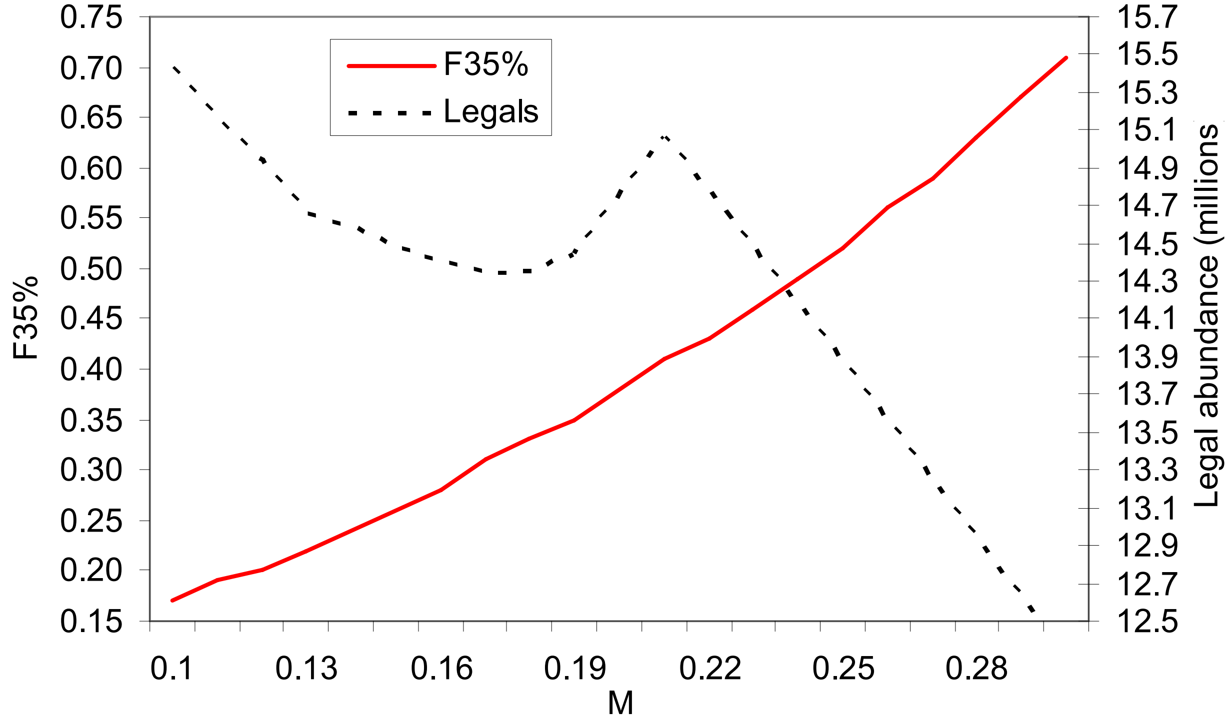


Figure 30. Comparison of legal male abundance estimates and mature male biomass on Feb. 15 for pot handling mortality rates of 0.1, 0.2 and 0.4.

74



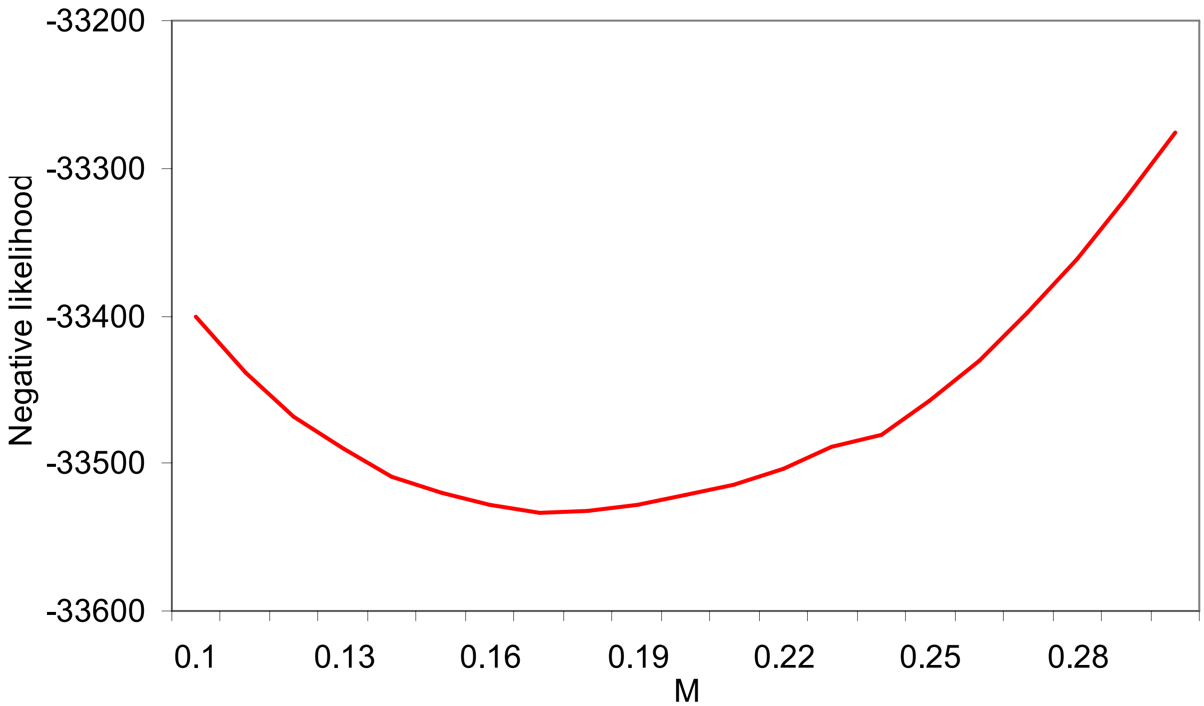


Figure 31. Estimated legal male abundances in 2008, $F_{35\%}$, likelihood profile as a function of natural mortality.

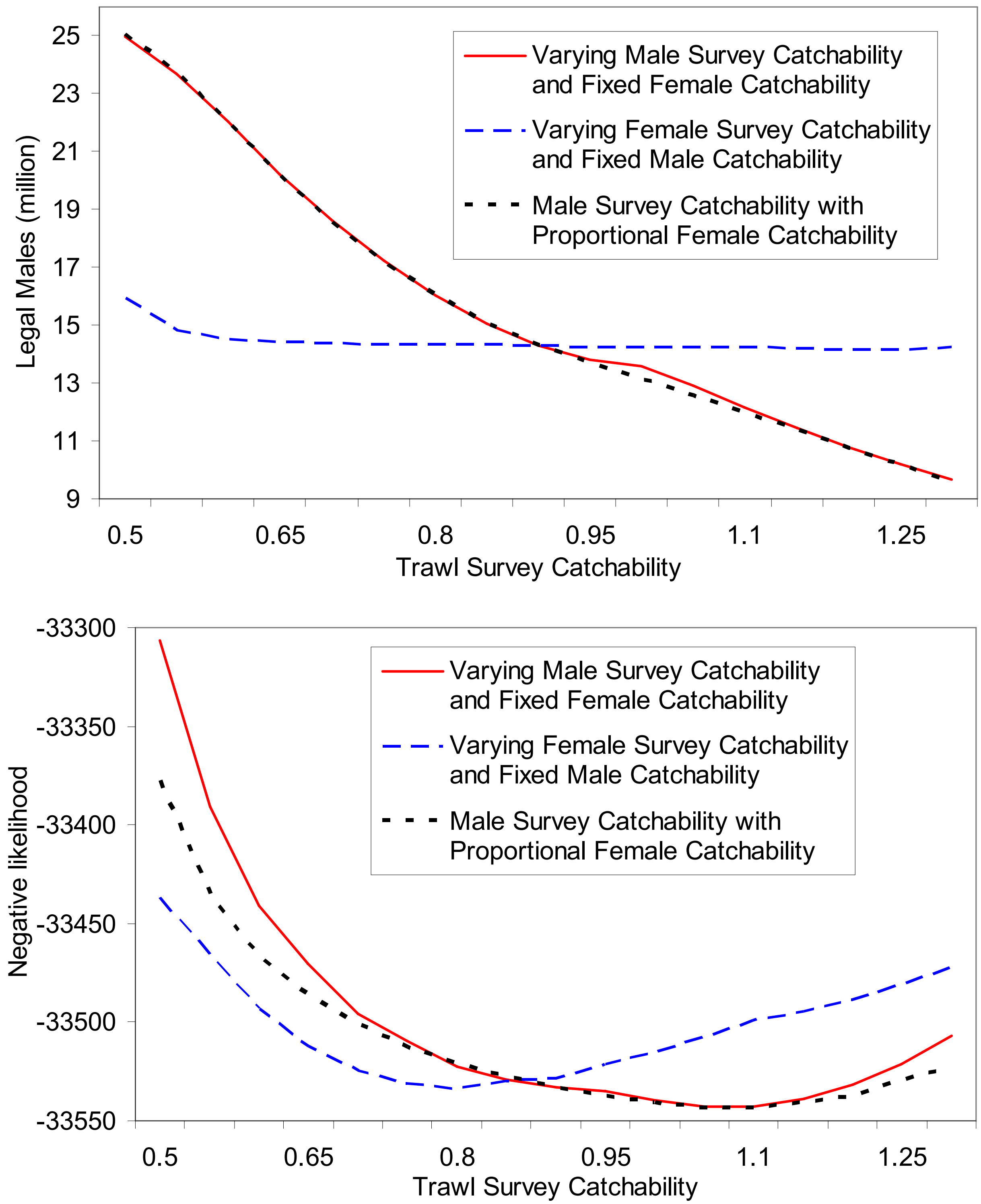


Figure 32. Estimated legal male abundance in 2008 and likelihood profiles as a function of trawl survey catchability. The ratio of male to female survey catchabilities was fixed to 1.1576 for the dotted line.

76

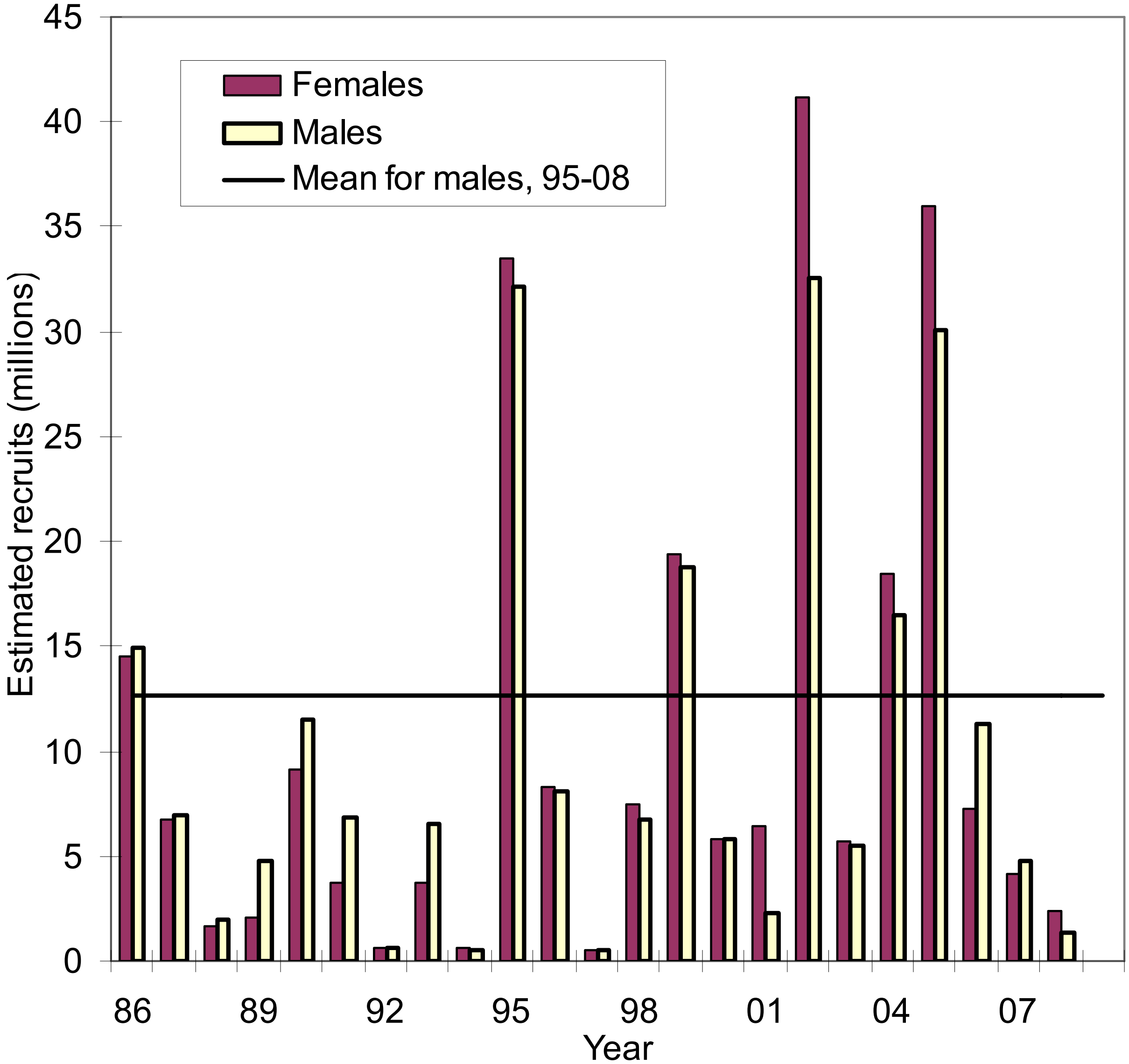


Figure 33. Estimated recruitment time series during 1986-2008. Mean male recruits during 1995-2008 was used to estimate $B_{35\%}$.

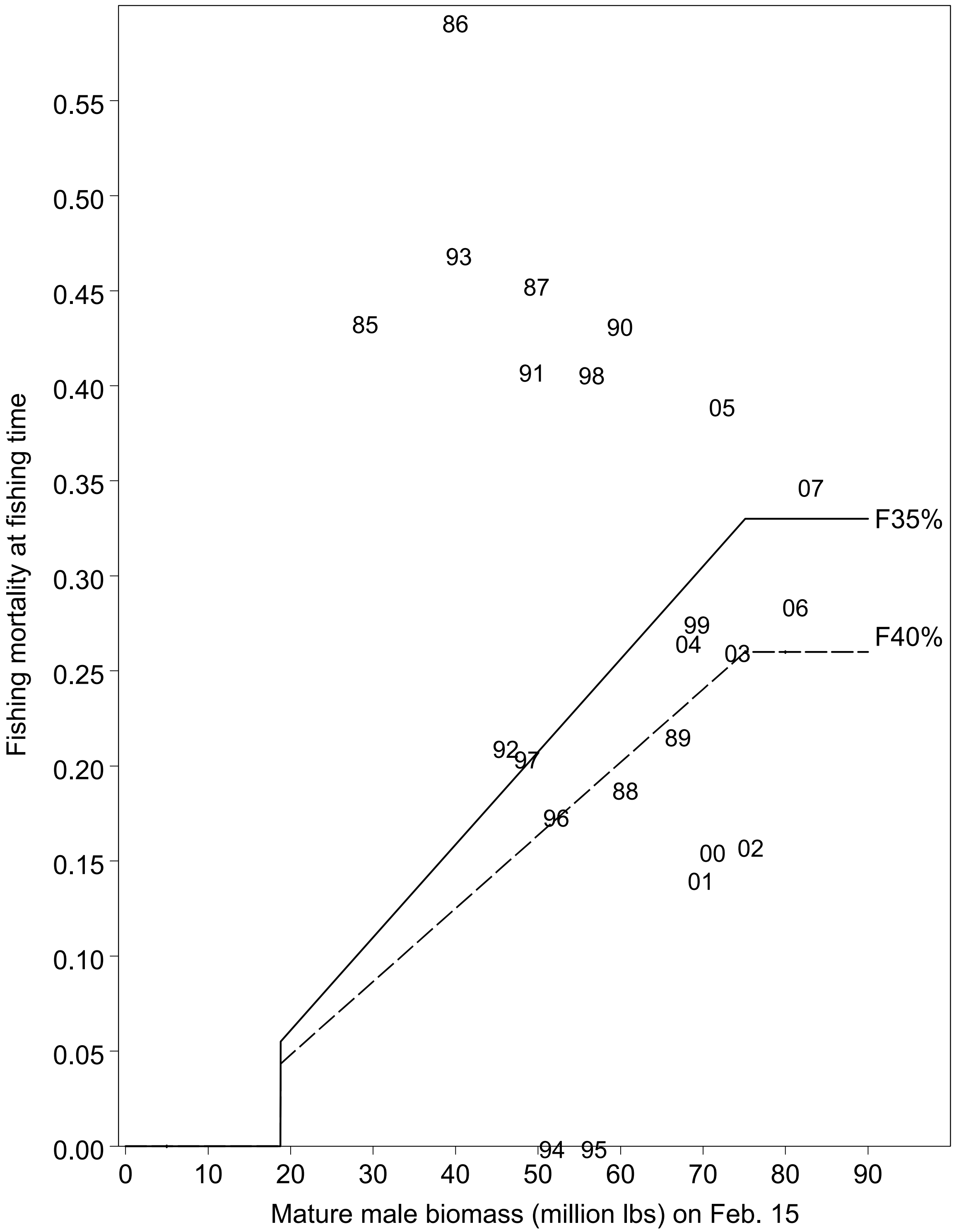


Figure 34. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985-2007. Pot handling mortality rate is 0.2.

78

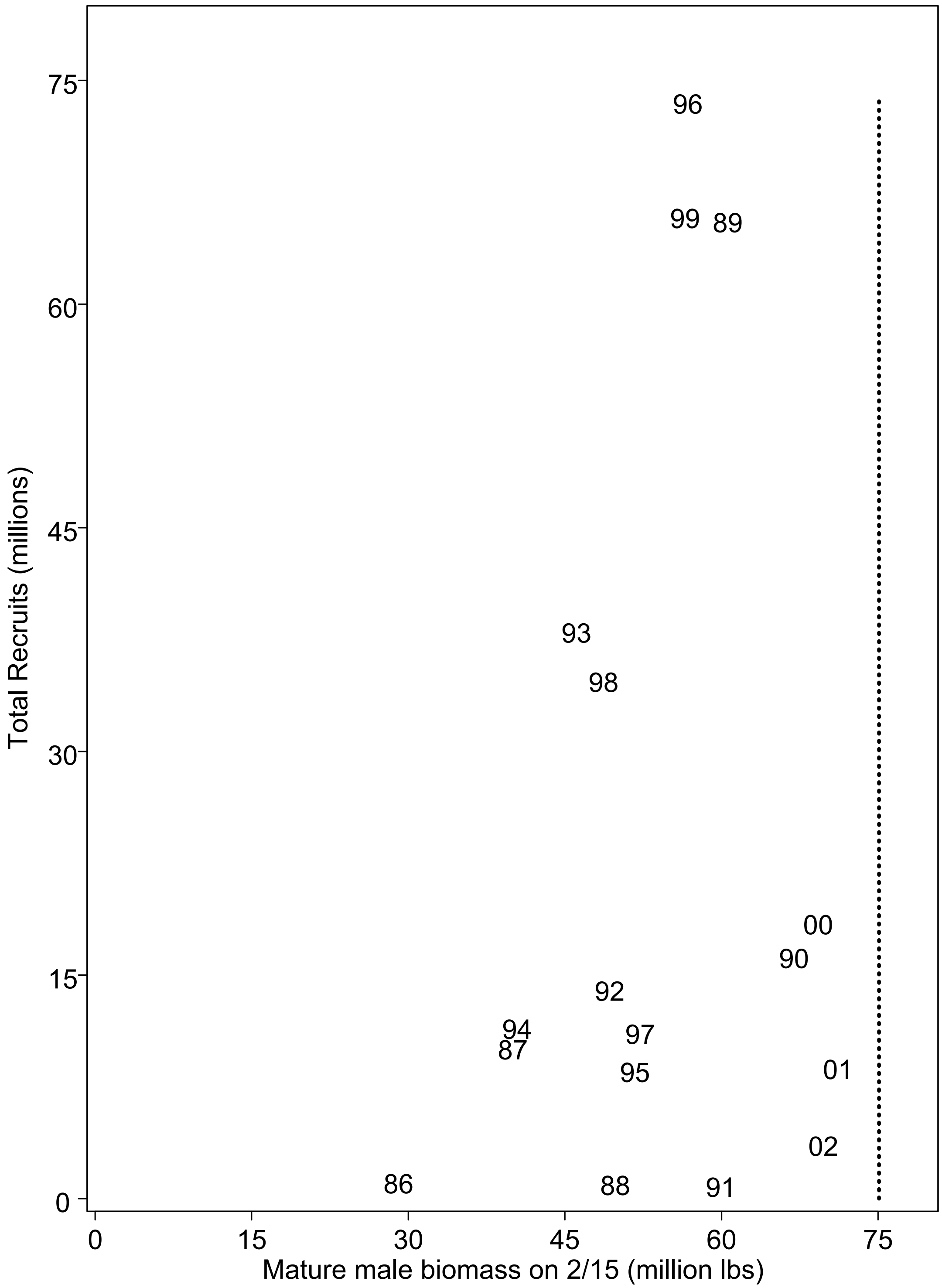


Figure 35. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$.

79

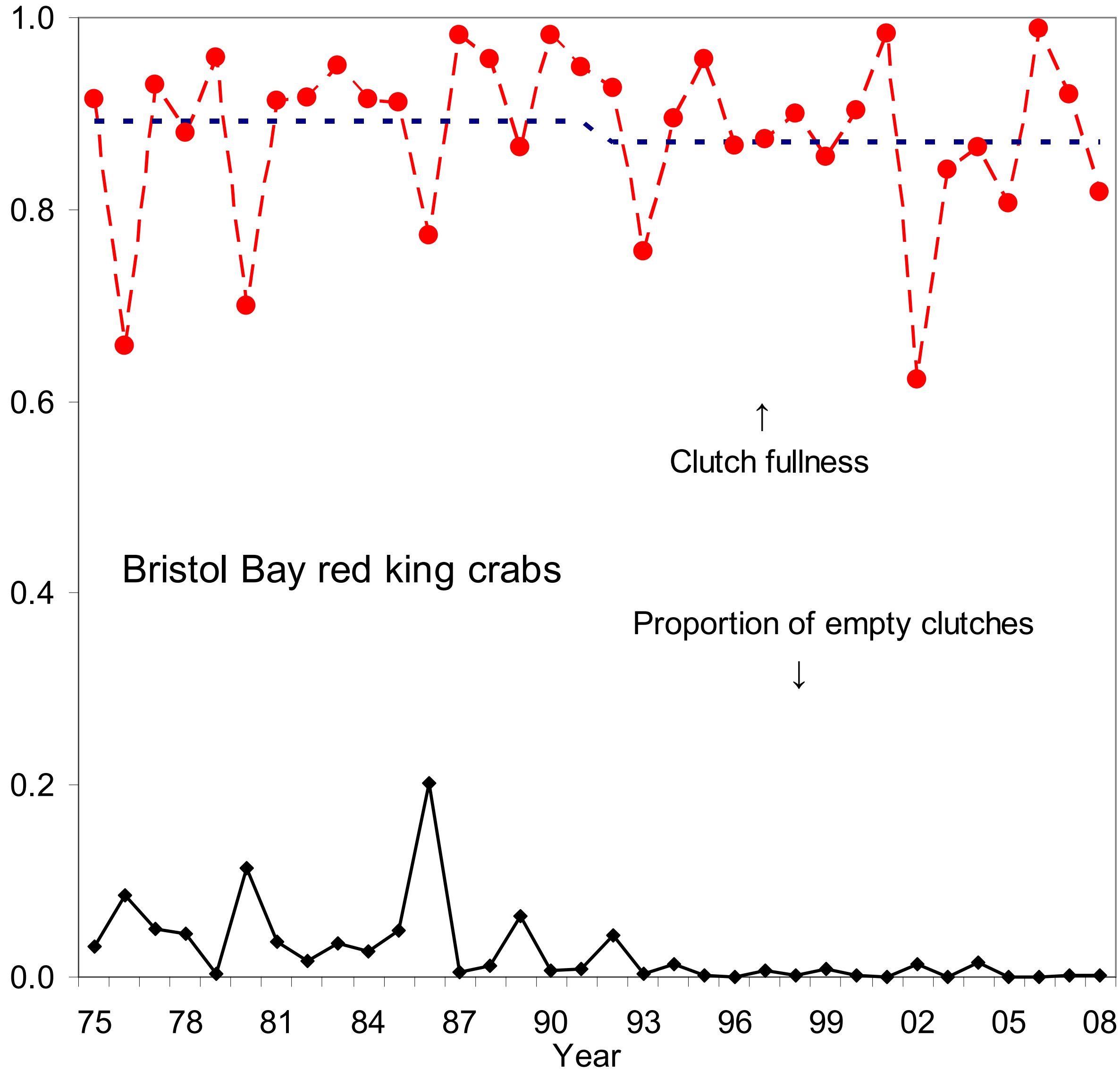


Figure 36. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crabs >89 mm CL from 1975 to 2008 from survey data. Oldshell females were excluded.

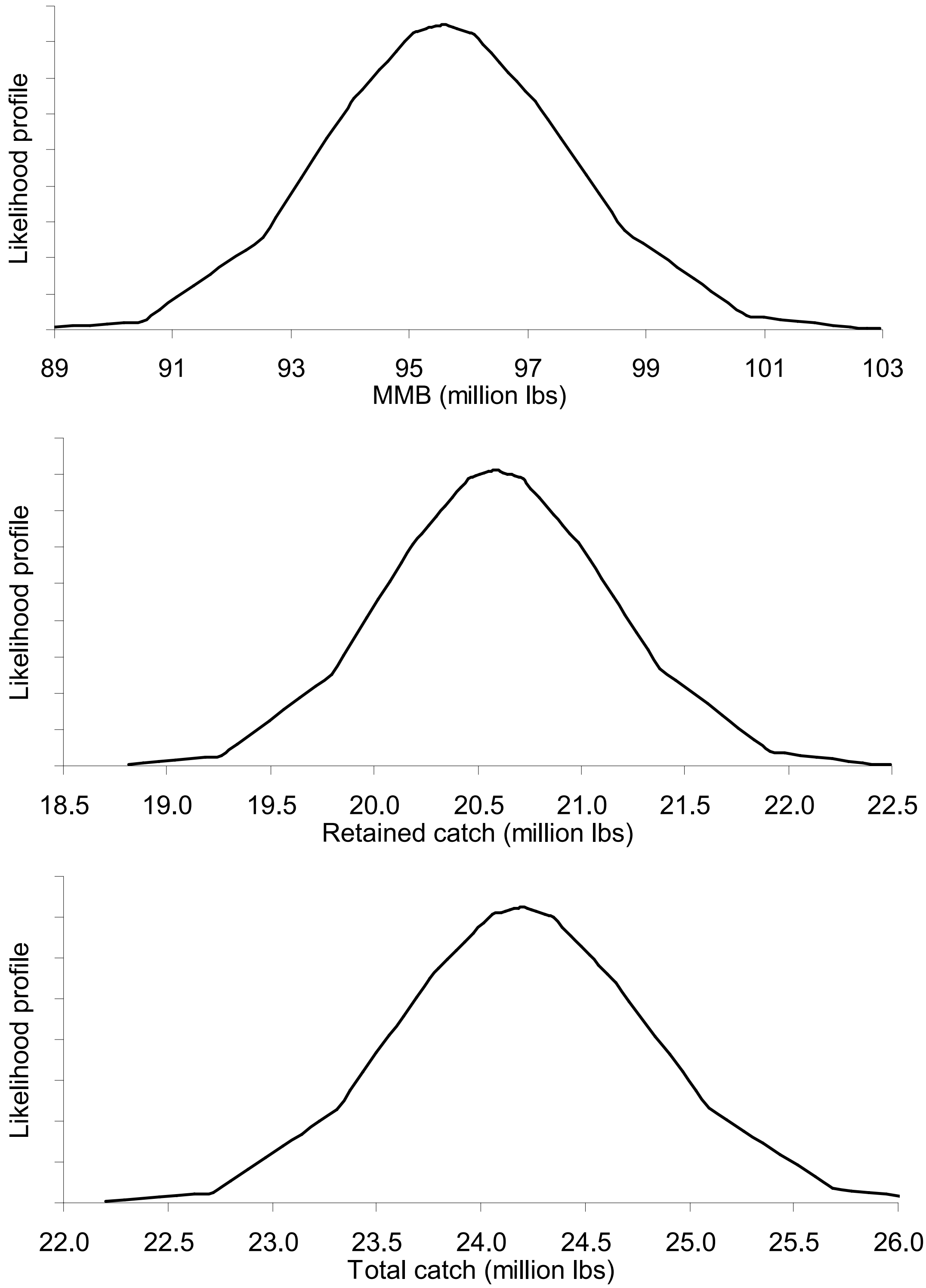


Figure 37. Likelihood profiles for estimated mature male biomass on Feb. 15 and overfishing limits of retained catch and total catch for the 2008 season with $F_{35\%}$. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

81

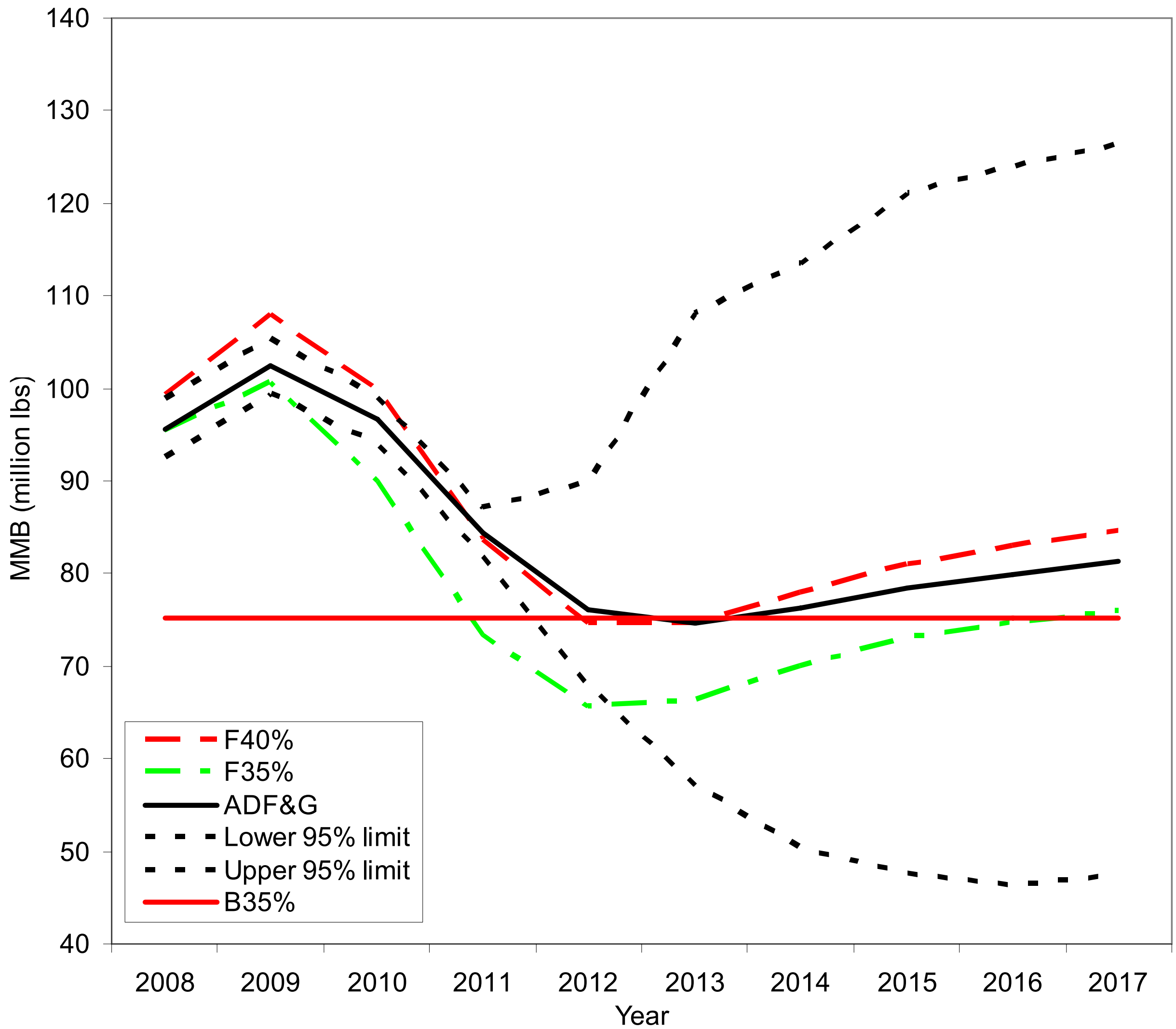


Figure 38. Projected mature male biomass on Feb. 15 with $F_{40\%}$, $F_{35\%}$ and the ADF&G harvest strategy with $F_{35\%}$ constraint during 2008-2117. Pot handling mortality rate is 0.2 and the confidence limits are for the ADF&G harvest strategy.

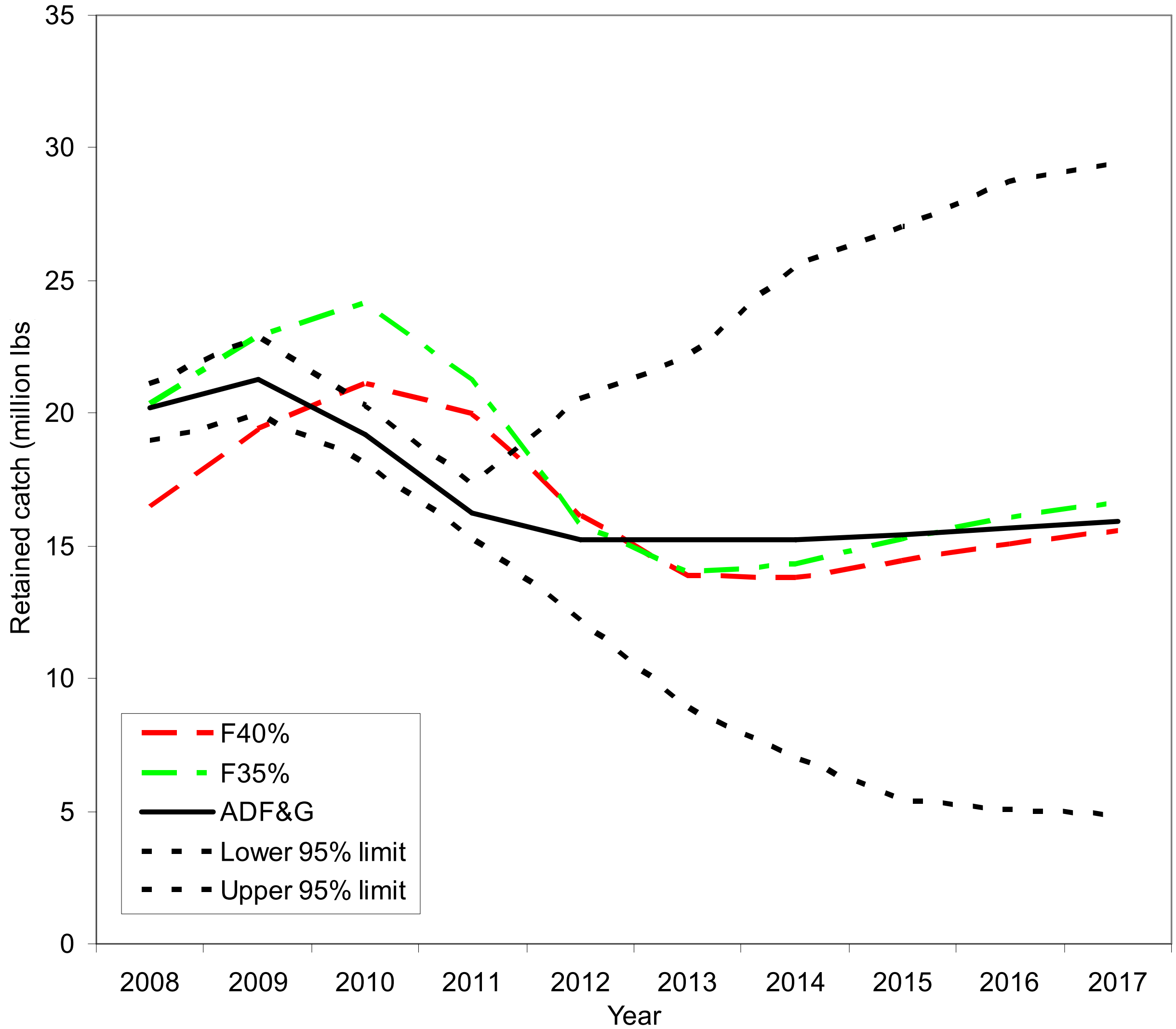
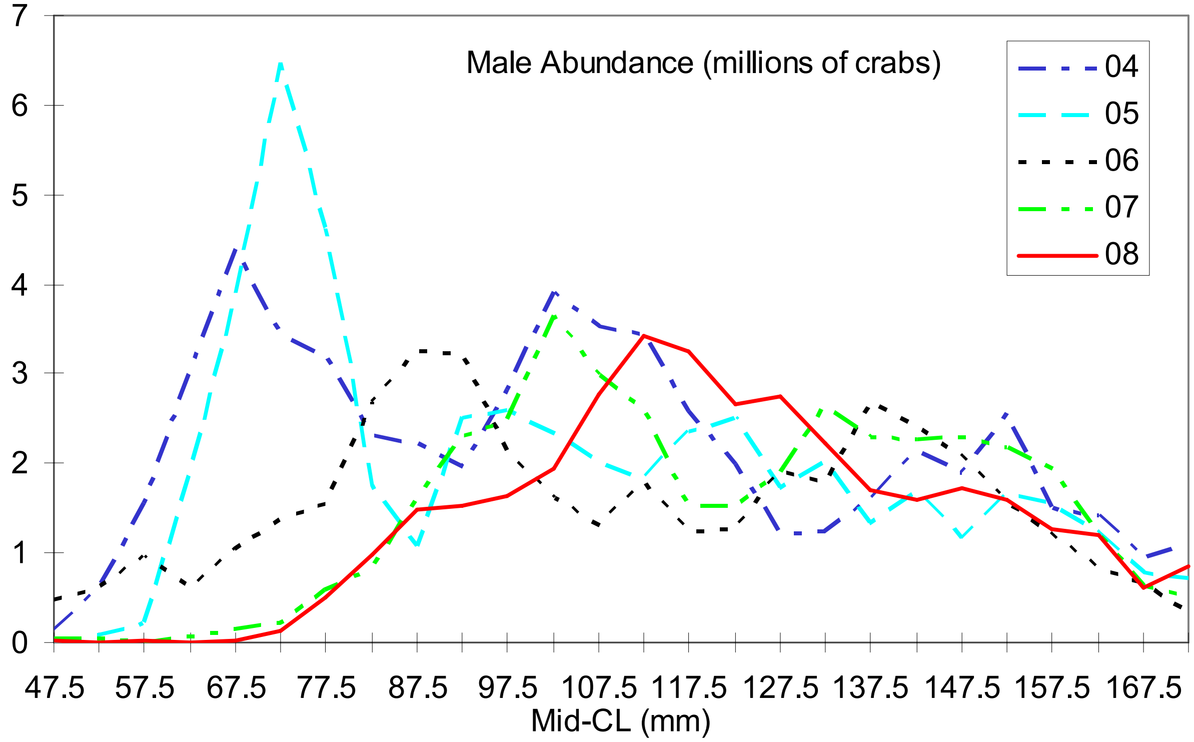


Figure 39. Projected retained catch biomass on Feb. 15 with $F_{40\%}$, $F_{35\%}$ and the ADF&G harvest strategy with $F_{35\%}$ constraint during 2008-2117. Pot handling mortality rate is 0.2 and the confidence limits are for the ADF&G harvest strategy.



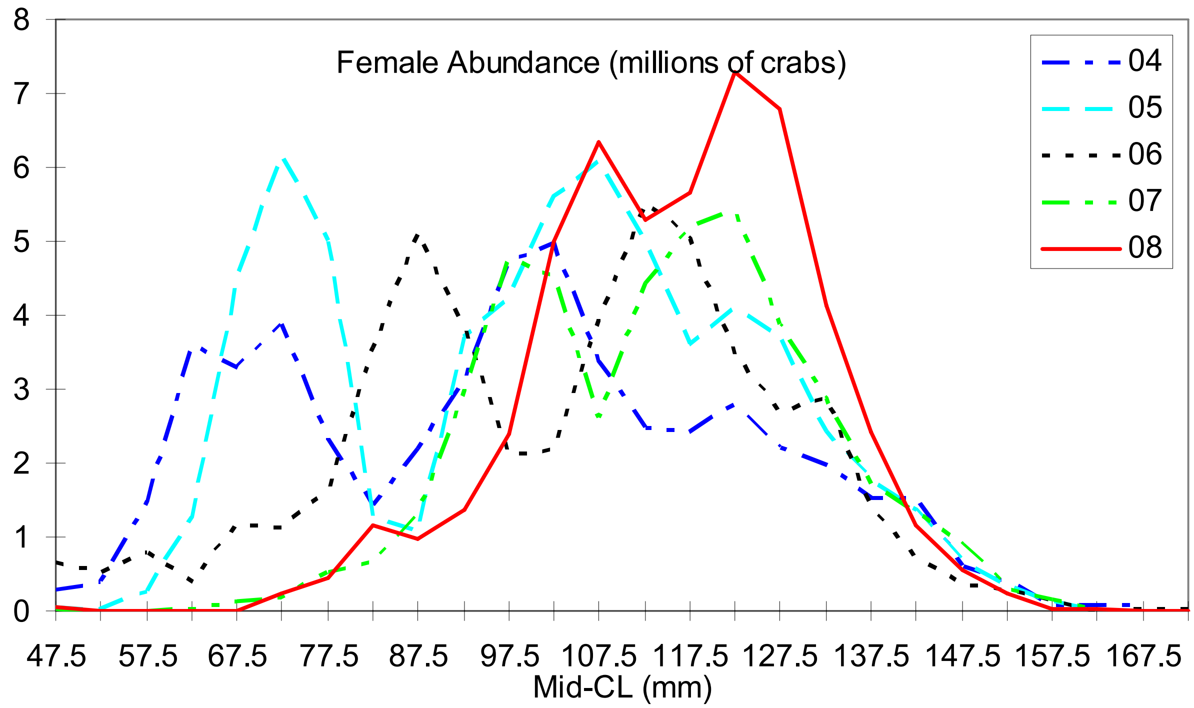


Figure 40. Length frequency distributions of male (top panel) and female (bottom panel) red king crabs in Bristol Bay from NMFS trawl surveys during 2004-2008. For purposes of these graphs, abundance estimates are based on area-swept methods.

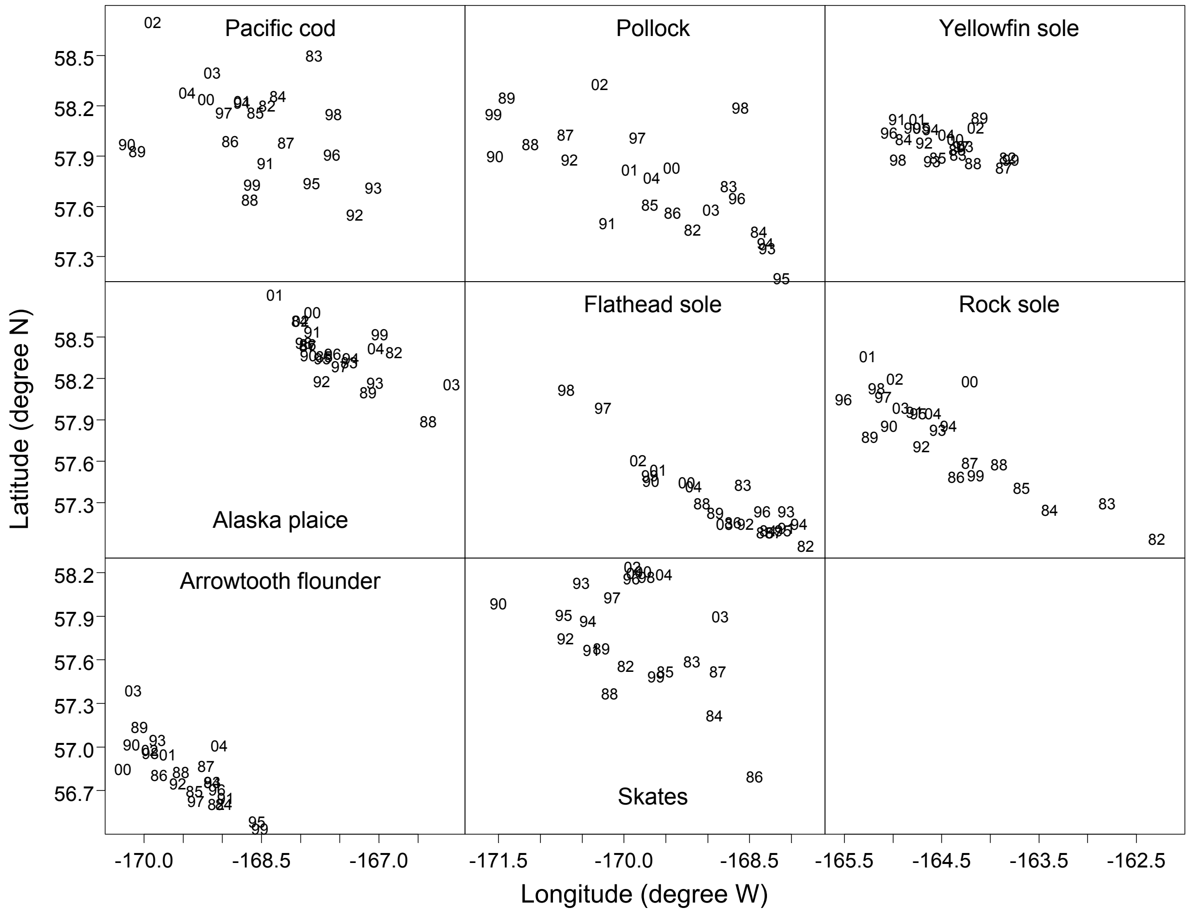


Figure 41. Biomass distribution centers of Pacific cod, walleye pollock, yellowfin sole, Alaska plaice, flathead sole, rock sole, arrowtooth flounder, and skates derived from NMFS summer trawl survey data in the eastern Bering Sea. (Source: Zheng and Kruse 2006).

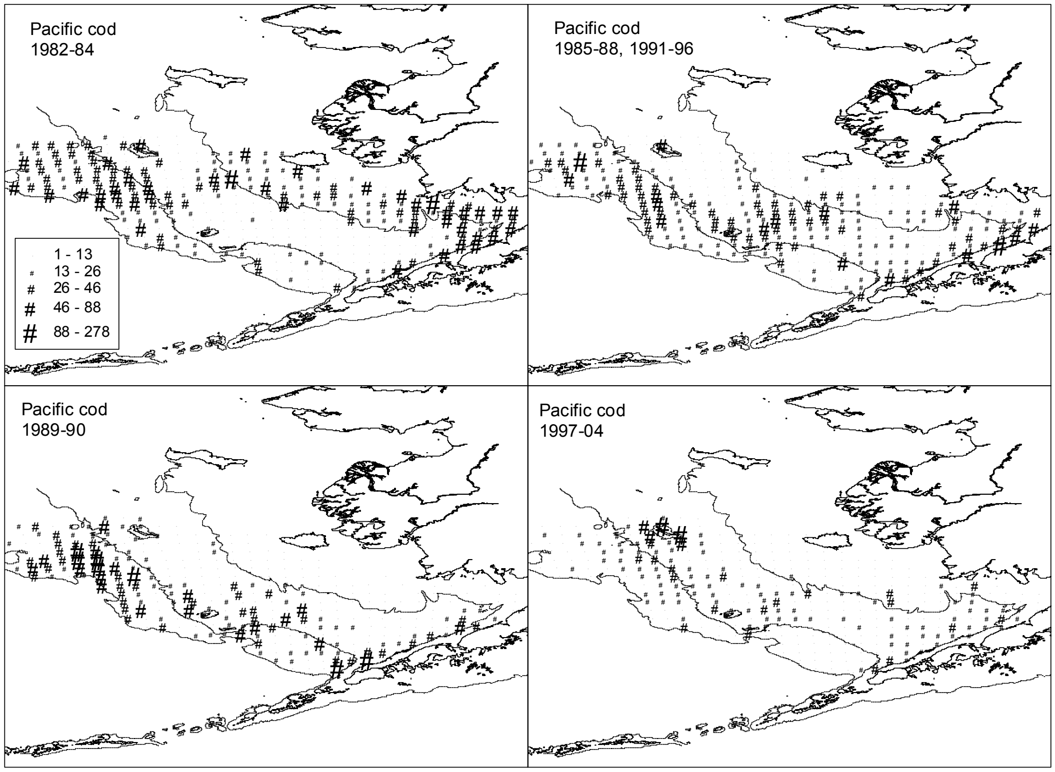


Figure 42. Distributions of relative biomass of Pacific cod in the eastern Bering Sea from 1982 to 2004 derived from NMFS summer trawl survey data. Relative biomass is expressed as kg/ha. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

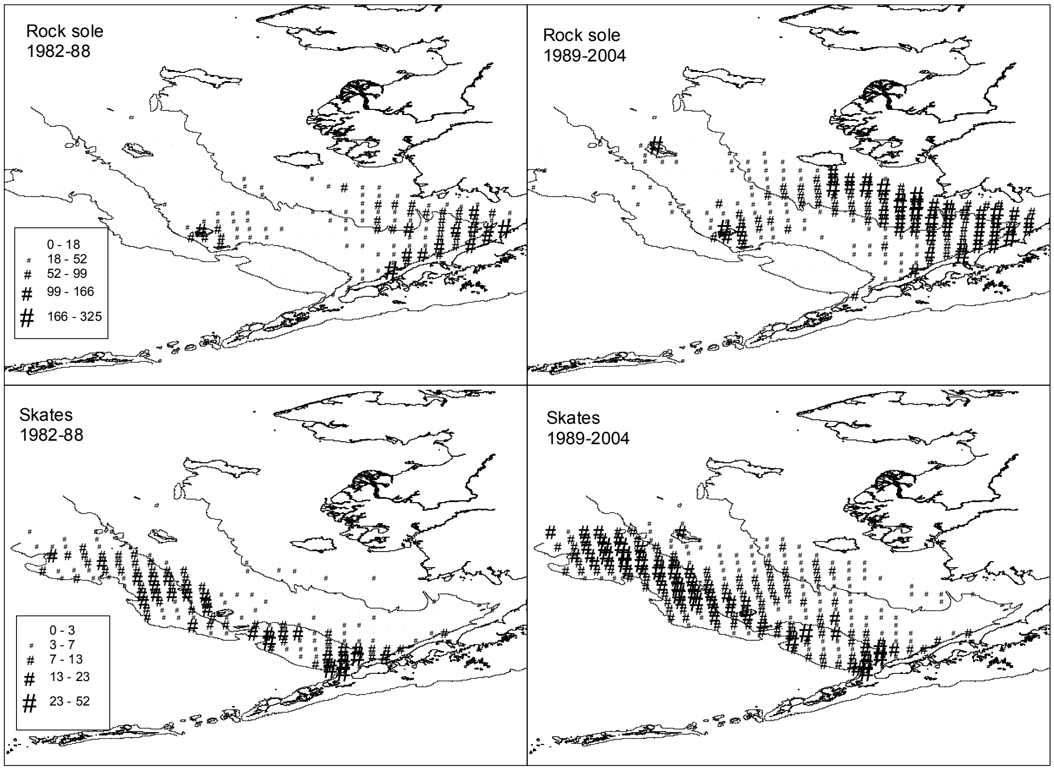


Figure 43. Distributions of relative biomass of rock sole and skates in the eastern Bering Sea from 1982 to 2004 derived from NMFS summer trawl survey data. Relative biomass is expressed as kg/ha. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

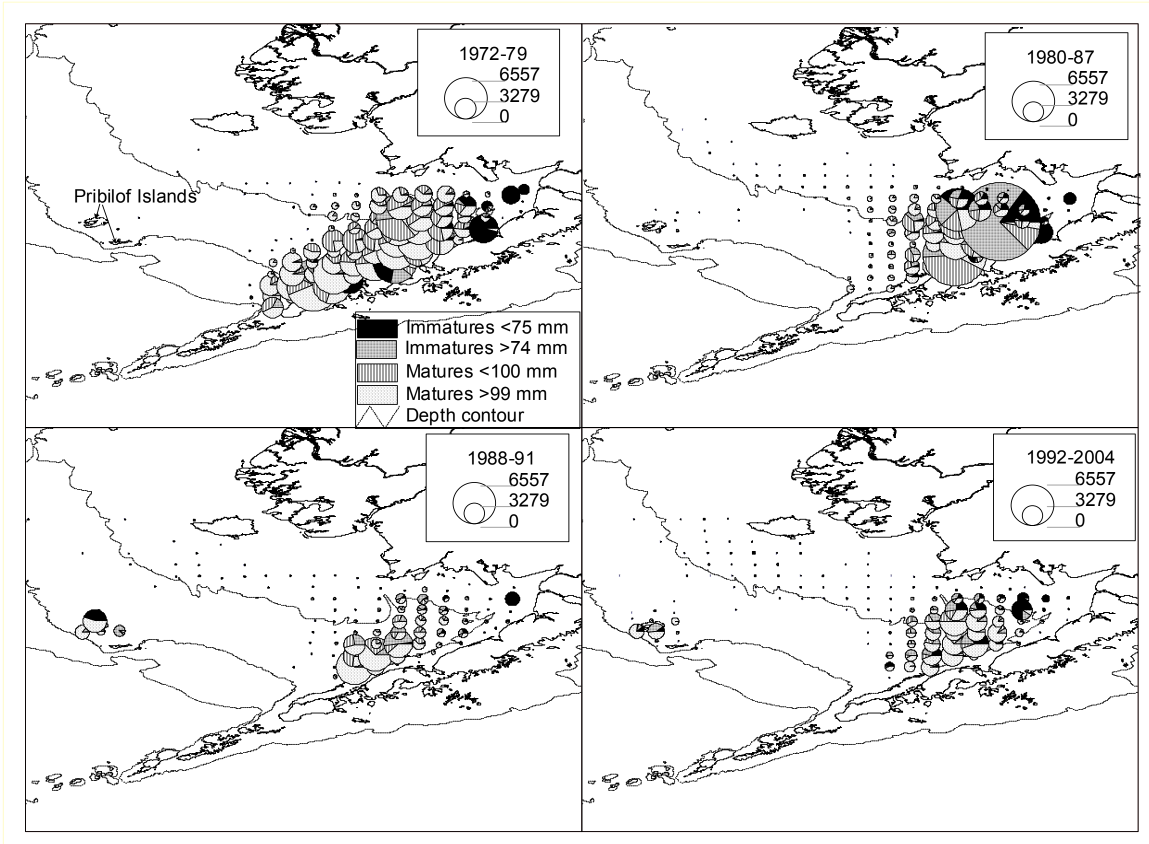


Figure 44. Geographic distributions of immature and mature female red king crabs from 1972 to 2004 in the eastern Bering Sea derived from NMFS summer trawl survey data. The diameter of each pie represents crab density expressed as the number of crabs per square nautical mile. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

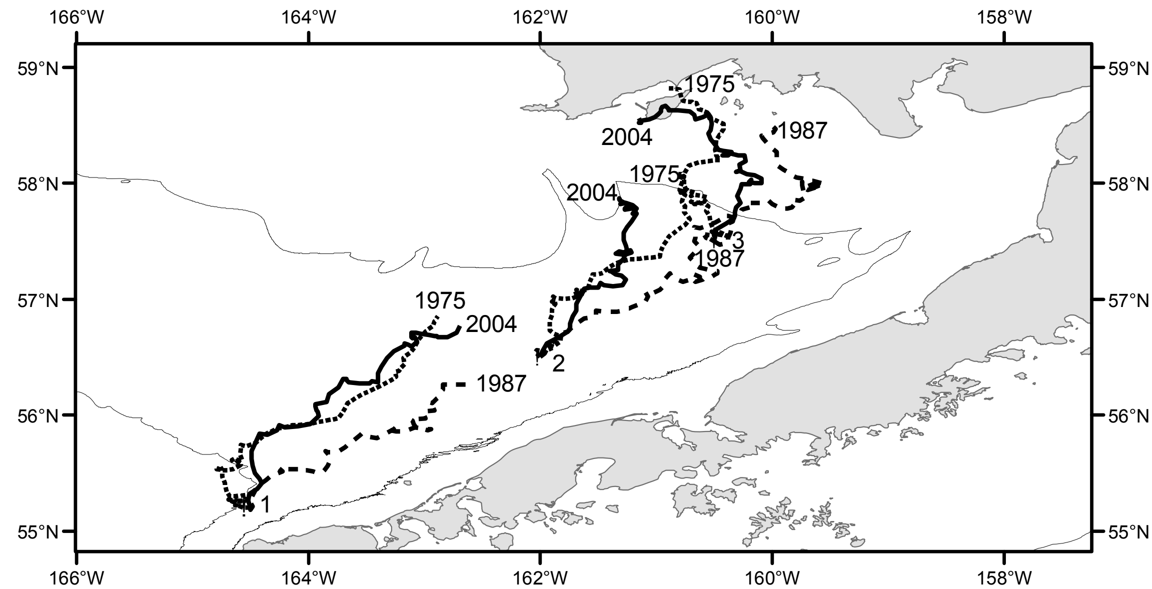


Figure 45. Larval movements after hatching on May 15, 1975, 1987, and 2004 from three different locations for Bristol Bay red king crab during two months. (Source: Zheng and Kruse 2008).

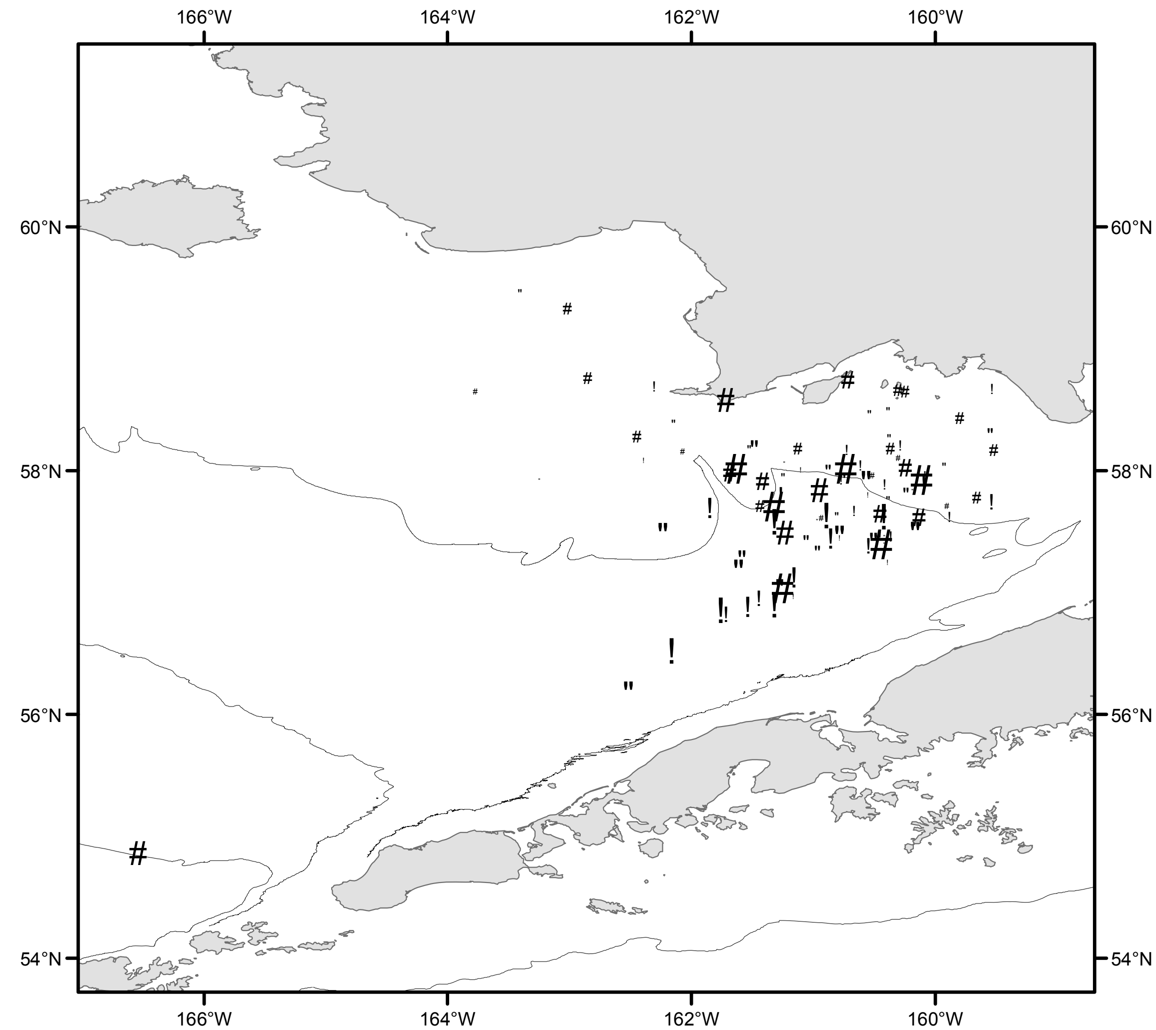


Figure 46. Estimated settling locations from the distribution centers of Bristol Bay mature female red king crabs >99 mm CL during 1967-1999. Hatching dates of April 15, May 15, and June 15 are triangles, squares, and circles, respectively. Symbol sizes are proportional to year-class strength.

90

2008 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

18 September 2008

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NOAA Fisheries

Executive Summary
In 2008, Tanner crab male mature biomass (MMB) and at the time of the survey was estimated at 143.1 million pounds. This represented a 22.7% decrease in mature male biomass relative to 2007. Legal males were sparsely distributed in 2008 with regions of highest abundance in southern Bristol Bay. The total abundance index for legal males was 13.1 million crabs which represented a 9% increase over 2007. Legal males were distributed 69.0% (9.1 million crabs) east and 31.0% (4.1 million crabs) west of 166° West longitude which compared to 44.5% and 55.5% respectively in 2007. The abundance index for pre-recruit male crabs declined 16.0%, and that for small males declined 55.1% relative to 2007. Total male abundance declined 43.2% between 2007 and 2008. Comparison of the 2006-2008 male size frequency distributions reveal persistently declining abundance across all size ranges, a general failure for modes to persist inter-annually, and a relatively increasing percentage of old shell crabs in the mature male stock.

In 2008, a single station sampled in southern-most Bristol Bay was a high density station for Tanner male crab. The legal male abundance estimated at this station (6.1 million crabs) represented 67.8% of all legal male crab in the Eastern District. It exceeded by 2.1 million the number of legal males in the Western District, and it comprised 46.7% of all legal males estimated throughout the EBS. Considerable uncertainty exists in the apparent strength (+9.0%) of the 2008 legal male estimate relative to 2007.

Large female Tanner crab showed a 21.4% decrease over 2007, and these were dominated (71.1%) by old shell females. Small female Tanner crab declined 38.8% relative to 2007. Total 2008 female abundance declined 35.9%, and the total abundance of male and female combined declined 43.2% since 2007. The survey length frequency distributions of female Tanner crab from 2006-2008 reveal consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually.

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} used in the OFL-setting process was B_{REF} = 189.76 million pounds male mature biomass estimated as the average MMB_{mating} for 1969-80. For Tier-4 stocks, the F_{OFL} is derived using and F_{OFL} Control Rule based on the relationship of current mature stock biomass to a reference biomass 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. However, 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 plus bycatch losses.

The value of M is 0.23 for eastern Bering Sea Tanner crab. For this analysis, gamma was set to 1.0. Relative to B_{REF} = 189.8 million pounds, the 2008 estimate of MMB at the time of mating (108.28 million pounds) represented B/B_{REF} = 0.571 resulting in and F_{OFL} = 0.120.

For the 2008 Tanner crab fishery, we estimated the Total Catch OFL = 15.52 million pounds. Directed and non-directed losses to MMB in 2008 are estimated to be 7.17 and 2.92 million pounds, respectively.

After accounting for expected losses to MMB, the projected catch of legal-sized Tanner crab is 5.07 million pounds. The retained part of the catch of legal-sized crab (4.36 million pounds) accounts for expected directed and non-directed losses to LMB by the fisheries. In comparison to the overfishing limit, the retained legal catch would comprise 30.2% of the total male mature biomass losses. A significant component of the Total Catch OFL therefore results from non-targeted losses under current EBS fisheries.

Expected discard losses of female Tanner crab from the 2008 ground fish fishery and the directed pot fishery combined was estimated at 1.07 million pounds. Therefore, total expected male plus female losses in 2008 comprising the Total Catch OFL = 15.521 million pounds. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.088 and 0.113 respectively.

Introduction

Scientific name and general distribution

Originally described by Rathbun (1924), *Chionoecetes bairdi* 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	Brachyura
Superfamily	Majoidea
Family	Oregoniidae
Genus	Chionoecetes

The common name for *C. bairdi* of "Tanner crab" (Williams et al. 1989), was recently been modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" has also been variously 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 generally 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 appears to be limited by water temperature (Somerton 1981a) (Figure 1). *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 (Figures 2 and 3). The southern range of the cold water congener, *C. opilio*, the snow crab in the EBS is near the Pribilof Islands (Turnock et al. 2008). 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).

Management units

Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the Bering Sea is managed under a federal fisheries management plan (FMP). The FMP defers Bering Sea Tanner crab management 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 FMP, 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 4) 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).

Stock structure

Tanner crabs in the eastern Bering Sea are considered to be a separate stock and distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998**.** The eastern Bering Sea stock is managed as a single unit, but may consist of two groups in the east and west that differ biologically (see Somerton 1981a).

Life history

Reproduction

In most majid crabs, it is thought that the molt to maturity is the final or terminal molt. For *Chionoecetes bairdi* specifically it is now generally accepted that both males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo terminal molt. 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 second 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). At least 2 consecutive egg fertilization events can follow a single copulation (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 male 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 also (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 eastern Bering Sea, seasonal differences have been observed between mating periods for pubescent and multiparous Tanner crab females in the Gulf of Alaska (GOA) and PWS. 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 eastern Bering Sea 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 EBS 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 or senescent females in the EBS often carry small clutches or no eggs at all suggesting that Tanner crabs may have only 2 or 3 primary reproductive years (NMFS 2004a). Donaldson et al. (1981) inferred a maximum age of 6 years after terminal molt for female Tanner crab.

Size at Maturity

Somerton (1981b) noted differences in the size of Tanner crab female maturity across its EBS range. There is no more current information on EBS Tanner crab growth than that provided by Sommerton (1981b). For the 5 survey years from 1975 to 1979, east of 167° 15' W longitude, 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 harvest strategy purposes, mature females are defined as females >=80mm CW (Bowers et al. 2008). For male Tanner crab during the same survey years and using the same longitude to partition the EBS, the estimated size at 50% maturity was 117.0 mm CW east of the partition, and 108.9 mm CW west of the partition (Somerton 1981b).

Mortality

Due to a lack of reliable age information, Somerton (1981a) estimated mortality separately for individual EBS cohorts of juveniles (pre recruits) and adults. He felt that because of net selectivity of the survey sampling gear, that 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 a catch curve model with two different data sets, Somerton then estimated natural mortality rates of adults (fished population) from data from the EBS population survey of 0.20 to 0.28. When using CPUE data from the Japanese fishery the estimated rates were 0.13 to 0.18. Somerton concluded that estimates (0.22 to 0.28) from models that used both the survey and fishery data were the best.

Zheng et al. (1998) used a nonlinear least-squares approach in an assessment model incorporating survey and fishery data through 1996 to estimate abundance, recruitment, and natural mortality for Bristol Bay Tanner crab. They limited their scope to crabs >=93 mm CW, also due to survey catchability concerns. Model estimates of natural mortality (2 scenarios) for males were 0.489 and 0.495 and for females 0.5231 and 0.551.

Data

Growth and Age

Somerton (1981a) studied growth of Tanner crab in the eastern Bering Sea and used size frequency data 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 4). Radiometric ageing has suggested that age after terminal molt may be 6 to 7 years (Nevisi et al. 1996).

Weight at length

Growth in weight data was collected during the 1975 EBS crab survey (Somerton 1981a). Carapace width and total weight were measured on 243 male Tanner crab. Only clean shell 2 or 3 crab were selected with no missing or regenerating appendages. The fitted equation was: $W=0.00019(CW)^{3.09894}$.

The Survey

The National Marine Fisheries Service conducts an annual trawl survey in the eastern Bering Sea to determine the distribution and abundance of commercially-important crab and groundfish fishery resources. The survey has been conducted since 1971 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 fishery resources targeted by this survey and enumerated annually by NMFS are red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), hair crab (*Erimacrus isenbeckii*), Tanner crab (*Chionoecetes bairdi*) and snow crab *(C. opilio*).

The 2008 trawl survey consisted of 378 bottom trawls taken over an area of approximately 139,548 nm^2. The survey was conducted onboard the FV *Arcturus* and FV *Aldebaran*, between 4 June and 24 July. Sampling methodology was identical to that of previous surveys since 1982, and most tows were made at the centers of squares defined by a 20 x 20 nmi (37 x 37 km) grid (Figure 1). 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 distribution of average bottom water temperatures across the area sampled in 2008 are is shown in Figure 1.

Both the FV *Arcturus* and FV *Aldebaran* fished an eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope which has been the standard gear since 1982. Each tow was approximately 0.5 h in duration towed at 3 knot, and conducted in strict compliance with established NOAA groundfish bottom trawl protocols (Stauffer 2004). The average tow length of all tows taken in 2008 was 1.49 nmi (2.78 km). The mean bottom water temperature of all 378 trawls was 1.08 ^{o}C. Crabs were sorted by species and sex, and then a sample of the catch measured to the nearest millimeter to provide a size-frequency distribution. Population estimates are indices of relative population abundance and biomass and do not necessarily represent absolute abundance or biomass measures. 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.

Stock Biomass

Tanner crab male mature biomass (MMB) and legal male biomass (LMB) exhibited periods of peak biomass in the early to mid-1970s and the early to mid-1990s (Table 5, Figures 5b and 7). LMB data are currently available only for 1980-2008. Although MMB estimates date to 1969, the variation in annual estimates between 1969-1975 reflect data quality and availability and retrospective analysis of the historical NMFS trawl survey data is required to complete the time series record. 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 7. The historical bimodal distribution in male biomass reflects that of the attendant directed fisheries with peak modes in the mid-1960s through mid-1970s and in the early-1990s (Table 5, Figure 7), and collapsed stock status following those modes. 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 2008, MMB rose at a moderate rate from a low of 25.1 million pounds in 1997 to 185.2 million pounds in 2007 before falling to 143.1 million pounds in 2008 . Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the B_{MSY} level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt.

The legal minimum size of 5.5 in cw (spine tip to spine tip) is equivalent to 138 mm cw measured between the spines. Legal males were sparsely distributed with regions of highest abundance in southern Bristol Bay and south of the Pribolof Islands (Figure 2). In 2005, the ADF&G stratified the management of the Bering Sea Tanner crab stock into two subareas, east and west of 166°W longitude, hereafter Eastern and Western Districts respectively. The abundance index for legal male C. bairdi for both Districts combined was 13.1 million crabs, a 9% increase over 2007. This abundance was distributed between management districts according to 69.0% Eastern and 31.0% Western compared to 44.5% and 55.5%, respectively in 2007. The abundance index (77.7 million crabs) for pre-recruit male crabs (110-

137 mm cw) showed a 16.0% decrease, and the index of 186.8 million for small males (< 110 mm cw) showed a 55.1% decrease relative to 2007 for all areas combined (Figure 10).. The 2006 male size-frequency revealed a prominent mode in the 70-75 mm cw range, which persisted to 2007 at 90 mm cw (Figure 11). However, this mode is absent from the 2008 male length frequency and total male abundance was observed to decline 46.7% between 2007 and 2008 (Figures 10 and 11). Legal-sized males represent only a small portion (8.9%) of total male abundance in 2008. Among legal males, 91.3% were new-hardshells, and 8.7% were oldshell and older. Pre-recruit Tanner crab in 2008 were widely distributed across the range of the survey from southern Bristol Bay northwest to St. Matthew Island (Figure 2).

In 2008, a single station sampled in southern-most central Bristol Bay revealed a high density of male Tanner crab. The legal male abundance estimated at this station (6.1 million crabs) represents 67.8% of all legal male crab in the Eastern District. It exceeded by 2.1 million crab the estimate of all legal males in the Western District, or 150.9% of Western District, and it comprised 46.7% of all legal males estimated in all EBS areas combined. Therefore, considerable uncertainty exists in the apparent strength (+9.0%) of the 2008 estimate of legal male abundance relative to 2007.

The combined Eastern and Western Districts abundance index (32.1 million crabs) of large females ($\geq$ 85 mm cw) showed a 21.4% decrease over 2007 (Figure 10). Among sampled mature females, 1.8% were softshells; 27.0% were new-hardshell, of which 98.4% carried new eggs; and 71.1% were oldshell and older, of which 81.8% carried new eggs. The vast majority of mature females sampled had completed hatching by the time of the survey. The small (<85 mm cw) female Tanner crab abundance estimate in 2008 (125.6 million crab) showed a 38.8% decline relative to 2007. Total 2008 female abundance (157.7 million crab) declined 35.9% in from 2007, and the total abundance of male and female combined declined 43.2% since 2007 (Figure 10). Ovigerous females were sparsely distributed from southern Bristol Bay westward to south of St. Matthew Island (Figure 3). Immature female Tanner crab displayed a similar distribution to mature females with the exception of an area of relatively high concentration west of Bristol Bay and north of the Pribiolof Islands (Figure 3). Barren mature females were intermittently distributed (Figure 3). The survey length frequency distributions of female Tanner crab from 2006-2008 are shown in Figure 12. The prominent length mode between 65-75 mm cw seen in 2006 is not shown to persist through 2007 or 2008. Rather, it is shown in consistently declining abundance through 2008. A significant portion (71.1%) of mature female Tanner crab are in old or older shell class condition (Figure 12).

The Fishery

The domestic Tanner crab (*Chionoecetes bairdi*) pot fishery rapidly developed in the mid-1970s (Table 1, Figures 5 and 6). As a note, we adopted the convention for tables in this document presenting biomass or fishery data, the 'year' refers to the survey year, and fishery data are those subsequent to the survey that year through but prior to the survey in the following year. United States landings were first reported for Tanner crab in 1968 at 1.01 million pounds taken incidentally to the eastern Bering Sea red king crab fishery. Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early-1970s, reaching a high of 66.6 million pounds in 1977. 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 40.1 million pounds, and then fell sharply through the mid-1990s. 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 1.7 million pounds retained catch between 2005-2007. Landings of Tanner crab in the foreign Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 44.0 million pounds in 1969 (Table 1, Figure 6). The Russian tangle net fishery was prosecuted between 1965-1971 with peak landings in 1969 at 15.6 million pounds. 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, the non-directed pot fisheries (notably, for snow crab and red king crab), and the groundfish trawl fisheries (Table 2). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for trawl fishery bycatch (NPFMC 2008). Total Tanner crab discard and bycatch losses by sex are shown in Table 2 for 1965-2007. The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 1). These losses were persistently high during the late-1960s through the late-1970s; male losses peaked in 1970 at 44.5 million pounds (Table 2). A subsequent peak mode of discard/bycatch losses occurred in the late-1980s through the early-1990s which, although briefer in extent, revealed higher losses for males than the earlier mode; peak=49.2 million pounds in 1990. From 1965-1975, the groundfish trawl fisheries contributed significantly to total bycatch losses, although the combined pot fisheries are the principal source of contemporaneous non-retained losses to the stock (Table 2). Total Tanner crab retained catch plus non-directed losses of males and females (Table 3, Figure 5a) reflect the performance patterns in the directed and non-directed fisheries. Total male catch rose sharply with the fishery development in the early 1960s and reveals a bimodal distribution between 1965 and 1980 with peaks of 104.7 million pounds in 1969 and 115.5 million pounds in 1977 (Table 3, Figure 5a). Total male catch rose sharply after the directed domestic fishery reopened in 1987 and reached a peak of 89.3 million pounds 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 mortalities by all pot and trawl fisheries combined to retained catch has shifted significantly relative to that between 1980-1996 (Tables 1 and 2). In the last three years, the ratio of total male non-retained losses to retained catch in terms of biomass is 4.4, 5.6 and 4.2 respectively. The majority of these male losses are sub-legal sized crab, and a principal contributor to these non-retained losses is the directed Tanner crab fishery (see Table 12a). This contrasts the pre-closure performance of the domestic fishery between 1980-1996 which averaged 1.1 (se=0.1) pounds of non-retained male mortalities to each 1.0 pound of retained catch. These ratios in terms of numbers of male non-retained losses to retained legal crab are more striking due to the contribution of sub-legal sized crab to total male discards. Note, discard and bycatch losses of male and female Tanner crab (Table 2) during the closures of the directed domestic fishery (1985-1986 and 1997-2004) reflect losses due to non-directed EBS pot fisheries and the domestic groundfish trawl fishery.

Exploitation Rates

The historical patterns of fishery exploitation on LMB and MMB were derived (Table 6, Figures 8a and 8b). 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 available only for 1980-2008. During that period, exploitation rate (μ) on LMB was highest in 1980 at 0.19 and fell with stock condition through the mid-1980s. LMB exploitation rate revealed a second prominent mode during 1989-1993, peaking at 0.18 in 1991 and averaging 0.17 (Table 6, Figure 8b). The pattern of μ on MMB from 1969-2007 reveals two high periods: one associated with the high total catches between 1969-1980; the other coincident with the mode of high catches in the late-1980s through early-1990s. The variability in μ on MMB during the early period (1969-1980) occurs as a result of the uncertainty in biomass estimates which require re-estimation. Exploitation rate on MMB during the 1990s peaked at 0.42 in 1990, averaged 0.21 between 1986-1997, and closely followed the build up in stock biomass during that period.

The Analytic Approach

Tier-4 OFL Control Rule and OFL-Determination

In the Environmental Assessment proposed as 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 is customarily available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Such modeling approaches 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 exploiting the stock at $F_{MSY.}$ For Tier-4 stocks, B_{MSY} is commonly estimated as the average biomass over a specified period that satisfies the expectation of equilibrium biomass yielding MSY by an applied 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 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. Use of the scaler γ is intended to allow adjustments in the overfishing definitions to account for differences in the biomass measures used in the EA 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/bycatch losses. For Tier-4 stocks, a minimum stock size threshold (MSST) is specified; if current MMB drops below MSST, the stock is considered to be overfished.

For Tier-4 stocks, the F_{OFL} is derived using and F_{OFL} Control Rule (Figure 9) according to whether current mature stock biomass metric (B_t) belongs to stock status levels a, b or c in the following algorithm. 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 levels where $\beta < B_t \leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B_t/B_{MSY}. The value of M is 0.23 for eastern Bering Sea Tanner crab. In the analysis of Tier-3 for snow crab, *Chionoecetes opilio,* and red king crab, *Paralithodes 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 be specified.

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

OFL Model Structure

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 conceptual approach for OFL-setting based on these metrics.

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

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

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

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

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

Total Catch OFL and Catch Components:
A total catch overfishing limit (Total Catch OFL) corresponding to the F_{OFL} can be estimated as the product of the annual fishing mortality rate ($1\text{-}e^{-Fofl}$) and the male mature biomass at the time of the fishery ($MMB_{survey}e^{-M/2}$). Here, the time lag from the survey to the fishery is 6 months.

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

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

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

Therefore, using these catch components,

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

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

Discard Catches:
Discard losses of mature male biomass by the directed fishery ($C_{dir\text{-}dsc,MMB}$) was estimated using data from the most recent 2007 Tanner crab fishery supplied by D. Barnard (ADF&G, 08/11/08) (Table 12a). The ratios of legal and sublegal male and female discards to the retained catch are used to project discard losses in the terminal 2008 OFL fishery. Here, DSC,MMB_{07} is the discarded mature male biomass by the directed 2007 Tanner crab fishery. For all pot discards, a post-release handling mortality rate of 50% was used (HM_{pot}=0.50). Directed fishery discard losses to MMB is given by:

$$C_{dir\text{-}dsc,MMB} = C_{ret,LMB}\ (DSC,MMB_{07}\ /\ C_{ret,LMB\ 07})\ HM_{pot} \quad (6)$$

Non-directed pot fishery discard losses to male mature biomass ($C_{non\text{-}dsc\text{-}pot,MMB}$) are principally attributed to the EBS snow crab fishery and to the Bristol Bay red king crab fishery to al lesser extent. In this analysis, we used data from the previous two fishing seasons (2006 and 2007) to estimate of the average ratio of combined Tanner crab mature male discards to snow crab retained catch (Table 12b). $C_{ret,opilio\ 2008}$ is the projected 2008 retained catch OFL (Turnock, pers. Comm.). Using this ratio, projected non-directed pot fishery discard losses to MMB in the terminal OFL fishery is given by:

$$C_{non\text{-}dsc\text{-}pot,MMB} = C_{ret,Opilio\ 2008}\ (C_{non\text{-}dsc\text{-}pot,MMB}\ /\ C_{ret,opilio})_{mean,07}\ HM_{pot} \quad (7)$$

Discard losses to MMB resulting from bycatch in the groundfish trawl fisheries ($C_{non\text{-}dsc\text{-}gf,MMB}$) was estimated using the average groundfish bycatch of Tanner crab over 2003-07 (Table 12c). We assumed that this average (5 y) bycatch of Tanner crab would occur in the 2008 OFL fishery. Reported bycatch are for males and females combined. The sex distribution and length frequency of this bycatch is unavailable for this analysis. The proportion of males in the bycatch was estimated assuming a sex ratio of 1:1 in the bycatch and apportioning the catch based on the ratio of mean weights of 120 mm cw male crab to 87.5 mm cw female crab resulting in a 60.2% v. 39.8% male to female split. For all trawl discards, a post-release handling mortality rate of 80% was used (HM_{gf}=0.80). Ground fish trawl fishery discard losses to MMB is given by:

$$C_{non\text{-}dsc\text{-}gf,MMB} = Mean_{03\text{-}07,dsc,gf}\ Porportion_{male}\ HM_{gf} \quad (8)$$

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as the ratio of total directed plus non-directed losses to LMB and MMB to respective legal and mature male biomass at the time of the fishery:

$$\mu_{LMB} = \text{Total LMB Losses} / LMB_{fishery} \quad (9)$$

$$\mu_{MMB} = \text{Total MMB Losses} / MMB_{fishery} \quad (10)$$

Using the F_{OFL} Control Rule (Figure 9), F_{OFL} is determined based on MMB at time of mating after extraction of the Total Catch OFL. Since the ratio of B/B_{REF} is dependent on the magnitude of the extracted catch and the catch OFL upon the estimated F_{OFL}, an iterative solution is found that solves for F_{OFL} and catch based on the relationship of MMB at mating to B_{REF}. The Total Catch OFL includes all sources of fishery-induced removals from the stock (directed retained catch, directed discards, and non-directed pot and trawl bycatch mortalities). Given specification of all component losses, the retained portion of the legal catch is a fishery control which could be set so not to exceed the OFL if the non-retained losses are as expected.

OFL-Setting Results

OFL-setting results for three scenarios are presented corresponding to the choice of three proxy B_{MSY} values. Under Scenario-1, the proxy B_{MSY} is B_{REF}=178.16 million pounds male mature biomass at the time of mating estimated as the average for 1975-1980 (CPT, May 2008). In June 2008, the SSC recommended the use of two alternative ranges of years for estimating proxy B_{MSY}. In Scenario-2, B_{REF}=189.76 million pounds estimated as the average for 1969-1980. Scenario-3 as recommended by the SSC, B_{REF}=103.81 million pounds estimated as the average for 1969-2007. The CPT accepted (September 2008) the SSC recommendation of using 1969-1980 estimates of MMB at the time of mating to specify B_{REF} despite both the author's and CPT's concerns about both the quality and availability of survey biomass data prior to 1975. The authors and CPT are not able to recommend Scenario-3 for OFL setting. From 1980-2007, the EBS Tanner crab stock collapsed twice resulting in two periods of fishery closures and a rebuilding plan by the Council. During this period, the stock experienced exploitation rates in excess of current F_{MSY} estimates. Specifically, at approximately three times that rate in the late-1970s, and twice that in the late-1980s, both preceded by stock collapses. Over 1980-2007, the stock has not been maintained itself at a level that could be reasonably construed as in dynamic equilibrium with its environment at a level indicative of B_{MSY} thereby capable of providing maximum sustainable yield to the fisheries. For the purpose of OFL-setting in the terminal 2008/09 fishery, therefore, results for Scenario-2 are the acceptable to the CPT.

We acknowledge that use of the average 1969-80 male mature biomass at the time of mating as a proxy for B_{MSY} is confounded by contemporaneous and antecedent high exploitation rates (Table 6, Figure 8a). As a result, we believe that even this B_{REF} underestimates the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries.

In May 2008, the CPT requested that an estimate of $F_{35\%}$ using fishery selectivity be presented to the SSC at its June 2008 meeting. Fishery selectivity used for the SSC analysis were those employed in the EA analysis and estimated based on historical fishery patterns prior to 1997 closure. The SSC recommended using fishery selectivity and maturity to estimate $F_{35\%}$ as the proxy F_{OFL} and to use the ratio of $F_{35\%}$ to M as an estimate of gamma. While it would be our preference to use the $F_{35\%}$ proxy for F_{MSY} where reliable data and understanding exist, we consider results of this analysis premature and do not recommend its use for OFL-setting. One principal concern is that fishery data for the last 3 years reveal that current selectivity in both the directed fishery and the snow crab pot fisheries differ profoundly from those employed in the EA analysis. The CPT did not have an opportunity to review our $F_{35\%}$ analysis or the results presented to the SSC in June. To adopt the SSC recommendation for 2008/09 OFL-setting, fishery selectivity would have to be estimated without the benefit of an assessment model. Neither would these results be reviewed by the CPT prior to the September 2008 meeting. We considered it ill-advised to attempt to estimate fishery selectivity ad hoc without improved understanding of the current fisheries as well as discussion and consent by the CPT. Since the EA selectivity pattern no longer applies, its use may provide non-informative or misleading results. The development of a Tanner crab stock assessment model is currently planned in which fishery selectivity will be estimated with data from contemporary fisheries.

For this analysis, gamma was set to 1.0. We accounted for discard/bycatch mortalities from the directed and non-directed pot fisheries and the groundfish trawl fisheries. By comparison, the EA simulations did not equivalently account for non-retained losses, thus it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. Further confounding specification of gamma is the fact that the MMB measure derived in this analysis employs a maturity schedule vs that of the EA simulations which employed knife-edge sex-specific maturity at size. The EA 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 5a) and stock biomass (Figure 7) reveals that the Tanner crab stock has not maintained itself in dynamic equilibrium over any sustained period, nor persisted in the face of exploitation rates (Table 6, Figures 8a and 8b) in excess of M. Differences between fishery selectivity and maturity in eastern Bering Sea crab stocks have also been suggested as a reason to allow gamma to exceed unity. Notwithstanding the problems noted in estimating current fishery selectivity, this argument relies on theoretical reproductive dynamical 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.

The 2008 Overfishing Limits

For the 2008 Tanner crab fishery, we estimated (Scenario-2) the Total Male Catch OFL = 14.45 million pounds (Table 8). Relative to B_{REF} = 189.76 million pounds, the 2008 estimate of MMB at mating (108.28 million pounds) represents B/B_{REF} = 0.571 resulting in and F_{OFL} = 0.120.

Directed and non-directed losses to MMB in 2008 are estimated to be 7.17 and 2.92 million pounds, respectively. After accounting for expected losses to MMB, the projected catch of legal-sized Tanner crab is 5.07 million pounds. The retained part of the catch of legal-sized crab (4.36 million pounds) accounts for expected directed and non-directed losses to LMB by the fisheries. In comparison to the overfishing limit, the retained legal catch would comprise 30.2% of the total male mature biomass losses. A significant component of the Total Male Catch OFL therefore results from non-targeted losses under current EBS fisheries.

Expected discard losses of female Tanner crab from the 2008 ground fish fishery and the directed pot fishery combined was estimated at 1.07 million pounds. Therefore, total expected male plus female losses in 2008 comprising the Total Catch OFL = 15.521 million pounds. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.088 and 0.113 respectively.

OFL-setting results for Scenario-1 (Table 7) and Scenario-3 (Table-9) are presented for illustration without discussion. The reader is referred to these tables to compare the results of the three scenarios. Results of the $F_{35\%}$ OFL-setting analysis using re-estimated selectivities from the 2007/08 Tanner crab fishery are presented in Appendix A.

Ecosystem Considerations

Ecosystem Effects on Stock

Prey availability or abundance trends

Tanner crab food habits in the EBS are largely unstudied, but a study near Kodiak (Jewett and Feder 1983) examined stomach contents from 1,025 Tanner crab > 40 mm CW Arthropods (mainly juvenile Tanner crab) dominated by weight; fishes and mollusks (mainly *Macoma* spp. and *Yoldia* spp.) were the second and third-most important food groups, by weight. In the western Bering Sea, the ascidian *Halocynthia autantium* is preyed upon by snow and Tanner crabs (Ivanov 1993). While the trends in EBS Tanner crab prey are largely unknown, it is thought that recent warmer temperatures may have put the Bering Sea food web into a top-down control regime (Hunt et al. 2002, Aydin and Mueter 2007) and so prey availability would not be limiting adult Tanner abundance. The relative importance, however, of climate effects is uncertain (Aydin and Mueter 2007).

Predator population trends

Several fishes, most notably Pacific cod (*Gadus macrocepahalus*), are documented as predators of Tanner crab in the eastern Bering Sea, Pacific halibut (*Hippoglossus stenolepis*) and skates (*Raja* sp.) being minor predators (Livingston 1989, Livingston et al. 1993, Lang et al. 2005). Pacific cod biomass increased steadily from 1978 through 1983, remained relatively constant from 1983 through 1988, fluctuated slightly from 1988 through 1994 (the highest observation) and in general has steadily declined since then with 2007 estimates being the lowest estimate in the time series (Thompson et al. 2007). Halibut biomass was lowest in 1982, fluctuated from 1983 through 1988, peaked in 1988, dropped in 1989 and increased from 1990 through 1996 when the highest biomass of the time series was observed, after 1998 biomass has fluctuated (personal communication, Steven Hare, IPHC). Biomass estimates of all skate species in the eastern Bering Sea are not reported, however biomass has been estimated for the Alaska skate (*Bathyraja parmifera*) since 1982. Estimated biomass for the Alaska skate fluctuated from 1982 through 1986, from 1986 through 1990 biomass in general increased and peaked in 1990, from 1991 through 1999 biomass tended to decrease and beginning in 1999 to the present biomass has been increasing (Ormseth and Matta 2007).

Disease effects on the stock
Bitter crab syndrome (BCS) is caused by a non-motile single celled protistan blood parasite *Hematodinium* sp. and is uniformly lethal to crab (Meyers et al. 1990). BCS has been detected in EBS Tanner crab for 20 years with no clear trends in prevalence. As discussed at a recent international workshop on the disease ("Hematodinum Associated Diseases: Research Status and Future Directions", Charlottetown, Prince Edward Island, Canada, Sept. 20-22, 2007), the long term effect of the disease on the crab populations is not well understood. Another potentially serious Tanner crab disease is black mat syndrome (BMS). BMS is a systemic fungal infection caused by *Trichomaris invadens* and is lethal to crab. Infection prevents molting therefore infected sublegal crabs would never grow to enter the fishery (Sparks 1982). BMS, however, has never been an important issue in the EBS (F. Morado, NOAA Fisheries, AFSC, Seattle, personal communication)

Changes in habitat quality
The ecosystem reorganization following the 1976/77 regime shift and to a lesser degree the 1998/1999 shift (Connors et al. 2002, Litzow 2006), have not in general favored Tanner populations in the EBS, but the exact nature of the biological response to these climate changes is poorly understood (Litzow 2006). In addition, it is proposed that future temperature increases and ocean acidification may directly affect the growth and survival of larval crab (M. Litzow, unpublished data, AFSC NOAA Fisheries), as well as causing drastic changes to the phytoplankton community in the Bering Sea (Hare et al. 2007) upon which larval Tanner crab are dependent (Incze et al. 1987, Incze and Paul 1983). The current effects of temperature increases and ocean acidification on Tanner crab are unknown.

Tanner Crab Fishery Effects on the Bering Sea Ecosystem
Fishery contribution to bycatch
The ADF&G observer program collects bycatch data on observed vessels (Table 10). Non-targeted sublegal male and female Tanner crab made up the largest number of bycatch followed by snow crab bycatch. Fish, including a number of crab predators, especially Pacific cod, Pacific halibut, yellowfin sole, and sculpin (*Myoxocephalus* spp.) were also caught (Barnard and Burt 2007, 2008, NMFS 2004). Invertebrates include sea stars, snails, hermit crabs, lyre crab, and others captured at low rates.

Handling mortality
It is generally accepted that there is a certain amount of mortality inflicted on the non-target species captured during fishing operations. Captured animals can die from handling stress, windchill, or while trapped in lost gear. Studies have been done to simulate handling injury but subsequent mortality was low and not significantly greater than controls (MacIntosh et al. 1996). Freezing due to windchill causes significant mortality to Tanner crabs (Carls 1989) and can result in leg loss or immediate mortality for Tanner crabs. Stevens and MacIntosh (1992) found average overall mortality of 11% for Tanner crab on one commercial crab vessel. Although it has been conclusively shown that windchill can effect high rates of mortality in Tanner crabs, there is also evidence that exposure of captured crabs to such windchill may not be common during actual fishing. The Crab Plan Team has estimated bycatch mortality to be higher in the snow and Tanner crab fisheries (24% and 20%, respectively) than in the king crab fisheries (8%) and that has been supported by higher incidence of pre-discard injuries during the snow crab fishery than in the red king crab fishery (Tracy and Byersdorfer 2000, Byersdorfer and Barnard 2002). Despite the research on handling mortality, the EIS for Bering Sea and Aleutian Islands (BSAI) crab fisheries (NMFS 2004) concludes there is not a good understanding of the effects of handling on crab bycatch mortality.

Increased mortality to fish and non-target invertebrates from ghost pot fishing in the Bering Sea has not been fully studied. ADF&G strictly enforces the requirement for a biodegradeable twine in each crab pot at the time vessels register for the fishery. The biodegrading twine requirement is intended to disable the ability of lost pots to fish after approximately 30 days but recent work indicates that the twine may stay intact for as long as 89 days in lost pots (Barnard 2008), much longer than the 30 days that was found to cause irreversible starvation effects in the laboratory (Paul et al. 1994).

Benthic species and habitat impacted by pot gear

In the final environmental impact statement for the BSAI crab fisheries the impact of pot gear on benthic species is discussed (NMFS 2004). These benthic species include fish, gastropods, coral, echinoderms (sea stars and sea urchins), non-FMP crab, and other invertebrates (sponges, octopuses, anemones, tunicates, bryozoans, hydroids, and jellyfish). Physical damage to the habitat by pot gear is dependent on habitat type. Sand and soft sediments where the Tanner crab fishery occurs are less likely to be impacted, whereas coral, sponge, and gorgonian habitats are more likely to be damaged (Quandt 1999, NMFS 2004). Despite the large number of pot lifts that occur during the fishery, the actual footprint impacted by the pots is much less than 1% of the Bering Sea shelf (NMFS 2004). It was concluded that the BSAI crab fisheries have an insignificant effect on benthic habitat. Since the bycatch species are widespread across the Bering Sea shelf, the impacts of pot gear on overall populations would also be minimal.

ESA and non-ESA marine mammals and seabirds

According to the ESA EIS report, crab fisheries do not adversely affect ESA listed species, destroy or modify their habitat, or comprise a measurable portion of the diet (NMFS 2004) including listed marine mammals or seabirds, although the possibility of strikes of listed seabirds with crab fishing vessels exists (NMFS 2000).

Of the marine mammals not listed under the ESA, the bearded seals (*Erignathus barbatus*) are the only marine mammal potentially impacted by the crab fisheries because crab are a measurable portion of the diet of these species (Lowry et al. 1980, NMFS 2004). No current data or information regarding bearded seal populations or conflicts or interactions with crab fisheries is available. For non-listed seabirds, the Alaska Groundfish Fisheries Final Programmatic SEIS (NMFS 2004b) provides life history, population biology and foraging ecology for marine birds. The SEIS concludes that the crab species under the FMP, including Tanner crab, have very limited interaction with non-listed seabirds.

Fishery Effects on Amount of Large Size Target Crab

While there have been some documented changes in the size of large fish available to fisheries as a result of removals of the fastest growing components of the population (ICES 2002), this phenomena has not been demonstrated in crustaceans.

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 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 for the crab fisheries.

Fishery Effects on Age-At-Maturity and Fecundity

No effects of overfishing on fecundity or size at maturity in female crabs would be expected in a crab fishery that targets only mature males (Orensanz et al. 1998) with little bycatch of females.

Ecosystem effects on the eastern Bering Sea Tanner crab stocks and fishery effects on the ecosystem are interpreted and evaluated in Table 11.

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Table 1. Eastern Bering Sea *Chionoecetes bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965-2007.

	Eastern Bering Sea *Chionoecetes baridi* Retained Catch (10^6 lb)				
	US Pot Fishery		Japan	Russia	Total
Year		[Crabs/Pot]			
1965			2.58	1.66	4.24
1966			3.73	1.66	5.39
1967			21.50	8.48	29.98
1968	1.01	12.00	29.95	8.73	39.69
1969	1.02	29.00	43.98	15.61	60.60
1970	0.17	8.00	41.73	14.31	56.20
1971	0.11	10.00	35.04	10.51	45.66
1972	0.23	6.00	37.04		37.27
1973	5.04	115.00	23.67		28.72
1974	7.03	72.00	26.58		33.60
1975	22.30	63.00	16.62		38.92
1976	51.50	68.00	14.67		66.17
1977	66.60	51.00	11.72		78.32
1978	42.50	42.00	4.00		46.50
1979	36.60	30.00	5.30		41.90
1980	29.60	21.00			29.60
1981	11.00	10.00			11.00
1982	5.27	8.00			5.27
1983	1.21	8.00			1.21
1984	3.15	12.00			3.15
1985	0	0			0
1986	0	0			0
1987	2.20	8.00			2.20
1988	7.01	16.00			7.01
1989	24.50	15.00			24.50
1990	40.10	19.00			40.10
1991	31.80	10.00			31.80
1992	35.10	13.00			35.10
1993	16.90	13.00			16.90
1994	7.80	13.00			7.80
1995	4.23	8.00			4.23
1996	1.81	5.00			1.81
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	0.95	0.00			0.95
2006	2.12	13.77			2.12
2007	2.11	17.00			2.11

Table 2. Eastern Bering Sea *Chionoecetes bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish trawl fisheries, 1965-2007.

Eastern Bering Sea *Chionoecetes bairdi* Discard and Bycatch Losses (10^6 lb)
[HM_{Pot}=0.50; HM_{GF}=0.80]

	All Pot		Groundfish		Total	
Year	Male	Female	Male	Female	Male	Female
1965	1.73	0.48	6.15	4.07	7.88	4.56
1966	2.20	0.62	11.16	7.38	13.36	8.00
1967	12.23	3.42	17.37	11.50	29.60	14.92
1968	16.20	4.53	13.18	8.72	29.37	13.25
1969	24.73	6.92	19.35	12.81	44.08	19.73
1970	22.94	6.42	21.52	14.24	44.46	20.66
1971	18.63	5.21	24.15	15.98	42.78	21.19
1972	15.21	4.25	13.86	9.18	29.07	13.43
1973	12.28	3.33	18.97	12.55	31.25	15.89
1974	14.52	3.91	26.25	17.37	40.77	21.29
1975	17.95	4.64	10.16	6.73	28.12	11.37
1976	28.29	7.68	4.40	2.91	32.70	10.59
1977	34.22	9.15	2.98	1.97	37.20	11.13
1978	22.76	5.67	3.42	2.27	26.18	7.93
1979	20.77	5.13	2.73	1.81	23.50	6.94
1980	17.62	3.91	2.24	1.48	19.86	5.39
1981	6.36	1.43	1.56	1.03	7.92	2.47
1982	3.34	0.72	0.48	0.32	3.82	1.03
1983	1.20	0.21	0.71	0.47	1.92	0.68
1984	2.49	0.47	0.69	0.45	3.18	0.93
1985	1.03	0.10	0.42	0.28	1.45	0.38
1986	1.46	0.14	0.69	0.46	2.15	0.60
1987	4.38	0.58	0.68	0.45	5.06	1.03
1988	11.26	1.60	0.49	0.33	11.75	1.93
1989	25.08	4.23	0.71	0.47	25.80	4.70
1990	48.17	7.60	1.00	0.66	49.17	8.27
1991	45.45	6.72	1.54	1.02	46.98	7.73
1992	27.25	2.41	2.07	1.37	29.32	3.78
1993	14.86	2.72	1.65	1.09	16.51	3.81
1994	7.74	2.34	1.23	0.81	8.97	3.15
1995	5.33	2.61	1.11	0.73	6.44	3.34
1996	1.21	0.36	1.02	0.68	2.23	1.03
1997	2.11	0.25	0.95	0.63	3.06	0.88
1998	2.32	0.20	0.73	0.48	3.06	0.68
1999	0.85	0.16	0.30	0.20	1.15	0.36
2000	0.23	0.03	0.38	0.25	0.62	0.28
2001	0.40	0.01	0.59	0.39	0.99	0.40
2002	0.68	0.04	0.72	0.47	1.40	0.52
2003	0.27	0.03	1.31	0.87	1.58	0.90
2004	0.14	0.02	0.95	0.63	1.09	0.65
2005	1.43	0.11	1.02	0.68	2.45	0.79
2006	6.61	0.20	1.64	1.09	8.25	1.29
2007	5.41	0.28	0.61	0.40	6.01	0.68

Table 3. Eastern Bering Sea *Chionoecetes bairdi* total catch losses in the directed (retained) and non-directed (discard + bycatch) fisheries, 1965-2007.

Eastern Bering Sea *Chionoecetes bairdi* Total Catch in the Directed + Non-Directed Fisheries (10^6 lb)

Year	Male	Female	Total
1965	12.12	4.56	16.68
1966	18.74	8.00	26.74
1967	59.58	14.92	74.50
1968	69.06	13.25	82.31
1969	104.68	19.73	124.41
1970	100.66	20.66	121.32
1971	88.44	21.19	109.63
1972	66.34	13.43	79.77
1973	59.97	15.89	75.85
1974	74.38	21.29	95.66
1975	67.03	11.37	78.40
1976	98.87	10.59	109.46
1977	115.52	11.13	126.64
1978	72.68	7.93	80.61
1979	65.40	6.94	72.34
1980	49.46	5.39	54.85
1981	18.92	2.47	21.39
1982	9.10	1.03	10.13
1983	3.12	0.68	3.80
1984	6.33	0.93	7.26
1985	1.45	0.38	1.82
1986	2.15	0.60	2.74
1987	7.26	1.03	8.29
1988	18.77	1.93	20.69
1989	50.30	4.70	55.00
1990	89.27	8.27	97.54
1991	78.78	7.73	86.52
1992	64.42	3.78	68.20
1993	33.41	3.81	37.22
1994	16.77	3.15	19.92
1995	10.68	3.34	14.02
1996	4.03	1.03	5.07
1997	3.06	0.88	3.94
1998	3.06	0.68	3.74
1999	1.15	0.36	1.52
2000	0.62	0.28	0.90
2001	0.99	0.40	1.39
2002	1.40	0.52	1.91
2003	1.58	0.90	2.48
2004	1.09	0.65	1.74
2005	3.41	0.79	4.19
2006	9.77	2.17	11.95
2007	8.12	0.68	8.80

Table 4. Age, growth, and instar number for male Tanner crab in Kodiak and the eastern Bering Sea.

Instar Number	Kodiak mean size (mm)	Kodiak age (months)	EBS mean size (mm)
1	3.4	1.8	-
2	4.5	2.5	-
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 5. Eastern Bering Sea *Chionoecetes bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1965-2008. (2008 MMB and LMB at mating are estimates based on extraction of respective 2008/09 catch OFLs under Scenario-2).

	Eastern Bering Sea Chionoecetes bairdi Survey Biomass (10^6 lb)					
	Male Mature Biomass (10^6 lb)			Legal Male Biomass (10^6 lb)		
Year	Survey	Fishery	Mating	Survey	Fishery	Mating
1965						
1966						
1967						
1968						
1969	604.93	539.22	414.26			
1970	151.81	135.32	29.57			
1971						
1972						
1973	208.44	185.80	118.84			
1974	396.83	353.72	266.04			
1975	623.89	556.11	468.16			
1976	318.43	283.83	174.29			
1977	344.02	306.65	179.60			
1978	179.55	160.05	81.35			
1979	121.38	108.20	38.73			
1980	205.47	183.15	126.80	170.86	152.30	116.97
1981	158.07	140.90	116.68	77.16	68.78	55.19
1982	113.32	101.01	88.11	55.67	49.62	42.48
1983	65.70	58.56	53.23	36.93	32.92	30.47
1984	45.41	40.48	32.63	31.97	28.49	24.27
1985	26.01	23.19	20.87	24.25	21.62	20.80
1986	35.49	31.64	28.30	17.09	15.23	14.66
1987	63.93	56.99	47.59	32.52	28.99	25.70
1988	139.55	124.39	100.95	78.81	70.25	60.60
1989	231.48	206.34	148.28	185.19	165.07	134.36
1990	240.30	214.20	116.87	248.57	221.57	173.13
1991	255.73	227.95	140.59	193.45	172.44	134.15
1992	246.92	220.09	147.39	230.38	205.35	162.53
1993	144.40	128.71	90.47	113.54	101.20	80.50
1994	95.02	84.70	64.74	84.88	75.66	65.01
1995	71.65	63.87	50.79	55.12	49.13	43.05
1996	58.64	52.27	46.27	50.71	45.20	41.69
1997	25.13	22.40	18.50	18.74	16.70	16.08
1998	25.35	22.60	18.69	12.13	10.81	10.40
1999	43.87	39.11	36.48	11.57	10.32	9.93
2000	39.24	34.98	33.05	27.56	24.56	23.64
2001	43.65	38.91	36.45	35.82	31.93	30.73
2002	44.53	39.70	36.80	38.58	34.39	33.10
2003	61.29	54.63	50.99	40.79	36.35	34.99
2004	65.48	58.36	55.08	29.76	26.53	25.53
2005	104.50	93.15	86.24	62.83	56.01	52.95
2006	158.95	141.68	126.58	80.19	71.48	66.67
2007	185.19	165.07	150.74	58.49	52.13	48.07
2008	143.06	127.52	108.28	64.80	57.76	50.53

Table 6. Eastern Bering Sea *Chionoecetes bairdi* fishery rate of exploitation on male mature biomass (MMB) and legal mature biomass (LMB) at the time of the fishery, 1965-2007. 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* Fishery
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	0.35	
1977	0.38	
1978	0.45	
1979	0.60	
1980	0.27	0.49
1981	0.13	0.40
1982	0.09	0.27
1983	0.05	0.10
1984	0.16	0.30
1985	0.06	0
1986	0.07	0
1987	0.13	0.15
1988	0.15	0.21
1989	0.24	0.33
1990	0.42	0.39
1991	0.35	0.38
1992	0.29	0.38
1993	0.26	0.34
1994	0.20	0.21
1995	0.17	0.18
1996	0.08	0.08
1997	0.14	0
1998	0.14	0
1999	0.03	0
2000	0.02	0
2001	0.03	0
2002	0.04	0
2003	0.03	0
2004	0.02	0
2005	0.04	0.04
2006	0.07	0.06
2007	0.05	0.04

Table 7. Catch overfishing limits, stock and fishery metrics for the 2008 Eastern Bering Sea *Chionoecetes bairdi* fishery under Scenario-1, where B_{REF}=mean 1975-1980 MMB at the time of mating. (μ on LMB is total legal retained catch/LMB at the time of the fishery, μ on MMB is Total Catch OFL/MMB at the time of the fishery).

2008 Eastern Bering Sea *Chionoecetes baridi*
Catch OFL, Stock and Fishery Metrics

Metrics (10^6lb):	
B_{REF}:	178.155
MMB @ Mating:	107.356
B/B_{REF}:	0.603
F_{OFL}:	0.128
Catch Components (10^6lb):	
Total Male Catch OFL:	15.371
Directed Discard Losses MMB:	7.744
Non-Directed Discard Losses MMB:	2.916
Projected Catch OFL:	5.420
Directed Discard Losses LMB:	0.102
Non-Directed Discard Losses LMB:	0.606
Retained Part of Catch OFL:	4.711
Directed Discard Losses ♀:	0.367
Groundfish Bycatch Losses ♀:	0.732
Total Catch OFL:	16.470
Rates:	
μ on LMB @ Fishery:	0.094
μ on MMB @ Fishery:	0.121

B_{REF}=mean 1975-80 MMB @ mating as proxy for B_{MSY}.

Table 8. Catch overfishing limits, stock and fishery metrics for the 2008 Eastern Bering Sea *Chionoecetes bairdi* fishery under Scenario-2, where B_{REF}=mean 1969-1980 MMB at the time of mating.. (μ on LMB is total legal retained catch/LMB at the time of the fishery, μ on MMB is Total Catch OFL/MMB at the time of the fishery).

2008 Eastern Bering Sea *Chionoecetes baridi*
Catch OFL, Stock and Fishery Metrics

Metrics (10^6lb):	
B_{REF}:	189.764
MMB @ Mating:	108.277
B/B_{REF}:	0.571
F_{OFL}:	0.120
Catch Components (10^6lb):	
Total Male Catch OFL:	14.450
Directed Discard Losses MMB:	7.171
Non-Directed Discard Losses MMB:	2.916
Projected Catch OFL:	5.065
Directed Discard Losses LMB:	0.102
Non-Directed Discard Losses LMB:	0.606
Retained Part of Catch OFL:	4.363
Directed Discard Losses ♀:	0.340
Groundfish Bycatch Losses ♀:	0.732
Total Catch Catch:	15.521
Rates:	
μ on LMB @ Fishery:	0.088
μ on MMB @ Fishery:	0.113

B_{REF}=mean 1969-80 MMB @ mating as proxy for B_{MSY}.

Table 9. Catch overfishing limits, stock and fishery metrics for the 2008 Eastern Bering Sea *Chionoecetes bairdi* fishery under Scenario-3, where B_{REF}=mean 1969-2007 MMB at the time of mating.. (μ on LMB is total legal retained catch/LMB at the time of the fishery, μ on MMB is Total Catch OFL/MMB at the time of the fishery).

2008 Eastern Bering Sea *Chionoecetes baridi*
Catch OFL, Stock and Fishery Metrics

Metrics (10^6lb):	
B_{REF}:	103.811
MMB @ Mating:	97.988
B/B_{REF}:	0.944
F_{OFL}:	0.216
Catch Components (10^6lb):	
Total Male Catch OFL:	24.739
Directed Discard Losses MMB:	13.568
Non-Directed Discard Losses MMB:	2.916
Projected Catch OFL:	9.032
Directed Discard Losses LMB:	0.102
Non-Directed Discard Losses LMB:	0.606
Retained Part of Catch OFL:	8.255
Directed Discard Losses ♀:	0.643
Groundfish Bycatch Losses ♀:	0.732
Total Catch OFL:	26.114
Rates:	
μ on LMB @ Fishery:	0.156
μ on MMB @ Fishery:	0.194

B_{REF}=mean 1969-2007 MMB @ mating as proxy for B_{MSY}.

Table 10. Total pot lift contents for 160 pot lifts sampled during the 2005/2006 (160 pot lifts) 2006/2007 (141 pot lifts) Bering Sea Tanner crab fisheries (Barnard and Burt 2007, 2008). A total of 29,693 and 49,192 pots were lifted during the 2005/2006 and 2006/2007 fisheries respectively (Bowers et al. 2008).

Species	Total Catch 2005/06	Total Catch 2006/07	Species	Total Catch 2005/06	Total Catch 2006/07
Tanner crab			Yellowfin sole	270	123
Legal male	6,612	12,130	Sea star (unidentified)	156	317
Sublegal male	18,578	20,222	Sculpin (inidentified)	132	60
Female	2,838	10,768	Snail (unidentified)	129	23
			Pribilof Neptune	62	0
Snow crab			Pacific cod	55	31
Legal male	2,726	889	Hermit crab (unidentified)	27	3
Sublegal male	258	13	Lyre crab	18	23
Female	16	0	Yellow Irish lord	16	96
			Jellyfish (unidentified)	10	0
Red King crab			Sea urchin (unidentified)	8	0
Legal male	0	3	Brittle star (unidentified)	7	5
Sublegal male	29	1	Pacific Halibut	5	1
Female	137	9	Arrowtooth flounder	2	0
			Bryozoan (unidentified)	1	0
Tanner x snow crab hybrid			Flatfish (unidentified)	1	0
Legal male	107	2	Prowfish	1	0
Sublegal male	50	94	Rock sole (unidentified)	1	2
Female	2	3	Sea cucumber	1	2
			Flathead sole	0	2
Blue King crab			Hydroid (unidentified)	0	2
Legal male	8	0	Decorator crab	0	1
Sublegal male	112	0	Snailfish (unidentified)	0	1
Female	0	1			

Table 11. Ecosystem effects on the eastern Bering Sea Tanner crab stocks and fishery effects on the ecosystem.

Ecosystem effects on Bering Sea Tanner crab stocks			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Plankton	During May spring bloom occurs during a seasonal thermocline along the north Aleutian Shelf in ice-free waters.	Promotes phytoplankton and *Pseudocalnus* production.	Concern
Predator population trends			
Fish predators (Pacific cod, arrwowtooth flounder, Pollock, sculpins)	Increase in Pacific cod, arrowtooth flounder, pollock, and juvenile sockeye salmon	Pacific cod predators of juvenile and adult Tanner crab. Juvenile sockeye feed on larval Tanner crab. Predation by planktivorous fishes may be significant in some years and seasons, but their overall effect on recruitment is unknown. Bottom temperatures during crab gonadal development and egg incubation may be more important.	Concern
Disease			
Britter crab syndrome		Prevalences in legal crabs low. More prevalent in smaller crab < 50 mm CW. Could affect recruitment.	Concern affecting recruitment and potential impact if it becomes epidemic.
Black mat syndrome	No prevalence in EBS for 20 years		No concern
Changes in Habitat Quality			

Temperature regime	Seasonal ice effects spring bloom. Early ice retreat then late bloom and more zooplankton, favors pelagic production and crab abundance goes down. Late ice retreat then early bloom and less zooplankton, favors benthic production and crab abundance goes up. Zooplankton biomass is declining.	Effect larval release, hatch timing, food availability for larvae, larval survival, recruitment success, and year class strength. Change in trophic structure and predator prey populations. Increase in predators- Pollock, cod, juvenile sockeye salmon, and arrowtooth flounder. Decreased crab abundance.	Concern
Ocean Acidification	Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects.	Lab studies have shown a ~15% reduction in growth and ~67% reduction in survival when pH was reduced 0.5 units. Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival. Decalcification of calcifying plankton.	Concern
Winter-spring environmental conditions	Affects pre-recruit survival	Recruitment success correlated with strength of NE winds during May-June which promote retention and larval settlement in favorable mud-sand mid-shelf regions of EBS.	Causes natural variability. Concern.
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability and recruitment in year class strength	Concern

Fishery effects on the eastern Bering Sea ecosystem			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibitive species (blue king crab, pacific halibut)	Stable, heavily monitored. Sublegal male Tanner have a high rate of bycatch.	Minor contribution to mortality. Use of degradable mesh and rings, Tanner boards and observers.	Concern

Forage (Pacific cod, sculpin, yellowfin sole)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Most HAPC biota are not concentrated in areas of fishery.	Low impact from pots.	No concern
ESA and non-ESA marine mammals and birds		Crab fisheries do not adversely affect listed species or destroy or modify their habitat	No concern
Sensitive non-target species	Likely minor impact	Minor contribution to mortality	No concern
Fishery concentration in space and time			
Fishery effects on amount of large size target crab	Fishery targets legal size males only.	Some concern of reduction of sex ratio and mean size of male crab in a fishery that targets legal-size males and high bycatch of sublegal males. Other sources of bycatch.	Concern
Fishery contribution to discards and offal production			
Fishery effects on age-at-maturity and fecundity	Fishery targets legal size males only.	Little bycatch of females. Some concern for overharvesting legal males and high bycatch of sublegal males. Other sources of bycatch.	Concern

Table 12. Data used to estimate discard and bycatch losses projected in the terminal 2008/09 Bairdi OFL fishery: (a) 2007/08 Tanner crab fishery performance, (b) 2006/07 and 2007/08 Tanner crab discards in the EBS pot fisheries and snow crab retained catch, and (c) 2003-07 EBS groundfish trawl fishery Tanner crab bycatch.

(a)

2007/08 Observer Fishery Data
EBS Tanner Crab Directed Fishery

		LB	Ratio
Discard"			
	S.Legal ♂:	6,842,396	3.24799
	Legal ♂:	82,896	0.03935
	All ♀:	328,283	0.15583
Retained:		2,106,655	1.0
	Total:	9,360,230	

(b)

Tanner Crab Non-Directed Pot Fishery Bycatch
(Combined Opilio + RKC Pot Fisheries)

Year	Opilio Retained (10^6 LB)	Bairdi Discard (10^6 LB)	Ratio
2006/07	37.00	3.19	0.086103
2007/08	63.03	3.89	0.061657
2008/09	49.00 *		
		Average:	0.073880
Projected 2008/09 Bairdi Discard (10^6 LB):			3.620116

* Projected 2008/09 Opilio retained catch OFL

(c)

Trawl Fishery Tanner Crab Bycatch
(Male + Female Combined)

Year		Bycatch (10^6 LB)
2003		2.7151
2004		1.9751
2005		2.1226
2006		3.4113
2007		1.2594
	Average:	2.2967

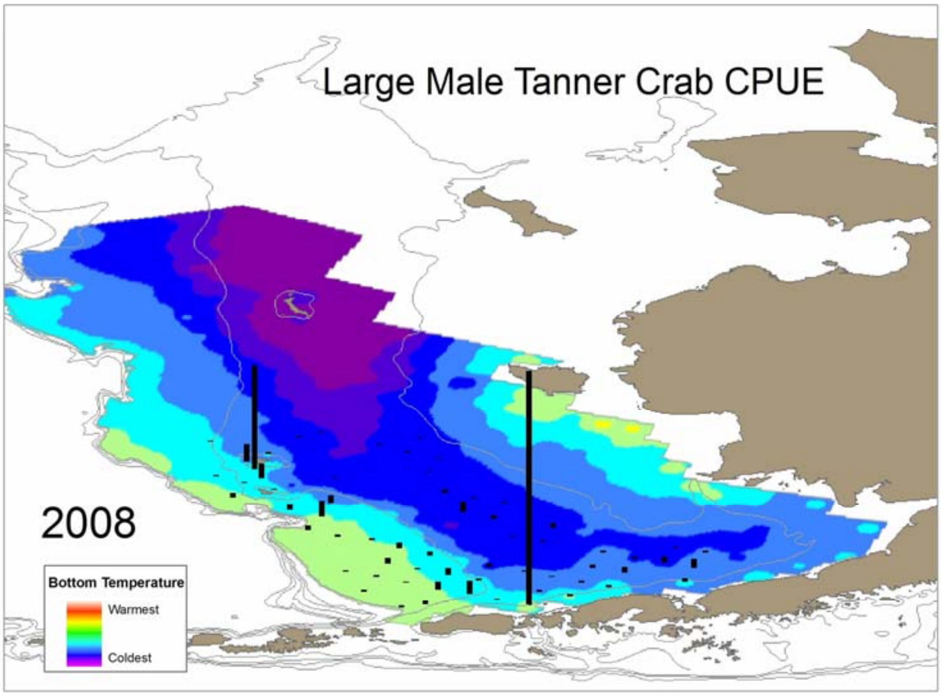
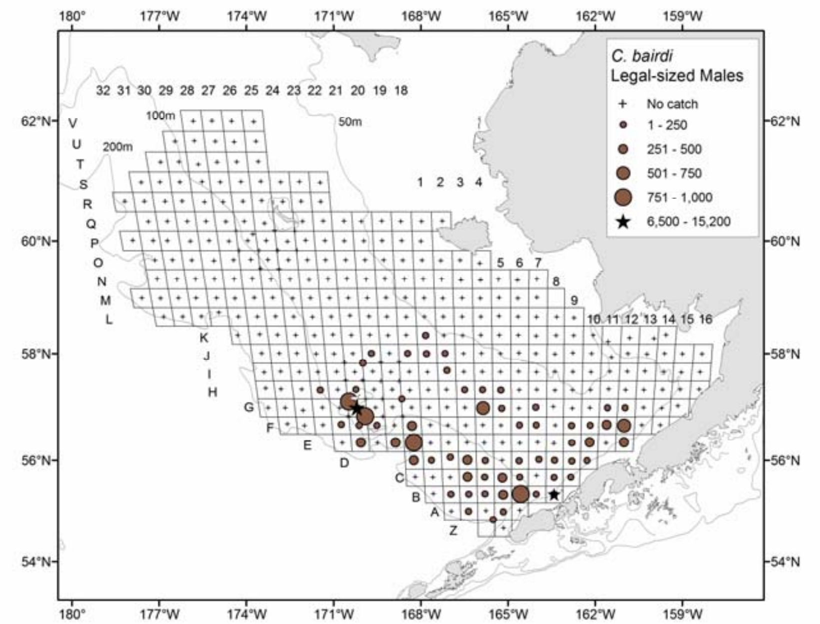


Figure 1. Distribution and abundance of large male Tanner crab with bottom temperature from the summer 2008 NMFS EBS trawl survey.



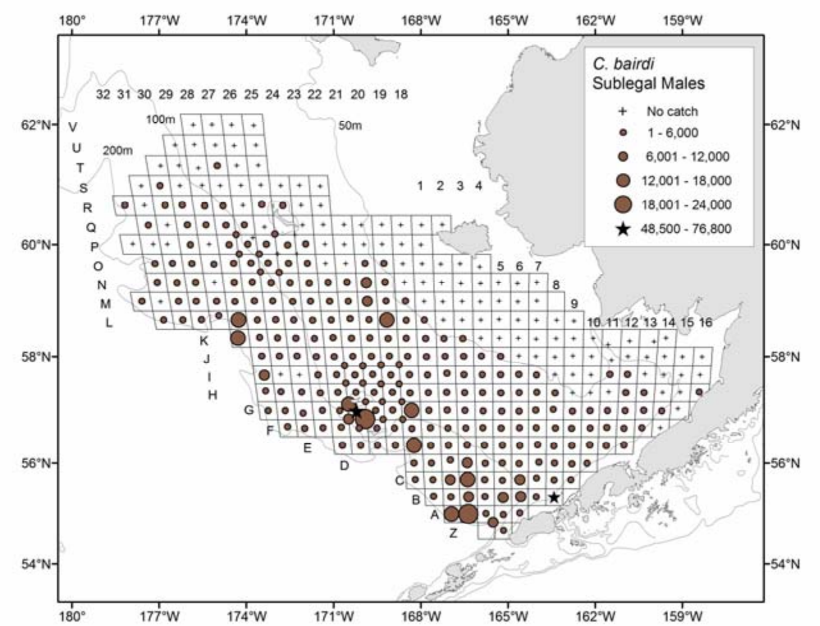


Figure 2. Distribution and abundance of legal (>= 138 mm cw) and sublegal (< 138 mm cw) male Tanner crab in the summer 2008 NMFS EBS trawl survey.

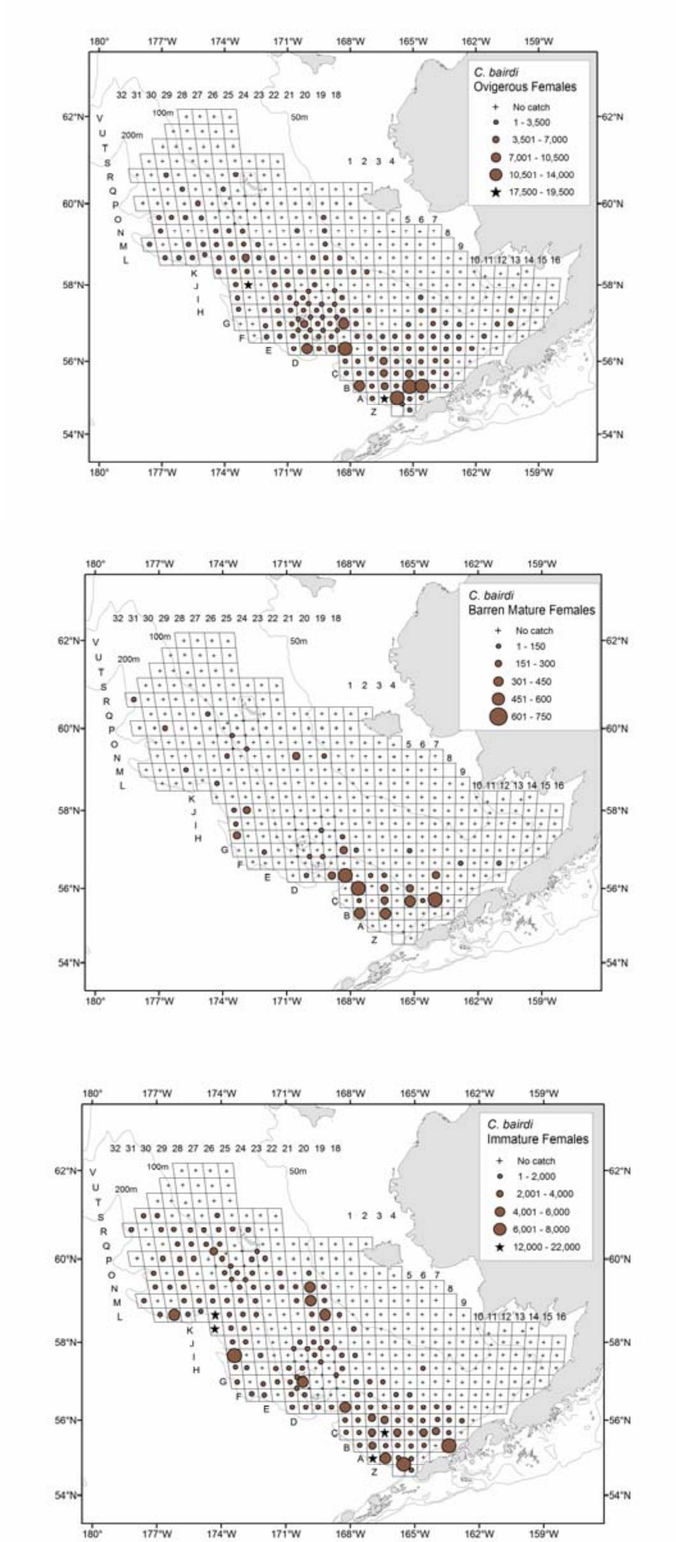


Figure 3. Distribution and abundance of ovigerous, barren mature, and immature female Tanner crab in the summer 2008 NMFS EBS trawl survey.

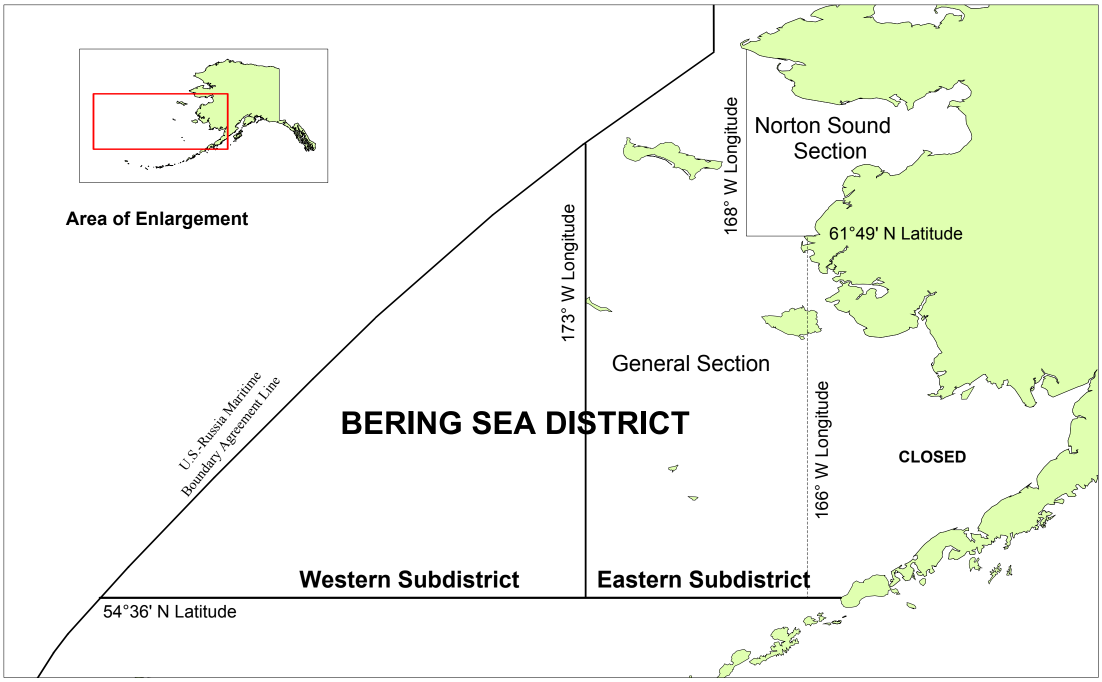
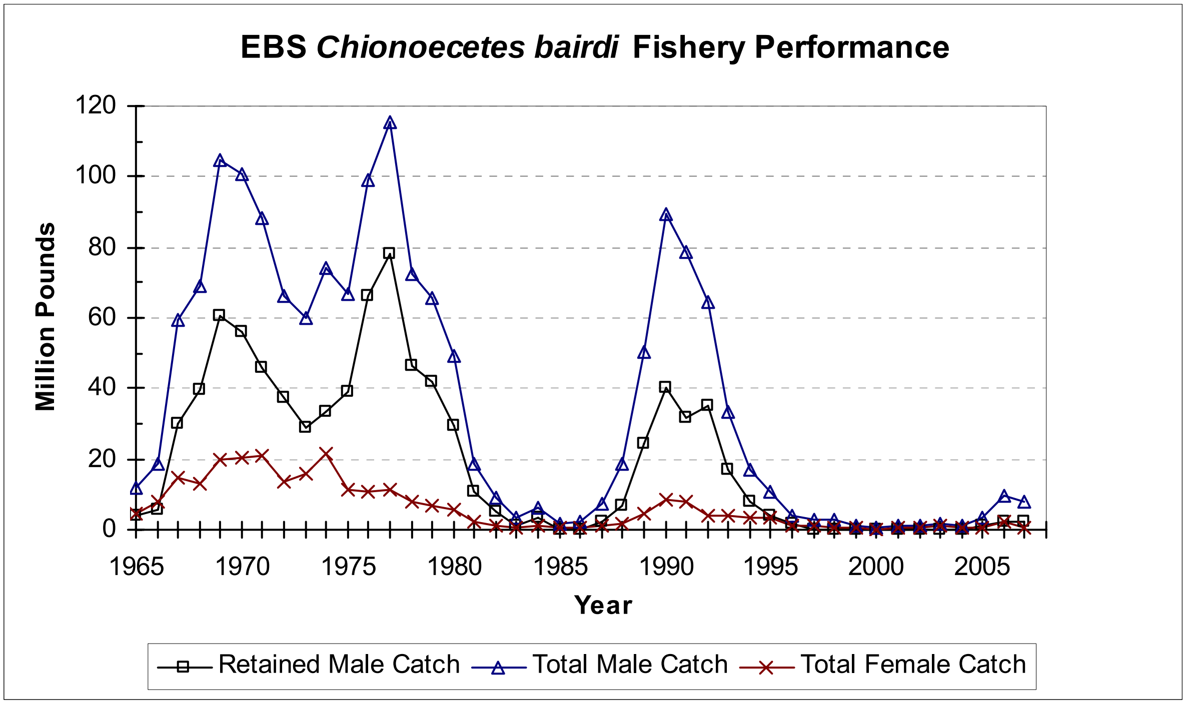


Figure 4. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)



(b)

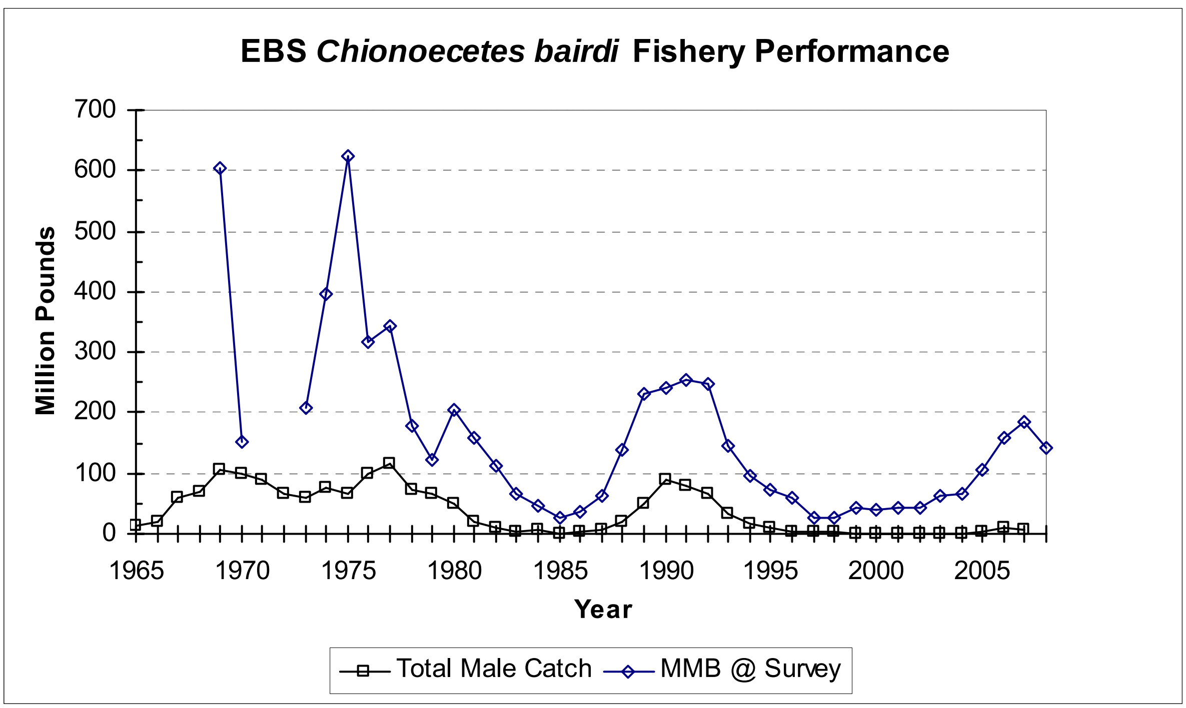


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch, total (retained + discard/bycatch) male catch and total female catch (a), and total male catch vs male mature biomass at the time of the survey (b), 1965-2008.

(a)

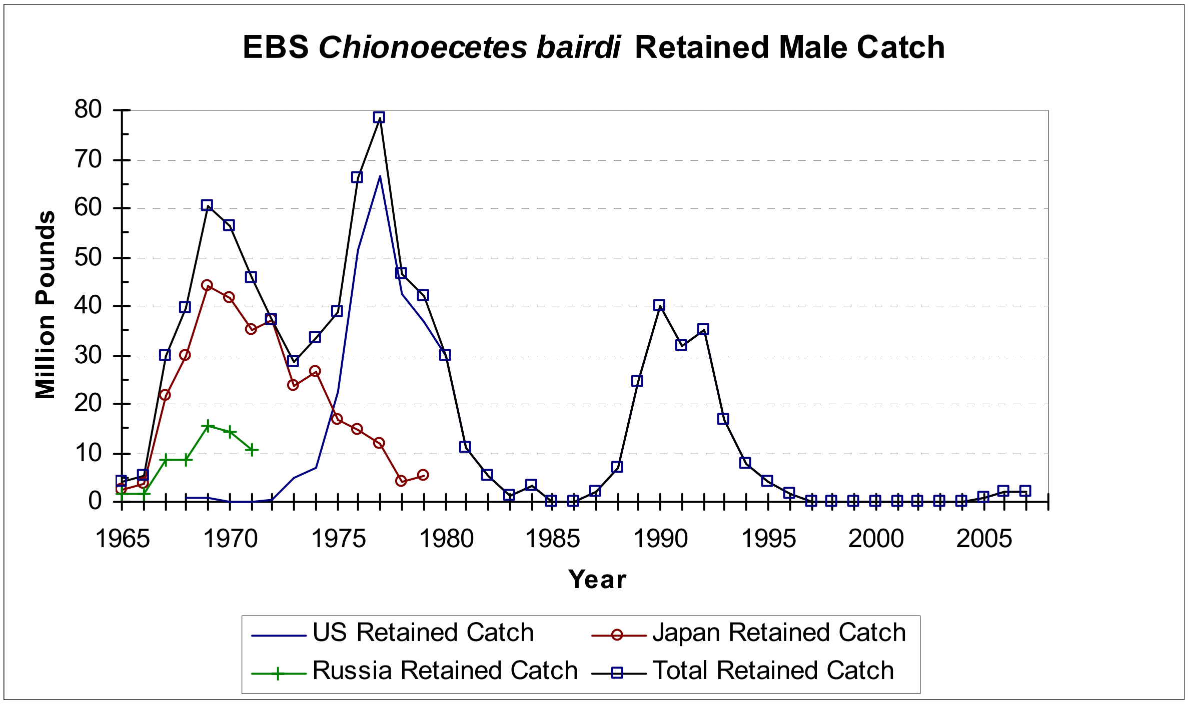


Figure 6. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965-2007.

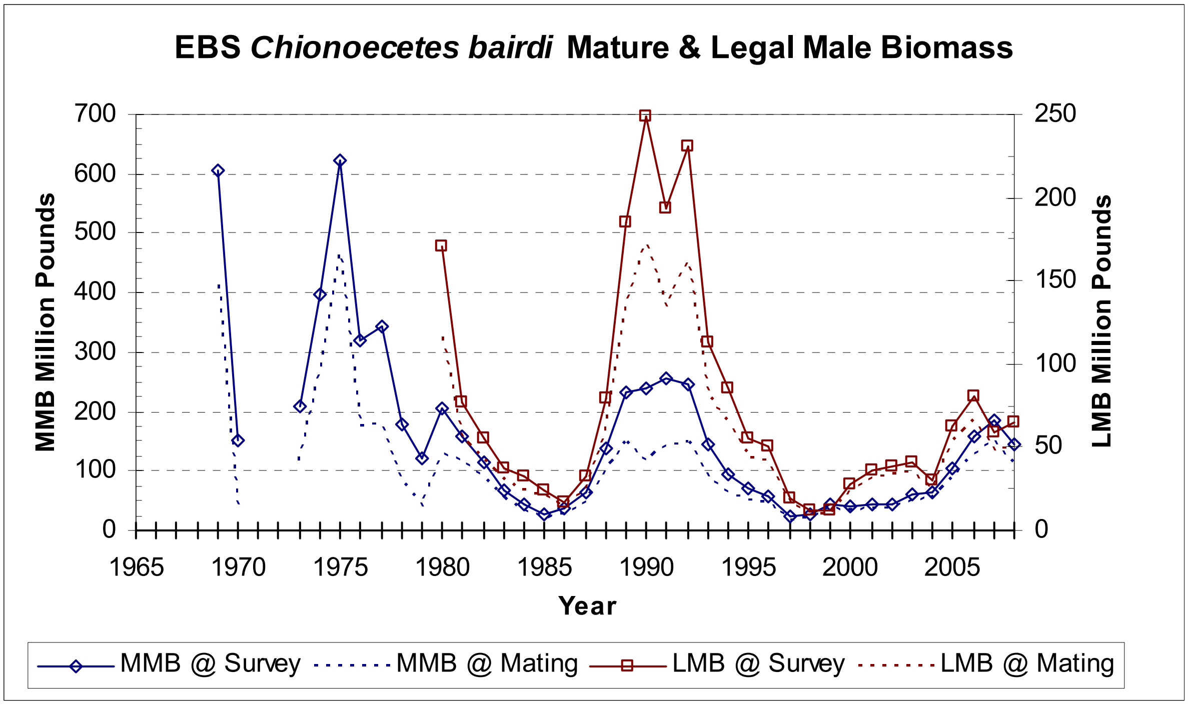
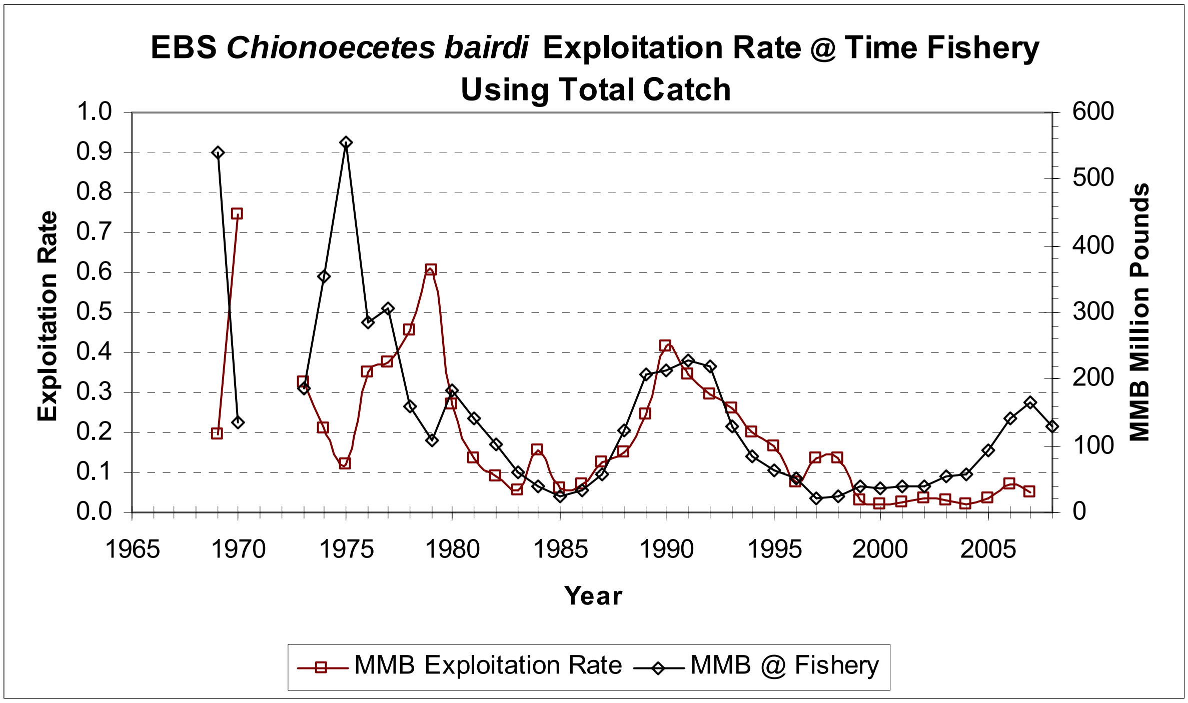


Figure 7. Eastern Bering Sea *Chionoecetes bairdi* mature and legal male biomass at time of the survey and subsequent mating, 1965-2008. (Note: 2008 MMB and LMB at time of mating are estimates based on extraction of respective 2008 catch OFLs).

(a)



(b)

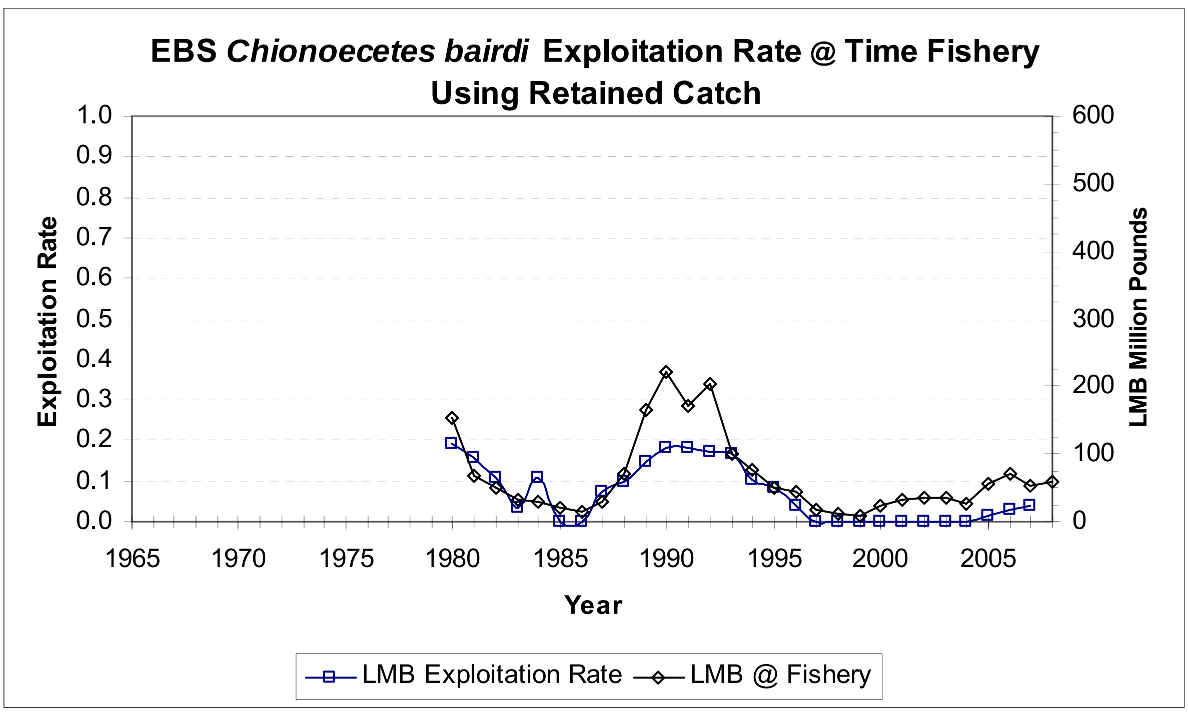


Figure 8. Eastern Bering Sea *Chionoecetes bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1965-2008.

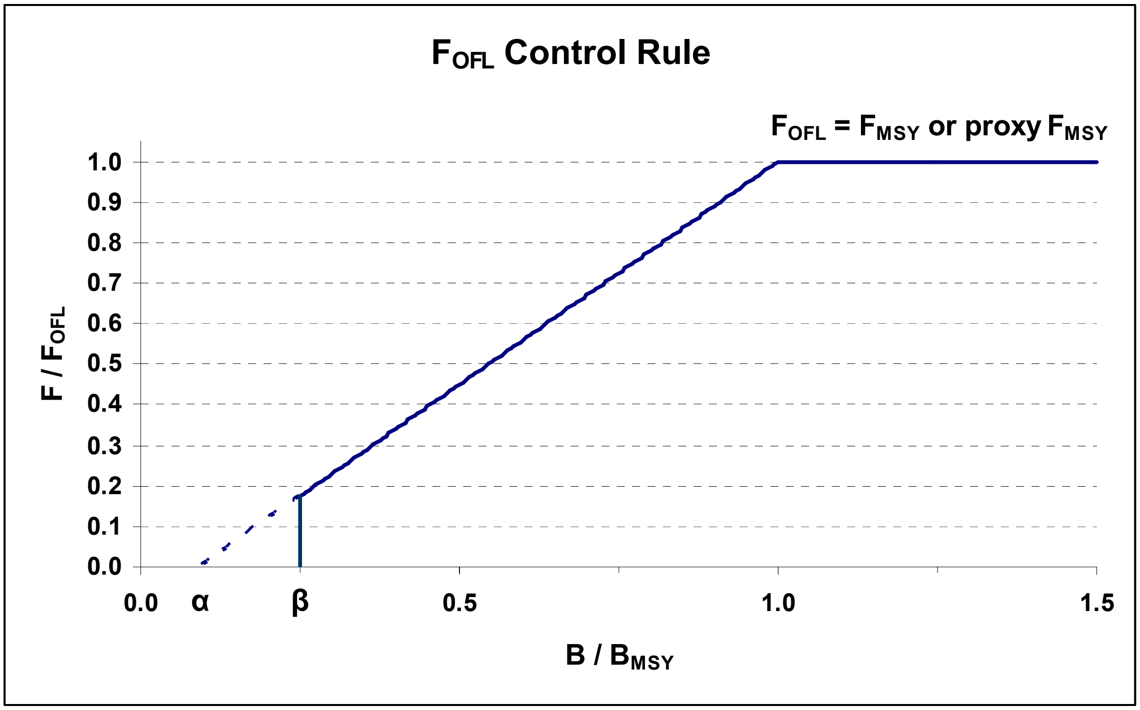


Figure 9. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

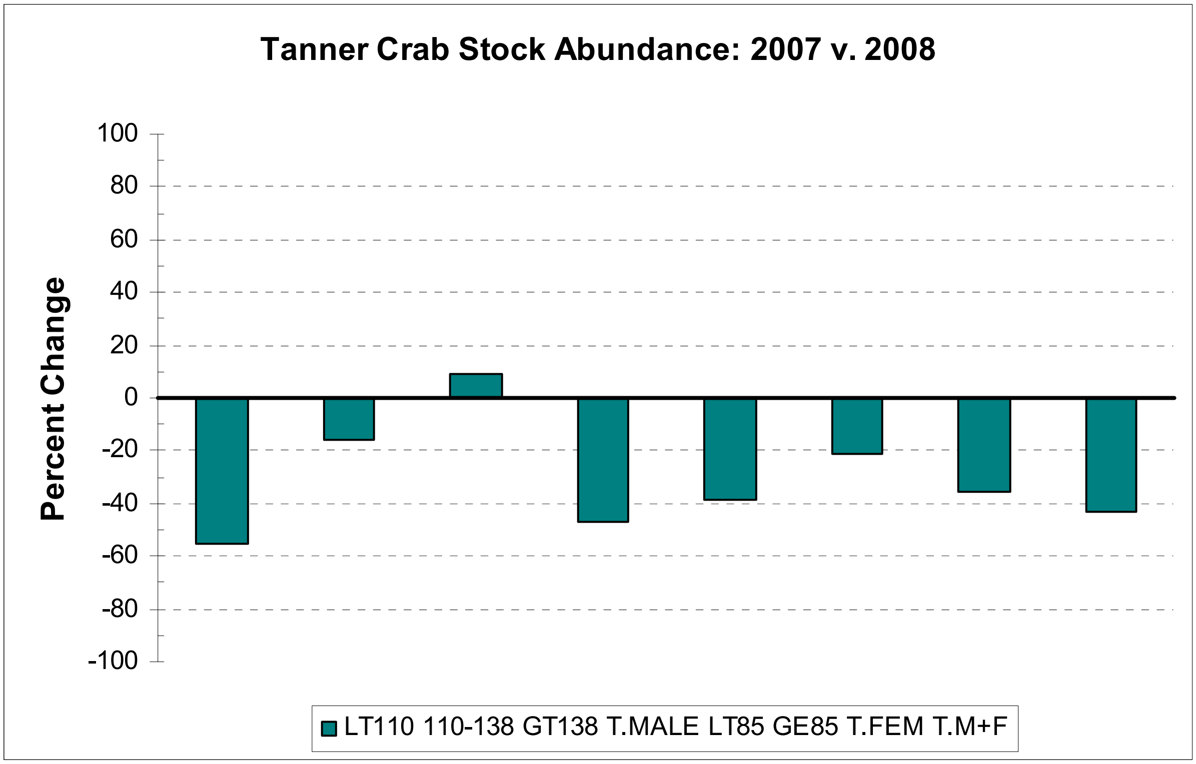


Figure 10. Percent change in Tanner crab stock abundance between 2007 and 2008 for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.

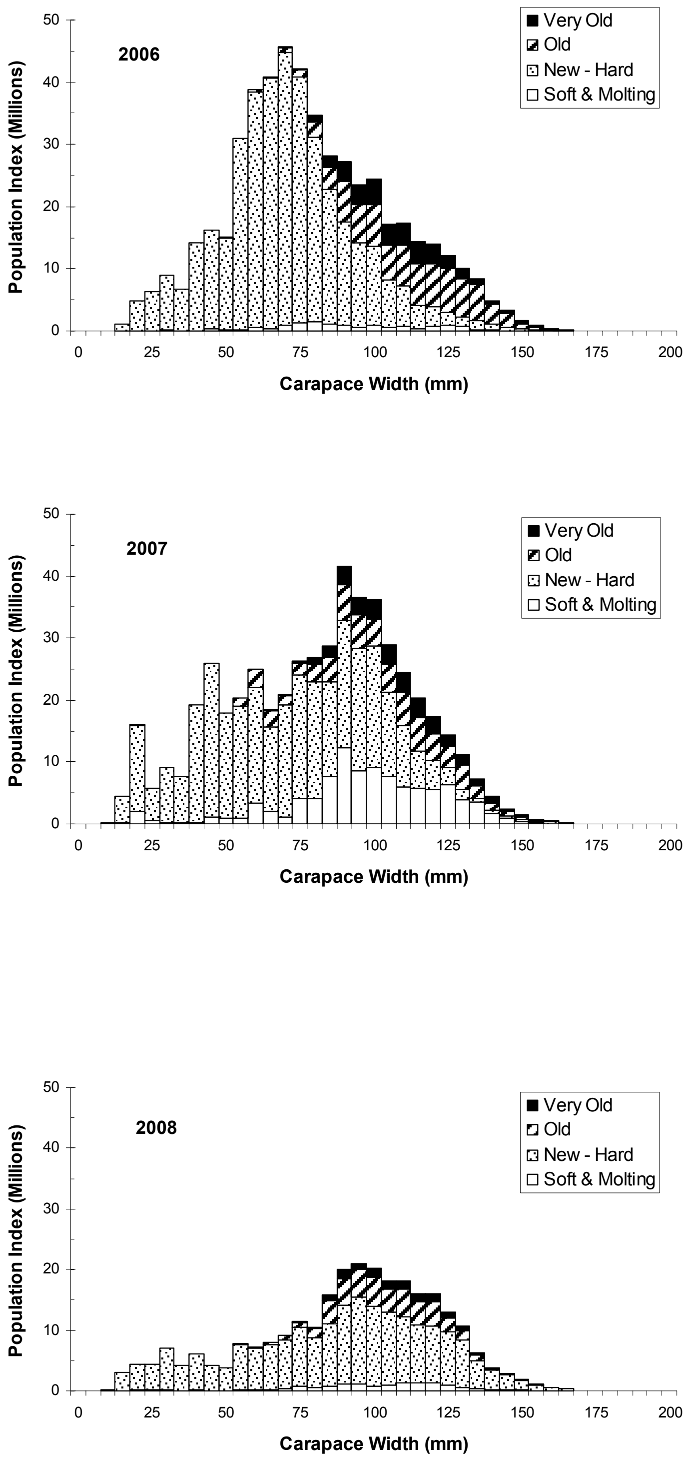


Figure 11. Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2008.

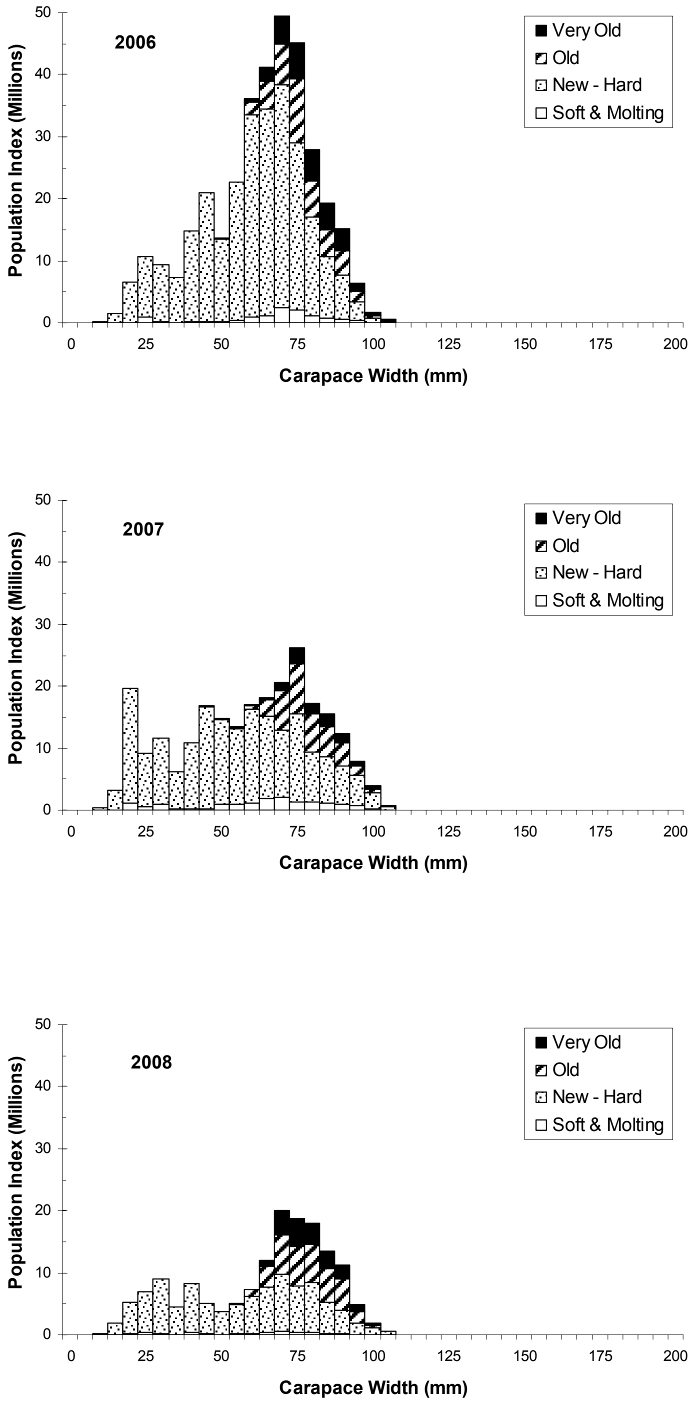


Figure 12. Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2008.

Appendix A. Estimation of eastern Bering Sea Tanner crab OFL using $F_{35\%}$ and estimated fishery selectivities.

The calculation of the OFL in this appendix follows the SSC recommended method from their June 2008 meeting. The SSC recommended using fishery selectivities, which at the time were taken from the EA on OFL definitions (Figure A-5), due to the lack of recent data on fishery selectivities. The F_{MSY} proxy was recommended as $F_{35\%} / M$ which was estimated as 2.1·M from the analysis presented in June 2008. The same method is used here, except that new fishery selectivity curves are estimated from the most recent year of fishery data and $F_{35\%}$ is calculated given the new selectivity curves. The F_{MSY} proxy for the control rule is,

F_{MSY} proxy = γ M

Gamma = $F_{35\%} / M$

Therefore,

F_{MSY} proxy = $(F_{35\%} / M) \cdot M = F_{35\%}$

So the use of $F_{35\%}$ as the F_{MSY} proxy in the control rule is equivalent to using γ, where γ is estimated as $F_{35\%} / M$. This value of $F_{35\%}$ is used with the estimated fishery selectivities as recommended by the SSC to estimate the OFL. Thus, γ is specific to the $F_{35\%}$ used in the ratio $F_{35\%} / M$, and it cannot be used without those fishery selectivities, for example in a simple multiplication on M and mature male biomass to estimate the total catch OFL.

The observer data from the 2006/7 and the 2007/8 fishery seasons were not available for analysis in June 2008 so the fishery selectivities used in the EA analysis for new OFL definitions were used in the June 2008 SSC presentation. However, the last two years of fishery data indicate a change in selectivity and an increase in the discarding in the directed Tanner crab fishery. Discard and retained selectivities were estimated using the length frequency of the observed catch from the 2007/8 season as well as the ratio of discarded to retained numbers of crab (Figure A-1 and Table A-2) and the predicted catch length frequency and numbers (discard and retained) using the 2007 survey abundance by length projected forward to the time of the fishery. The discard fishery selectivities were used along with trawl selectivities to estimate bycatch in the snow crab and trawl fisheries (Figure A-2). $F_{35\%}$ was then determined base on the estimated fishery selectivities and the OFL calculated. Two fishery selectivity scenarios were estimated, one with retained selectivity at 1.0 for the 140-145 mm length bin and then dropping to 0.5 for larger sizes (Figure A-1 and Table A-2), and scenario 2 were retained selectivity was 1.0 for all crab > 140mm (Figure A-4 and Table A-2). The scenario with retained selectivity at 1.0 for all crab larger than 140mm did not fit the length frequency of the catch as well and also did not fit the ratio of discard to retained numbers as well as the scenario with retained selectivity at 0.5 at > 145mm (Figures A-3 and A-5).

The discard fishery selectivities were estimated differently for each scenario to fit the total length frequency and the ratio of retained and discarded numbers in the 2007/8 fishery using the 2007 survey length frequency projected forward. The current Tanner crab fishery may not be targeting specifically on Tanner crab, which results in the drop in selectivity at larger sizes fitting the fishery data better than selectivity of 1.0 at larger sizes.

The 2008 survey abundance by length was projected forward to estimate catch and MMB using $F_{35\%}$ and the estimated fishery selectivities (Table A-1). The total catch OFL for scenario 1 (0.5 selectivity size>145mm) was 16.1 million pounds with a retained directed fishery catch of 5.27 million pounds. The total catch OFL for scenario 2 (1.0 selectivity size>140mm) was 15.67 million pounds with a retained directed fishery catch of 5.21 million pounds. The total catch OFL with F=M was 15.37 million pounds with a retained directed fishery catch of 4.71 million pounds.

Table A-1. Total male catch OFL (million pounds) using $F_{35\%}$ and 2008 survey numbers by length and mature biomass at mating. Ratio of numbers of discard to retained was 4.09 in the 2007/8 fishery. Scenario 1 ratio in the fitting was 4.37, for the selectivity = 1.0 ratio was 5.05.

	Scenario 1	Scenario 2
	Retained sel >145mm = 0.5	Retained sel >140 mm = 1.0
Directed Legal Catch	5.62	5.57
Retained Directed Legal Catch	5.27	5.21
Directed Discard	7.13	6.75
Non-Directed Discard (snow crab + groundfish trawl)	3.35	3.36
Total Male Catch OFL	16.10	15.67
MMB	106.03	106.47
B_{REF}	178.2	178.2
MMB/ B_{REF} (%)	59.49	59.75
Directed $F_{35\%}$	0.585	0.411
Directed Control Rule F 2008/9	0.322	0.227
F Snow Crab Fishery	0.105	0.09

Table A-2. Estimated retained and discard selectivity. Discard selectivity estimated as a logistic function with slope 0.17 and size at 50% selected 120 mm from 95 mm to 135 mm. Value at 135-140 mm fixed at 0.5, and discard selectivity 0 after 140 mm. Values of retained selectivity set at 1 and 140-145 mm other values (0.5) estimated to fit the length frequency of the catch and the split in catch between retained and discarded.

	Scenario 1		Scenario 2	
CW (mm)	Retained sel	Discard sel	Retained sel	Discard sel
97.5	0	0.014064	0	0.032295
102.5	0	0.032295	0	0.072426
107.5	0	0.072426	0	0.154465
112.5	0	0.154465	0	0.299433
117.5	0	0.299433	0	0.5
122.5	0	0.5	0	0.700567
127.5	0	0.700567	0	0.845535
132.5	0	0.845535	0	1
137.5	0.5	0.5	0.5	0.5
142.5	1	0	1	0
147.5	0.5	0	1	0
152.5	0.5	0	1	0
157.5	0.5	0	1	0
162.5	0.5	0	1	0
167.5	0.5	0	1	0
172.5	0.5	0	1	0
177.5	0.5	0	1	0

Table A-3. Fishery selectivities for discard and retained males by shell condition used in the EA analysis.

	Discard		Retained	
CW (mm)	New	Old	New	Old
97.5	0.097	0.053	0	0
102.5	0.098	0.053	0	0
107.5	0.158	0.055	0	0
112.5	0.302	0.096	0	0
117.5	0.327	0.121	0	0
122.5	0.482	0.124	0	0
127.5	0.701	0.138	0	0
132.5	0.955	0.2	0	0
137.5	0.5	0.16	0.5	0.16
142.5	0	0	1	0.317
147.5	0	0	1	0.317
152.5	0	0	1	0.317
157.5	0	0	1	0.317
162.5	0	0	1	0.317
167.5	0	0	1	0.317

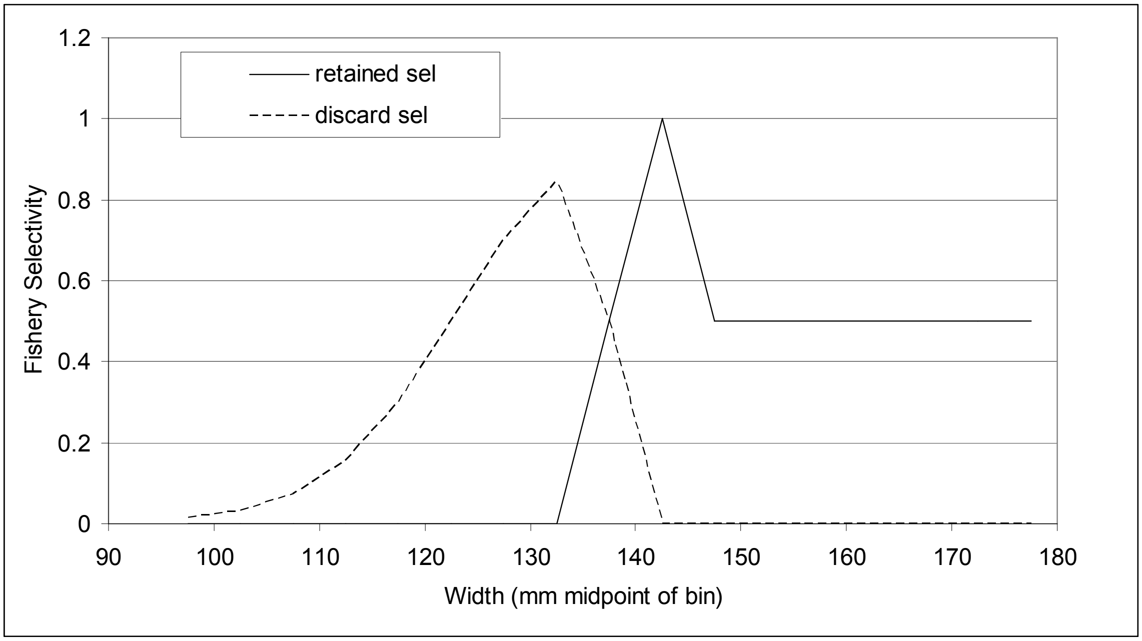


Figure A-1. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery (before discard mortality is applied).

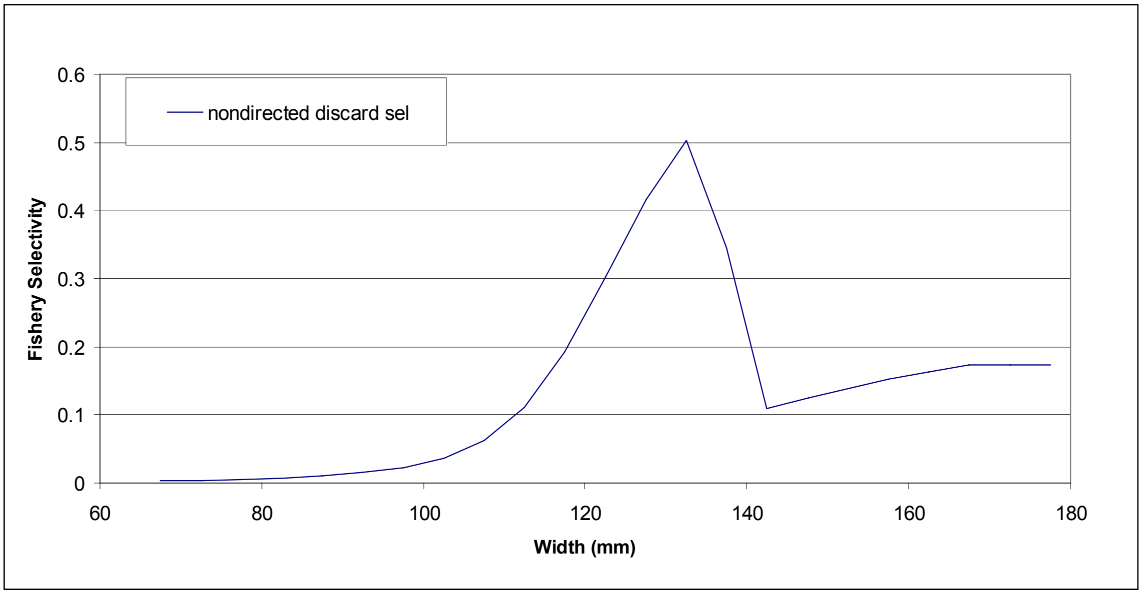


Figure A-2. Non-directed discard fishery selectivities with 50% mortality in the snow crab fishery and 80% mortality from trawl fisheries. The directed Tanner crab discard selectivity was used for snow crab fishery discards. Selectivity for the trawl discard is from the EA on overfishing analysis.

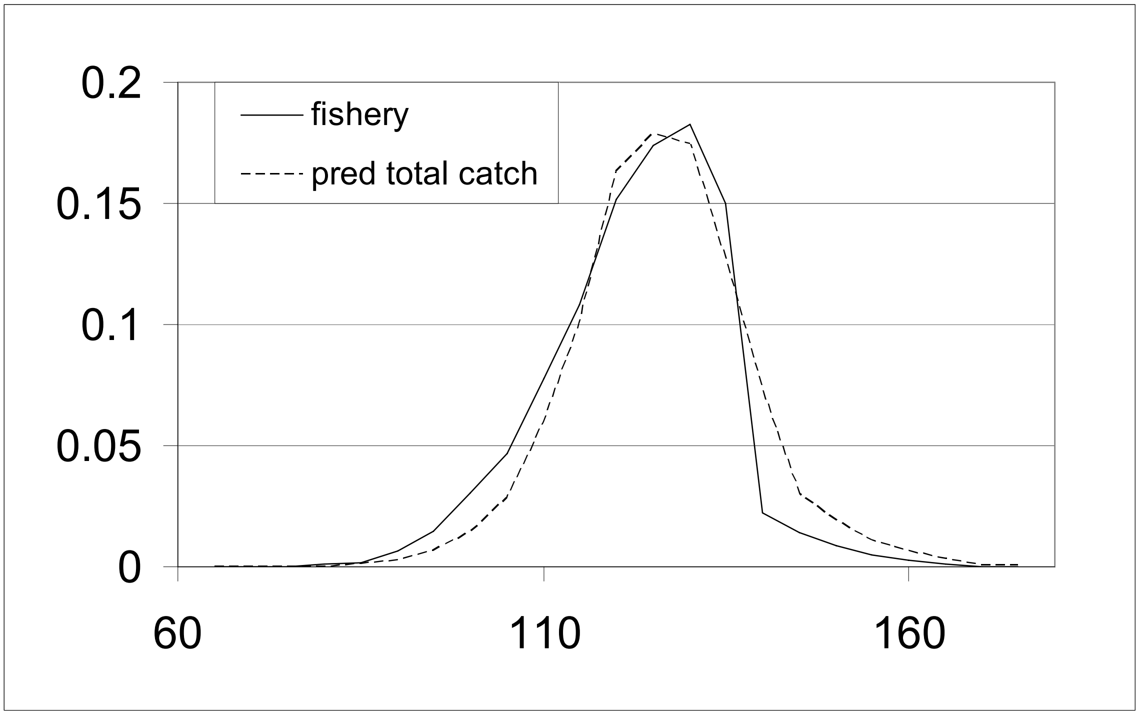


Figure A-3. Length frequency of total directed Tanner fishery catch (fishery) and predicted total directed Tanner fishery catch with estimated discard and retained fishery selectivities (Figure 1) using the 2007 survey data and 2007/8 fishery observer data.

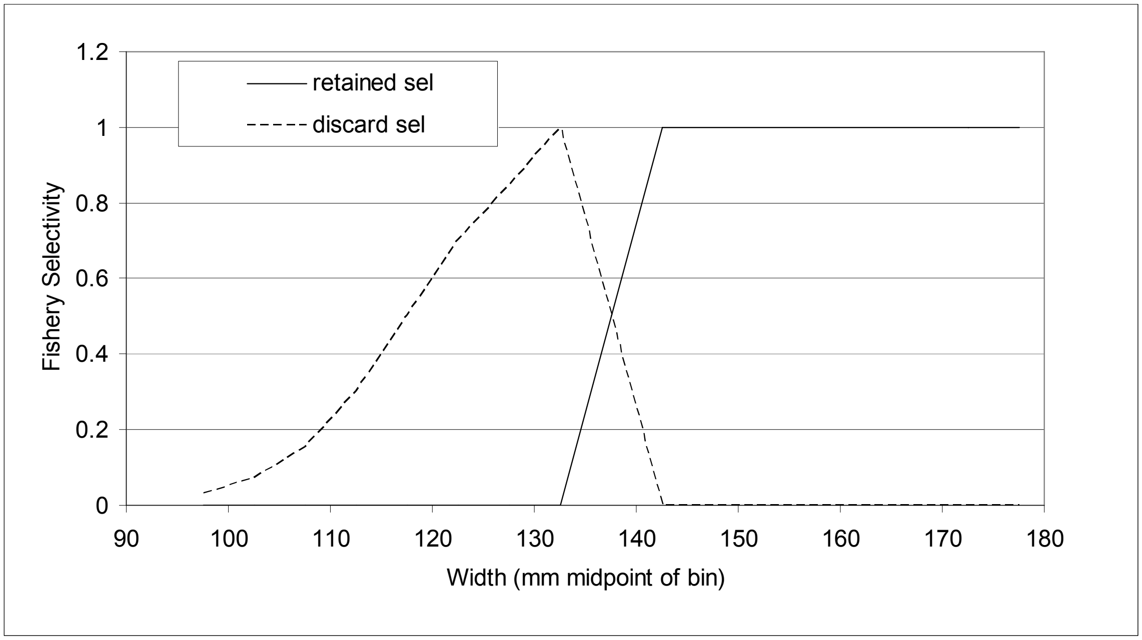


Figure A-4. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery (before discard mortality is applied), with retained selectivity of crab >140mm fixed at 1.0.

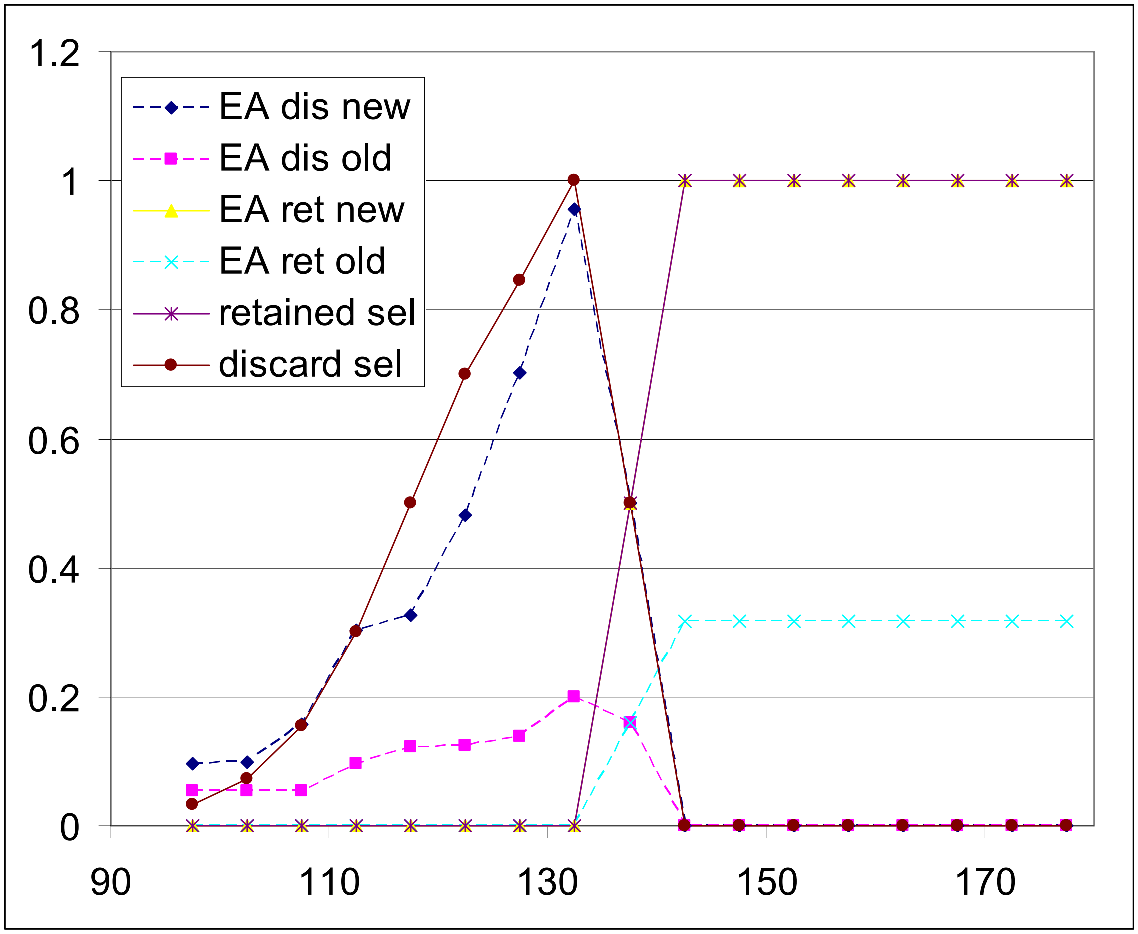


Figure A-5. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery (shell condition combined, before discard mortality is applied). Selectivities on discard and retained split by new and old shell from the EA analysis.

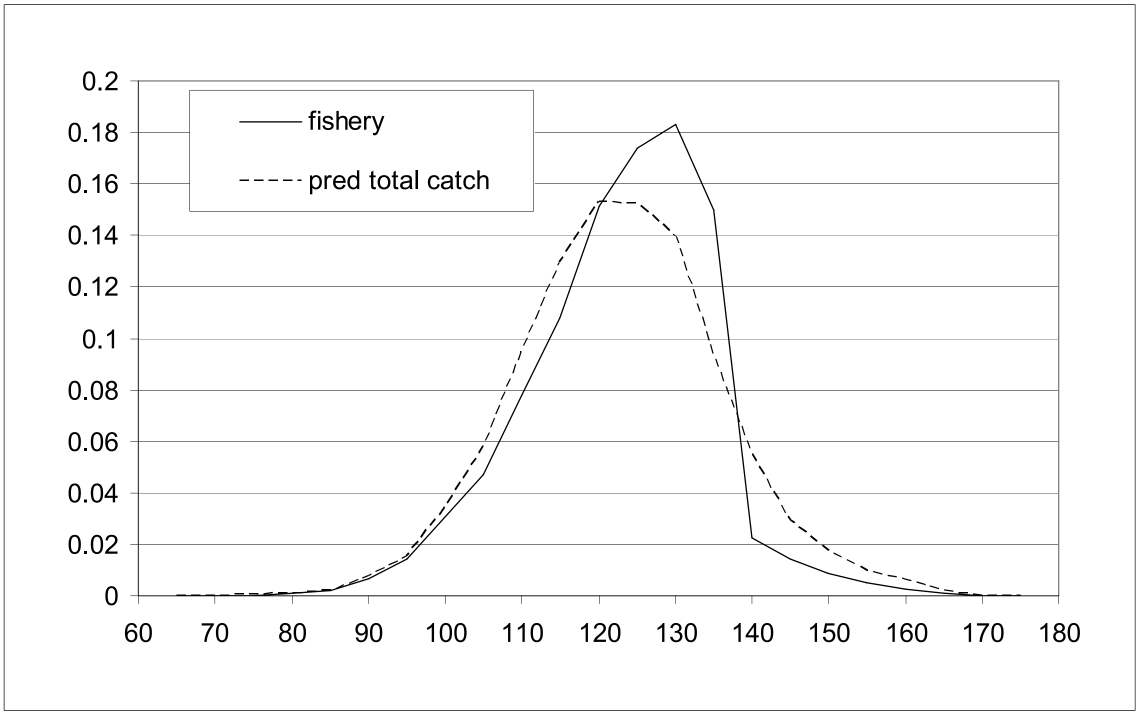


Figure A-6. Fit to total catch length frequency using retained selectivity at 1.0.

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

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Executive Summary

Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*

Summary of Major Changes:

- Additional alternative B_{MSY}^{prox} years were used to incorporate the entire survey data set.
- The calculations for reference points and estimations of catch were explicitly detailed.

Responses to SSC Comments:

- The June 2008 SSC requested that the entire time series of biomass estimates be used starting in 1980. The 1980 to 2007 time series was added to the assessment to estimate B_{MSY}^{prox}.
- The June 2008 SSC recommended development of the catch-survey analysis model for next years assessment to obtain more stable abundance estimate. This will be assessed before May 2009.
- The June 2008 SSC recommended development of analyses for choice of gamma. This will be assessed before May 2009.
- The June 2008 SSC recommended expanded ecosystem sections to include prey and predator interactions. This will be assessed before May 2009.

Summary

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

Year	Total Catch OFL	Biomass (MMB_{mating})	TAC	Retained Catch	Total catch
2005/06	na	2.59	0	0	0.064
2006/07	na	13.87	0	0	0.024
2007/08	na	14.70	0	0	0.008
2008/09	3.32	9.26*			

*projected

Tier	4
Stock Status Level	a
F_{OFL}	0.18
B_{MSY}^{proxy}	8.66 million lbs of MMB_{mating}
Years	1991 to 2007
2008/2009 projected MMB_{mating}	9.26 million lbs
2008/2009 projected MMB_{mating}/MMB_{MSY}	1.07
Gamma	1
M	0.18
2008/2009 total catch OFL	3.32 million lbs

Introduction

Red king crabs, *Paralithodes camtschaticus* (Tilesius, 1815) are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995). 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 1).

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 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 will be 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 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).

Fishery

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 2). A red king crab fishery in the Pribilof District opened for the first time in September 1993 following an increase in the abundance of red king crabs observed around the Pribilof Islands during the 1993 NMFS summer crab and groundfish trawl survey. For the 1993 fishery a Guideline Harvest Level (GHL) of 3.4 million lbs was set and 2.6 million lbs were harvested and in 1994 the GHL was 2 million lbs and 1.3 million lbs were harvested (Bowers et al. 2008). 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 combined red and blue king crab GHLs from 1996 though 1998 were 2.5, 1.8, 1.5, and 1.25 million lbs and corresponding red king crab harvests were 0.87, 0.20, 0.76, 0.51 million lbs (Bowers et al. 2008). From 1999 to 2006/07 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 (Bowers et al. 2008).

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. The Alaska Department of Fish and Game manages the crab CDQ fisheries and the Central Bering Sea Fishermen's Association (CBSFA) is allocated 100% of the Pribilof red and blue king crab. Due to fishery closures, Pribilof red king crab were only harvested under a CDQ in 1998 where 3.5% of the overall GHL was allocated to the CDQ resulting in 35,958 lbs, harvest data is confidential due to limited participation in the fishery (Bowers et al. 2008).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 3) 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. The Bering Sea snow crab fishery has remained opened but ADF&G observers have not recorded any red king in their sampled pots during the last two fishing seasons (Barnard and Burt 2007, 2008). The eastern Bering Sea Tanner crab fishery recently re-opened west of 166^{o} longitude (the fishery was closed from 1997-2004). ADF&G observers recorded 1.0 red king crab per sampled pot during the 2005/2006 fishery, but only 0.08 during the 2006/2007 fishery (Barnard and Burt 2007, 2008). The Bering Sea hair crab fishery has been closed since 2001, and the Pribilof blue king crab fishery has been closed since 1999. In addition, Pribilof red king crab catch has been limited in groundfish trawl fisheries since 1995 because of the Pribilof Islands Habitat Conservation Area trawl closure. Non-directed catch still exists in groundfish pot and hook and line fisheries (see 2008 Data).

The highest catches of Pribilof red king crab during the last directed fishery occurred in the Alaska Department of Fish and Game statistical area to the east of St. Paul Island. However, red king crabs were also harvested in the statistical areas south, southwest, west and northeast of St. Paul Island (ADFG 1998). Historically, the statistical area east of St. Paul Island had the highest catches, followed by the areas southeast, west and southwest of the Island (personal communication, Robert K. Gish, ADFG).

2008 Data

Survey Data

The 2008 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 4). Weight (equation 1) and maturity (equation 2) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass (million lbs).

$$\text{Weight (kg)} = 0.00036 * \text{CL(mm)}^{3.16}/1000 \quad (1)$$

$$\text{Proportion mature} = 1/(1 + (5.842 * 10^{14}) * e^{(\text{CL(mm)} * -0.288)} \quad (2)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 1, Figure 5). In 2008, Pribilof Islands District red king crab were observed in eight of the 41 stations in the Pribilof District high-density sampling area (Chilton et al. in press, Figure 6). The density of legal-sized males (>138 mm CL) caught at a station ranged from 71 to 1,666 crab/nm^2. Legal-sized male red king crab were caught at 7 stations in the Pribilof District high-density sampling area and were estimated at 1.2 ± 1.1 million crab, which is a decrease of 25% from the 2007 abundance estimate (Figure 7).

Fishery Data-ADF&G pot fisheries

The 2007/2008 ADF&G assessments of retained and non-retained catch from all pot fisheries are included in this SAFE report (D. Barnard and D. Pengilly, ADF&G, personal communications).

Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (Table 2 and 3; Figure 8; Bowers et al. 2008), 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 2007/2008 fishing season.

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=0.000361, B=3.16; females: A=0.022863, B=2.23382), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 4).

$$\text{Weight (g)} = A * \text{CL(mm)}^B \quad (3)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (4)$$

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 4; Figure 9; Bowers et al. 2008) although data may be incomplete for some of these fisheries. Prior to 1998 limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here. In 2008, 0.003, 0.004, and 0.005 million lbs of sublegal males, legal males, and females, respectively, were incidentally caught in the Tanner crab fishery (Table 4).

Fishery Data-AKRO groundfish pot, trawl, and hook and line fisheries
The 2007/2008 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 2007 to June 2008. 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 2008 catches, sex ratios by size and sex from the 2008 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 4, Figure 10). In 2007/2008, 0.011 million lbs of male and female red king crab were caught in groundfish fisheries which is lower than the 0.037 million lb estimate of non-retained crab catch in 2006/2007 pot, trawl, and hook and line groundfish fisheries.

Analytic Approach
Although a catch survey analysis has been used for assessing the stock in the past, the OFL control rule and OFL determination in 2008 were based on MMB_{mating} relative to the EBS bottom trawl survey and incorporated commercial catch and at-sea observer data. Based on available data, the author, 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).

Tier 4 stocks are characterized as those where essential life-history and recruitment information are lacking. Although a full assessment model cannot be specified for Tier 4 stocks, or stock-recruitment relationship defined, sufficient information is available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Reliable estimates of current survey biomass, instantaneous M, and historical fishery and survey performance are explicit in a Tier 4 assessment. This approach provides the annual status determination criteria to assess stock status and to establish harvest control rules.

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, environmental conditions and fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets. 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}.

In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} (Figure 11) 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 11) where Stock Status Level (level a, b or c; equations 5-7) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

Stock Status Level:	F_{OFL}:	
a. $B/B_{MSY}^{prox} > 1.0$	$F_{OFL} = \gamma \cdot M$	(5)
b. $\beta < B/B_{MSY}^{prox} \leq 1.0$	$F_{OFL} = \gamma \cdot M\,[(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(6)
c. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0$; $F_{OFL} = F_{MSY}$	(7)

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. 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.

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 8).

$$MMB_{Mating} = MMB_{Survey} \cdot e^{-PM(sm)} \quad (8)$$

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.

B_{MSY}^{prox} for the 2008 assessment was calculated as 1) the average MMB_{mating} from 1991 to 2007 given that previous years were indicative of a stock at depressed levels and the current years will include stock highs and lows and 2) the average MMB_{mating} for the entire survey period 1980 to 2007.

The projected MMB_{mating} is calculated by decreasing the EBS bottom trawl survey biomass of mature male crabs by the natural mortality incurred between the survey and mating and by the projected catch removals (directed retained, directed discards, and non-directed pot, trawl, and hook and line catch mortalities) of mature males (equation 9). The proportion of each of the previous years catch removals of mature males to the entire catch are multiplied by the current years EBS bottom trawl survey of mature biomass to estimate a projected catch.

Projected MMB_{Mating} =

$$MMB_{Survey} \cdot e^{-PM(sm)} – \text{(projected legal male catch OFL)-(projected non-retained catch)} \quad (9)$$

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),

For a total catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the total crab biomass at the fishery (equation 10).

$$\text{Projected Total Catch OFL} = [1–e^{-Fofl}] \cdot \text{Total Crab Biomass}_{Fishery} \quad (10)$$

where $[1–e^{-Fofl}]$ is the annual fishing mortality rate.

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.

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as:

$$\mu_{LMB} = \text{[Total LMB retained and non-retained catch]} / LMB_{Fishery} \quad (11)$$

$$\mu_{MMB} = \text{[Total MMB retained and non-retained catch]} / MMB_{Fishery} \quad (12)$$

OFL Control Rule and Determination Results

For 2008/2009, two levels of B_{MSY}^{prox} were defined. $B_{MSY}^{prox}{}_1$=8.66 million lbs of MMB_{mating} derived as the mean of 1991 to 2007 and is recommended by the authors, CPT and SSC. $B_{MSY}^{prox}{}_2$=5.91 million lbs derived mean of 1980 to 2007 which was requested by the SSC for comparison purposes. The stock demonstrated highly variable levels of MMB_{mating} during both of these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

Male mature biomass at the time of mating for 2008/2009 is estimated at 9.26 million lbs for both $B_{MSY}^{prox}{}_1$ and $B_{MSY}^{prox}{}_2$ options. The B/B_{MSY}^{prox} ratios and F_{OFLs} corresponding to the two biomass reference options are, respectively, [$B/B_{MSY}^{prox}{}_1$=1.07, F_{OFL}=0.18] and [$B/B_{MSY}^{prox}{}_2$=1.57, F_{OFL}=0.18]. For both biomass reference options B/B_{MSY}^{prox} is < 1, therefore the stock status level is a (equation 5). For the 2008/2009 fishery, total catch OFLs were estimated at 3.32 million lbs of crab and legal male catch OFLs were estimated at 1.81 million lbs of crab for both options. The projected exploitation rates based on full retained catches up to the OFL for LMB and $MMB_{fishery}$ under for both B_{MSY}^{prox} options are: 0.182 and 0.197 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.

Reference points for both B_{MSY}^{prox} options:

Projected Total Catch OFL	**3.32 million lbs**
Projected MMB_{mating}	**9.26 million lbs**
Projected Legal Male catch OFL at fishery	**1.81 million lbs**
Projected Exploitation Rate on MMB	**0.18**
Projected Exploitation Rate on LMB	**0.20**

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

There have been no directed studies of the prey of Pribilof red king crab so the feeding habits can only be inferred from studies of red king populations from other areas. Several food-habit studies summarized in Jewett and Onuf (1988) report that red king crab diet varies with life stage and that red king crab are opportunistic omnivorous feeders, eating a wide variety of microscopic and macroscopic plants and animals. More specifically, red king crab larvae consume diatoms, small planktonic animals and fragments of plants (Bright 1967) and in the Bering Sea, important food items for adult red king crab are bivalve mollusks, gastropod mollusks, sea urchins, sand dollars, polychaete worms, and crustaceans, including other crabs (McLaughlin and Hebard 1961; Feder and Jewett 1981). Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not been re-sampled since. Because red king crab are opportunistic omnivores, it likely that they are not food limited.

Predator population trends

Predators of Pribilof Island red king crab have not been specifically studied, but predation on red king crab in the eastern Bering Sea has been studied. Pacific cod (*Gadus macrocephalus)* are the primary predators of red king crab with walleye pollock (*Theragra chalcogramma*), Pacific halibut (*Hippoglossus stenolepis*) and skates (*Raja* sp.) being minor predators (Lang et al. 2005). Larvae and newly settled juveniles are consumed by walleye pollock and yellowfin sole (*Limanda aspera*) (Livingston et al. 1993). Although Pacific cod are the primary predators of red king crab, Livingston (1989) concluded that cod were not the major force behind reduced numbers of female red king crab observed in the eastern Bering Sea from 1981 to 1985.

Pribilof Islands specific predator population trend data is not available so trends for the eastern Bering Sea are presented. Pacific cod biomass increased steadily from 1978 through 1983, remained relatively constant from 1983 through 1988, fluctuated slightly from 1988 through 1994 (the highest observation) and in general has steadily declined since then with 2007 estimates being the lowest estimate in the time series (Thompson et al. 2007). Walleye pollock biomass increased from 1979 to the mid 1980’s, is characterized by peaks in the mid 1980s and mid 1990s with a substantial decline by 1991 and stocks are currently facing another low point with the stock projected to drop to the lowest levels since the late 1970s (Ianelli et al. 2007). Halibut biomass was lowest in 1982, fluctuated from 1983 through 1988, peaked in 1988, dropped in 1989 and increased from 1990 through 1996 when the highest biomass of the time series was observed, after 1998 biomass has fluctuated (personal communication, Steven Hare, IPHC). Biomass estimates of all skate species in the eastern Bering Sea are not reported, however biomass has been estimated for the Alaska skate (*Bathyraja parmifera*) since 1982. Estimated biomass for the Alaska skate fluctuated from 1982 through 1986, from 1986 through 1990 biomass in general increased and peaked in 1990, from 1991 through 1999 biomass tended to decrease and beginning in 1999 to the present biomass has been increasing (Ormseth and Matta 2007). Yellowfin sole biomass was at low levels during most of the 1960s and early 1970s after a period of high exploitation after which time biomass increased and peaked by 1984, biomass has been in a slow decline but has remained high and stable in recent years (Wilderbuer et al. 2007).

Pansporoblastic microsporidan (*Thelohania* sp.) and rhizocephalan infections (*Briarosaccus* sp.) were found in red king crab of the northeastern Pacific (Sparks and Morado 1997). In Bristol Bay, red king crabs with rhizocephalan, microporidan, and viral or putative viral diseases were found (Sparks and Morado 1985). The microsporidan disease in red king crabs is almost certainly fatal however rhizocehalan infection appears to be of little importance among red king crab (Sparks and Morado 1990). Otto et al. (1990) found three of 243 red king crab egg clutches from Bristol Bay to contain nemertian worms, which are known predators of embryos.

Changes in habitat quality
The past decade has been warmer in the Bering Sea, however winter and spring 2007 surface air temperatures were colder than normal and 2006 was close to normal, but these cold anomalies are not in the range of pre-1977 temperatures (Wang et al. 2008). In the Bering Sea, a northward biogeographical shift is being observed in response to a retreat of cold ocean temperatures and atmospheric forcing (Overland and Stabeno 2004). Distribution changes of Pribilof Islands red king crab has not been studied, however the distribution of ovigerous red king crab in southeastern Bering Sea shifted to the northeast during the late 1970s and early 1980s and this distribution change coincided with increased early summer near-bottom temperatures (Loher and Armstrong 2005). Water temperature may be important is structuring the distribution of ovigerous red king crab (Loher and Armstrong 2005).

Recruitment trends for red king crabs in Alaska may be partly related to decadal shifts in climate and physical oceanography. Strong year classes for eastern Bering Sea red king crab 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 red king crab (Zheng and Kruse 2000). In Bristol Bay, there is a relationship between red king crab brood strength and the intensity of the Aleutian Low atmospheric pressure system, 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.

Ice cover has changed in the Bering Sea including the area around the Pribilof Islands. In 1972 through 1976, ice cover remained around St. Paul Island for more than a month (Schumacher et al. 2003). Spring 2007 was cold and sea ice lasted for almost 2 months just north of the Pribilof Islands which is close to normal conditions observed from 1979 through 1999 and in contrast to the warm years of 2000-2005 (Wang et al. 2008). In the Bering Sea, if seasonal ice pack were to decrease in extent or melt earlier, a shift from ice-edge blooms to later open-water blooms may cause long-term declines in sediment organic matter (Lovvorn et al. 2005). In these shelf systems, much of the production from spring blooms at the retreating ice edge sink to the bottom with little grazing by zooplankton, therefore supporting abundant benthic communities (Overland and Stabeno 2004; Lovvorn et al. 2005). The importance of this settled phytoplankton to the macrobenthos will partially determine the effects of long-term changes in ice cover (Lovvorn et al. 2005). The presence of sea ice in 2007 along with below normal ocean temperatures likely resulted in the first ice edge bloom since 1999 (Wang et al. 2008). The changes in ice cover on the benthic community of the Pribilof Islands are not well understood.

Unless red king crab distribution around the Pribilof Islands change, the critical habitat that Pribilof Islands red king crab inhabit will not be altered by bottom trawling because the Pribilof Islands Habitat Conservation Area protects the majority of crab habitat in the area (NPFMC 1994).

Fishery Effects on the Ecosystem

Bycatch information from the Pribilof district king crab fishery is scant due to limited observer coverage during the years of the fishery. The percent of the fleet observed was 1.8 in 1993, 0.8 in 1995 and 0.0 for every other year (Boyle and Schwenzfeier 2002), therefore it is difficult to estimate the fishery-specific contribution to the bycatch of prohibited and forage species. The Pribilof district king crab fishery does not occur in any areas designated as Habitat Areas of Particular Concern (HAPC) (NPFMC 2003). 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). NMFS concluded that the crab fisheries are not likely to result in the direct take or compete for prey for the protected marine mammal species, destroy or adversely modify designated Steller sea lion critical habitat, adversely affect listed seabirds or destroy or adversely modify designated critical habitat. The only plausible biological interaction between the crab fisheries and threatened and endangered seabirds identified in the biological assessment is vessel strikes by seabirds, but NMFS (2002) concluded that available evidence is not sufficient to suggest that these interactions occur in today’s fisheries and limit recovery of seabirds.

The Pribilof Islands red king crab fishery was only executed for 6 seasons (1993-1998). The stocks and area are not well studied and so information is not available on the effects of fishery removals on predator needs, the effects of removing large male crabs from the population, and the effects of the fishery on the age-at maturity and fecundity of the stock. Additionally, information is not available on the fishery-specific contribution to discards and offal production.

The extent that pot gear impacts benthic habitat is not well know and most likely depends on the substrate. It is likely that habitat is affected during both setting and retrieval of pots, but little research has been done. There is no evidence that pot gear adversely affects mud and sandy substrates where red king crab are primarily fished (NMFS 2004). It has been estimated that for each pot set 49 ft^2 of substrate is impacted and that the estimated number of sets per year for the Pribilof red and blue king crab fishery would be 28,381 resulting in 1,390,669 ft^2 possibly impacted by pot gear which is 0.0% of the Bering Sea shelf (NMFS 2004).

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Table 1. Pribilof Islands District red king crab abundance, mature biomass, and legal male biomass (million lbs), and totals estimated from the NMFS annual EBS bottom trawl survey.

	Mature Crabs (10^6 Crab)		Mature Biomass (10^6 LB)		Legal Males >=135mm CL (10^6 LB)	Total males (10^6 LB)	Total females (10^6 LB)	Total Crab (10^6 LB)
Year	Male	Female	Male	Female	Male			
1979/1980	na	na	na	na	na			
1980/1981	0.73	0.39	5.82	1.07	5.82			
1981/1982	0.73	0.39	5.82	1.07	5.82			
1982/1983	0.31	0.43	2.98	1.36	2.98			
1983/1984	0.09	0.13	0.77	0.42	0.70			
1984/1985	0.11	0.05	0.81	0.16	0.67			
1985/1986	0.03	0.00	0.22	0.00	0.22			
1986/1987	0.03	0.04	0.27	0.11	0.27			
1987/1988	0.01	0.01	0.09	0.02	0.09			
1988/1989	0.09	0.23	0.28	0.51	0.08			
1989/1990	0.70	1.04	3.11	2.05	1.77			
1990/1991	0.85	0.93	2.40	1.62	0.13			
1991/1992	2.06	3.59	8.11	7.03	2.45			
1992/1993	1.36	2.37	6.81	5.22	5.22			
1993/1994	2.84	4.79	16.84	11.27	15.72			
1994/1995	2.52	2.30	16.34	5.64	14.46			
1995/1996	1.24	1.01	8.51	2.54	7.65			
1996/1997	0.48	0.92	4.43	2.71	4.37			
1997/1998	1.46	0.82	11.60	2.31	10.76			
1998/1999	0.81	0.95	5.07	2.56	3.79			
1999/2000	0.00	2.14	0.02	6.77	0.02			
2000/2001	1.42	0.59	8.73	1.42	7.76			
2001/2002	3.49	3.38	17.44	7.96	11.51			
2002/2003	1.81	0.42	14.88	1.23	14.84			
2003/2004	1.38	1.14	11.05	3.46	10.85			
2004/2005	0.88	0.61	8.55	2.09	8.55			
2005/2006	0.28	1.39	2.98	5.16	2.95			
2006/2007	1.46	0.89	15.65	3.24	14.97			
2007/2008	1.75	1.63	16.58	5.69	15.98	17.01	5.99	23.00
2008/2009			12.49	4.68	11.64	13.76	7.61	21.37

Table 2. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2008; D. Barnard and D. Pengilly, ADF&G, personal communications).

	Retained catch		
	OA/IFQ 10^6 lbs	CDQ 10^6 lbs	Total 10^6 lbs
1979/1980			
1980/1981			
1981/1982			
1982/1983			
1983/1984			
1984/1985			
1985/1986			
1986/1987			
1987/1988			
1988/1989			
1989/1990			
1990/1991			
1991/1992			
1992/1993			
1993/1994	2.608		2.608
1994/1995	1.339		1.339
1995/1996	0.898		0.898
1996/1997	0.200		0.200
1997/1998	0.757		0.757
1998/1999	0.544		0.544
1999/2000			
2000/2001			
2001/2002			
2002/2003			
2003/2004			
2004/2005			
2005/2006			
2006/2007			
2007/2008			

Table 3. 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
1999-2007/08	Fishery Closed			

Table 4. Non-retained total catches from directed and non-directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2008; D. Barnard and D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Discard/bycatch				
	All EBS Pot Fisheries				Groundfish Fisheries
	Legal non-retained	Sublegal male	All Female	Total (all crab)	Both sexes
	10^6 lbs	10^6 lbs	10^6 lbs	10^6 lbs	10^6 lbs
1979/1980					
1980/1981					
1981/1982					
1982/1983					
1983/1984					
1984/1985					
1985/1986					
1986/1987					
1987/1988					
1988/1989					
1989/1990					
1990/1991					
1991/1992					0.112
1992/1993					0.190
1993/1994					0.132
1994/1995					0.010
1995/1996					0.023
1996/1997					0.015
1997/1998					0.012
1998/1999		0.004	0.050	0.055	0.006
1999/2000	0.006		0.036	0.042	0.034
2000/2001					0.018
2001/2002					0.025
2002/2003					0.014
2003/2004					0.023
2004/2005					0.039
2005/2006		0.001	0.008	0.009	0.118
2006/2007	0.005	0.001	0.005	0.011	0.037
2007/2008	0.004			0.005	0.011

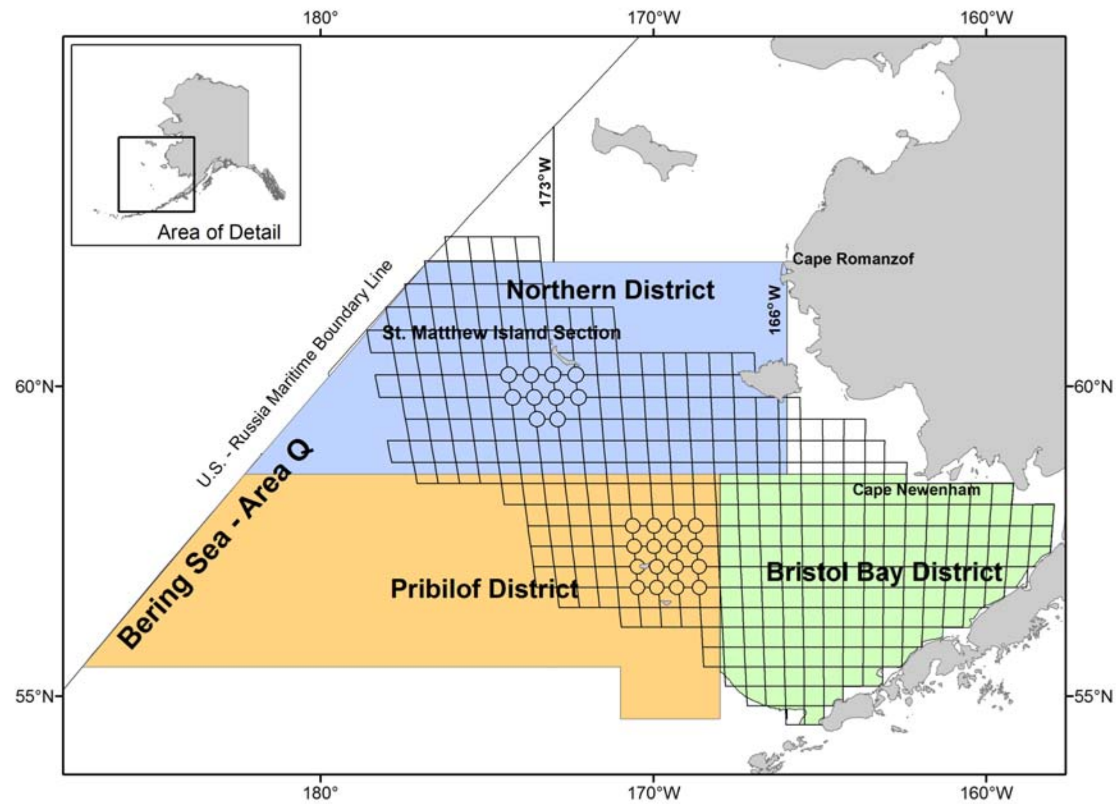

Figure 1. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

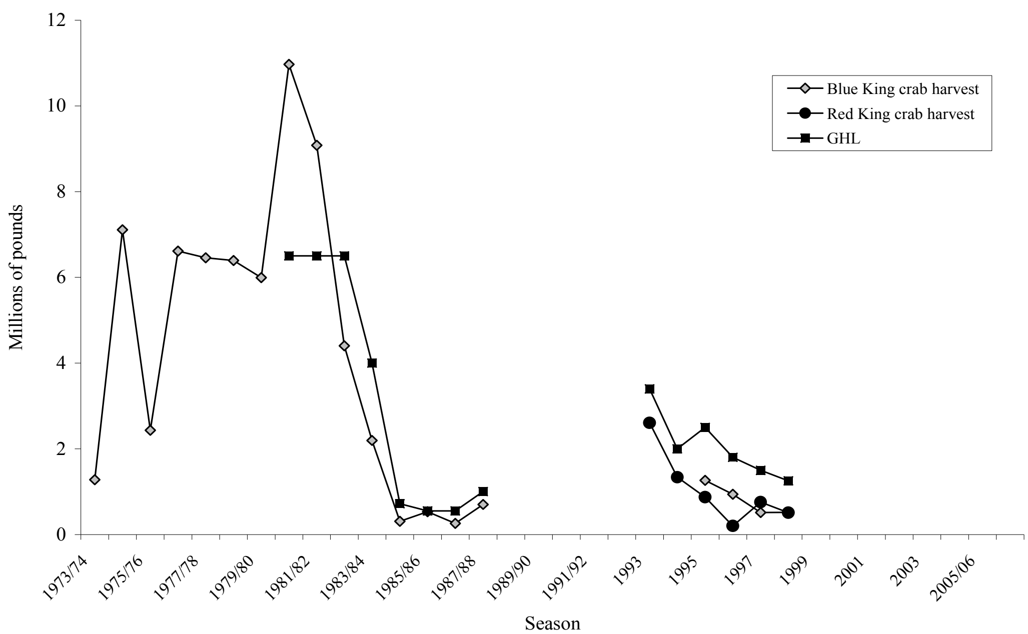

Figure 2. Historical harvests and GHLs for Pribilof Island red king crab (Bowers et al. 2007).

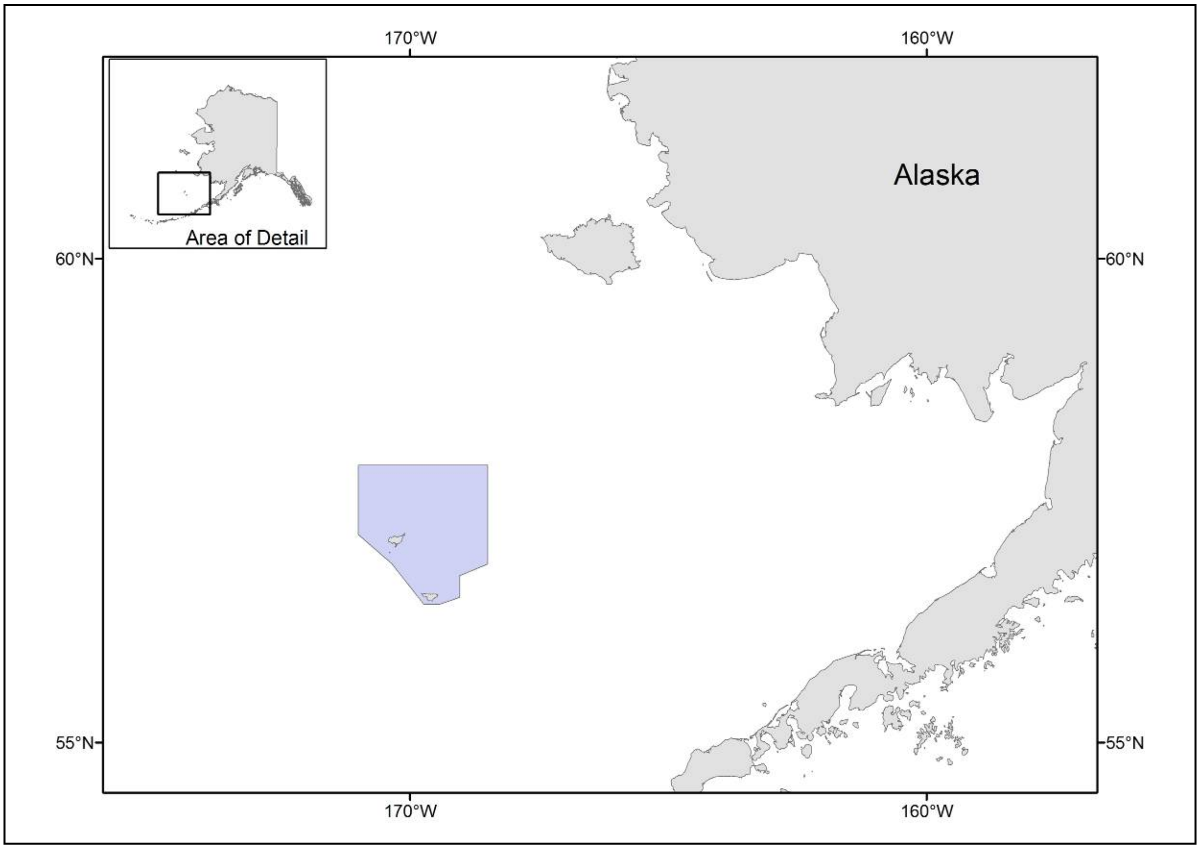

Figure 3. The shaded area shows the Pribilof Islands Habitat Conservation area

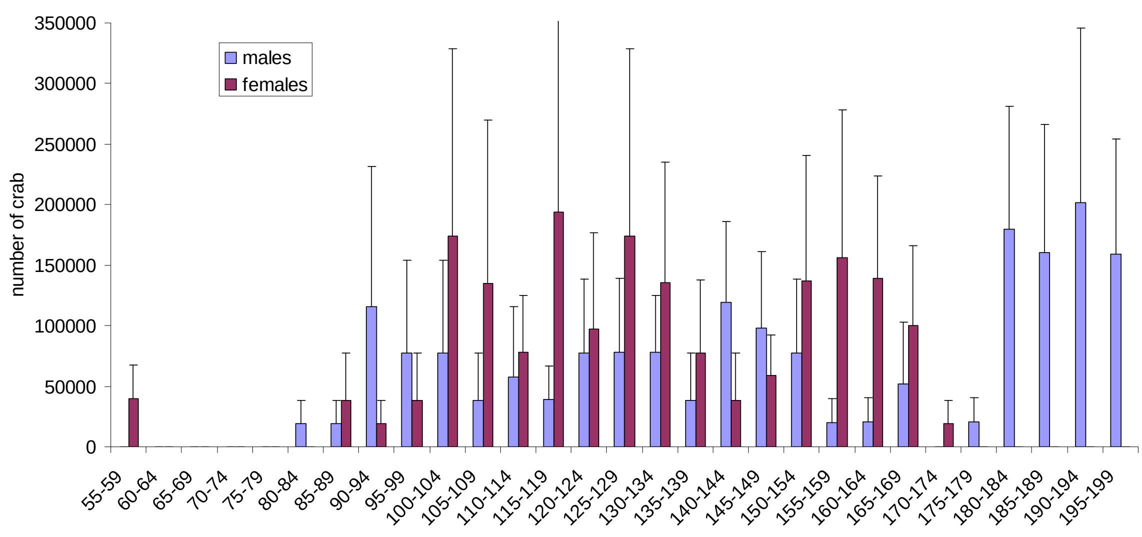

Figure 4. Distribution of average (SE) counts of Pribilof Island red king crab in 5 mm length bins.

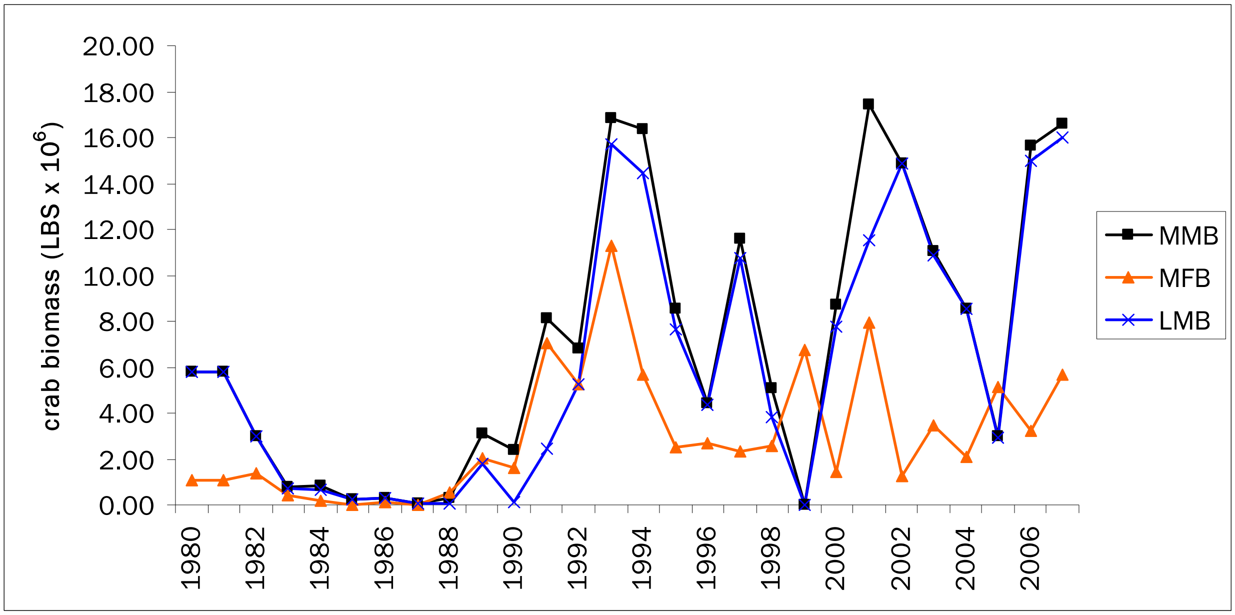

Figure 5. Historical trends of Pribilof Island red king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

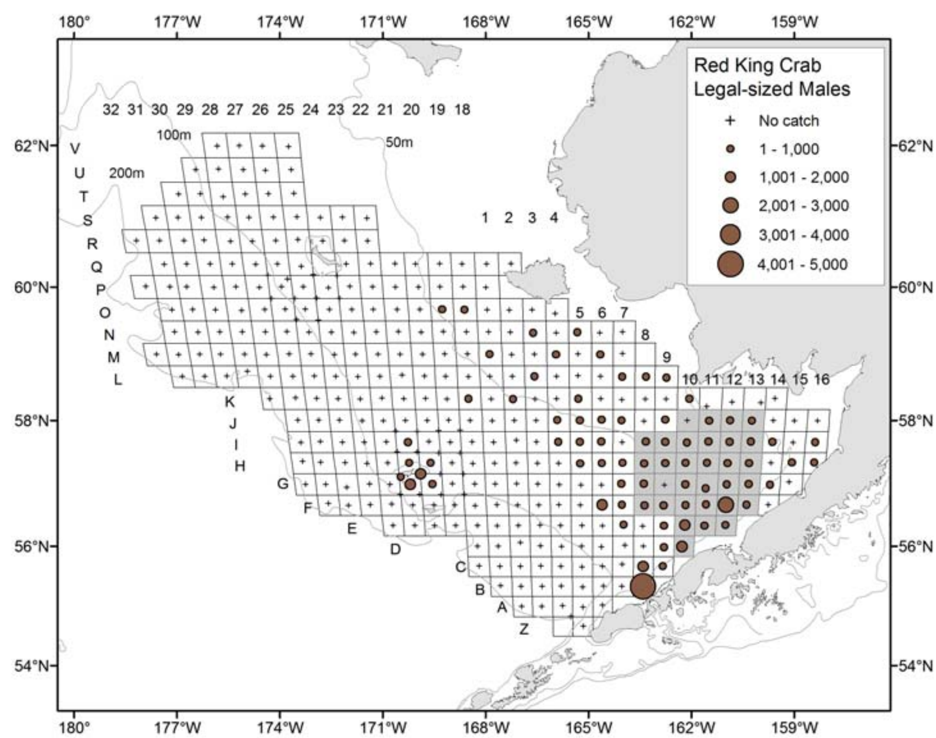

Figure 6. 2008 EBS bottom trawl survey distribution and relative abundance of legal size red king crab males.

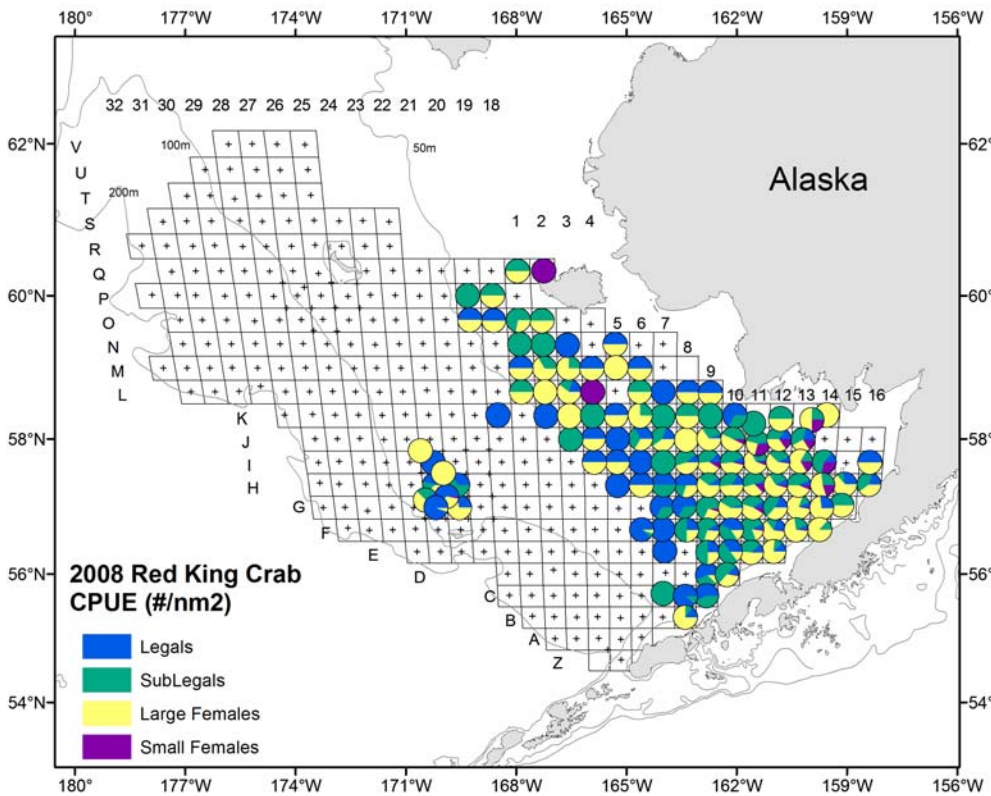

Figure 7. 2008 EBS bottom trawl survey size class distribution of red king crab.

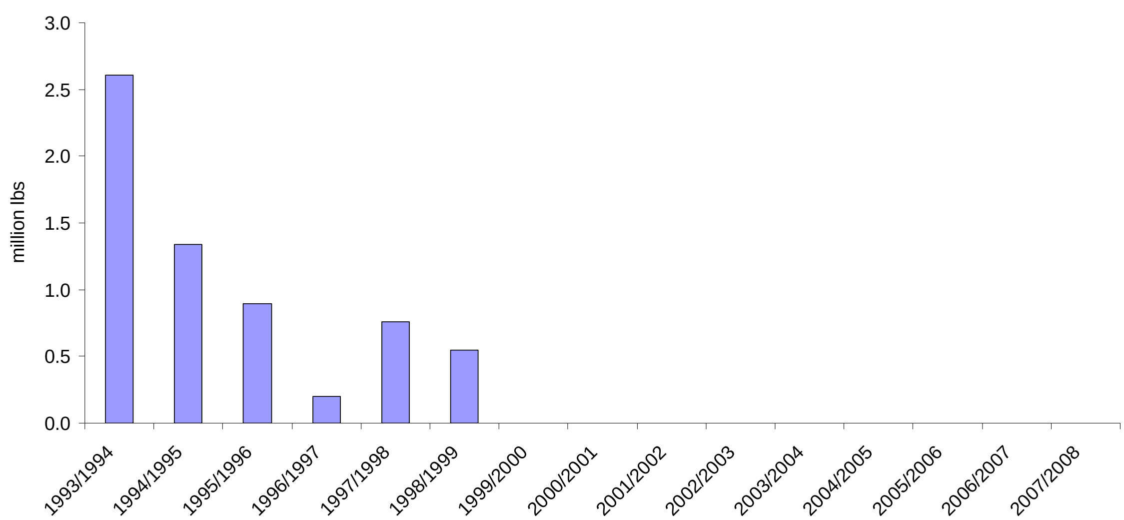

Figure 8. Retained catches from directed fisheries for Pribilof Islands District red king crab.

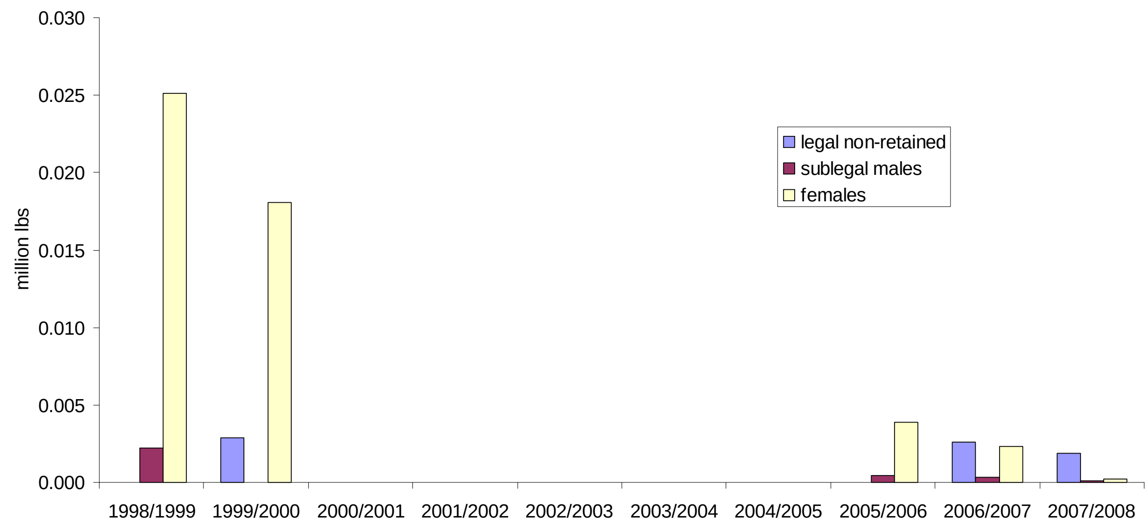

Figure 9. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District red king crab.

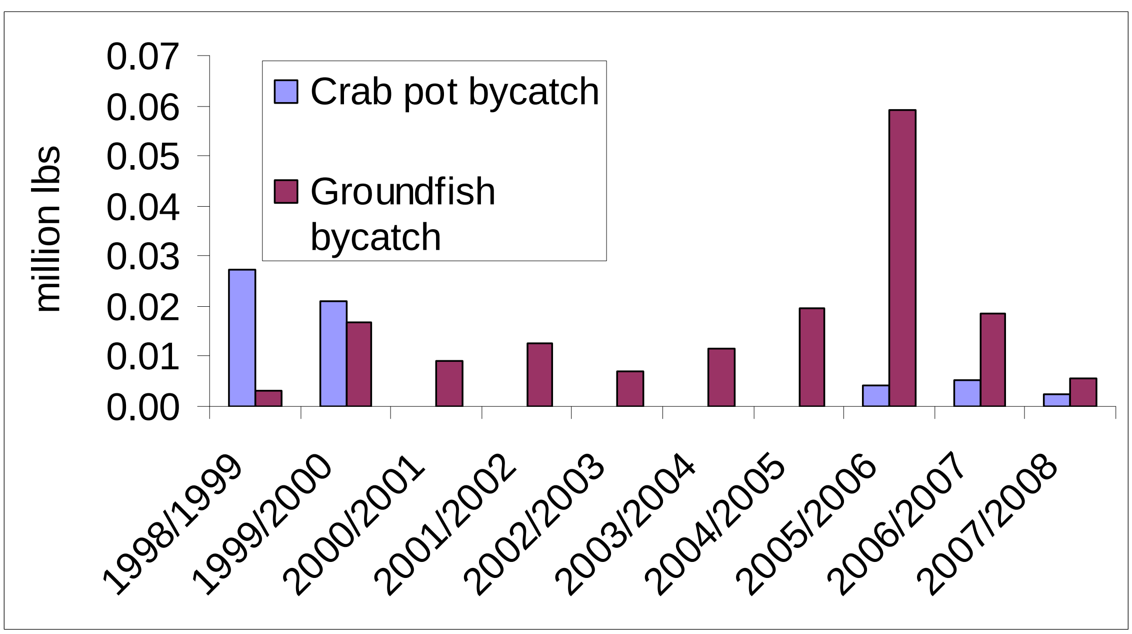

Figure 10. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District red king crab

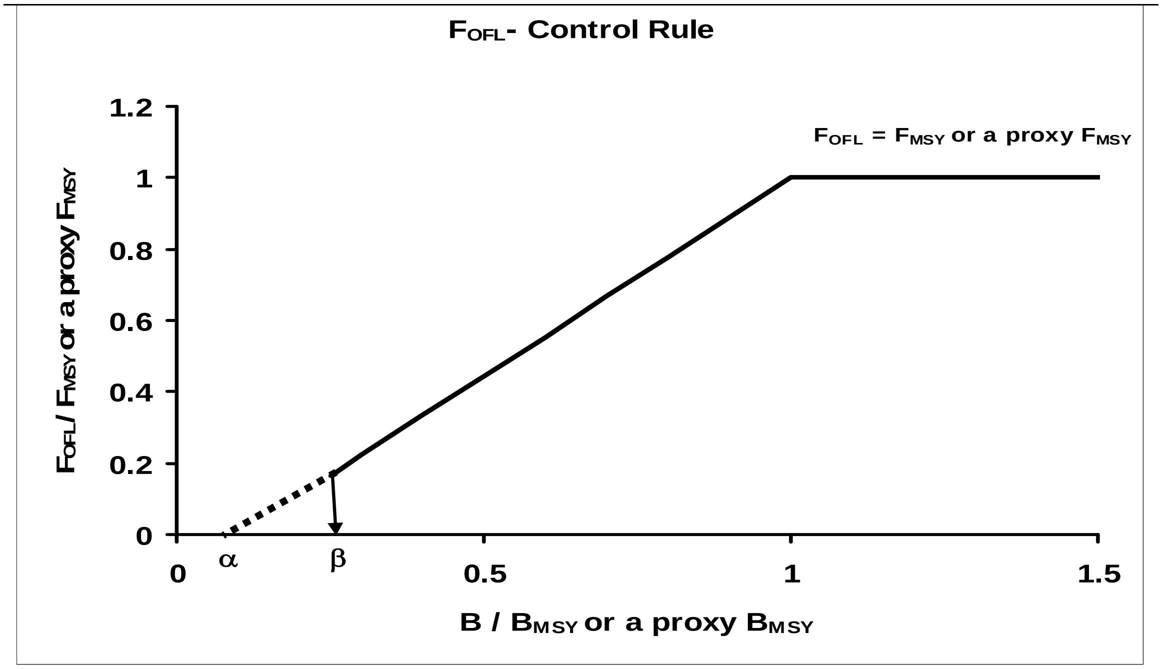

Figure 11. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

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

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Executive Summary

Stock: Pribilof Islands blue king crab, *Paralithodes platypus*

Summary of Major Changes

- Additional alternative B_{MSY}^{prox} years were used to incorporate the entire survey data set.
- The calculations for reference points and estimations of catch were explicitly detailed.
- Calculations for $F_{OFL} \leq F_{MSY}$ in a Tier 4c situation are presented.

Responses to SSC Comments:

- The June 2008 SSC recommended development of the catch-survey analysis model for next years assessment to obtain more stable abundance estimate. This will be assessed before May 2009.
- The June 2008 SSC recommended development of analyses for choice of gamma. This will be assessed before May 2009.
- The June 2008 SSC recommended expanded ecosystem sections to include prey and predator interactions. This will be assessed before May 2009.

Summary

Status and catch specifications (million lbs) of Pribilof Islands blue king crab

Year	Total Catch OFL	Biomass (MMB_{mating})	TAC	Retained Catch	Total catch
2005/06	na	0.68	0	0	0.002
2006/07	na	0.33	0	0	0.014
2007/08	na	0.66	0	0	0.014
2008/09	0	0.25*			

*projected for Stock Status determination

Tier	4
Stock Status Level	c
F_{OFL}	0
B_{MSY}^{proxy}	9.28 million lbs of MMB_{mating}
Years	1980 to 1984 and 1990 to 1997
2008/2009 projected MMB_{mating}	0.25 million lbs
2008/2009 projected MMB_{mating}/MMB_{MSY}	0.03
Gamma	1
M	0.18
2008/2009 total catch OFL	0.004 million lbs (non-directed)

Introduction

Scientific name and description of general distribution

Blue king crab (*Paralithodes platypus*) 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).

Description of management units

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).

Stock structure

Based on catch-survey analysis from the 2007 NMFS trawl survey, the estimated total mature biomass of 1.3-million pounds is the second lowest on record, exceeding only that of 0.6-million pounds in 2004. Estimated 2007 abundance of 0.1-million mature-sized male is the second lowest on record, whereas estimates of 0.1-million legal males and 0.3-million mature-sized females are the lowest on record. A continued decline in mature male and female abundances is anticipated for at least two years. Although relatively high numbers of small crabs (< 70 mm-CL) were caught, mainly at one haul, during the 2005 NMFS trawl survey, there was very little representation of juvenile crabs in the 2006 and 2007 surveys. The Pribilof blue king crab stock continues to show no indications of near-term recovery (NPFMC 2007).

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 at al 2002).

Fishery

Description of fishery

The Pribilof blue king crab fishery has been closed since 1999. The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990, ADF&G 2008). The fishery used mesh covered steel box-shaped pots set on single lines (NOAA 1995). Standard commercial king crab pots are rectangular with length and width dimensions ranging from 150 to 240 cm and height from 67 to 99 cm. The pot has two tunnels at opposite ends, two side panels, one top panel and one bottom panel. Fish are placed inside as bait and the pot is sunk to the sea floor. The king crab are sorted once they are brought to the surface, and any not meeting the regulation requirements are thrown back. The fishery was male only, and legal size was >16.5 cm carapace width (NOAA 1995). The king crab are then typically stored live in a holding tank until the boat reaches shore, where they are sold and processed. TAC was 10 percent of the abundance of mature male or 20 percent of the number of legal males (ADF&G 2006).

The Pribilof Islands Area Habitat Conservation Zone was established in 1995, under authority of the Magnuson-Stevens Fishery Conservation and Management Act. Trawl fishing has been prohibited year-round in the Pribilof Islands Habitat Conservation Area since (Figure 3).

Information on bycatch and discards

Bycatch in the blue king crab fisheries consist almost entirely of non-legal blue king crabs (NOAA 1995). State regulations prescribe gear modifications to inhibit the bycatch of small crab, female crab, and other species of crab. Gear modifications include escape rings, tunnel size, and a requirement that crab pots be fitted with a degradable escape mechanism.

Blue king crab in the Pribilof District can occur as bycatch in the following crab fisheries: the eastern Bering Sea snow crab (*Chionocetes opilio*) fishery, the eastern Bering Sea Tanner crab (*chionocetes bairdi*) fishery, the Bering Sea hair crab (*Erimacrus isenbeckii*) fishery, and the Pribilof red and blue king crab fisheries. Of those fisheries, only the eastern Bering Sea snow crab fishery has remained open; the eastern Bering Sea Tanner crab fishery closed from 1997-2004, the Pribilof red and blue king crab fisheries have been closed since 1999, and the Bering Sea hair crab fishery has been closed since 2001. Although St. Matthew blue king crab account for the majority of blue king crab captured in the snow crab fishery (D. Barnard, ADF&G, Kodiak, personal communication), the total bycatch of blue king crab in the snow crab fishery is relatively low (estimated at <25,000 crabs annually during 1995-2002). It should be noted that only limited data is available for estimating bycatch in the Pribilof king crab fisheries that occurred during 1995-1998. Bycatch of blue king crab in groundfish fisheries is small relative to total population abundance (NPFMC 2003).

Summary of historical catch distributions

The king crab fishery in the Pribilof District began in 1973 with a reported catch of 1.3 million pounds by eight vessels. Landings increased during the 1970s and peaked at a harvest of 11.0 million pounds in the 1980/81 season with an associated increase in effort to 110 vessels

(ADF&G 2008). A decline in landings followed, and by 1988 the fishery was closed. In 1993 new regulations set pot limits based on vessel length for crab fisheries in the Bering Sea. In the Pribilof District pot limits were set at 50 pots for vessels over 125 feet overall length and 40 pots for vessels at or under 125 feet in overall length.

In 1995, an increase in blue king crab abundance and a continued harvestable surplus of red king crabs resulted in a combined red and blue king crab GHL of 2.5 million pounds (ADF&G 2008). The fishery was reopened and a total of 1,154,386 pounds was landed in that year. 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 Fisheries Management Council's (NPFMC) comprehensive rebuilding plan for the stock (Zheng and Pengilly 2003).

2008 Data

Survey Data

The 2008 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 (Figures 4and 5). Weight (equation 1) and maturity (equation 2) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass (million lbs).

$$\text{Weight (kg)} = 0.00047 * \text{CL(mm)}^{3.103}/1000 \qquad (1)$$

$$\text{Proportion mature} = 1/(1 + (3.726 * 10^{15}) * e^{(\text{CL(mm)} * -0.332)} \qquad (2)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 1, Figure 6). In 2008, Pribilof Island District blue king crab were observed in six of the 75 stations in the Pribilof District, all of which were in the high-density sampling area (Chilton et al. in press, Figure 7). Legal-sized males were caught at one station north of St. Paul Island with a density of 80 crab/nm^2 (Figure 8). The 2008 abundance estimate of legal sized males decreased from 2007 to 0.02 ± 0.04 million crab, well below the average of 0.6 million crab for the previous 20 years.

Fishery Data-ADF&G pot fisheries

The 2007/2008 ADF&G assessments of retained and non-retained catch from all pot fisheries are included in this SAFE report (D. Barnard and D. Pengilly, ADF&G, personal communications).

Retained pot fishery catches (live and deadloss landings data) are provided for 1973/1974 to 2007/2008 (Table 2; Figures 9 and 10; Bowers et al. 2008), 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 Guideline Harvest Level (GHL). There was no GHL and therefore zero retained catch in the 2007/2008 fishing season.

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 (Figure 11). Catch weight (lbs) was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was calculated from length frequency tables where the CL (mm) was converted to g (see equation 3: males: A=0.000329, B=3.175; females: A=0.114389, B=1.9192), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 4).

$$\text{Weight (g)} = A * CL(mm)^{B} \quad (3)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (4)$$

Finally, weights were the product of average weight, CPUE, and total pot lifts in the fishery. The total weight in g was then converted to lbs by dividing the gram weight by 453.6 g/lb. To assess crab mortalities in these pot fisheries a 50% handling mortality rate is applied to these estimates.

Historical non-retained catch data are available from 1996/1997 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 3, Bowers et al. 2008) although data may be incomplete for some of these fisheries. Prior to 1998, limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here. In 2008, 0, 0, and 0.0003 million lbs of sublegal males, legal males, and females, respectively, were incidentally caught in the Tanner crab fishery (Table 3).

Fishery Data-AKRO groundfish pot, trawl, and hook and line fisheries
The 2007/2008 NOAA Fisheries Regional Office assessments of non-retained catch from all groundfish fisheries are included in this SAFE report (Figure 12; 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 2007 to June 2008. 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 2008 catches, sex ratios by size and sex from the 2008 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 2007/2008, 0.027 million lbs of male and female blue king crab were caught in groundfish fisheries which is the same as the estimate of non-retained crab catch in 2006/2007 groundfish fisheries. In the groundfish fisheries, 98% of the non-retained crab catch occurred in the Pacific cod pot fishery followed by 1% in the yellowfin sole trawl fishery, <1% in the flathead trawl fishery, and <1% in the Pacific cod longline fishery.

Analytic Approach

Although a catch survey analysis has been used for assessing the stock in the past, the OFL control rule and OFL determination in 2008 were based on MMB_{mating} relative to the EBS bottom trawl survey and incorporated commercial catch and at-sea observer data. Based on available data, the author, 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).

Tier 4 stocks are characterized as those where essential life-history and recruitment information are lacking. Although a full assessment model cannot be specified for Tier 4 stocks, or stock-recruitment relationship defined, sufficient information is available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Reliable estimates of current survey biomass, instantaneous M, and historical fishery and survey performance are explicit in a Tier 4 assessment. This approach provides the annual status determination criteria to assess stock status and to establish harvest control rules.

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, environmental conditions and fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets. 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}.

In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} (Figure 13) 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 13) where Stock Status Level (level a, b or c; equations 5-7) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

<u>Stock Status Level</u>:	<u>F_{OFL}</u>:	
a. $B/B_{MSY}^{prox} > 1.0$	$F_{OFL} = \gamma \cdot M$	(5)
b. $\beta < B/B_{MSY}^{prox} \leq 1.0$	$F_{OFL} = \gamma \cdot M\,[(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(6)
c. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$	(7)

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. 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.

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_{mating} (equation 8).

$$MMB_{Mating} = MMB_{Survey} \cdot e^{-PM(sm)} \quad (8)$$

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.

B_{MSY}^{prox} for the 2008 assessment was calculated as 1) the average MMB_{mating} from 1980 to 1984 and 1990 to 1997 to avoid time periods of low abundance possibly caused by high fishing pressure and 2) the average MMB_{mating} for the entire survey period 1980 to 2007.

The projected MMB at mating is calculated by decreasing the EBS bottom trawl survey biomass of mature male crabs by the natural mortality incurred between the survey and mating and by the projected catch removals (directed retained, directed discards, and non-directed pot, trawl, and hook and line catch mortalities) of mature males (equation 9). The proportion of each of the previous years catch removals of mature males to the entire catch are multiplied by the current years EBS bottom trawl survey of mature biomass to estimate a projected catch.

$$\text{Projected } MMB_{Mating} =$$

$$MMB_{Survey} \cdot e^{-PM(sm)} - (\text{projected legal male catch OFL}) - (\text{projected non-retained catch}) \quad (9)$$

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),

For a total catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the total crab biomass at the fishery (equation 10).

$$\text{Projected Total Catch OFL} = [1 - e^{-Fofl}] \cdot \text{Total Crab Biomass}_{Fishery} \quad (10)$$

where $[1 - e^{-Fofl}]$ is the annual fishing mortality rate.

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_{mating} drops below MSST, the stock is considered to be overfished.

Under Stock Status Level c, $F_{directed} = 0$ and the $F_{OFL} \leq F_{MSY}$ as directed in the rebuilding plan for the stock. The maximum OFL would therefore be F_{MSY} = M. Alternative OFLs may also take into account historical catch mortalities.

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as:

$$\mu_{LMB} = [\text{Total LMB retained and non-retained catch}] / LMB_{Fishery} \quad (11)$$

$$\mu_{MMB} = [\text{Total MMB retained and non-retained catch}] / MMB_{Fishery} \quad (12)$$

OFL Control Rule and Determination Results

For 2008/2009, two levels of B_{MSY}^{prox} were defined. $B_{MSY}^{prox}{}_1$=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. $B_{MSY}^{prox}{}_2$=5.40 million lbs derived mean of 1980 to 2007 to assess the use of the entire time series. The stock demonstrated highly variable levels of MMB during both of these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

Male mature biomass at the time of mating for 2008/2009 is estimated at 0.25 million lbs for both $B_{MSY}^{prox}{}_1$ and $B_{MSY}^{prox}{}_2$ options. The B/B_{MSY}^{prox} ratios and F_{OFLs} corresponding to the two biomass reference options are, respectively, [$B/B_{MSY}^{prox}{}_1$=0.03, F_{OFL}=0.00] and [$B/B_{MSY}^{prox}{}_2$=0.05, F_{OFL}=0.00]. For both biomass reference options B/B_{MSY}^{prox} is $< \beta$, therefore the stock status level is c, $F_{directed} = 0$, and $F_{OFL} \leq F_{MSY}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). If $F_{MSY} = M = 0.18$ then the maximum total catch OFL is 0.36 million lbs at the time of the fishery and 0.34 million pounds at the time of mating. Alternative total catch OFL calculations were explored to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality. The first alternative was to set the total catch OFL at the maximum non-directed total catch mortality in the past 10 years which was 0.016 million lbs in 1999/2000. The second alternative recommendation was a total catch OFL equivalent to the 2007/2008 proportion of total crab catch mortalities to the 2007/2008 survey total crab biomass estimate applied to the 2008/2009 survey total crab biomass estimate. This was 0.02 million lbs of crab which reflects the increase in total Pribilof Island blue king crab due to survey increases in female crab. The third and 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. Appendix 1 is a final alternative to calculate a total catch OFL using a surplus yield estimate for Pribilof Islands blue king crab revealing that losses to natural mortality over the period considered in the analyses exceed recruitment during this period.

Reference points for both B_{MSY}^{prox} options:

Projected Total Catch OFL (non-directed only)	**0.004 million lbs**
Projected MMB_{mating} (for Stock Status determination)	**0.251 million lbs**
Projected MMB_{mating} (with non-directed mortality)	**0.247 million lbs**
Projected Legal Male catch OFL at Fishery	**0 million lbs**
Projected Exploitation Rate on MMB	**0**
Projected Exploitation Rate on LMB	**0**

Ecosystem Considerations

Ecosystem Effects on Stock

1) Prey availability/abundance trends

Blue king crab diet varies with life stage. The four planktonic larval zoeal stages consume phytoplankton and zooplankton, the fifth larval glaucothoe stage is non-feeding, and the early juveniles feed on benthic organisms such as diatoms, protozoa, hydroids, and crab. Juveniles and adults are opportunistic omnivorous scavengers. Based on stomach-content analysis, juvenile crabs consume diatoms, foraminifera, algae, sponge spicules, bryozoans, polychaetes, copepods, and sediment; detritus may also be a major component of their diet (Feder et al. 1980). At age 1+, crabs will eat many different foods, including bivalves, worms, seastars, barnacles, polychaetes, snails, Tanner crab, echinoids, and hydroids (Feder and Jewett 1981). The adult diet includes crustaceans, worms, clams, mussels, snails, brittle stars, sea stars, sea urchins, sand dollars, barnacles, fish parts, and algae. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. With regards to larval stages, plankton abundance is effected by climatic conditions; strong vertical mixing and an unstable water column associated with a strong Aleutian Low inhibits growth of *Thalassiosira* spp diatoms which provide important nutrients to zoeal king crabs (Zheng and Kruse 2000).

2) Predator population trends

During each life stage, crab are consumed by different predators; however, minimal data exists on predation of blue king crab. NMFS stomach analysis records show only 34 stomachs from the EBS that contained blue king crab as prey (NPFMC 2003).
Mean prey weights were as follows:

Pacific cod (2) *Gadus macrocephalus* 303.524 g/crab
Walleye pollock (25) *Theragra chalcogramma* 0.005 g/crab
Yellowfin sole (8) *Pleuronectes asper* 0.007 g/crab

These observations were taken from June to August during the NMFS summer bottom trawl survey for crab and groundfish in the eastern Bering Sea (NPFMC 2003). Additionally, Pacific cod have been observed to feed on molting adult female blue king crabs in February (NPFMC 2003). The size of crabs in stomachs of yellowfin sole and walleye pollock indicates that they prey on larvae and very early juveniles and cod appear to prey on juveniles and adults (NPFMC 2003). Sampling has been limited for blue king crab, but it seems very likely that the same set of species that prey on other king crabs would prey on blue king crab. This would include red king crab predators, such as skates (*Raja* spp), several sculpins (cottidae), northern rock sole (*Lepidopsetta polyxystra*), Alaska plaice (*Pleuronectes quadratuburculatus*), flathead sole (*Hippoglossoides elassodon*) and Pacific halibut (*Hippoglossus stenolepis*), as predators of blue king crabs. Juveniles may additionally fall prey to yellowfin sole (*Limanda aspera*), and arrowtooth flounder (*Atheresthes stomias*), Irish lords (*Hemilepidotus* sp), snailfish (*Liparis* sp.), and octopus (*Enteroctopus dofleini*) (Livingston et al. 1983). As crabs grow older however, they begin to exceed the mouth gape of many of these predators (NPFMC 2003). Juvenile red king crab suffer mortality due to cannibalism by older red king crab and this is likely the case with blue king crab juveniles as well (Stevens and Swiney 2005).

Coincident with the stock decline of Pribilof blue king in the early 1980s, the abundance of cod and flatfishes 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 Pribilof blue king crab stock and the increase in the stocks of groundfish that are predators of and competitors with blue king crab remains speculative, however. Time series analysis of year classes of blue king crab and selected EBS fish stocks (Pacific cod, yellowfin sole, rockfish) have not revealed any correlation between groundfish predation or competition and the decline in blue king crab stocks (Zheng and Kruse 2000).

Mortality is also ascribed to ghost fishing of lost crab pots and groundfish pots. The term ghost fishing describes continued fishing by lost or derelict gear. Crab caught in ghost or 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 and High and Worlund (1979) estimated an effective fishing life of 15 years for king crab pots. Testimony from crabbers and pot manufacturers indicate that all pots currently fished in Bering Sea crab fisheries contain escape mechanisms (NPFMC 2007).

3) Changes in habitat quality

Blue king crab larvae spend three and a half to four months in pelagic larval stages before settling to the benthic life stage. Larvae are found in waters of depths between 40 to 60 m. Release of larvae in the nearshore areas and local current patterns and eddies may increase the chances for settlement and metamorphosis of glaucothoe in the nearshore "shell hash " (a mixture of broken bivalve and gastropod shells) habitat. However, conditions that would transport larvae away from the nearshore habitat probably occur at least occasionally, and such events would be expected to drastically reduce post-settlement survivorship (Armstrong et al. 1987). Additionally, conditions that affect the production of plankton will impact larval survival. Strong vertical mixing and an unstable water column associated with a strong Aleutian Low inhibit the growth of the *Thalassiosira* spp diatoms that provide important nutrients to zoeal king crabs (Zheng and Kruse 2000). In spring 2007, Bering Sea ice lasted for almost two months just to the north of the Pribilof Islands, contrasting with previous years since 2000 (ADF&G 2008). The presence of sea ice together with below normal ocean temperatures likely resulted in the first ice edge primary production bloom since 1999 (ADF&G 2008). Increased primary production could result in increased prey items for king crab larvae.

Juveniles occur primarily on substratum of gravel and/or cobble overlaid with shell hash (Armstrong et al. 1985). These habitat areas have been found at depths of 40-60 m around the Pribilof Islands and exist within 10-15 km of St. Paul Island and on a narrow ridge just east of St. George Island (Armstrong et al. 1985, 1987). This association suggests a habitat requirement for juvenile blue king crab in the Bering Sea that is limiting to the species' distribution. Shell hash habitat may be important to juveniles as a refuge from predators; juvenile blue king crab lack the long spines present on juvenile red king crabs and may have a greater requirement for the cover afforded by shell hash (Armstrong et al. 1985; 1987; Palacios et al. 1985). Blue king crab juveniles in their first year of life often have white carapaces that blend in with shell hash. Later juvenile stages have a mottled color pattern that blends into the background epifauna. Survival 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. Over 80 percent of juveniles live at depths < 50 m, and >90 percent live between 0-1°C (Armstrong et al. 1985).

Adult blue king crabs in the Pribilof Islands do not show the same restrictions to the nearshore habitat as juveniles (Palacios et al. 1985, Armstrong et al. 1987). Instead, adults show a seasonal distribution, with a high density in the nearshore areas to the east of St. Paul Island in spring and a more dispersed distribution in the offshore areas in the summer (Armstrong et al. 1987). The spring aggregations indicate a shoreward migration for egg hatching and mating and suggest the importance of the nearshore habitat around St. Paul Island for those purposes (NPFMC 2003). Adult female blue king crab prefer substratum of sandy mud (in 95 percent of samples) with gastropod shells, at depths of 40-80 m (Armstrong et al. 1985). Over 90 percent of legal males and mature females live at depths >50 m (Armstrong et al. 1985). Sixty-five percent of adults live between 2-3°C, the remainder live at temperatures <2°C.

Blue king crab are a cold-adapted species. Bottom temperature in the Pribilof Habitat Conservation Area during EBS summer survey catches of blue king crab range between 1.5 and 7.7 ˚C with an average of 3.08 ˚C (NMFS, unpublished data). Laboratory studies have shown a temperature effect on hatching timing, embryonic development, larval growth and survival (Stevens 2006b). Rising water temperatures could further limit habitat range by increasing competition from the more warm-water adapted red king crab and exclusion by warm-water predators (Somerton 1985, Armstrong et al 1985; 1987). Movement of the cold pool of bottom water northward with warming is thought be causing a reorganization of Bering Sea biogeography (Mueter and Litzow 2008). This is cause for possible concern for Pribilof Islands blue king crab.

The increasing acidification of the oceans' waters may also impact blue king crab at various life stages. Crabs use calcite (a stable form of $CaCO_3$) to harden chitinous exoskeletons and may be exposed to conditions of calcite undersaturation in areas where seawater pH has decreased. Currently, acidification research has only been conducted on larval blue king crab. Preliminary studies have indicated that a decrease in pH of 0.3 to 0.5 units from ambient (7.95) negatively affects growth, survival, and calcium mass (NMFS, unpublished data). However, Nakanishi (1987) found that survival of all zoeal stages was 100 percent at pH values from 6.5 to 8.0, and was very poor at pH values below 6.

4) Disease

Blue king crab may contract two potentially fatal diseases including a herpes-type viral disease of the bladder and systemic infections by a microsporidian of the genus *Thelohania* (Sparks and Morado 1985). Prevalence of these diseases during the early 1980s, as well as their general nature, suggests that they could cause considerable mortalities (ADF&G 2003). Although there is a high prevalence of parasitic barnacles (rhizocephalans) identified as *Briarosaccus callosum* in blue king crab populations in southeastern Alaska (Shirley et al 1995; Hawkes et al 1985), there is no record of rhizocephalan infections of blue king crab in the eastern Bering Sea (ADF&G 2003).

Fishery Effects on the Ecosystem

1) *Fishery-specific contribution to bycatch of prohibited species, forage (including herring and juvenile pollock), HAPC biota*

There has been no fishery for blue king crab since 1999; however, benthic species that may be caught as bycatch in the crab fishery include fish, gastropods (snails), coral, echinoderms (stars and sea urchin), non-FMP crab, and other invertebrates (sponges, octopus, anemone, and jelly fish). Fish, including a number of crab predators, especially Pacific cod, halibut, yellowfin sole, and sculpin (*Myoxocephalus* spp.) account for the greatest proportion of estimated crab pot bycatch. These species are widely distributed and highly abundant representatives of the greater groundfish community (NPFMC 2003). The fishery does not occur in any areas designated as HAPC (NPFMC 2003).

NMFS Sustainable Fisheries concluded that the effects of the crab fisheries prosecuted under the FMP are not likely to (1) result in the direct take or compete for the prey of the seven large protected whale species, Northern Right Whale (*Balaena glacialis*), Bowhead Whale (*Balaena mysticetus*), Sei Whale (*Balaenoptera borealis*), Blue Whale (*Balaenoptera musculus*), Fin Whale (*Balaenoptera physalus*), Humpback Whale (*Megaptera novaeangliae*), Sperm Whale, (*Physeter acrocephalus*), or the western and eastern population of Steller sea lions (*Eumetopias jubatus*) or (2) destroy or adversely modify designated Steller sea lion critical habitat (ADF&G 2003).

2) 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.

The blue king crab fishery occurred in the area of highest large male abundance, northeast of the Pribilof Islands. The season for the Pribilof Islands blue king crab fisheries opened September 15 and lasted until the GHL was harvested, which was usually about a week. Relative to predator needs in space and time, the fishery targeted large males which are not known to be a common prey item. Mating occurs in late March through mid-April so the fishery would have had no impact except to reduce the number of mature males available to mate.

3) *Fishery-specific effects on amount of large size target fish.*

The fishery may have had an effect on reducing the amount of large size target crab in the population; however there are no studies conclusive on the fishery being the cause behind the decline in the population.

4) *Fishery-specific contribution to discards and offal production.*

Discards would have consisted of undersized king crabs (NMFS 1995).

5) *Fishery-specific effects on age-at-maturity and fecundity of the target species.*

It is unknown what effect the fishery may have had on age-at-maturity and fecundity. It is probable that the fishery did not affect age-at-maturity but it is possible that the loss of mature male crabs to the fishery could have created an absence of mates for mature female crabs, thus decreasing fecundity.

6) *Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance).*
It is unknown what effect the setting and retrieval of pots from the sea floor has on EFH non-living substrate. Bottom trawls and dredges could disrupt nursery and adult feeding areas (NMFS 1995).

Ecosystem effects on the Pribilof Islands blue king crab stocks and fishery effects on the ecosystem are interpreted and evaluated in Table 4.

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Table 1. Mature Pribilof Islands District blue king crab abundance, mature biomass, and legal male biomass (million lbs), and totals estimated from the NMFS annual EBS bottom trawl survey.

	Mature Crabs (10^6 Crab)		Mature Biomass (10^6 LB)		Legal Males >=135mm CL (10^6 LB)	Total males (10^6 LB)	Total females (10^6 LB)	Total Crab (10^6 LB)
Year	Male	Female	Male	Female	Male			
1979/1980	na	na	na	na	na			
1980/1981	5.63	101.00	32.63	260.14	28.00			
1981/1982	5.63	10.80	32.19	27.56	27.56			
1982/1983	3.00	8.23	16.95	20.86	14.57			
1983/1984	2.19	8.87	11.51	21.32	8.66			
1984/1985	0.86	3.05	4.92	7.56	3.97			
1985/1986	0.48	0.52	2.51	1.23	1.93			
1986/1987	0.45	1.85	2.84	4.72	2.80			
1987/1988	0.82	0.57	5.27	1.53	4.96			
1988/1989	0.20	0.38	1.40	0.99	1.39			
1989/1990	0.42	0.95	2.02	1.81	1.59			
1990/1991	1.72	2.04	6.17	4.19	2.29			
1991/1992	2.04	2.39	8.80	4.92	5.53			
1992/1993	2.24	1.65	9.17	3.28	5.51			
1993/1994	1.88	1.88	8.73	3.90	5.78			
1994/1995	1.30	3.95	6.24	8.51	4.63			
1995/1996	3.18	3.80	16.49	8.27	12.74			
1996/1997	1.96	4.48	9.94	10.71	7.63			
1997/1998	1.18	2.31	6.11	5.53	4.96			
1998/1999	1.31	1.74	6.75	4.12	5.45			
1999/2000	0.72	2.42	3.73	5.71	2.93			
2000/2001	0.73	1.38	4.14	3.31	3.37			
2001/2002	0.54	1.61	3.17	3.84	2.78			
2002/2003	0.22	1.23	1.36	3.17	1.29			
2003/2004	0.22	1.08	1.34	2.76	1.28			
2004/2005	0.07	0.10	0.29	0.29	0.11			
2005/2006	0.10	0.31	0.76	0.88	0.76			
2006/2007	0.08	0.45	0.39	1.21	0.28			
2007/2008	0.17	0.20	0.76	0.55	0.41	1.02	0.65	1.67
2008/2009	0.29	1.33			0.10	0.57	1.74	2.31

Table 2. Retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2008; D. Barnard and D. Pengilly, ADF&G, personal communications).

	Retained catch		
	OA/IFQ	CDQ	Total
	10^6 lbs	10^6 lbs	10^6 lbs
1973/1974	1.277		1.277
1974/1975	7.107		7.107
1975/1976	2.434		2.434
1976/1977	6.611		6.611
1977/1978	6.457		6.457
1978/1979	6.396		6.396
1979/1980	5.995		5.995
1980/1981	10.970		10.970
1981/1982	9.081		9.081
1982/1983	4.405		4.405
1983/1984	2.193		2.193
1984/1985	0.307		0.307
1985/1986	0.528		0.528
1986/1987	0.259		0.259
1987/1988	0.701		0.701
1988/1989			
1989/1990			
1990/1991			
1991/1992			
1992/1993			
1993/1994			
1994/1995			
1995/1996	1.385		1.385
1996/1997	0.937		0.937
1997/1998	0.512		0.512
1998/1999	0.518		0.518
1999/2000			
2000/2001			
2001/2002			
2002/2003			
2003/2004			
2004/2005			
2005/2006			
2006/2007			
2007/2008			

Table 3. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2008; D. Barnard and D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Discard/bycatch				
	All EBS Pot Fisheries				Groundfish Fisheries
	Legal non-retained	Sublegal male	All Female	Total (all crab)	Both sexes
	10^6 lbs	10^6 lbs	10^6 lbs	10^6 lbs	10^6 lbs
1979/1980					
1980/1981					
1981/1982					
1982/1983					
1983/1984					
1984/1985					
1985/1986					
1986/1987					
1987/1988					
1988/1989					
1989/1990					
1990/1991					
1991/1992					0.149
1992/1993					0.209
1993/1994					0.070
1994/1995					0.008
1995/1996					0.006
1996/1997		0.0018		0.0018	0.004
1997/1998					0.048
1998/1999	0.0051	0.0010	0.0082	0.0143	0.010
1999/2000	0.0077	0.0095	0.0043	0.0215	0.009
2000/2001					0.005
2001/2002					0.013
2002/2003					0.001
2003/2004					0.001
2004/2005					0.002
2005/2006			0.0001	0.0001	0.003
2006/2007			0.0002	0.0002	0.027
2007/2008			0.0003	0.0003	0.027

Table 4. Ecosystem effects on Pribilof blue king crab			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton, phytoplankton, benthic infauna	Stomach contents, plankton surveys	Stable, though phytoplankton varies inter-annually	Possible concern
Predator population trends			
Marine mammals (Sea otters)	Population trends vary by location	Not likely to affect surveyed stock	No concern
Birds	NA	NA	No concern
Fish (Pollock, Pacific cod, halibut)	Stable	stable	Possible concern
Changes in habitat quality			
Temperature regime	Cold-water restricted species so warming trends could limit population	Likely to affect surveyed stock	Definite concern
Winter-spring environmental conditions	Affects larval survival	Affects timing of larval release and timing of molt intervals	Definite concern
Production	Affects larval survival	Inter-annual variability dependent on a number of climatic conditions	Definite concern
Pribilof blue king crab effects on ecosystem			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Likely minor impact	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Likely minor impact	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	No impact	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern

Fishery concentration in space and time	Low exploitation rate by predators; possible impact on fecundity	Little detrimental effect on predators; possible impact on fecundity	No concern for predators; possible concern for fecundity
Fishery effects on amount of large size target fish	High exploitation rate	Natural fluctuation	Definite concern
Fishery contribution to discards and offal production	unknown	data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	unknown	NA	Possible concern

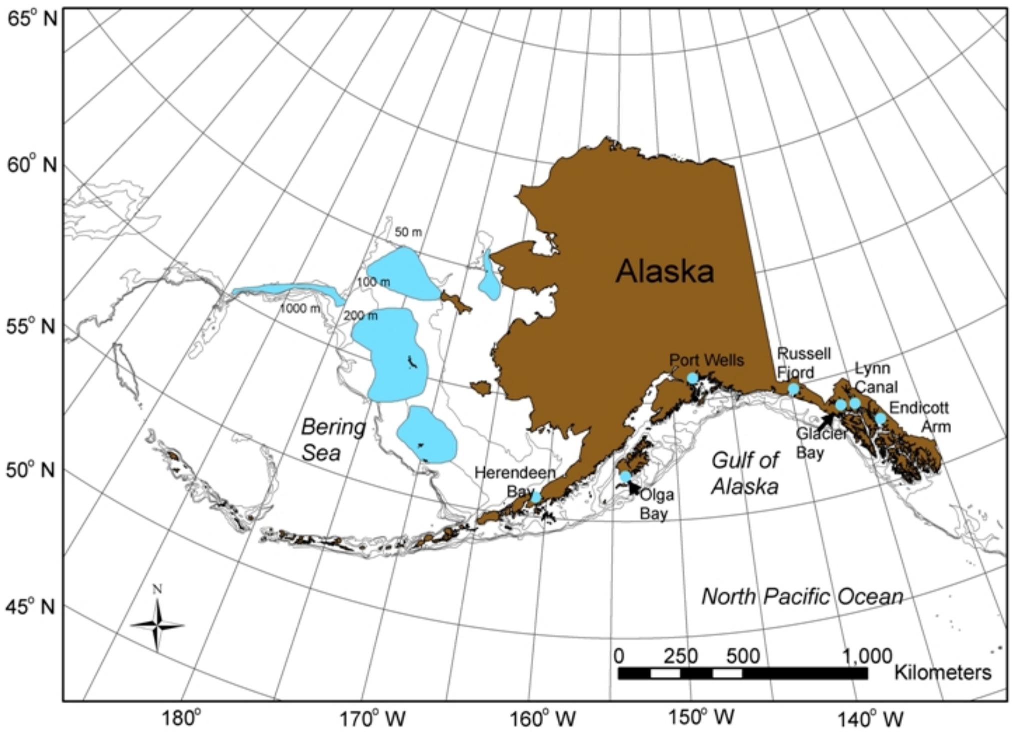

Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

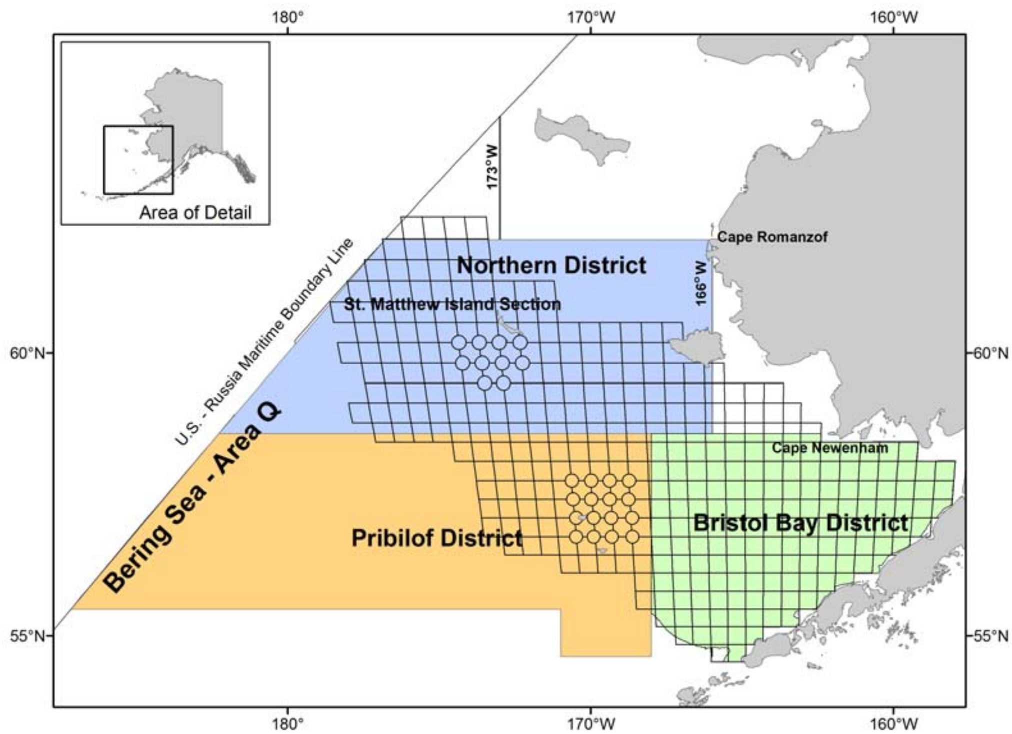

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

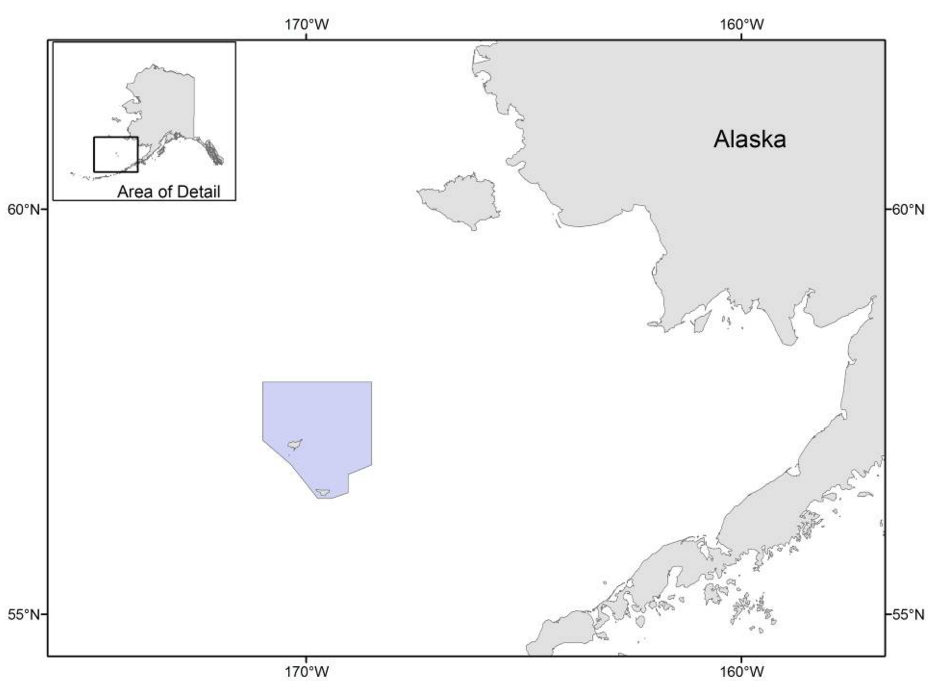

Figure 3. The Pribilof Islands Area Habitat Conservation Zone. Trawl fishing is prohibited year-round in this zone.

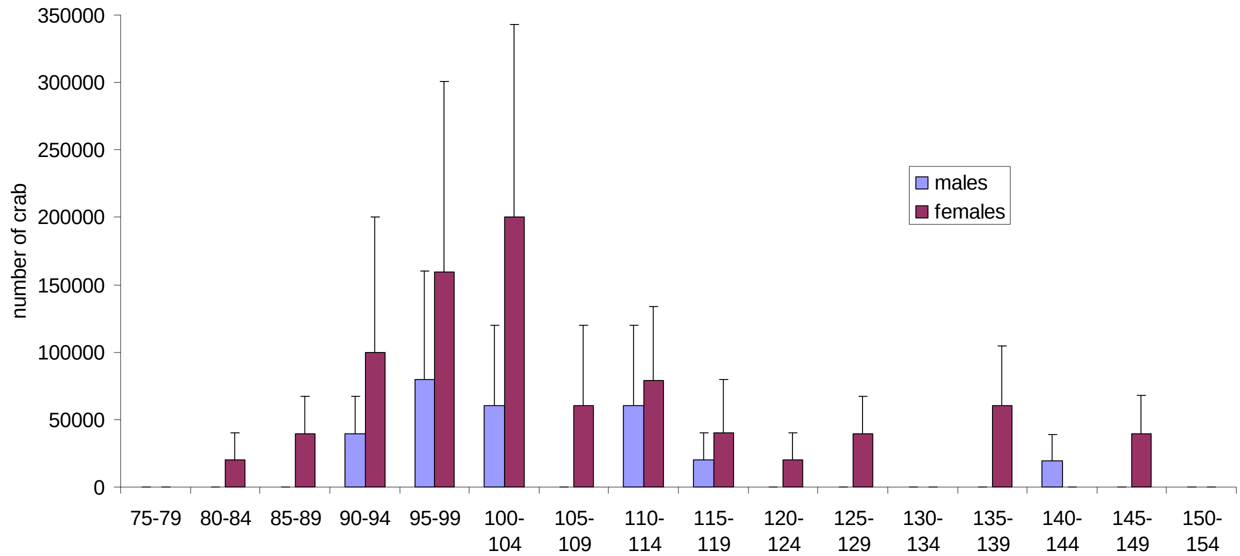

Figure 4. Distribution of average (SE) counts of Pribilof Island blue king crab in 5 mm length bins.

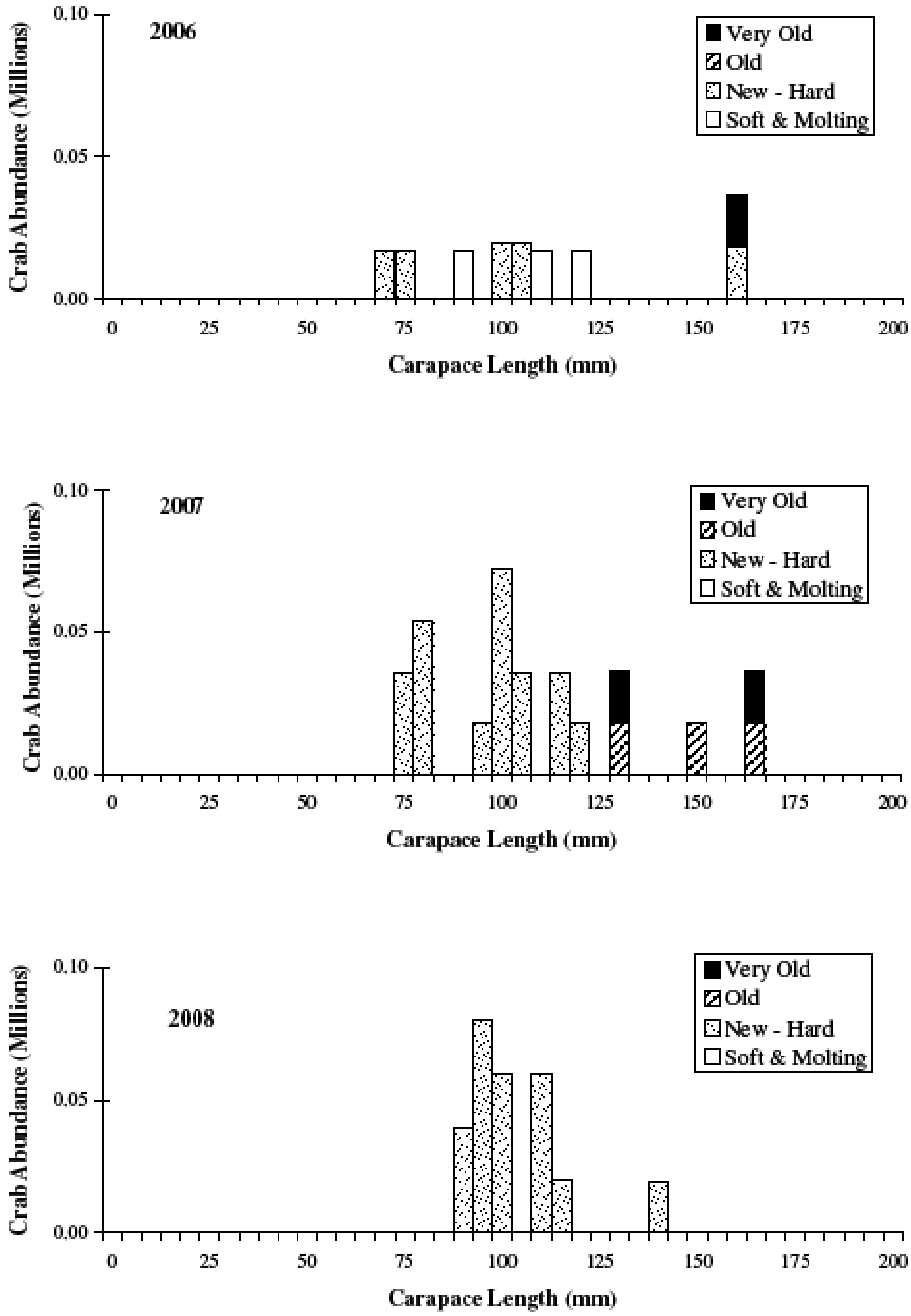

Figure 5. Distribution of average (SE) counts of Pribilof Island blue king crab in 5 mm length bins from 2006 to 2008.

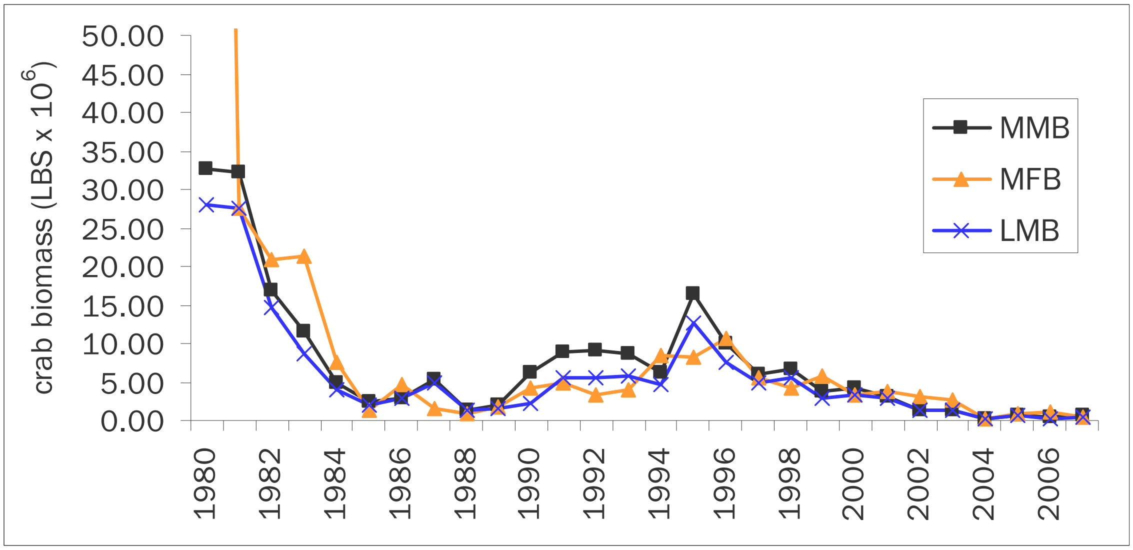

Figure 6. Historical trends of Pribilof Island blue king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

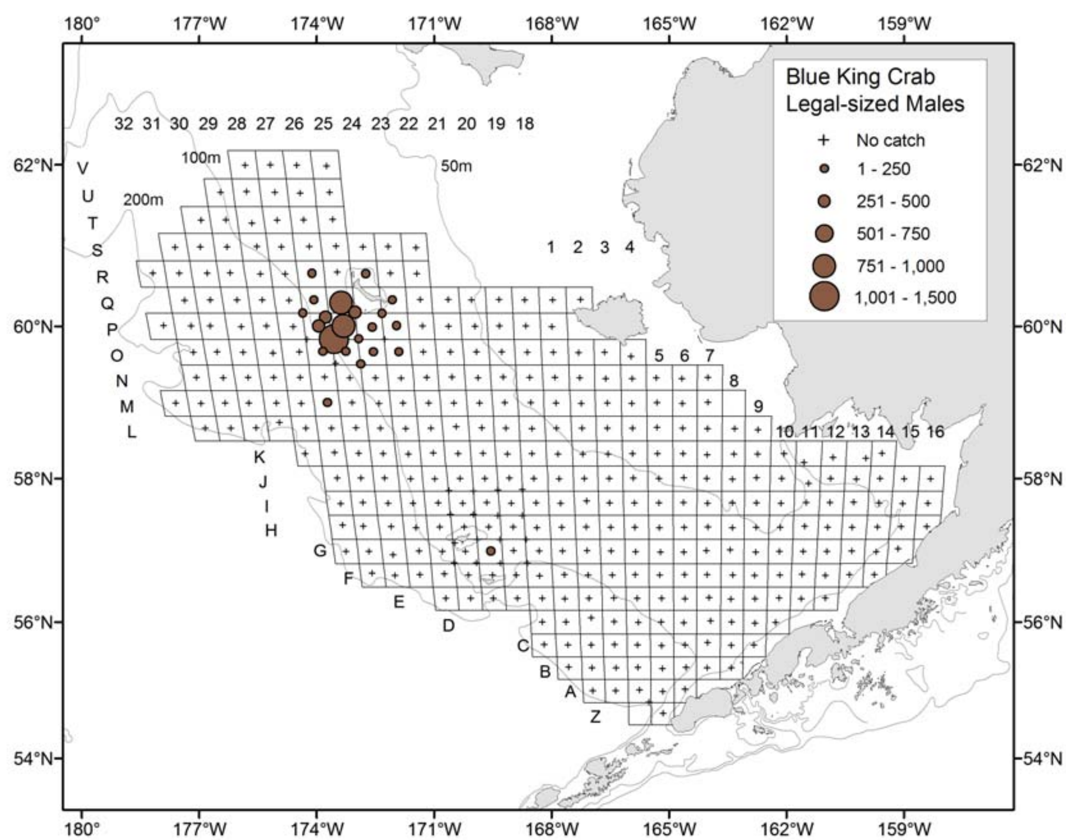

Figure 7. Location and relative abundance of blue king crab in the eastern Bering Sea (2008 NMFS bottom trawl survey data).

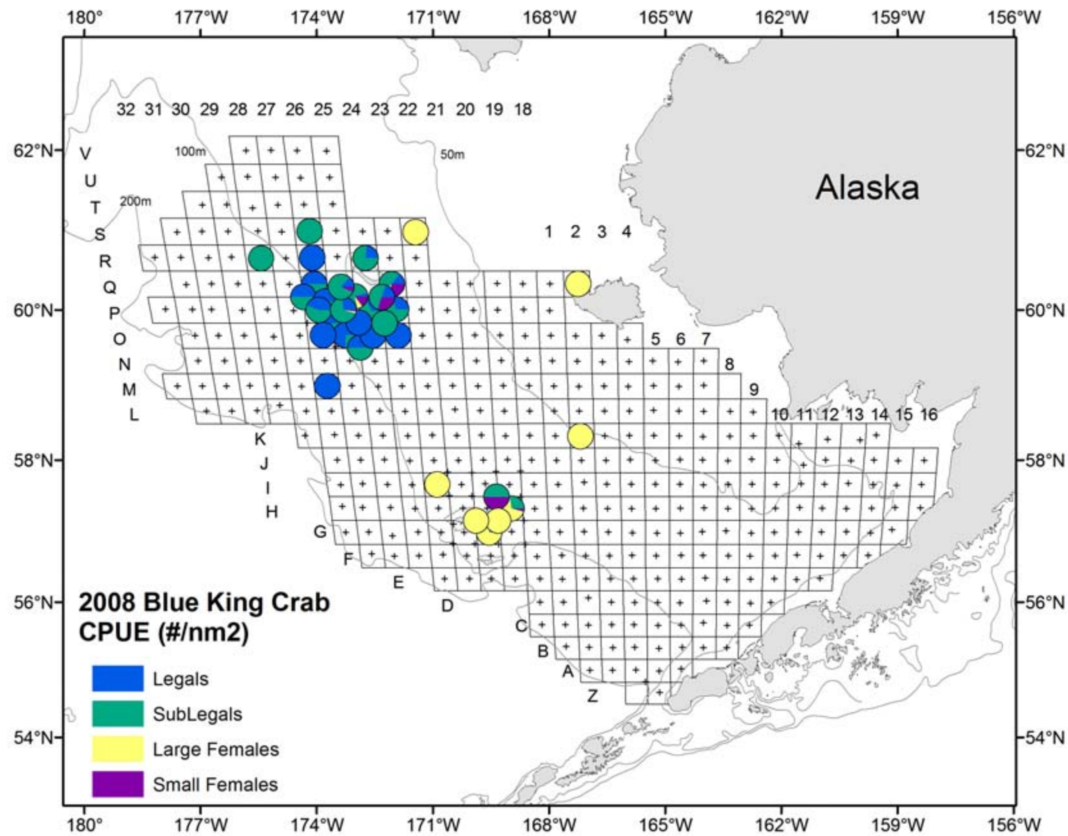

Figure 8. 2008 EBS bottom trawl survey size class distribution of blue king crab.

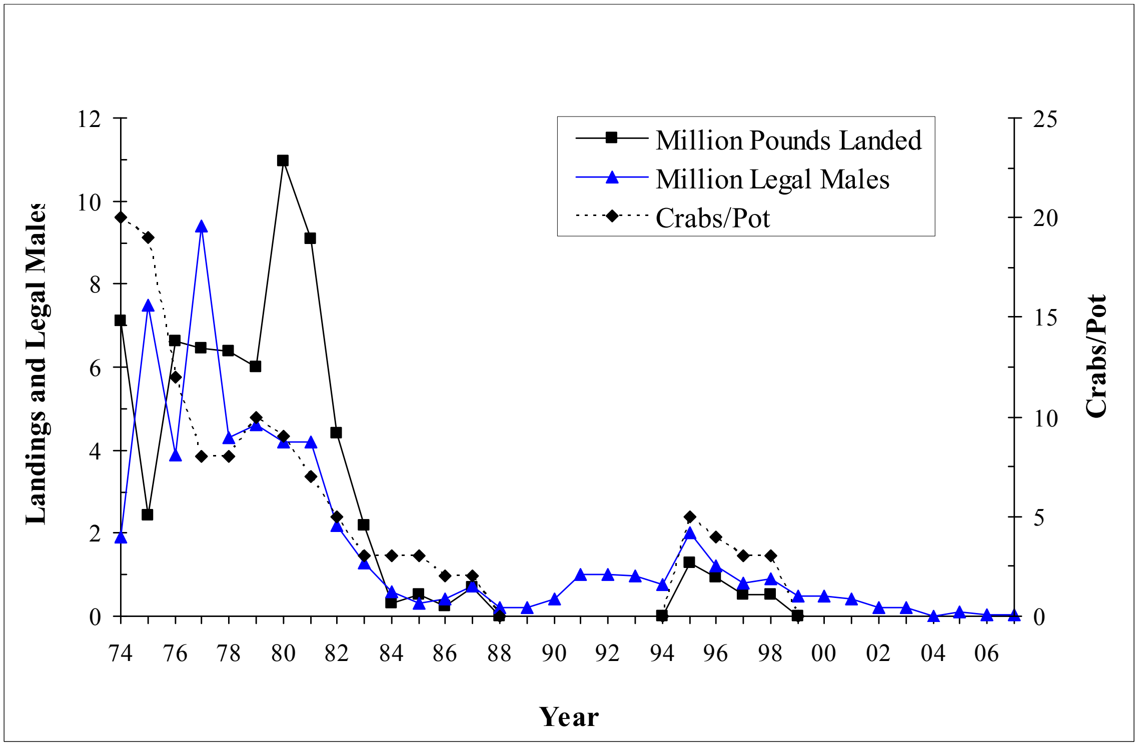

Figure 9. Historical harvests, CPUEs for Pribilof Island blue king crab (Bowers et al. 2007) and the NMFS EBS bottom trawl survey trends in legal male abundance.

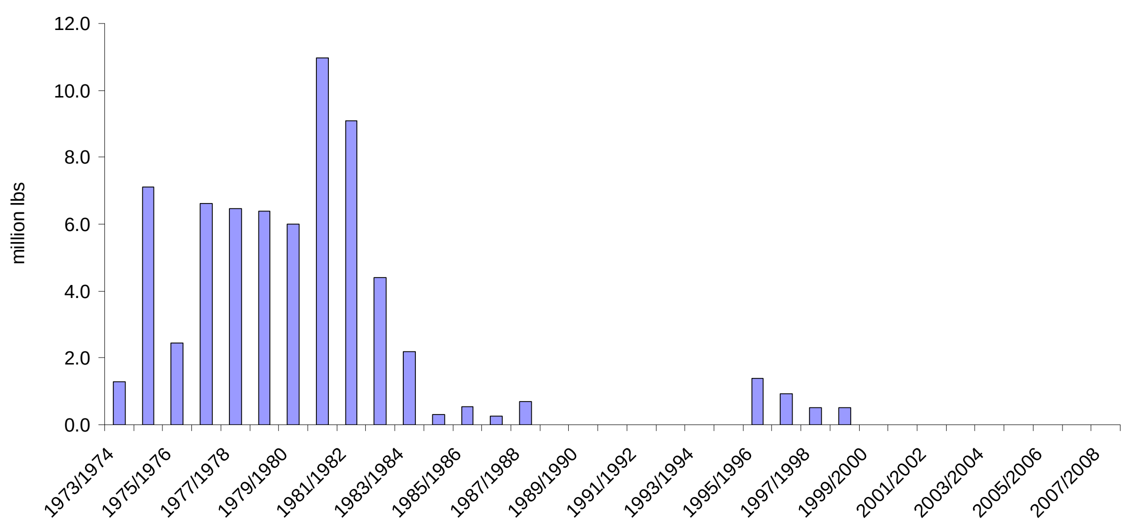

Figure 10. Retained catches from directed fisheries for Pribilof Islands District blue king crab

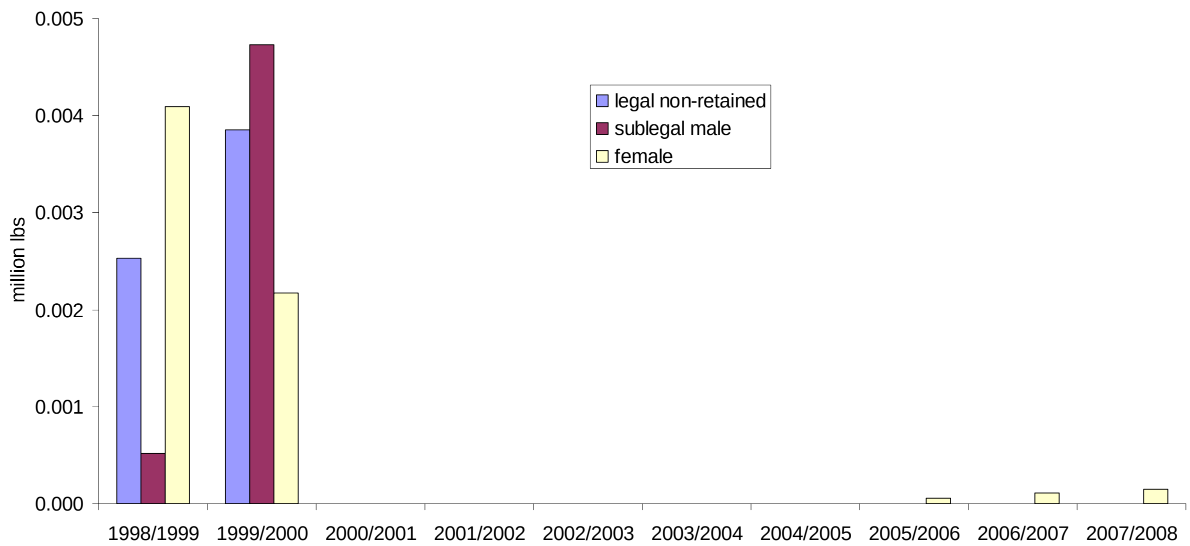

Figure 11. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District blue king crab.

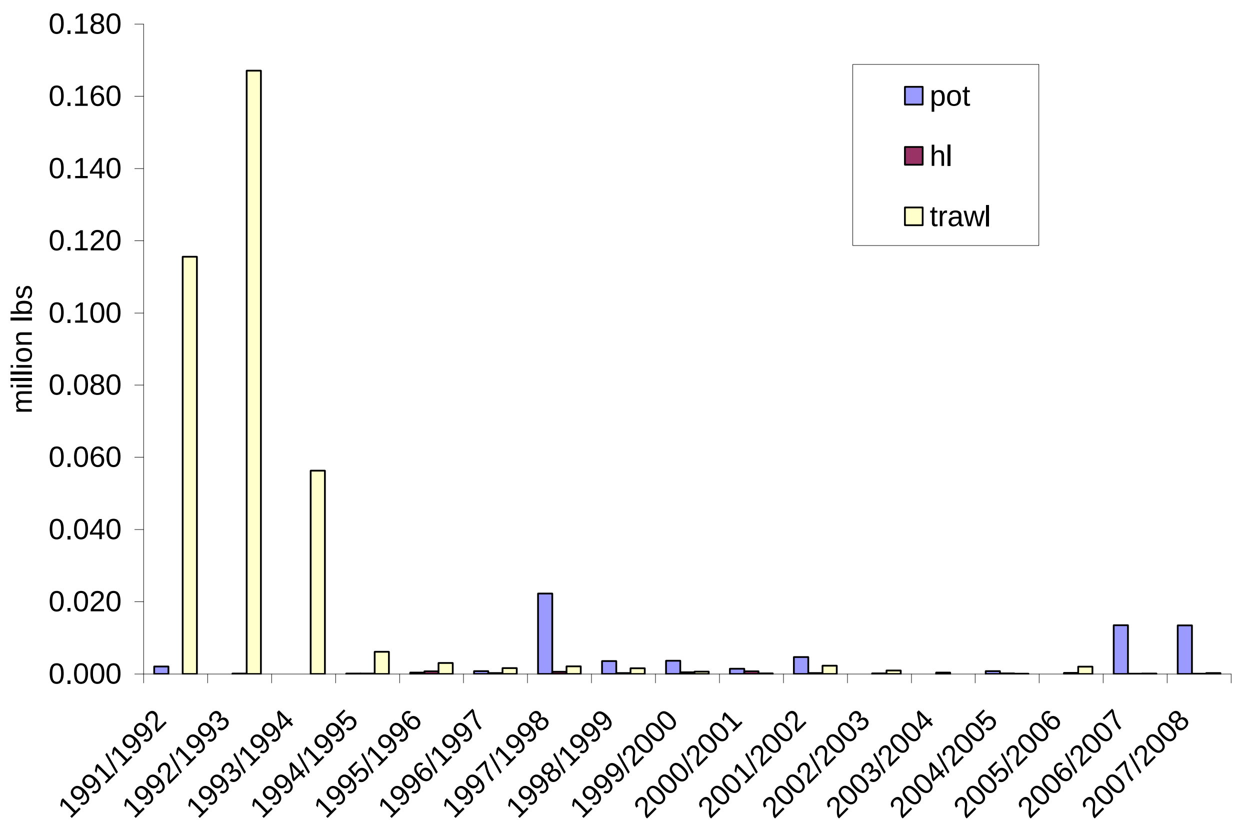

Figure 12. Catch mortalities from non-directed groundfish fisheries for Pribilof Islands District blue king crab in federal reporting area 513. Data for both golden king crab and blue king crab are combined from 1991/1992 to 2002/2003 and then only blue king crab are presented from 2003/2004 to 2007/2008. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the total catches.

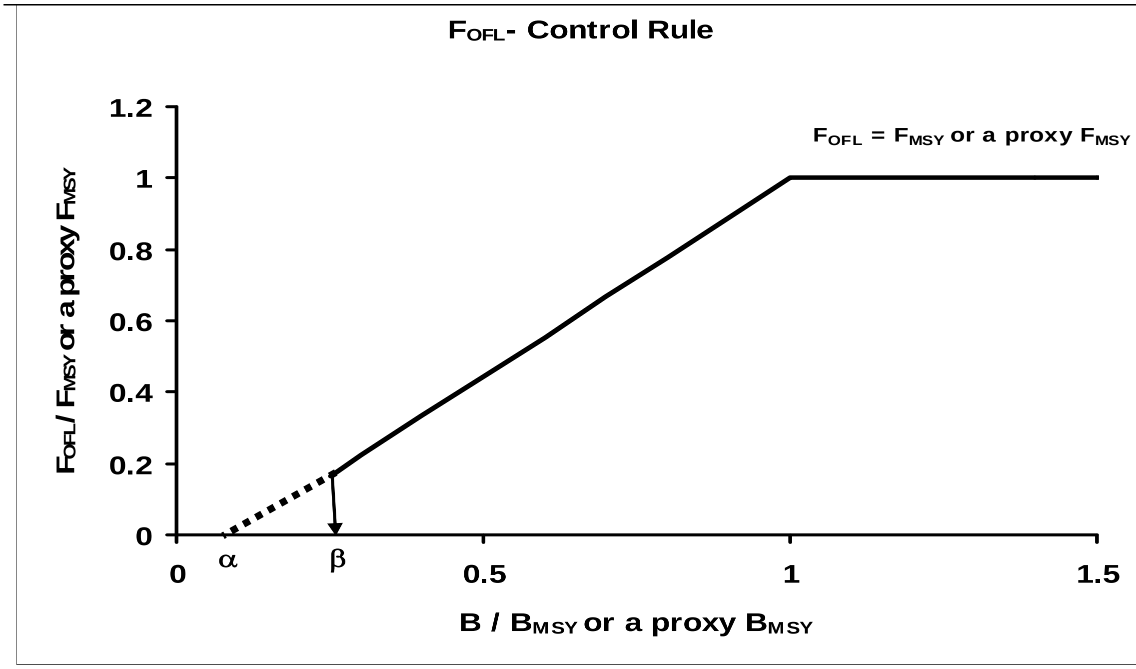

Figure 13. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

Appendix 1. Surplus Yield Estimate for Pribilof Islands Blue King Crab (A. Punt, personal communication)

The dynamics of mature males can be modelled using the following equation, under the assumption of constant recruitment:

$$B_{t+1} = B_t + R - C_t \tag{1}$$

where B_t is the mature biomass at the start of year *t*,
C_t is the catch (of mature males) during year *t*, and
R is the recruitment to the mature male biomass.

Table 1 lists the survey estimates of mature male biomass for 1999/2000 – 2007/2008 (the years following the closure of the directed fishery) and the estimate of total (male+female) non-retained catch from directed and non-directed fisheries. An estimate of (mean) recruitment can be estimated as:

$$\hat{R} = \overline{(B_{t+1} - B_t)} - \overline{C_t} \tag{2}$$

Application of Equation 2 results in an estimate of -0.48 million lbs, i.e. the average losses to natural mortality over the period considered in the analyses exceed recruitment during this period. Note that this estimate will be positively biased because the catches in Table 1 include, *inter alia* females.

Table 1. Data used when estimating mean recruitment.

Year	Survey MMB	Non-retained catch
1999/2000	3.73	0.022
2000/2001	4.14	0.005
2001/2002	3.17	0.013
2002/2003	1.36	0.001
2003/2004	1.34	0.001
2004/2005	0.29	0.002
2005/2006	0.76	0.003
2006/2007	0.39	0.027
2007/2008	0.76	0.027

St. Matthew Blue King Crab Stock Assessment in Fall 2008

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Executive Summary

A catch-survey analysis was updated with trawl survey data from 1978 to 2008, triennial pot survey data from 1995 to 2007, and commercial catch data from 1978 to 2007 to assess St. Matthew Island blue king crab abundance in 2008. A maximum likelihood approach was used to estimate abundance and recruitment. Five scenarios of the model were evaluated. Scenario (1) fixed natural mortality for both 1978-1998 and 2000-2008 (M=0.18) and trawl survey catchability (Q=1) with estimating M in 1999; scenario (2) fixed Q = 1 and estimated two M values (one for 1978-1998 and 2000-2008 and one for 1999); scenario (3) fixed M=0.18 for 1978-1998 and 2000-2008 and estimated Q and also estimated M for 1999; scenario (4) fixed a constant M = 0.18 for the whole time series and Q = 1; and scenario (5) fixed Q = 1 and estimated a constant M for the whole time series. Estimated legal abundance and mature male biomass in 2008 are:

	Scenario (1)	Scenario (2)
Legal males:	2,244,000 crab or 10.200 million lbs,	2,007,000 crab or 8.876 million lbs
Mature male biomass (γ= 1):	10.743 million lbs	7.944 million lbs.

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
Based on average during 1978-2008:	7.509 million lbs,	6.877 million lbs,
Based on average during 1983-1998:	7.085 million lbs,	6.526 million lbs,

Based on average during 1983-2008:	6.570 million lbs.	5.854 million lbs,
Based on average during 1989-2008:	7.387 million lbs.	6.528 million lbs.

Estimated F_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
$\gamma = 1$:	0.180,	0.308,
$\gamma = 1.5$:	0.270,	0.462.

Estimated mature male biomass in 2008 was above any of the suggested B_{MSY} proxies. The stock appears to have increased greatly during the last few years.

If $\gamma = 1$ to 1.5, F_{MSY} proxy can range from 0.18 to 0.462, corresponding to harvest rates ranging from 16.5% to 37.0% of legal abundance at the time of fishing. After adjusting the time difference of surveys and the directed fishery, the overfishing limits for retained catch in 2008 range from 1.630 million lbs to 2.338 million lbs for model scenario (1) and from 2.227 million lbs to 3.109 million lbs for model scenario (2) depending on the γ value.

Response to CPT Comments (from May 2008)

"Bycatch data needs to be compiled with an analysis to generate a total catch OFL for next year's assessments. Bycatch estimates from the model should be tabulated to provide information for estimating a total catch OFL. Figures of standardized residuals should be provided, along with providing clarification on whether the residual patterns reflect a cohort effect or a growth effect. The assessments need to include figures showing data and fits to these data for both pot and trawl surveys including confidence intervals on data and model results. The assessment should also examine the sensitivity of the weighting choices employed in the model to examine relative influence on results [e.g. conducting the assessment using each of the two indices of abundance in turn (pot and trawl survey)]. The plan team recomends examining the sensitivity of constant M over the whole time period."

Lack of trawl bycatch estimates for this stock from NMFS and limited pot bycatch data make it difficult to use total catch as OFL this year. Standardized residuals were plotted in the May, 2008 report and are re-graphed in this report for a better presentation. The residuals are highly dependent on the choice of natural mortality. There are no apparent growth or cohort effects from the residuals. In addition to the abundance residual plots, the model fits are also compared by graphing model estimates and survey abundance estimates in this report. The CVs of the survey data may be used in the assessment next year. The relative influence on results from each of two survey indices can be examined next year. Prior to this year, the sensitivity of a constant *M* over the whole time period had been examined every year since 1999. The reasons that a constant *M* over the whole time period does not work well (bad fits of the survey data and leading to overexploiting the stock) have been addressed in a paper. The constant *M* scenario is added to this report to satisfy the request of the CPT.

Response to SSC Comments specific to this assessment (from June 2008)

"The Plan Team was uncomfortable with some features of the assessment data (particularly the failure to include available bycatch data) and model fit, and therefore chose not to place this stock in Tier 3. Instead the team for this year preferred to use the biomass estimates from the model fit but to use the standard Tier 4 procedures to set OFL. ***The SSC agrees with management of this stock under tier 4 this year and all the plan team recommendations with respect to years of data, gamma, and natural mortality rate.*** *However, we look forward to having the authors and the team resolve the questions about the assessment model fit so that it can be used in the near future for the OFL determination. The SAFE document has a preface stating that the authors will get together before the September plan team meeting to work through some of the issues. The SSC would like to get a progress report and the opportunity to review the model at the October meeting."*

So far, NMFS has not been able to provide trawl bycatch estimates for this stock. Pot bycatch observer data are available for a few years for mostly 1 to 3 catcher processor vessels only. There has been no observer coverage for catcher vessels (about 168 of total 174 fishing vessels). So pot bycatch estimates are also highly uncertain and are not used in the model directly. The model assumes a bycatch selectivity to assess the impact of pot bycatch on abundance estimates. Because of these bycatch estimation problems, we use retained catch for OFL in this report.

The authors have not been able to meet before the September plan team meeting to discuss the issues. However, the authors discussed the issues during the CPT meeting in May 2008.

Response to SSC Comments in General (from June 2008)

"General recommendations to all assessment authors for future assessments:

1. *To the extent possible, a consistent format should be used for the assessments; sections that are not relevant to a particular stock should be omitted."*

Agree.

2. *"Each assessment should provide a range of alternatives for the Plan Team and SSC to consider when setting OFLs, for example, alternative model configurations for Tier 1-3 stocks, alternative*

parameter values where these are highly uncertain and cannot be estimated, or alternative time periods used in Tier 4 and Tier 5 calculations."

Agree.

3. *"Model-based stock assessments should clearly document all data sources, model equations, the number of parameters, a list of which parameters are estimated in the model, and a list of fixed parameters, and a justification for the selected parameter values."*

Agree.

4. *"The rationale for selecting a specific time period for establishing B_{MSY} proxies based on time series of recruitment (Tier 1-3) or biomass (Tier 4) or for establishing an OFL based on catch histories (Tier 5) should be clearly articulated. Unless compelling reasons exist to choose a different period, the default should be the full time series for which data are available. When alternative time periods are considered, the rationale and the resulting reference points should be presented for consideration by the Plan Team and SSC."*

Agree.

5. *"The crab OFL definitions are designed to provide a guide for defining the best available proxy for MSY when data are insufficient to directly estimate MSY. The guidelines allow gamma in the formula for computing F_{OFL} under Tier 4 to be set at a value higher or lower than 1. A gamma less than 1 might be justifiable if the available biomass measure includes a large portion of small crab that has not recruited to the fishery. A gamma greater than 1 might be justifiable if the directed fishery can be expected to harvest male crab with carapace widths well above the size at 50% maturity. The SSC agrees with the Plan Team recommendation that* **future stock assessments should provide analyses to support the choice of gamma**. *These analyses could include an exploration of fishery selectivity and a comparison of minimum size limits and size at 50% maturity for male crab. The SSC does not recommend the use of an $F_{35\%}/M$ ratio derived from one stock as a default for gamma on an unrelated stock unless there is a strong rationale for concluding that the fishery is likely to be prosecuted in an identical manner and knowledge of stock status is sufficient to justify the harvest rate."*

Agree. The gamma value can be evaluated next year.

6. *"To the extent possible, bycatch information should be provided for all stocks included in the SAFE so that stock OFLs can be moved from "retained catch OFL" to "total catch OFL"".*

See the response above. Due to lack of bycatch data, retained catch is used as OFL in this report.

7. *"For stocks with an assessment model, the SSC requests that the authors include a table summarizing the fit to data (including number of parameters, likelihood for each data component, etc.)."*

These are included in this report.

8. *"The ecosystem considerations sections could be expanded to include information on prey and predator composition in a consistent format (e.g., pie charts similar to the groundfish assessments). A discussion of seabird predation on crab would be a useful addition. We note that seabirds feed on larval through juvenile crab, particularly in shallow or nearshore areas, such as the Pribilof Islands. Plankton-feeding birds eat larval crab and juveniles are consumed by seaducks and seabirds, particularly during winter months."*

Few prey and predator data are available for this stock.

9. *"Each assessment should include figures showing the available time series of catch and survey biomass, in addition to tables, to facilitate comparisons and the selection of appropriate time periods."*

Agree. These are in this report.

10. *"The presentation of recruitment time series should be standardized as to year (examples include year of recruitment to maturity for spawner/recruit data, or perhaps year of hatching; and year of recruitment to legal size for catch data) to clearly illustrate specific cohort strength."*

Recruitment is referred to year of recruitment to the model in this report. The year of recruitment to the mode is one year less than the year of recruitment to maturity.

11. *"Assessment authors should provide alternative options for setting OFLs to the Plan Team and the SSC, particularly where there are large uncertainties about correct model structure or parameter estimates."*

Agree.

Introduction

Blue king crab, *Paralithodes platypus* (Brant 1850), are sporadically distributed throughout their range in the North Pacific Ocean from Hokkaido, Japan to southeastern Alaska. In the eastern Bering Sea, small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in cold water areas of the Gulf of Alaska at Olga Bay- Kodiak Island and at Port Wells- Prince William Sound, Russell Fjord, Glacier Bay, Lynn Canal, and Endicott Arm- Southeast Alaska (Figure 1) (Somerton 1985). Adult blue king crab are found at depths less than 180 meters and in average bottom water temperatures of 0.6° C (NPFMC 1998). The St. Matthew Island Section for blue king crab is within the Northern District of the Bering Sea king crab registration area (Area Q2) and includes the waters north of the latitude of Cape Newenham (58°39' N. lat.) and south of the latitude of Cape Romanzof (61°49' N. lat.) (Figure 2) (Bowers et al. 2008).

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional populations between blue king crab collected from St. Matthew Island and the Pribilof

Islands based on a limited number of variable genetic markers using allozyme electrophoresis methods (1997, NOAA grant Bering Sea Crab Research II, NA16FN2621). Tag return data from studies by the National Marine Fisheries Service (NMFS) on blue king crab in the Pribilof Islands (n = 317) and St. Matthew Island (n = 253) support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). These two stocks are managed separately based on different life history characteristics and exploitation by the fishery.

Catch History

Fisheries

The St. Matthew Island fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990); 10 U.S. vessels harvested 1.202 million pounds in 1977. Harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (Figure 3). The fishing seasons were generally short, lasting less than a month (Table 1). From 1986 to 1990 the fishery was fairly stable, harvesting a mean of 1.252 million pounds by <70 vessels (Figure 3; Table 2). The mean catch increased to 3.297 million pounds during 1991-1998. Participation increased from 68 vessels in 1991 to 174 vessels in 1992. After 1992, the St. Matthew and Pribilof Islands blue king crab fisheries were opened concurrently, dividing vessel effort between the two fisheries and initially stabilizing vessel participation at about 90 vessels. To reduce total fishing effort and improve manageability of the relatively small allowable harvests, maximum limits of 60 pots and 75 pots were set in 1993 for vessels <38.1 m and ≥38.1 m, respectively. Those limits reduced the number of pots registered by a third from 1992 to 1993 (Bowers et al. 2008). However, the number of potlifts in the fishery increased slightly because the season length doubled and pot turnover rates increased. During 1996-1998 participation increased to an average of 123 vessels per year and the average number of potlifts increased 54% from 1992 (Bowers et al. 2008).

This fishery was declared overfished and closed in 1999 when the stock size estimate was below the minimum stock size threshold (MSST) of 11.0 million pounds as defined by the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1998). In November of 2000, Amendment 15 to the FMP for the Bering Sea/Aleutian Islands King and Tanner crabs was approved to implement a rebuilding plan for St. Matthew Island blue king crab stock. The rebuilding plan included an Alaska Board of Fisheries approved harvest strategy and area closures to control bycatch as well as gear modifications and an area closure for habitat protection. Since 1999, the abundance estimates calculated from the National Marine Fisheries Service (NMFS) annual eastern Bering Sea shelf survey data have not met the harvest strategy threshold defined in the rebuilding plan although 2006 and 2007 abundance estimates, 11.2 and 15.6 million pounds respectively, were above MSST and the stock is considered rebuilding (Bowers et al. 2008). Currently, there is no directed commercial fishery for blue king crab in the St. Matthew Island district.

Zheng and Kruse (2002) hypothesized a high level of natural mortality in the St. Matthew blue king crab stock from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998 commercial fishery and in the 1999 ADF&G nearshore pot survey, as well as the low numbers across all male crab size groups caught in the eastern Bering Sea NMFS annual trawl survey from 1999 to 2005. Watson (2005) has found similar trends in the population estimates for St. Matthew blue king crab based on the 1995-2004 ADF&G pot survey conducted triennially in the St. Matthew Island district.

Commercial crab fisheries near St. Matthew Island have been scheduled in the fall and early winter to reduce the potential for bycatch from handling mortalities due to molting and mating crabs. Some bycatch has been observed of non-retained St. Matthew blue king crab in both the St. Matthew blue king crab fishery and the eastern Bering Sea snow crab fishery. The St. Matthew Island golden king crab fishery, the third commercial crab fishery in that area, is executed in areas with depths deeper than blue king crab distribution. Discard mortality rates have been established by the NPFMC (1999), and could be species or fishery specific. Bycatch mortality rates for all crab species were set at 80% in trawl fisheries, 40% in dredge fisheries and 20% in fixed gear fisheries. The directed crab fishery mortality rate was set at 8% for blue king crab, averaged across different crab fisheries (NPFMC 2006).

Harvest Strategy

Subject to the federal overfishing limits, the current TAC is determined based on the state harvest strategy (**5 AAC 34.917**), which was adopted by the BOF in March 2000 as part of a rebuilding plan developed for the stock (NPFMC 2000). The harvest strategy has four components for determining the TAC:

- A threshold of 2.9-million pounds of mature male biomass,
- An exploitation rate on mature male abundance that is a function of mature male biomass,
- A 40% cap on the harvest of legal males, and
- A minimum 2.778-million pound TAC for a fishery opening.

Mature male biomass (MMB) is defined for the harvest strategy as the biomass of males ≥105-mm carapace length (CL) in July. When MMB is below the 2.9-million-pound threshold of the State's harvest strategy, the stock is closed to commercial fishing. When the stock is above that threshold, an exploitation rate on mature male abundance (defined for management purposes as the abundance of all males ≥105-mm CL) is determined as a function of MMB. The exploitation rate on mature male abundance increases linearly from 10% when MMB = 2.9-million pounds to 20% when MMB = 11.6-million pounds. For MMB >11.6-million pounds, the exploitation rate remains at 20%. Application of the mature male exploitation rate to mature male abundance determines the targeted number of legal-sized males for commercial harvest. Minimum legal size is 5.5-in carapace width (CW), but 120-mm CL is used as a proxy for the size limit in stock-assessment computations. To protect from excessive harvest of the legal-sized component of the mature male stock, the targeted number of legal-sized males for commercial harvest is capped at 40% of the estimated legal-sized male abundance.

The BOF originally adopted a minimum guidline harvest level (GHL) as a management tool to help prevent harvest from exceeding low GHLs. With rationalization, this has been retained as a 2.5-million-pound minimum TAC for the "non-CDQ" portion of the overall TAC. The CDQ fishery is allocated 10% of the overall TAC; hence for the fishery to open, the TAC, including the allocation to the CDQ fishery, must be 2.778-million pounds or higher. It is important to note that, although the minimum GHL was adopted as management tool, it also plays an important role in promoting stock rebuilding. The minimum GHL was included as a management measure in the analyses of the effectiveness of the current harvest strategy when the BOF considered alternative strategies for managing and rebuilding the St. Matthew blue king crab stock. The analyses showed the minimum GHL to be an important determinant of the rebuilding schedule.

Besides the directed commercial fishery, some St. Matthew Island blue king crab have been caught in the eastern Bering Sea snow crab fishery and groundfish trawl fisheries.

Data

Fishery Catch Data

Vessel numbers, potlifts, catches in number and weight and CPUE for the directed pot fishery are summarized in Table 2. In this report, total annual retained catches were used in the catch-survey analysis.

Trawl Survey Data

NMFS has conducted annual summer trawl surveys of St. Matthew Island blue king crab since 1978. Indices of St. Matthew Island blue king crab abundance are affected by the portion of the stock occupying inshore rocky untrawlable grounds. Only 55 legal males (≥ 5.5 in CW or 120 mm CL) and eight large females (≥80 mm CL) were captured on the 2007 NMFS annual eastern Bering Sea shelf survey. On the NMFS 2008 survey, 69 legal males and nine large females were caught.

The catch-survey model was fit to NMFS trawl survey and commercial catch data from 1978 to 2008. Survey stations were stratified based on the approach developed by Zheng et al. (1997). Basically, the number of tows per station was used as a criterion to stratify the stations: (1) frequent two-tow stations were grouped together as one stratum, (2) frequent one-tow stations formed another stratum, and

(3) any single station with four or more tows was regarded as a separate stratum. The stratification was constant over time and similar to that used by NMFS during recent years.

The area-swept approach was used to estimate average crab density (abundance per nmi^2) for each stratum. Crab abundance by length, sex, and shell condition was estimated for each stratum by taking the product of average crab density and total stratum area. Total abundance of the stock was estimated by summing the abundances from all strata. Stage-specific survey abundances for the catch-survey model are summarized in Table 3.

Pot Survey Data

ADF&G performed a triennial pot survey for Saint Matthew Island blue king crab in 1995, 1998, 2001, 2004 and 2007 (Watson 2008), which is able to sample from areas of important habitat for blue king crab, particularly females, that the NMFS trawl survey cannot sample from. The pot surveys were usually conducted during late July and August with a chartered commercial crab pot vessel. The 2007 survey station grid encompassed the 2,850 nmi^2 area between 59º30' - 60º30' N. latitude and 172º00' - 174º00' W. longitude and contained 141 primary stations and 24 secondary stations (Figure 4, Watson 2008). Watson (2008) described the detailed survey design, pot structures and biological sampling.

Ninety-six stations were fished in common in each of the five surveys (Figure 5, Watson 2008). Among all stations fished in each survey year, the peak catch of legal male blue king crab declined from a high of 256 crabs in 1995 to a low of 57 crabs in 2004 and increased to 119 crabs in 2007 (Figure 6). The peak catch of sublegal male crabs also declined, from a high of 167 crabs in 1995 to a low of 37 crabs in 2004 and increased to 86 crabs in 2007 (Figure 7). Peak catches of females mirrored that observed for male crabs, with a peak catch of 590 crabs in 1995 declining to a low of 50 crabs in 2004; in 2007, however, the peak catch rebounded to 490 crabs (Figure 8). The CPUE indices from these 96 stations (Table 4) were used in the catch survey analysis.

Analytical Approach

Main Assumptions for the Model

A list of main assumptions for the model:

(1) Natural mortality is constant over time and stages except for 1999, which was estimated separately in the model. For scenarios with a fixed natural mortality value, it was estimated with a maximum age of 25 and the 1% rule (Zheng 2005).

(2) Survey selectivities are a function of stage and are constant over time.

(3) Growth is a function of stage and does not change over time.

(4) Molting probability is a function of stage and changes over time with a random walk process.

(5) A fishing season for the directed fishery is short.

(6) Handling mortality was assumed to be 0.2 and bycatch selectivities were assumed to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s, which are similar to bycatch selectivities estimated for Bristol Bay red king crab (Zheng and Siddeek 2008).

(7) Annual retained catch was measured without error.

(8) Trawl survey catchability was set to be 1.0 for legal males when fixed in the model.

(9) Male crab are mature at sizes ≥105 mm CL.

(10) Abundance had a log-normal error structure.

Model Structure

A four-stage catch survey analysis (CSA) is principally similar to a full length-based analysis (Zheng et al. 1995) with the major difference being coarser length groups for the CSA. Because of large size categories, the CSA is particularly useful for a small stock with low survey catches each year. Currently, a four-stage CSA is used to assess abundance and prescribe fishery quotas for the St. Matthew Island blue king crab fishery.

Only male crab abundance is modeled by CSA because the analysis requires commercial catch data and only males may be retained by the fishery. Male crab abundance was divided into four groups: prerecruit-2s (*P*2), prerecruit-1s (*P*1), recruits (*R*), and postrecruits (*P*). To be of legal size, St. Matthew Island male king crab must be ≥140 mm carapace width (regulatory measurement), corresponding to males ≥120 mm carapace length (CL). The average growth increment per molt is about 14 mm CL for adult male blue king crab (Otto and Cummiskey 1990). We categorized St. Matthew Island male blue king crab into *P*2 (90-104 mm CL), *P*1 (105-119 mm CL), *R* (newshell 120-133 mm CL), and *P* (oldshell ≥120 mm CL and newshell ≥134 mm CL).

For each stage of crab, the molting portions of crab "grow" into different stages based on a growth matrix, and the non-molting portions of crab remain the same stage. The model links the crab abundances in four stages in year t+1 to the abundances and catch in the previous year through natural mortality, molting probability, and the growth matrix:

$$
\begin{aligned}
P2_t^b &= P2_t\{1-[h\,H2^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
P1_t^b &= P1_t\{1-[h\,H1^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
P2_{t+1} &= P2_t^b[(1-m2_t)+m2_t\,G_{P2,P2}]e^{-M_t}+N_{t+1},\\
P1_{t+1} &= \{P1_t^b[(1-m1_t)+m1_t\,G_{P1,P1}]+P2_t^b\,m2_t\,G_{P2,P1}\}e^{-M_t},\\
R_{t+1} &= (P2_t^b\,m2_t\,G_{P2,R}+P1_t^b\,m1_t\,G_{P1,R})e^{-M_t},\\
P_{t+1} &= (P_t+R_t+P2_t^b\,m2_t\,G_{P2,P}+P1_t^b\,m1_t\,G_{P1,P})e^{-M_t}-C_t\,e^{(y_t-1)M_t},
\end{aligned}
\qquad (1)
$$

where $P2_t^b$ and $P1_t^b$ are prerecruit-2 and prerecruit-1 abundances after handling mortality in year t, h is handling mortality rate, $H2^q$ and $H1^q$ are fishery selectivities for prerecruit-2s and prerecruit-1s, N_t is new crab entering the model in year t, $m2_t$ and $m1_t$ are molting probabilities for prerecruit-2s and prerecruit-1s in year t, $G_{i,j}$ is a growth matrix containing the proportions of molting crab growing from stage i to stage j, M_t is natural mortality in year t, C_t is commercial catch in year t, and y_t is the time lag from the survey to the mid-point of the fishery in year t. By definition, all recruits become postrecruits in the following year.

We modeled molting probability for prerecruit-1s, $m1_t$, as a random walk process:

$$m1_{t+1} = m1_t e^{\eta_t}, \quad (2)$$

where η_t are independent, normally distributed random variables with a mean of zero.

Parameters Estimated Independently

Five scenarios of the model were developed for St. Matthew Island blue king crab, depending on parameters estimated independently and conditionally. In scenarios (1) and (4), both M for 1978-1998 and 2000-2008 and Q were fixed (estimated independently) and M for 1999 was independently estimated for scenario (1) and fixed for scenario (4); in model scenarios (2) and (5), M was estimated conditionally whereas Q was fixed and M was constant for the whole time series for scenario (5) and a different M value was independently estimated for 1999 for scenario (2); and in model scenario (3), Q was estimated conditionally and M was fixed for 1978-1998 and 2000-2008 and estimated for 1999:

	Scenario				
	(1)	(2)	(3)	(4)	(5)
M for 1978-1998, 2000-2008	0.18	Estimate	0.18	0.18	Estimate
M for 1999	Estimate	Estimate	Estimate	0.18	Same as above
Q	1.0	1.0	Estimate	1.0	1.0

The independently-estimated Q is 1. To reduce the number of parameters estimated, we used the ratio (1.44) of $m1$ to $m2$ from tagging data to estimate $m2$ from $m1$. The growth matrix was estimated from tagging data (Table 5; Otto and Cummiskey 1990). We assumed that the relative frequencies of length groups from the first-year trawl survey data approximate the true relative frequencies. Thus, we did not need to conditionally estimate length-specific abundance for the first year. Handling mortality rate was assumed to be 0.2, and to be 0.0 and 0.5 in a sensitivity study. Observer coverage was very limited for the directed fishery, and only 1-3 out of 90-131 vessels were covered from 1995 to 1998 (Moore et al. 2000). Due to limited observer data, fishery selectivities of pre-recruits 2 and 1 in the directed pot fishery were assumed to be 0.4 and 0.6 relative to legal crab, respectively, based on the results of Bristol Bay red king crab (Zheng and Siddeek 2008).

Natural Mortality

The estimate of natural mortality for all species of king crab in the eastern Bering Sea is 0.2 as defined by the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (1998). Siddeek et al. (2002) reexamined tagging experiments conducted around St. Matthew Island in 1995 and 1998 to estimate natural mortality (M). Based on a multinomial likelihood M estimator using returned the tag data, values of Z (annual instantaneous total mortality) for both male and female blue king crab ranged from 0.65 to 0.74 assuming that M and SR (initial tagging survival/recapture ratio) did not vary by sex. Using the combined sexes return tag data (80-157 mm CL) from the 1995 tagging experiment, the mean estimate of M = 0.19. One other natural mortality estimate has been reported for St. Matthew Island blue king crab based on tagging data. Values ranged from 0.19 to 2.04 with a mean estimate of 0.81 for adult male blue king crab (105-139 mm CL) (Otto and Cummiskey 1990).

The independently-estimated *M* is 0.18 in this report, based on a maximum age of 25 and the 1% rule (Zheng 2005).

Length-weight Relationships

Based on 136 samples collected in 1978 to 1981 from St. Matthew Island (Somerton and MacIntosh 1983b), the carapace length (mm)-weight (g) relationship for blue king crab males (range = 59-147 mm) is described by the equation:

$$W = 0.000329 * CL^{3.175}$$

Somerton and MacIntosh (1983b) compared the carapace size-weight relationship of blue king crab males collected in the Bering Sea and found no statistical difference between St. Matthew Island and the Pribilof Islands stocks. Recent samples collected from both the Pribilof Islands and St. Matthew Island area in 2006 and 2007 on the annual AFSC eastern Bering Sea shelf trawl survey provide an updated carapace length-weight relationship for male blue king crab (n = 172, range = 57-172 mm) described by the equation: $W = 0.0005257 * CL^{3.1040800}$. The carapace size-weight relationship for blue king crab ovigerous females is: $W = 0.114389 * CL^{1.919200}$ and non-ovigerous females is: $W = 0.035988 * CL^{2.155575}$.

Sizes at Maturity

Blue king crab males do not have a specific morphometric indication of maturity. Earlier studies exploring the relationship of the major chela height measurement to the carapace length (CL) of an individual crab as a measurement of male maturity did not produce statistically sound results, although one study reports males from St. Matthew were considered mature at 77 mm CL based on this relationship (Somerton and MacIntosh 1983a). St. Matthew blue king crab males were found to produce spermatophores at the 50-59 mm CL size range which indicates these crab are reaching sexual maturity at a smaller size than estimated using chela height morphology (Paul et al. 1991). ADF&G considers males mature at carapace length of ≥ 105 mm when estimating total mature biomass (TMB) to determine guideline harvest levels (GHL). Size at functional maturity used by the North Pacific Fishery Management Council (NPFMC 1998) in fishery management for blue king crab males in the St. Matthew district is 105 mm carapace length.

Blue king crab females in the St. Matthew Island area are considered mature at 80.6 mm CL based on 50% maturity estimates determined by the presence of eggs or empty egg cases (Somerton and MacIntosh 1983a). They are biennial spawners, with a 14-15 month period of embryonic development, and are less fecund but with larger sized eggs (1.2 mm) than red king crab females (Somerton and MacIntosh 1985, Jensen and Armstrong 1989). Molting is necessary for egg extrusion, thus the intermolt period is two years for blue king crab females. Somerton and MacIntosh (1985) suggested that blue king crab females live longer and have larger sized eggs than red king crab females as a reproductive strategy to compensate for their biennial spawning cycle. Reproductive studies on Pribilof Island blue king crab females supports a biennial reproduction cycle for large multiparous females but found smaller, primiparous (first year of maturity) females were often able to reproduce in two consecutive years (Jensen and Armstrong 1989).

Parameters Estimated Conditionally

Estimated parameters include natural mortality, molting probabilities, catchabilities, selectivities, M in 1999, crab entering the model for the first time each year except the first, and total abundance in the first year (Tables 6-9). Depending on the model scenario, M and Q may be estimated conditionally (Table 6).

Measurement errors of survey estimates of relative abundances were assumed to follow a lognormal distribution. Parameters of the model were estimated using a maximum likelihood approach:

$$\begin{aligned} Ln(L) = -\sum_t \{ & [\ln(P2_t Q\, S2+1)-\ln(p2_t+1)]^2 + [\ln(P1_t Q\, S1+1)-\ln(p1_t+1)]^2 \\ & + [\ln(R_t\, Q+1)-\ln(r_t+1)]^2 + [\ln(P_t\, Q+1)-\ln(p_t+1)]^2 \\ & + [\ln(P2_t s2/q+1)-\ln(ip2_t+1)]^2 + [\ln(P1_t s1/q+1)-\ln(ip1_t+1)]^2 \\ & + [\ln(R_t/q+1)-\ln(ir_t+1)]^2 + [\ln(P_t/q+1)-\ln(ip_t+1)]^2 + 10\eta_t^2 \} \end{aligned} \quad (3)$$

where $p2_t$, $p1_t$, r_t, and p_t are relative trawl survey (area-swept) abundances (thousands of crabs) of prerecruit-2s, prerecruit-1s, recruits, and postrecruits in year t; $ip2_t$, $ip1_t$, ir_t, and ip_t are catches per 1000 pot lifts of prerecruit-2s, prerecruit-1s, recruits, and postrecruits from pot surveys in year t; $S2$ and $S1$ are trawl survey selectivities for prerecruit-2s and prerecruit-1s; Q is a trawl survey catchability, $s2$ and $s1$ are pot survey selectivities for prerecruit-2s and prerecruit-1s; and q is a scaling parameter (per millions of pot lifts) to convert crab per pot lift to absolute crab abundance. P_t/q is the expected postrecruits per 1000 pot lifts in year t. Using AD Model Builder (Otter Research Ltd. 1994), we estimated parameters using the quasi-Newton method to minimize –Ln(L).

Model Results

Abundance and Parameter Estimates

Estimated abundance, recruitment to the model and mature male biomass are summarized in Tables 7-10 for five scenarios. Scenarios (1) and (4) with fixed Q and M resulted in relatively high abundance and biomass estimates during recent 10 years (Figure 9). Scenario (2) fitted both trawl and pot survey abundance best whereas scenario (4) was the worst (Figures 9 and 10; Table 6). All scenarios indicate an increasing abundance and biomass since 1999, and projected legal abundance and mature male biomass in 2008 were the highest values since 1999 (Figure 9; Tables 7-10). Residuals were about random for both trawl and pot survey data except that the residuals for post-recruit abundance from the trawl survey after the stock collapse in 1999 were mostly negative (Figures 11 and 12). This may suggest a higher mortality than we assumed in the model for the post-recruit crab. When M was estimated in the model, its value (0.308) was much higher than the fixed value of 0.18.

Legal harvest rate was defined as the ratio of retained catch to estimated legal abundance adjusted by natural mortality to the midpoint of each fishing season. Estimated harvest rates were very high during 1982-1985, above 45% (Figure 13). The fishery has been closed since 1999.

Likelihood profiles of estimated M, Q and mature male biomass on February 15, 2009 are illustrated in Figure 14. With a fixed $Q = 1$, estimated M was 0.308, much higher than we assumed in the model. The likelihood was very low for $M = 0.18$. When fixing $M = 0.18$, estimated Q was greater than 1, an unlikely value (Figure 14). Both model scenarios (1) and (2) were evaluated for setting overfishing limits in this report.

Handling mortality may also affect abundance estimates. Handling mortality reduces future recruitment to fisheries by reducing both prerecruit abundance and spawning biomass. Besides mortality, handling may also produce sublethal effects on crab, such as reduced growth (Kruse 1993). Based on limited observer data, bycatch of sublegal male and female crabs from the directed blue king crab fishery off St. Matthew Island was relatively high, and total bycatches were often twice as high or higher than total catch of legal crabs (Moore et al. 2000). But observer data were extremely limited for the St. Matthew Island blue king crab directed pot fishery. We assumed fishery selectivities to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s and handling mortality rate to be 0.2, based on the results of Bristol Bay red king crab (Zheng and Siddeek 2008). Although estimated recruitment to the model is affected by handling mortality, handling mortality rates ranging from 0 to 50% do not affect legal male abundance and mature male biomass estimates much (Figure 15).

Retrospective Analyses

Two kinds of retrospective analyses are presented in this report: (1) historical results and (2) the 2008 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 2008 as the baseline values, we can also evaluate how well the model had done in the past. The 2008 model results are based on leaving one-year data out at a time to evaluate how well the current model performs with less data.

Historically, the model performed very well. The model scenario (2) assumed Q=1 and estimated M up to the 2008 model. The trajectories of biomass and abundance from the assessments made during 1999-2007 were very close to each other and close to those made in 2008 with scenario (2) estimating M and fixed Q (Figure 16). Since the model has not been changed during the last nine years, the performance of the 2008 model (scenario 2) is also the same as Figure 16.

The 2008 model with scenario (1) of fixed M and Q did not perform as well as scenario (2) when leaving one-year of data out at a time for a retrospective analysis (Figure 17). Because of relatively low legal abundance from the trawl survey data during the early and mid 2000s, the estimated legal males and mature male biomass during the terminal years tended to be higher during this period than those estimated with the terminal year of 2008 for scenario (1) (Figure 17). The 2008 model with scenario (4) of fixed M for the whole period and Q performed poorly (Figure 18). The estimated legal abundance and mature male biomass during the terminal years were systematically higher during 1999-2007 than those estimated with the terminal year of 2008 for scenario (4) (Figure 18).

Overfishing Limits for 2008

The St. Matthew Island blue king crab stock has been recommended for placement in Tier 4 (NPFMC 2007). For Tier 4 stocks, abundance estimates are available, but complete population parameters are not available for computer simulation studies and spawning biomass per recruit analyses needed for Tier 3 stocks. Average of estimated biomasses for a certain period was used to develop B_{MSY} proxy for Tier 4 stocks. We evaluated averages of mature male biomasses from three periods for a B_{MSY} proxy: 1978-2008, 1983-1998, 1983-2008, and 1989-2008 (Figures 19 and 20).

Besides B_{MSY} proxy, a γ value also needs to be determined. We evaluated two γ values for setting overfishing limits for 2008: γ = 1 and γ =1.5. Model scenario (1) (fixed M=0.18 and Q=1) and scenario (2) (fixed Q=1 and estimating M=0.308) were also evaluated (Figures 19 and 20).

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
Based on average during 1978-2008:	7.509 million lbs,	6.877 million lbs,
Based on average during 1983-1998:	7.085 million lbs,	6.526 million lbs,
Based on average during 1983-2008:	6.570 million lbs.	5.854 million lbs,
Based on average during 1989-2008:	7.387 million lbs.	6.528 million lbs.

Estimated F_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
$\gamma = 1$:	0.180,	0.308,
$\gamma = 1.5$:	0.270,	0.462.

Estimated mature male biomass in 2008 was 10.743 and 7.944 million lbs, respectively for model scenarios (1) and (2) under an assumption of $\gamma = 1$. The estimated mature male biomass in 2008 will exceed all six B_{MSY} proxies even after adjusting the catch should directed fishing be allowed in 2008. Year classes after the 1976/77 regime shift (Overland et al. 1999) were about to reach the mature population after 1982, so two of the three periods used to estimate B_{MSY} proxy started in 1983. The stock collapsed and was at a low level during the early and mid 2000s, so this period might reasonably be excluded from estimating the B_{MSY} proxy, resulting in use of the period of 1983-1998. The CPT suggested a period of 1989-2008. The period of 1978-2008 includes all data. For a given model scenario, the averages from the three periods were not greatly different.

The F_{MSY} proxy can range from 0.18 to 0.462, corresponding to harvest rates ranging from 16.5% to 37.0% of legal abundance at the time of fishing. Estimated legal male biomass in 2008 at the time of fishing was 9.879 million lbs and 8.403 million lbs for model scenarios (1) and (2). Therefore, the overfishing limits for retained catch in 2008 range from 1.630 million lbs to 2.338 million lbs for model scenario (1) and from 2.227 million lbs to 3.109 million lbs for model scenario (2), depending on the γ value.

The high abundance estimate for 2008 was primarily caused by the relatively good trawl survey abundance of prerecruit-2s in 2006, very high trawl survey abundance of prerecuti-1s and prerecruit-2s in 2007 and high trawl survey abundance of postrecruits in 2008, and high pot survey abundance in 2007. The abundance estimated by the model for 2008 is subject to potential sampling errors of these surveys and is uncertain. Considering that the stock is still rebuilding from the "overfished" declaration in 1999, we should consider a low γ value for overfishing determination for 2008.

Ecosystem Considerations

Ecosystem Effects on Stock

Prey Availability/Abundance Trends

Early juvenile and larval *Paralithodes* spp. are planktotrophic, actively feeding on diatoms, nauplii and copepods (Paul et al. 1979, Abrunhosa and Kittaka 1997). Blue king crab larvae are described as obligate plankton feeders (Otto 2006). Zheng and Kruse (2000) found a relationship between periods of weak year class strength in blue king crab stocks in the eastern Bering Sea and decadal climate shifts, which exhibit strong winter Aleutian lows with periods of unstable water columns due to vertical mixing. These winter Aleutian lows may prevent diatom growth, such as *Thalassiosira* spp., that are rich in nutrients and are important prey for early stages of larval blue king crab.

Recently settled blue king crab juveniles switch from a planktivorous diet to benthic prey such as echinoderms (including sea stars, sea urchins and sand dollars), mollusks (bivalves and snails), and polychaetes, as well as other crustaceans including crab. Invertebrates accounted for 23% of the total demersal animal biomass of 15.4 million tons estimated for the eastern Bering Sea shelf. The 2007 biomass of invertebrates was composed primarily of crustaceans minus commercially important crab and shrimp species (1.4 million t), echinoderms (1.3 million t), and crab (1.3 million t) (Acuna and Lauth 2008).

Predator Population Trends

Since it is difficult to distinguish between red and blue king crab prey without the whole carapace, there is no predator information specific to blue king crab in data published by the AFSC food habitats laboratory. Pacific cod, Pacific halibut and skate stomachs contained small amounts of unidentified king crab collected from the eastern Bering Sea annual summer shelf survey (Lang et al. 2005).

The 2007 abundance estimate for Pacific cod in the eastern Bering Sea shelf was 423,703 metric tons, with the highest catch rate of Pacific cod occurring in the northwestern part of the eastern Bering Sea shelf. Biomass estimates of Pacific cod have been declining, although there has been an increase in population size indicating an increase in a number of smaller sized fish and suggesting the emergence of a strong year class (Acuna and Lauth 2008).

The International Pacific Halibut Commission predicts low levels of recruitment and even lower estimates of productivity for Pacific halibut in the St. Matthew Island area, resulting in a 2008 harvest level below the optimal rate of 20% (IPHC 2008). Low commercial and survey catch rates support a general decline in abundance estimates of Pacific halibut in the eastern Bering Sea (Clarke 2008).

Paralithodid species are especially vulnerable as adults when in the soft shell state just after the molting process (Loher et al. 1998) and as recently settled juveniles. Numerous planktivorous fishes prey on *Paralithodid* larvae (Livingston et al. 1993, Wespestad et al. 1994).

Changes in Habitat Quality

Table 12 lists the potential ecosystem effects by changes in habitat quality. According to Somerton (1985), blue king crab (BKC) have a restricted distribution in Alaska waters made up of isolated populations which are thought to be relicts from a former, broader distribution (Figure 1). The general rise in water temperature that has occurred during the present inter-glacial period is thought to be the primary factor in shaping their distribution into these isolated refuges. Somerton (1985) attributed the isolated distribution of BKC to three mechanisms either singly or in combination: reproductive interference, competitive displacement and predatory exclusion. Due to these restricted and discrete isolated populations of BKC, they are particularly susceptible to any perturbations during critical life history stages and to their critical habitats. An increase in temperature, ocean acidification, and oil mishaps could affect their survival, reproductive success, distribution, habitat quality, recruitment success, year class strength, and predator or prey distribution.

Early life history studies of blue king crab around the Pribilof Islands during the spring of 1983 and 1984 by Armstrong et al. (1985) have demonstrated that larvae hatch in mid to late April. Although the average current patterns in the southeastern Bering Sea show a general northwest direction and slow speeds along the shelf breaks of the islands, for the local scale of the Pribilof and presumably St. Matthew Island there must be current patterns and eddies that will retain the larvae nearshore to enhance settlement to the preferred but limited refuge in the area. Armstrong et al. (1985) also pointed out that in certain years it would be probable that anomalous events could occur that would transport larvae well beyond the Pribilof Islands, resulting in settlement into unfavorable habitats and very low survival.

Juvenile blue king crab (<30 mm carapace length) are known to occur predominately along nearshore rocky and shell hash (a mixture of broken bivalve and gastropod shells) habitats near the Pribilof Islands, and these habitats are considered vital refuge from predation and for successful recruitment (Palacios et al. 1985). Shell hash is a key material for refuge and thus the survival of blue king crab is ultimately linked to certain mollusk species that are abundant within the species assemblage that characterize the BKC juvenile habitat along the Pribilof Islands (Armstrong et al. 1985). The preferred shelltype epibenthic substrate for juvenile BKC was composed primarily of four species of bivalves (*Serripies groenlandicus*, *Spisula polynyma*, *Chlamys sp*., *Modiolus modiolus*), and large neptunid gastropods. Shells of this type were usually intact or in large pieces and usually covered with dense epiphytic growth including feathery bryozoans, barnacles, anemones, and ascidians.

Male and female adult blue king crab along the Pribilof Islands had a high occurrence offshore on deeper, mud-sand substrates. In August of 1989, ovigerous females occurred in high abundance and dominated all catches (99% females, almost all ovigerous) along mostly rocky habitats in nearshore waters sampled during St Matthew Island pot surveys (Blau and Watson 1999). A high percentage of mature blue king crab also occurred in the vicinity of St. Matthew Island during a trawl survey (NMFS 1984) and have not been located anywhere else in the Bering Sea (Armstrong et al. 1985, Palacios et al. 1985, Moore et al. 1998). The high incidence of ovigerous females ranged in depth from 7 to 20 fathoms in mostly rocky habitats and CPUE (number of crab per pot) ranged from 10 at 7 fm and 146 at 8 fm, while all male CPUE were <2. The nearshore rocky habitats of St Matthew Island are very important habitat for ovigerous females during the summer and fall months. Nearshore dive surveys along St. Matthew Island by the Alaska Department of Fish & Game (ADF&G) have not revealed juvenile blue king crab nor has habitat associations been described (Blau 2000).

Recently several studies have investigated the effects of temperature on embryonic development, hatch timing, respiration, and larval survival of BKC (Stevens 2006a, Stevens 2006b, Stevens et al. 2008). This research will aid in an understanding of the impacts of climate change, especially seawater warming, has on the reproduction of BKC.

Due to their restricted distribution along the Pribilof and St Mathews Islands, blue king crab are considered highly vulnerable to oil mishaps (Armstrong et al. 1987). There have been numerous studies that have investigated the potential impacts of oil on blue king crab along the Pribilof Islands (Armstrong et al. 1983, Armstrong et al. 1987, Laevastu et al. 1985). The life history stage considered most vulnerable is the larval stages since they are in the water column and would follow the same currents as the oil. The restricted distribution of early juveniles on and in substrates such as shellhash and gravel/cobble that are limited to the Pribilof Islands (compared to hundreds of km in all directions) underscores the unique habitat required by this species. The high concentrations and dominance by ovigerous females that occur in nearshore waters during the summer and fall would be at great risk during an oil mishap for St. Matthew and the Pribilof Islands. If oil reaches these islands the impact on BKC could be great depending on a variety of biological and physical factors (Laevastu et al. 1985).

Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects (M. Sigler, AFSC NOAA Fisheries, pers. comm.). These effects have been measured as decreased pH of the water, as well as measurable increases in dissolved inorganic carbon over a large section of the northeastern Pacific suspected to be a problem in surface water effecting calcifying planktonic organisms in the northeast Pacific Ocean (R. Feely, NOAA PMEL, pers. comm.). Some investigators believe that the effects of decreased calcification in microscopic algae and animals could impact food webs and, combined with other climatic changes in salinity, temperature and upwelled nutrients, could substantially alter the biodiversity and productivity of the ocean (Orr et al. 2005). A recent trial laboratory study has shown a 15% reduction in growth and 67% reduction in survival when pH was reduced 0.5 units (Litzow et al., trial data, AFSC NOAA Fisheries). Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival. Current studies underway will investigate the effect pH has on survival, growth, and morphology of larval and juvenile blue and red king crab (K. Swiney, NMFS/AFSC/Kodiak Lab, pers. comm.).

Disease

Diseases that may infect *Paralithodid* species include a herpes-type viral disease of the bladder, a pansporoblastic microsporidian (*Thelohania* sp.), and a parasitic rhizocephalan (*Briarosaccus* sp.) which feeds on female egg clutches (Sparks and Morado 1997).

Fishery Effects on the Ecosystem

The St. Matthew blue king crab commercial fishery has been closed since 1999. Non-retained blue king crab such as females and sub-legal males may have been caught in previous directed fishing for St. Matthew blue king crab and eastern Bering Sea snow crab commercial fisheries (see bycatch in directed fishery section).

Seapens or seawhips, corals, anemones, and sponges are species groups in the eastern Bering Sea considered as Habitat Areas of Particular Concern (HAPC), which are defined as living substrates in shallow or deep waters, although not many corals (gorgonians, soft corals and stony corals) are encountered on the EBS shelf. Relative CPUE from EBS shelf survey data 1982-2007 is available for these species groups but the survey gear is not appropriate for effective sampling of these types of organisms and survey results provide imprecise abundance information. Since most of the eastern Bering Sea survey stations are repeated from survey to survey, apparent decreases in abundance for many of the slow growing HAPC organisms could result from repeated trawling of these areas by the survey (Lauth 2007).

Acknowledgments

We thank Doug Woodby of ADF&G for reviewing the earlier draft of this report. The study was funded, in part, by cooperative agreement from the National Oceanic and Atmospheric Administration (NOAA). The views expressed are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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Table 1. Harvest level, economic performance and season length summary for the Saint Matthew Island Section commercial blue king crab fishery, 1983 -2006/07 (Bowers et al., 2008).

		Value		Season Length	
Season	GHL/TAC[a]	Ex-vessel[b]	Total[c]	Days	Dates
1983	8	$3.00	$25.80	17	08/20-09/06
1984	2.0-4.0	$1.75	$6.50	7	09/01-09/08
1985	0.9-1.9	$1.60	$3.80	5	09/01-09/06
1986	0.2-0.5	$3.20	$3.20	5	09/01-09/06
1987	0.6-1.3	$2.85	$3.10	4	09/01-09/05
1988	0.7-1.5	$3.10	$4.00	4	09/01-09/05
1989	1.7	$2.90	$3.50	3[d]	09/01-09/04
1990	1.9	$3.35	$5.70	6	09/01-09/07
1991	3.2	$2.80	$9.00	4	09/16-09/20
1992	3.1	$3.00	$7.40	3[d]	09/04-09/07
1993	4.4	$3.23	$9.70	6	09/15-09/21
1994	3.0	$4.00	$15.00	7	09/15-09/22
1995	2.4	$2.32	$7.10	5	09/15-09/20
1996	4.3	$2.20	$6.70	8	09/15-09/23
1997	5.0	$2.21	$9.80	7	09/15-09/22
1998	4.0[e]	$1.87	$5.34	11	09/15-09/26
1999-2006/07			FISHERY CLOSED		

[a]Guideline harvest level in millions of pounds. Total allowable catch for IFQ beginning in 2005.

[b]Average price per pound.

[c]Millions of dollars.

[d]Actual length - 60 hours.

[e]General fishery only.

Table 2. Saint Matthew Island Section commercial blue king crab fishery data, 1977 - 2006/07 (Bowers et al., 2008).

	Number of				Number of Pots		Percent	Average			
Season	Vessels	Landings	Crabs[a]	Harvest[a,b]	Registered	Pulled	Recruits	Weight[b]	CPUE[c]	Length[d]	Deadloss[b]
1977	10	24	281,665	1,202,066	NA	17,370	7	4.3	16	130.4	129,148
1978	22	70	436,126	1,984,251	NA	43,754	NA	4.5	10	132.2	116,037
1979	18	25	52,966	210,819	NA	9,877	81	4.0	5	128.8	128.8
1980					CONFIDENTIAL						
1981	31	119	1,045,619	4,627,761	NA	58,550	NA	4.4	18	NA	53,355
1982	96	269	1,935,886	8,844,789	NA	165,618	20	4.6	12	135.1	142,973
1983	164	235	1,931,990	9,454,323	38,000	133,944	27	4.8	14	137.2	828,994
1984	90	169	841,017	3,764,592	14,800	73,320	34	4.5	11	135.5	31,983
1985	79	103	441,479	2,200,781	13,000	47,748	9	5.0	9	139	2,613
1986	38	43	219,548	1,003,162	5,600	22,073	10	4.6	10	134.3	32,560
1987	61	62	227,447	1,039,779	9,370	28,230	5	4.6	8	134.1	600
1988	46	46	302,098	1,325,185	7,780	23,058	65	4.4	30	133.3	10,160
1989	69	69	247,641	1,166,258	11,983	30,803	9	4.7	8	134.6	3,754
1990	31	38	391,405	1,725,349	6,000	26,264	4	4.4	15	134.3	17,416
1991	68	69	726,519	3,372,066	13,100	37,104	12	4.6	20	134.1	216,459
1992	174	179	545,222	2,475,916	17,400	56,630	9	4.6	10	134.1	1,836
1993	92	136	630,353	3,003,089	5,895	58,647	6	4.8	11	135.4	3,168
1994	87	133	827,015	3,764,262	5,685	60,860	60	4.6	14	133.3	46,699
1995	90	111	666,905	3,166,093	5,970	48,560	45	4.8	14	135	90,191
1996	122	189	660,665	3,078,959	8,010	91,085	47	4.7	7	134.6	36,892
1997	117	166	939,822	4,649,660	7,650	81,117	31	4.9	12	139.5	209,490
1998	131	255	612,440	2,869,655	8,561	89,500	46	4.7	7	135.8	15,107
1999-2006/07					FISHERY CLOSED						

[a]Deadloss included.
[b]In pounds.
[c]Number of legal crabs per pot lift.
[d]Carapace length in millimeters.
NA = Not available.

Table 3. Summer trawl survey abundance (million of crab) for 4 length groups.

Year	Pre-R 2	Pre-R 1	R	Post-R	Matures	Legals
1978	2.336	2.175	1.187	0.587	3.948	1.773
1979	2.258	1.793	1.455	0.333	3.581	1.788
1980	1.717	2.588	1.699	1.197	5.484	2.897
1981	0.637	1.480	1.195	1.648	4.323	2.844
1982	1.713	2.615	3.617	3.263	9.495	6.880
1983	1.052	1.639	1.399	1.956	4.993	3.354
1984	0.416	0.500	0.788	0.762	2.050	1.550
1985	0.434	0.431	0.541	0.708	1.680	1.249
1986	0.190	0.425	0.164	0.185	0.774	0.349
1987	0.350	0.757	0.492	0.292	1.541	0.785
1988	0.362	0.703	0.417	0.411	1.530	0.827
1989	2.181	1.235	0.940	0.954	3.129	1.894
1990	0.942	0.957	0.954	1.164	3.075	2.119
1991	1.031	1.636	1.353	0.889	3.878	2.242
1992	1.178	1.582	1.338	1.247	4.167	2.585
1993	1.653	1.994	1.605	2.000	5.599	3.605
1994	0.908	1.350	1.246	1.120	3.716	2.366
1995	1.118	1.321	0.993	0.902	3.216	1.895
1996	1.290	1.970	1.950	1.331	5.251	3.281
1997	1.211	2.319	2.213	1.853	6.385	4.066
1998	0.714	1.843	1.397	1.766	5.006	3.163
1999	0.244	0.215	0.179	0.436	0.830	0.615
2000	0.304	0.310	0.323	0.488	1.121	0.811
2001	0.432	0.527	0.345	0.681	1.554	1.026
2002	0.133	0.266	0.186	0.576	1.028	0.762
2003	0.535	0.330	0.188	0.379	0.898	0.567
2004	0.281	0.210	0.286	0.348	0.844	0.634
2005	0.600	0.445	0.295	0.259	0.999	0.554
2006	1.019	0.760	0.766	0.635	2.162	1.402
2007	2.756	2.224	0.752	0.565	3.540	1.317
2008	1.430	0.873	0.580	1.006	2.459	1.585

Table 4. Crabs per pot lift for the pot surveys from the common 96 stations.

Year	Pre-R 2	Pre-R 1	R	Post-R
1995	1.919	3.198	3.214	3.708
1998	0.964	2.763	3.906	4.898
2001	1.266	1.737	2.378	3.109
2004	1.719	0.453	0.299	0.826
2007	0.500	2.721	2.773	2.063

Table 5. Growth matrix for St. Matthew Island blue king crab.

	Growth Matrix (*G*): From	
	Prerecruit-2s	Prerecruit-1s
Prerecruit-2s	0.11	0.00
Prerecruit-1s	0.83	0.11
Recruits	0.06	0.83
Postrecruits	0.00	0.06

Table 6. Parameter estimates and negative likelihood values for a catch-survey analysis of St. Matthew Island blue king crab with data from 1978 to 2008. Five scenarios of the model are (1) fixed *M* = 0.18 and *Q*=1 with 2 *Ms*, (2) fixed *Q* = 1 and estimating *M* with 2 *Ms*, (3) fixed *M* = 0.18 and estimating *Q* with 2 *Ms*, (4) fixed *M* = 0.18 for the whole time series and *Q*=1, (5) fixed *Q* = 1 and estimating *M* for the whole time series. An *M* value is estimated for 1999 with the "2 *Ms*" scenario. A value of "fix" indicates that it is fixed in the model.

	Model Scenario				
Parameter	(1)	(2)	(3)	(4)	(5)
Natural mortality (*M*) for years other than 1999	fix	0.308	fix	fix	0.356
Natural mortality in 1999	1.864	1.724	1.865	fix	0.356
Trawl survey catchability (*Q*)	fix	fix	1.209	fix	fix
Trawl survey selectivity: prerecruit-2s (*S*2)	0.630	0.500	0.561	0.711	0.500
Trawl survey selectivity: prerecruit-1s (*S*1)	0.849	0.872	0.775	0.856	0.747
Pot survey selectivity: prerecruit-2s (*s*2)	0.214	0.165	0.218	0.231	0.153
Pot selectivity: prerecruit-1s (*s*1)	0.583	0.622	0.605	0.561	0.493
Pot scaling parameter (*q*)	0.323	0.318	0.300	0.268	0.274
Molting probability in 1978: prerecruit-1s	0.721	0.909	0.729	0.692	0.802
Negative likelihood components					
Trawl survey: prerecruit-2s	5.261	6.269	5.434	5.740	7.315
Trawl survey: prerecruit-1s	3.326	3.165	3.308	5.651	5.189
Trawl survey: recruits	5.733	4.099	4.415	9.077	5.653
Trawl survey: postrecruits	6.380	5.252	6.573	8.603	6.453
Pot survey: total	6.717	5.911	6.789	8.003	6.000
Molting probability variation penalty	0.556	0.209	0.724	1.266	1.218
Total	27.973	24.905	27.243	38.339	31.827

Table 7. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (1) fixing *M* and *Q*. Recruits and abundance are in million of crab and biomass is in million lbs. F = 0.18 was assumed for 2008.

Year	Model R	Pre-R2	Pre-R1	R	Post-R	Legals	Matures	Bio215	Molt1
1978	NA	1.919	1.786	0.975	0.482	1.456	3.243	7.244	0.721
1979	2.963	3.135	1.822	0.960	0.910	1.870	3.692	10.706	0.734
1980	2.698	2.986	2.695	1.082	1.584	2.666	5.361	16.051	0.739
1981	1.064	1.338	2.838	1.528	2.298	3.827	6.664	16.769	0.761
1982	1.481	1.601	1.654	1.522	2.420	3.942	5.596	11.194	0.784
1983	0.659	0.801	1.470	0.931	1.717	2.648	4.119	5.562	0.787
1984	0.401	0.471	0.868	0.780	0.617	1.397	2.265	3.724	0.770
1985	0.839	0.881	0.527	0.458	0.484	0.941	1.468	2.751	0.757
1986	0.564	0.642	0.725	0.305	0.390	0.695	1.420	3.303	0.772
1987	1.119	1.177	0.619	0.407	0.420	0.827	1.446	3.503	0.794
1988	0.958	1.064	0.947	0.389	0.514	0.902	1.849	4.235	0.808
1989	2.477	2.572	0.936	0.564	0.532	1.096	2.032	5.113	0.808
1990	1.593	1.825	1.970	0.639	0.741	1.379	3.350	7.783	0.790
1991	1.676	1.840	1.715	1.138	0.893	2.030	3.745	8.230	0.777
1992	1.764	1.928	1.669	0.980	1.134	2.114	3.783	9.421	0.763
1993	1.971	2.145	1.748	0.955	1.361	2.315	4.064	10.130	0.750
1994	1.716	1.910	1.931	0.989	1.455	2.443	4.375	10.191	0.739
1995	2.599	2.770	1.826	1.048	1.397	2.445	4.271	10.606	0.744
1996	2.215	2.465	2.385	1.051	1.533	2.584	4.969	12.378	0.735
1997	1.553	1.775	2.350	1.305	1.674	2.978	5.328	12.606	0.717
1998	1.235	1.394	1.891	1.216	1.759	2.975	4.866	3.832	0.692
1999	0.526	0.550	0.291	0.181	0.341	0.522	0.813	2.721	0.680
2000	0.367	0.425	0.470	0.164	0.446	0.610	1.080	3.521	0.648
2001	0.539	0.598	0.442	0.231	0.525	0.756	1.198	4.030	0.595
2002	0.069	0.186	0.530	0.208	0.644	0.852	1.382	4.688	0.589
2003	0.449	0.486	0.320	0.224	0.728	0.952	1.272	4.681	0.612
2004	0.354	0.440	0.420	0.158	0.805	0.963	1.383	5.035	0.655
2005	1.281	1.339	0.435	0.211	0.818	1.029	1.464	5.291	0.692
2006	1.636	1.759	1.068	0.276	0.875	1.151	2.218	7.069	0.708
2007	1.388	1.550	1.549	0.612	0.999	1.611	3.161	9.682	0.712
2008	2.128	2.271	1.549	0.843	1.401	2.244	3.792	10.743	NA

Table 8. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (2) fixing *Q* and estimating *M*. Recruits and abundance are in million of crab and biomass is in million lbs. F = 0.308 was assumed for 2008.

Year	Model R	Pre-R2	Pre-R1	R	Post-R	Legals	Matures	Bio215	Molt1
1978	NA	2.233	2.079	1.134	0.561	1.695	3.773	7.964	0.909
1979	4.298	4.476	1.625	1.223	0.999	2.222	3.847	10.541	0.935
1980	4.013	4.374	2.925	1.121	1.660	2.781	5.707	15.551	0.943
1981	2.013	2.366	3.010	1.874	2.140	4.014	7.024	16.074	0.967
1982	2.199	2.387	1.722	1.836	2.294	4.129	5.851	10.843	0.991
1983	0.943	1.131	1.558	1.099	1.653	2.752	4.310	5.496	0.994
1984	0.553	0.641	0.783	0.931	0.613	1.544	2.327	3.700	0.980
1985	1.051	1.101	0.448	0.472	0.530	1.002	1.450	2.575	0.968
1986	0.889	0.976	0.695	0.300	0.383	0.683	1.378	2.913	0.982
1987	1.476	1.553	0.646	0.446	0.363	0.809	1.454	3.135	1.000
1988	1.407	1.530	0.981	0.450	0.442	0.893	1.874	3.832	1.000
1989	3.182	3.303	0.991	0.646	0.466	1.112	2.103	4.749	1.000
1990	2.367	2.630	2.065	0.735	0.670	1.406	3.471	7.297	0.998
1991	2.370	2.579	1.742	1.339	0.821	2.160	3.901	7.870	1.000
1992	2.507	2.711	1.676	1.140	1.097	2.237	3.913	8.945	0.998
1993	2.499	2.715	1.763	1.115	1.298	2.412	4.175	9.488	0.993
1994	2.464	2.680	1.775	1.160	1.359	2.519	4.294	9.130	0.987
1995	3.510	3.722	1.755	1.152	1.283	2.435	4.190	9.385	1.000
1996	2.997	3.293	2.369	1.204	1.347	2.551	4.920	10.965	0.994
1997	2.033	2.295	2.172	1.544	1.462	3.006	5.178	11.035	0.972
1998	1.566	1.748	1.581	1.349	1.569	2.918	4.500	3.897	0.947
1999	0.654	0.688	0.302	0.239	0.388	0.627	0.929	2.871	0.942
2000	0.549	0.605	0.456	0.204	0.473	0.677	1.132	3.420	0.926
2001	0.654	0.703	0.428	0.284	0.516	0.800	1.227	3.772	0.882
2002	0.220	0.276	0.496	0.261	0.604	0.865	1.361	4.206	0.849
2003	0.528	0.550	0.258	0.269	0.654	0.923	1.181	3.983	0.868
2004	0.563	0.607	0.378	0.161	0.688	0.849	1.227	4.048	0.884
2005	1.538	1.587	0.430	0.231	0.638	0.869	1.299	4.136	0.912
2006	2.069	2.197	1.027	0.309	0.656	0.965	1.992	5.570	0.915
2007	1.781	1.958	1.480	0.670	0.750	1.421	2.900	7.851	0.907
2008	2.702	2.860	1.404	0.905	1.103	2.007	3.411	7.944	NA

Table 9. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (3) fixing *M* and estimating *Q*. Recruits and abundance are in million of crab and biomass is in million lbs. F = 0.18 was assumed for 2008.

Year	Model R	Pre-R2	Pre-R1	R	Post-R	Legals	Matures	Bio215	Molt1
1978	NA	1.699	1.582	0.863	0.427	1.290	2.871	6.220	0.729
1979	2.938	3.091	1.598	0.856	0.764	1.620	3.218	9.253	0.752
1980	2.784	3.067	2.578	0.985	1.368	2.353	4.931	14.524	0.766
1981	1.083	1.364	2.809	1.520	2.037	3.557	6.366	15.523	0.797
1982	1.469	1.592	1.589	1.573	2.198	3.771	5.360	10.294	0.828
1983	0.612	0.754	1.396	0.942	1.575	2.517	3.913	4.858	0.836
1984	0.378	0.443	0.770	0.781	0.507	1.288	2.059	3.087	0.816
1985	0.790	0.829	0.458	0.428	0.391	0.818	1.277	2.117	0.801
1986	0.553	0.626	0.655	0.279	0.286	0.565	1.219	2.613	0.813
1987	1.023	1.079	0.567	0.385	0.309	0.694	1.262	2.843	0.833
1988	0.891	0.988	0.849	0.369	0.402	0.771	1.620	3.480	0.843
1989	2.272	2.361	0.837	0.524	0.420	0.944	1.781	4.285	0.839
1990	1.497	1.710	1.780	0.590	0.611	1.201	2.980	6.655	0.819
1991	1.560	1.714	1.549	1.060	0.738	1.798	3.347	6.969	0.803
1992	1.665	1.818	1.508	0.910	0.935	1.845	3.354	7.986	0.787
1993	1.829	1.992	1.601	0.887	1.132	2.019	3.620	8.590	0.771
1994	1.606	1.785	1.757	0.926	1.203	2.129	3.886	8.518	0.758
1995	2.432	2.592	1.663	0.973	1.129	2.102	3.765	8.842	0.759
1996	2.030	2.263	2.193	0.974	1.242	2.216	4.409	10.434	0.747
1997	1.387	1.590	2.131	1.212	1.360	2.572	4.703	10.473	0.723
1998	1.118	1.261	1.685	1.106	1.412	2.518	4.203	3.109	0.692
1999	0.469	0.491	0.261	0.161	0.269	0.429	0.690	2.266	0.672
2000	0.322	0.377	0.418	0.146	0.367	0.513	0.931	2.997	0.637
2001	0.479	0.537	0.392	0.202	0.442	0.643	1.035	3.456	0.581
2002	0.056	0.169	0.470	0.180	0.549	0.729	1.200	4.042	0.575
2003	0.398	0.435	0.289	0.195	0.623	0.817	1.107	4.046	0.600
2004	0.312	0.395	0.374	0.139	0.691	0.831	1.204	4.364	0.644
2005	1.136	1.193	0.388	0.185	0.706	0.891	1.279	4.602	0.687
2006	1.448	1.565	0.946	0.244	0.758	1.002	1.948	6.184	0.706
2007	1.273	1.417	1.379	0.542	0.870	1.412	2.790	8.519	0.714
2008	1.978	2.108	1.402	0.753	1.229	1.982	3.384	9.551	NA

Table 10. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (4) fixing *M* for the whole time period and *Q*. Recruits and abundance are in million of crab and biomass is in million lbs. F = 0.18 was assumed for 2008.

Year	Model R	Pre-R2	Pre-R1	R	Post-R	Legals	Matures	Bio215	Molt1
1978	NA	1.951	1.816	0.991	0.490	1.481	3.297	7.395	0.692
1979	2.996	3.172	1.891	0.942	0.929	1.871	3.762	10.879	0.709
1980	2.778	3.069	2.775	1.086	1.585	2.671	5.446	16.235	0.717
1981	0.973	1.254	2.964	1.532	2.302	3.834	6.798	17.053	0.741
1982	1.490	1.603	1.674	1.541	2.428	3.969	5.643	11.338	0.764
1983	0.644	0.786	1.500	0.920	1.739	2.659	4.160	5.670	0.767
1984	0.383	0.451	0.886	0.776	0.625	1.401	2.287	3.779	0.750
1985	0.854	0.894	0.531	0.454	0.487	0.941	1.472	2.760	0.736
1986	0.528	0.608	0.743	0.300	0.389	0.689	1.432	3.320	0.747
1987	1.147	1.202	0.613	0.402	0.415	0.817	1.430	3.455	0.765
1988	0.903	1.012	0.975	0.374	0.504	0.879	1.854	4.202	0.771
1989	2.601	2.692	0.932	0.552	0.512	1.064	1.996	4.976	0.761
1990	1.510	1.753	2.082	0.613	0.712	1.324	3.406	7.789	0.733
1991	1.605	1.763	1.776	1.112	0.845	1.957	3.734	8.060	0.707
1992	1.679	1.836	1.719	0.924	1.069	1.992	3.712	9.046	0.678
1993	1.887	2.080	1.777	0.874	1.254	2.128	3.905	9.440	0.645
1994	1.321	1.613	1.929	0.865	1.290	2.155	4.083	9.027	0.617
1995	1.782	2.053	1.667	0.862	1.144	2.006	3.673	8.534	0.594
1996	0.955	1.352	1.827	0.749	1.148	1.897	3.724	8.505	0.553
1997	0.499	0.818	1.477	0.728	1.063	1.791	3.269	6.166	0.508
1998	0.471	0.699	1.040	0.521	0.721	1.243	2.283	4.465	0.464
1999	0.125	0.352	0.798	0.340	0.533	0.873	1.670	5.145	0.463
2000	0.279	0.398	0.555	0.268	0.747	1.015	1.570	5.395	0.483
2001	0.461	0.587	0.457	0.200	0.861	1.061	1.518	5.500	0.482
2002	0.001	0.187	0.501	0.173	0.897	1.071	1.572	5.674	0.503
2003	0.441	0.497	0.326	0.182	0.907	1.089	1.414	5.377	0.543
2004	0.252	0.377	0.411	0.142	0.918	1.060	1.471	5.483	0.599
2005	1.277	1.350	0.386	0.187	0.898	1.085	1.471	5.480	0.652
2006	1.483	1.666	1.017	0.238	0.919	1.157	2.174	7.047	0.673
2007	1.152	1.340	1.463	0.555	1.001	1.556	3.019	9.333	0.677
2008	1.867	2.011	1.394	0.753	1.349	2.102	3.496	9.990	NA

Table 11. Ecosystem effects on the St. Matthew Island blue king crab stock. Changes in habitat quality.

Ecosystem effects on St. Matthew Island blue king crab stocks			
Indicator	Observation	Interpretation	Evaluation
Changes in Habitat Quality			
EFH-HAPC	Rocky/shellhash nearshore habitats are critical habitat/vital refuge for juveniles in the Pribilof Islands. Ovigerous females dominate nearshore rocky habitats during the warmer months.	Effects on population dynamics of mollusk species that compose the shellhash and associated epiphytes, such as oil mishaps, coastal development, and dredging.	Concern
Temperature regime	Experimental studies.- temperature effects on hatch timing, embryonic development, larval growth and survival.	Lower temperatures delay development, hatch timing, and growth. Higher temperatures may increase all of the above and decrease survival.	Concern
Ocean Acidification	Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects.	Lab studies have shown a ~15% reduction in growth and ~67% reduction in survival when pH was reduced 0.5 units. Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival.	Concern
Oil exploration	Restricted distribution makes them vulnerable to oil mishaps.	Oil mishap would impact planktonic larvae the most. Juveniles in shallow water nearshore habitats would be impacted. As well as ovigerous females that occur in shallower warmer water during the summer and fall.	Concern
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability. Concern.
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability and recruitment in year class strength	Possible concern

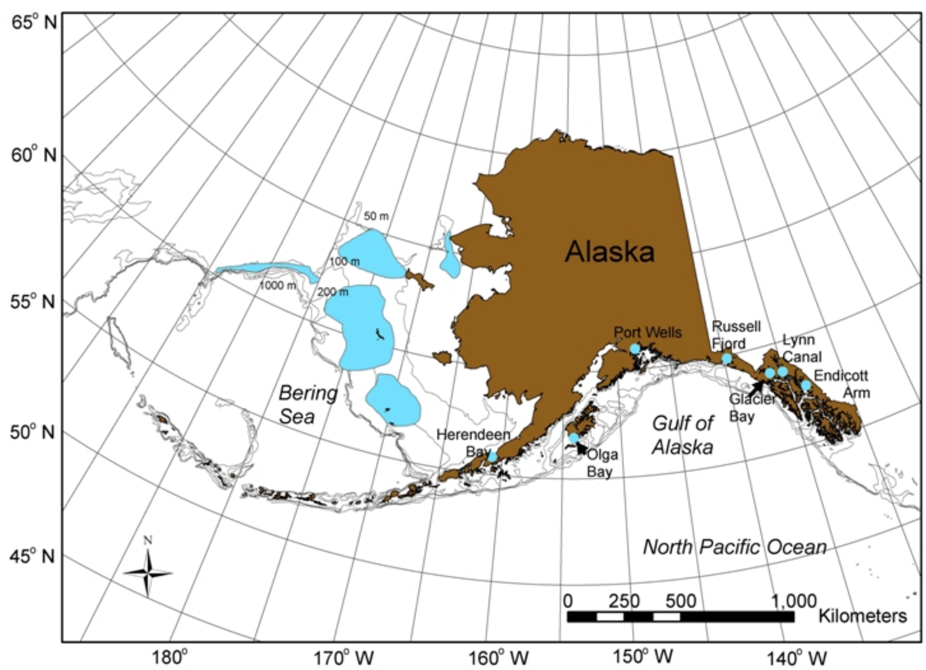


Figure 1. Distribution map of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters.

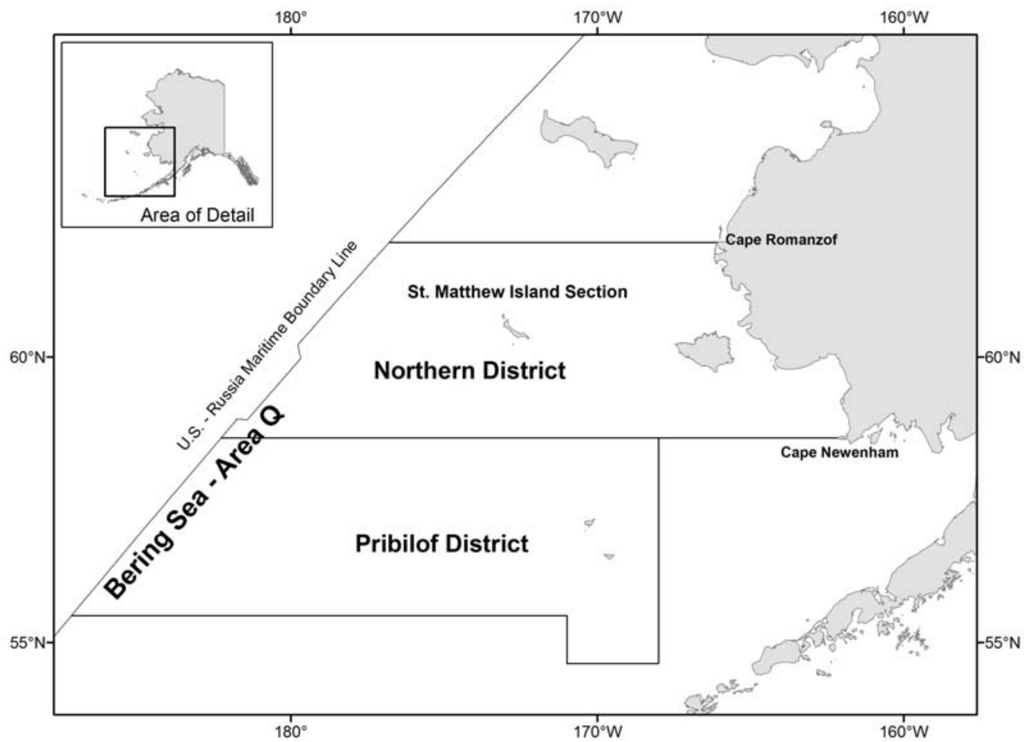


Figure 2. King crab Registration Area Q (Bering Sea).

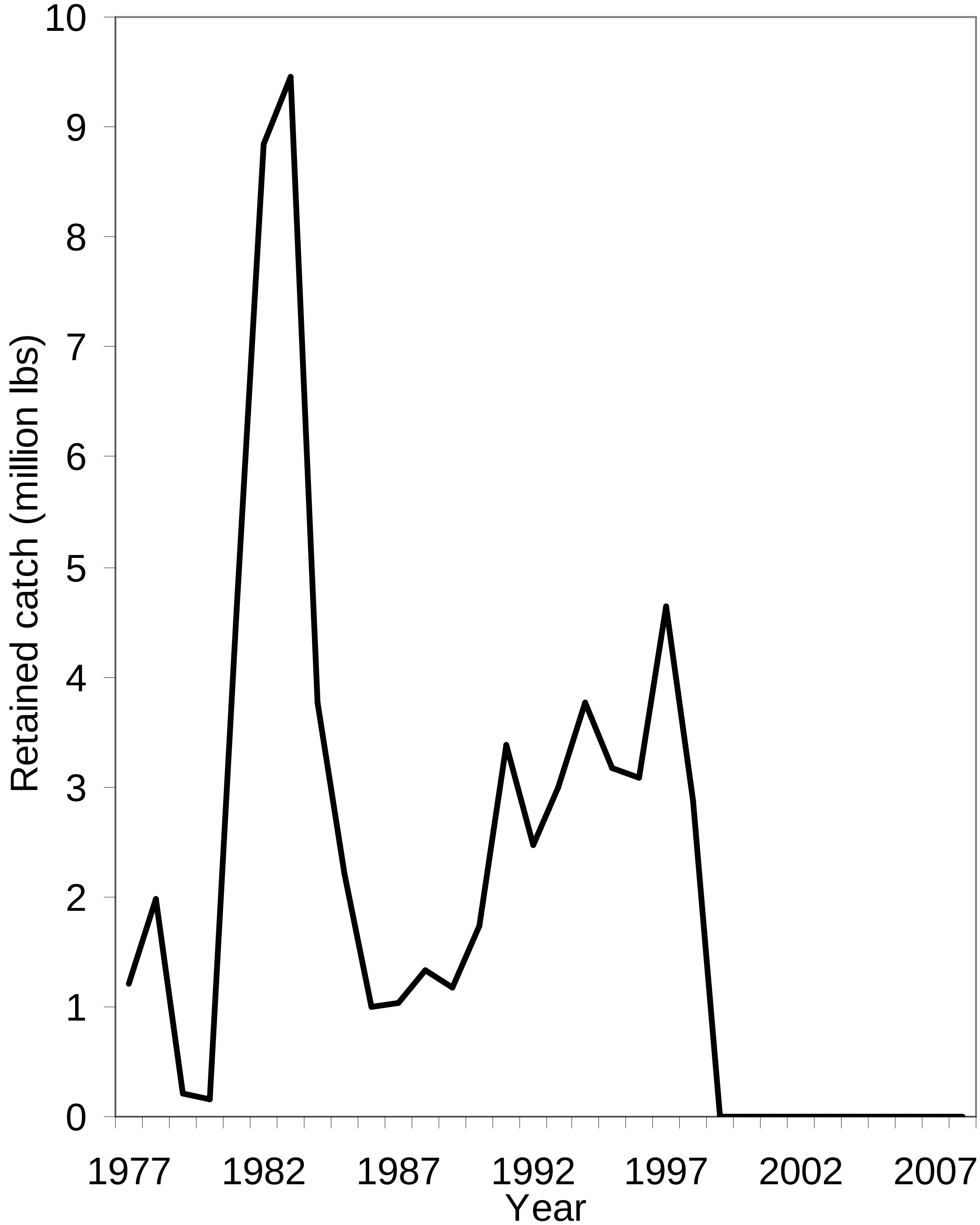


Figure 3. Retained catch over time for St. Matthew Island blue king crab.

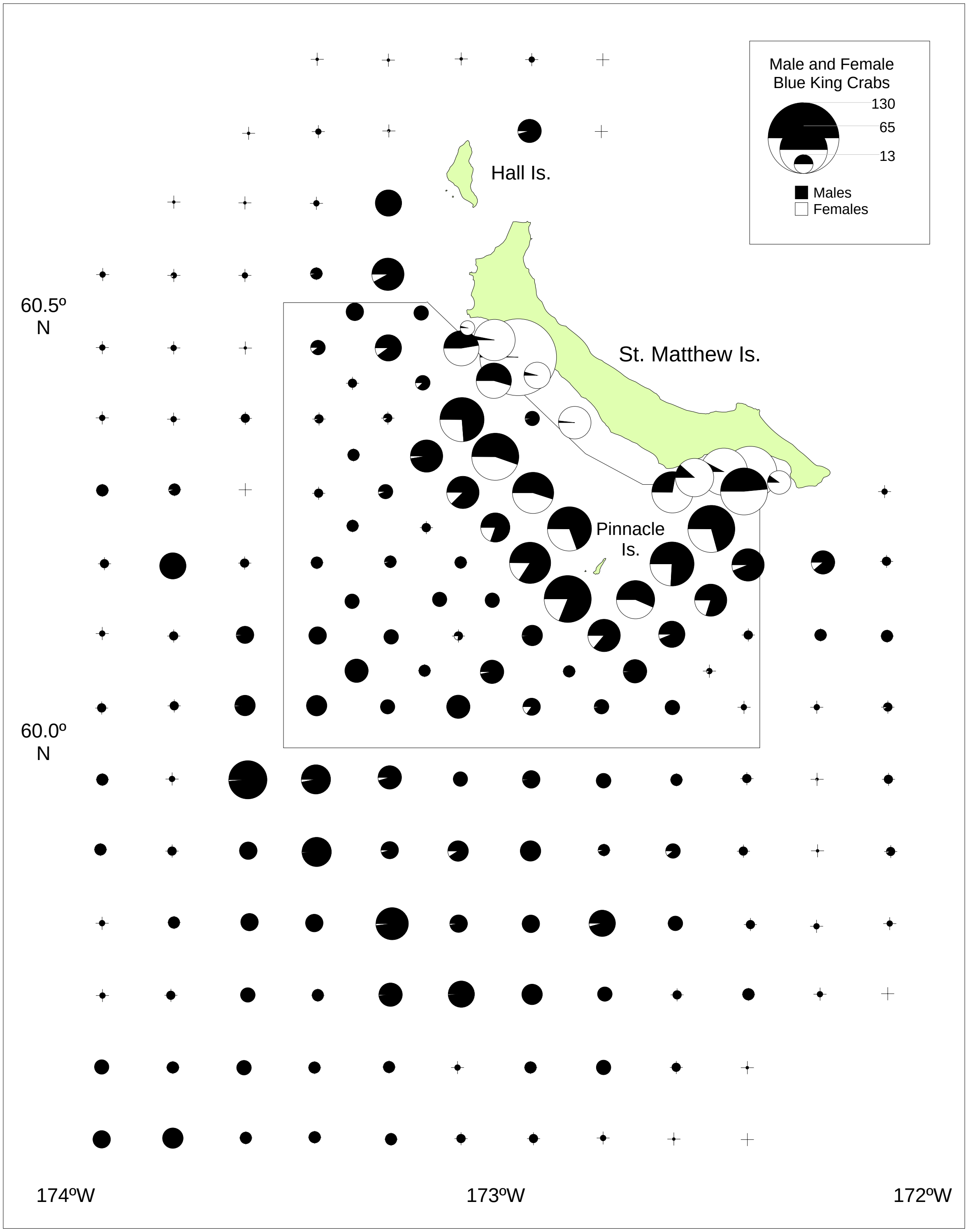


Figure 4. Male and female blue king crab catch per unit effort (CPUE) by station in the 2007 St. Matthew Island survey. (Source: Watson 2008).

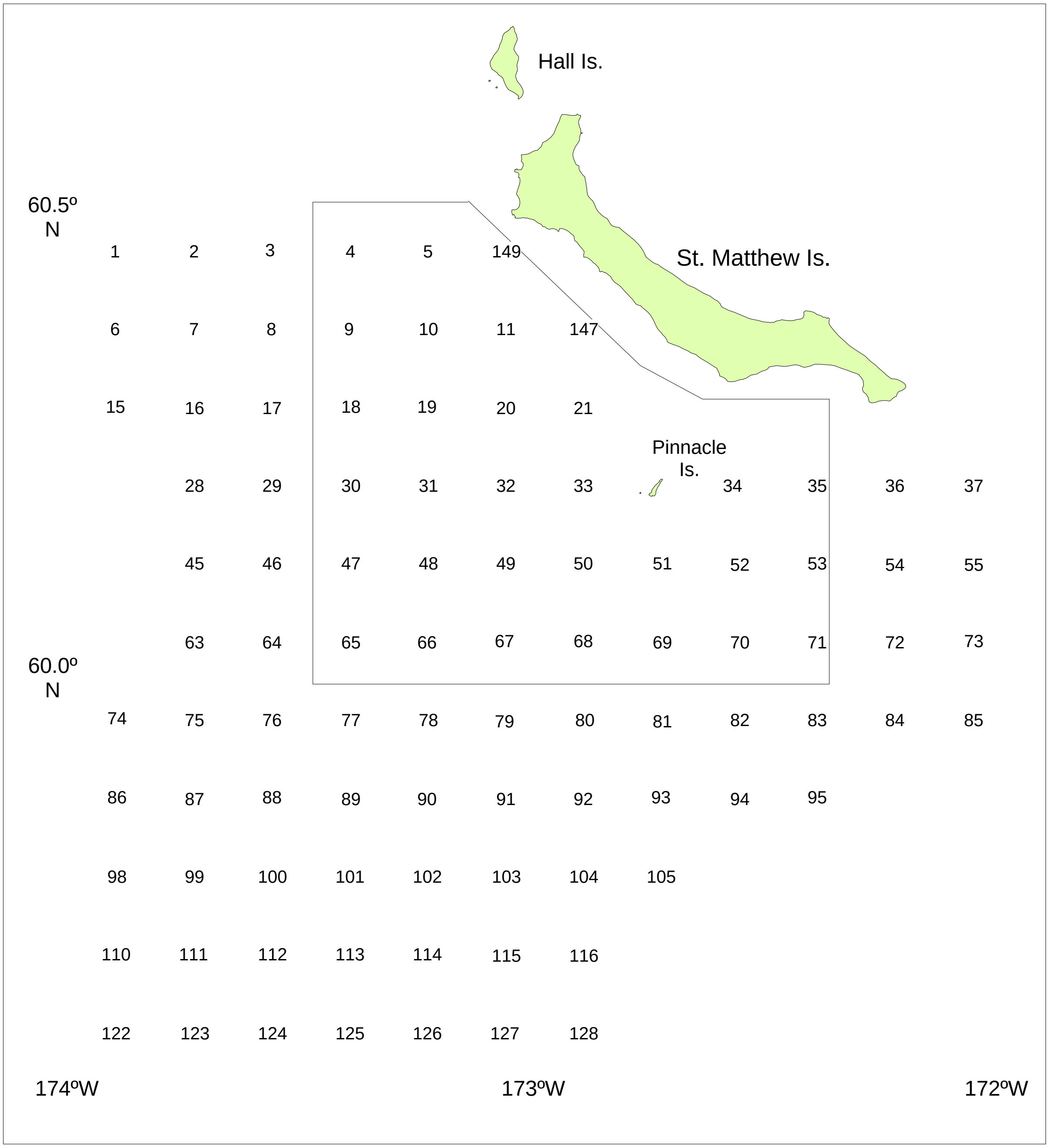


Figure 5. Location of the 96 stations fished in common during the five triennial St. Matthew Island blue king crab surveys, 1995 - 2007. (Source: Watson 2008).

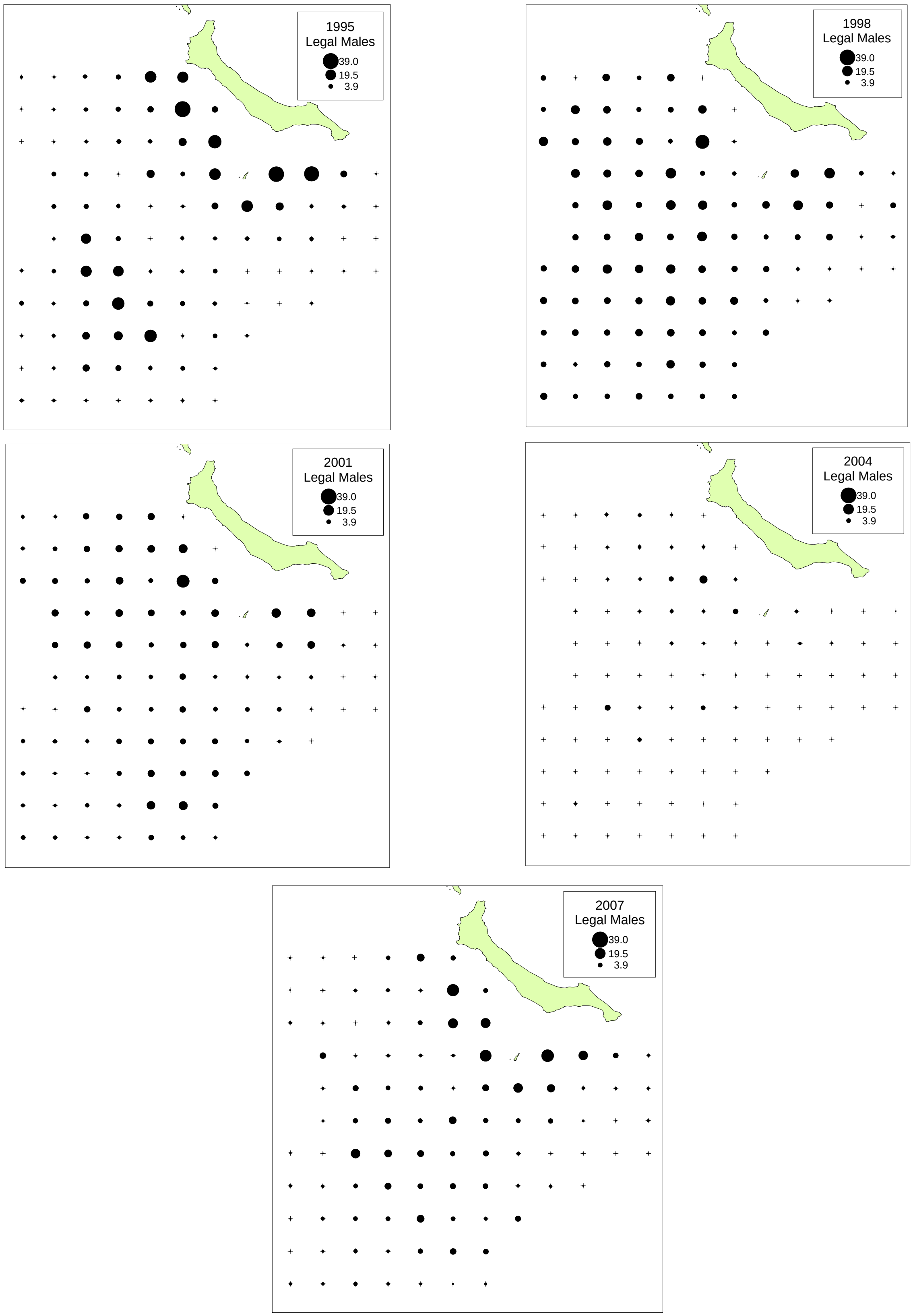


Figure 6. Legal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

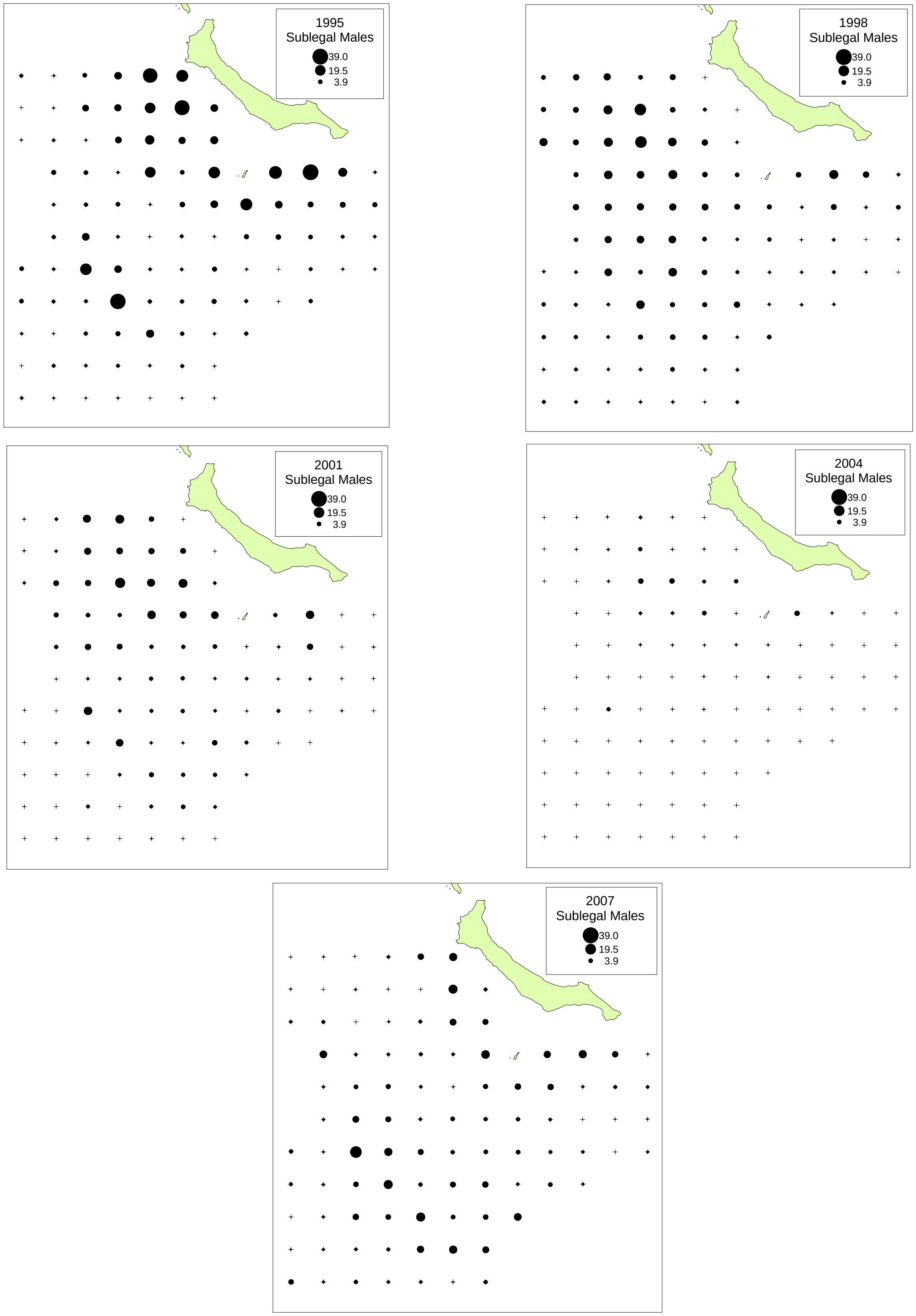


Figure 7. Sublegal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

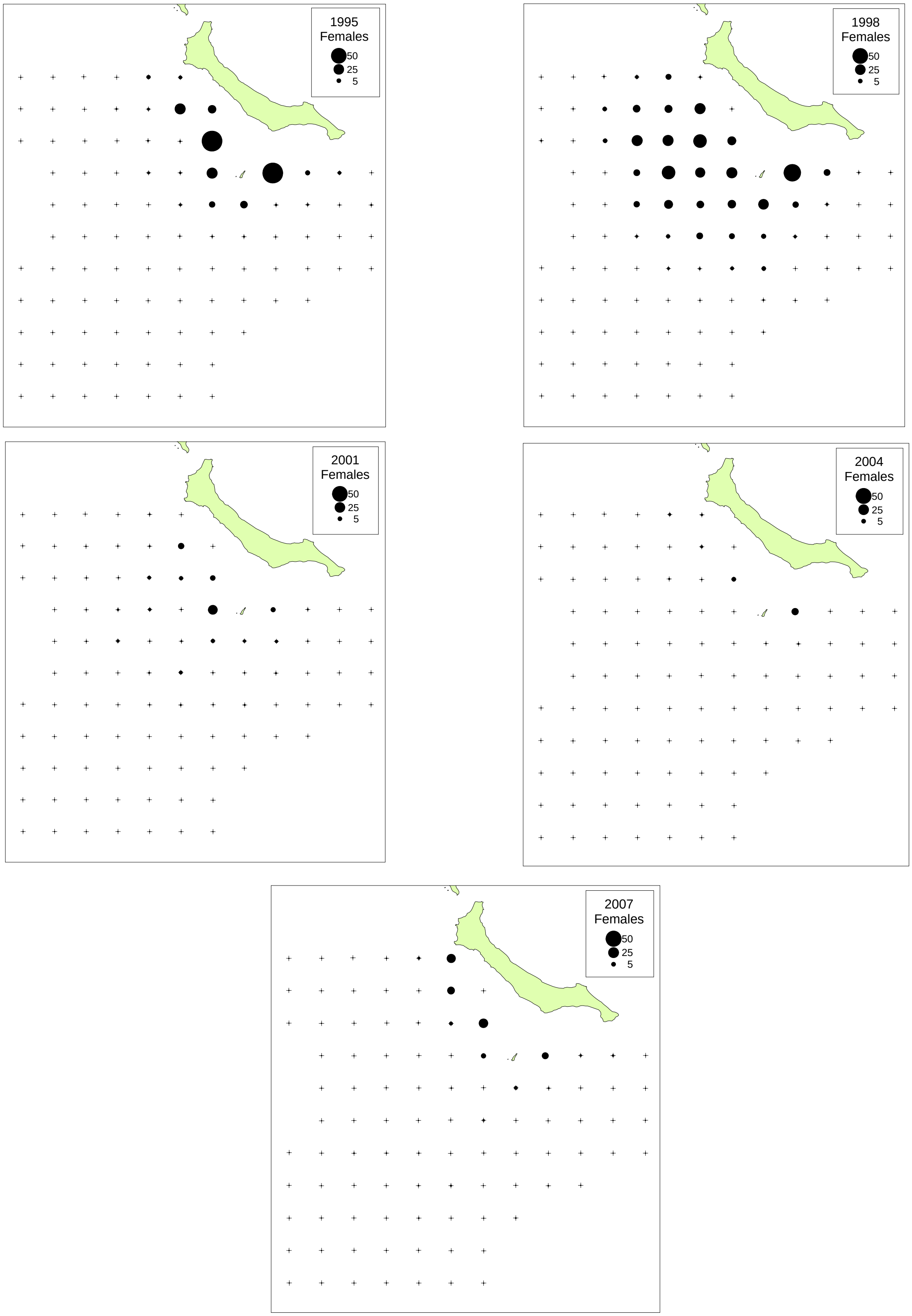
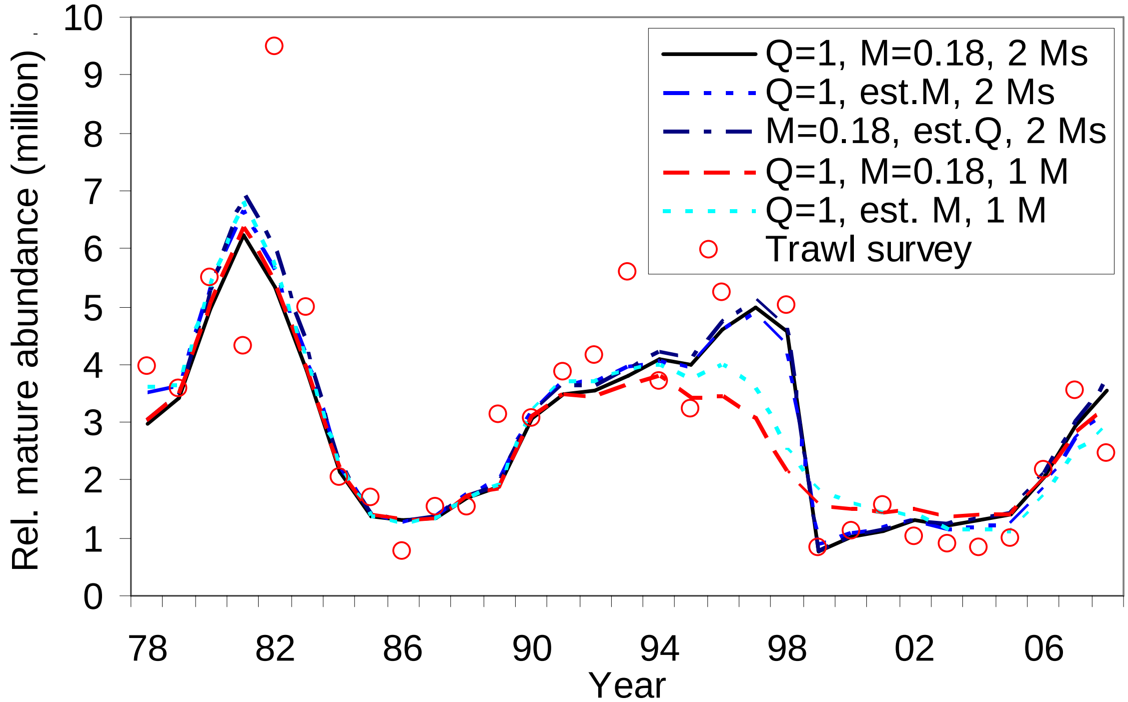


Figure 8 Female blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).



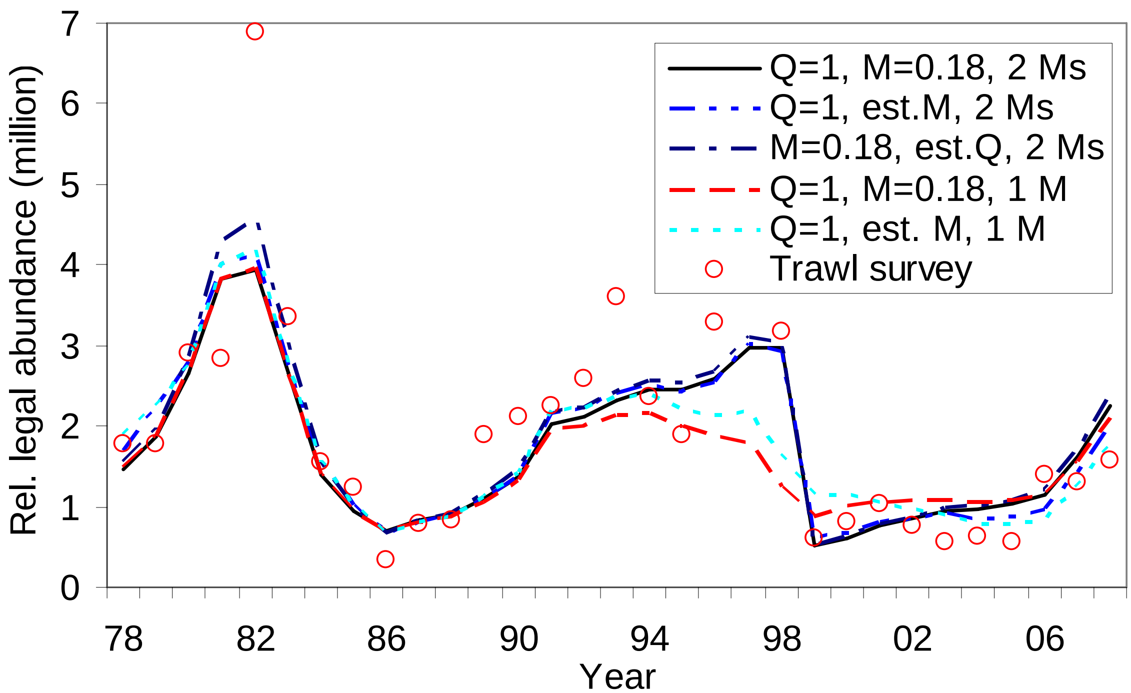


Figure 9. Comparison of relative mature male (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with five scenarios of the catch-survey analysis and trawl survey abundance.

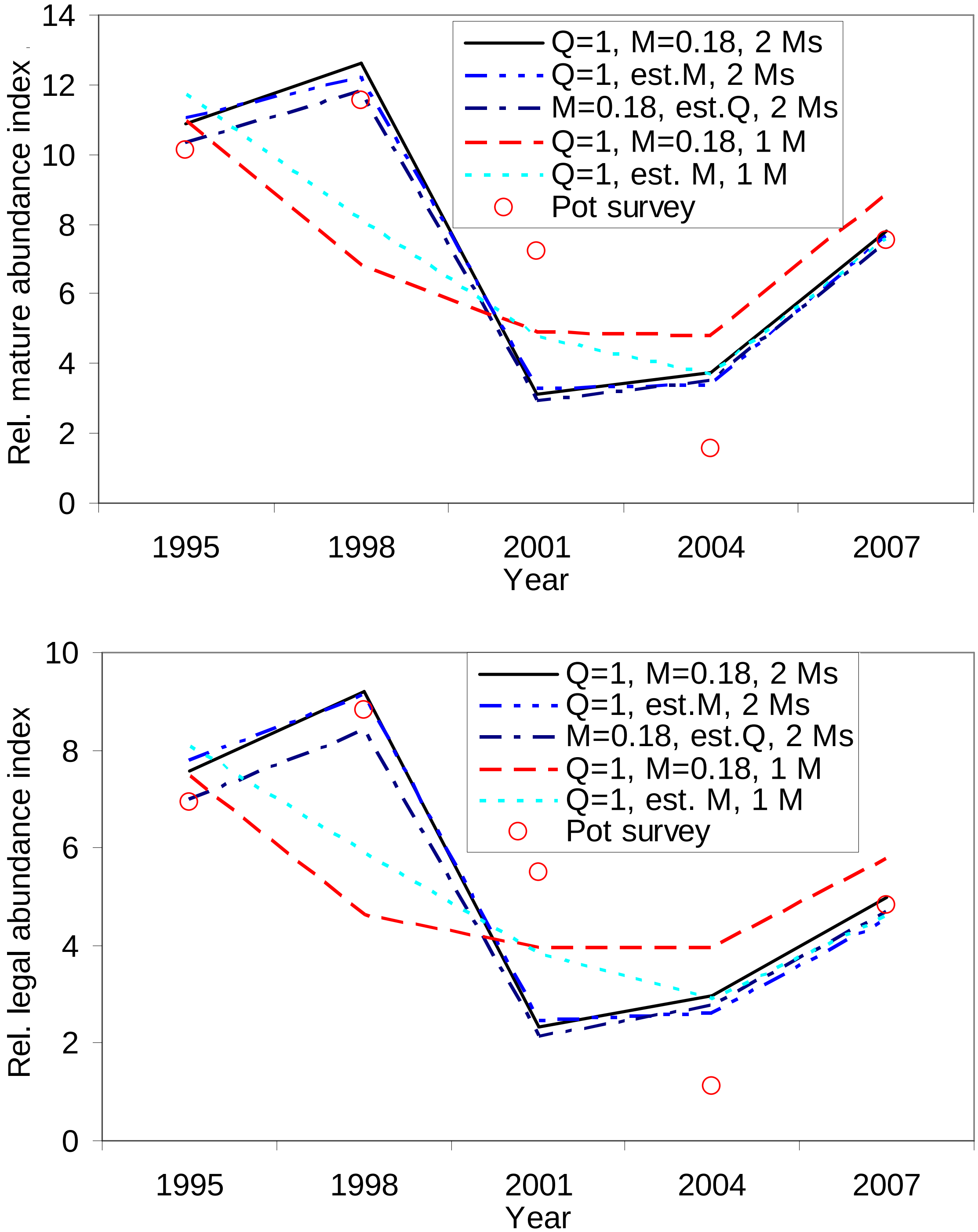
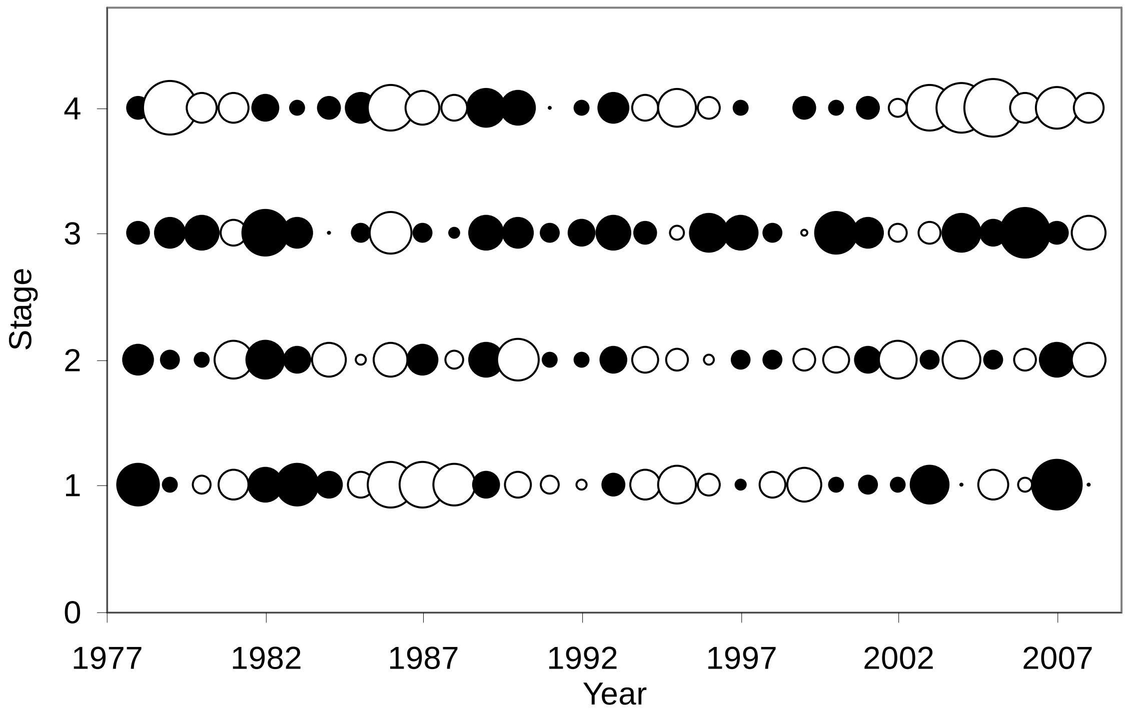


Figure 10. Comparison of relative mature male (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with five scenarios of the catch-survey analysis and pot survey abundance.



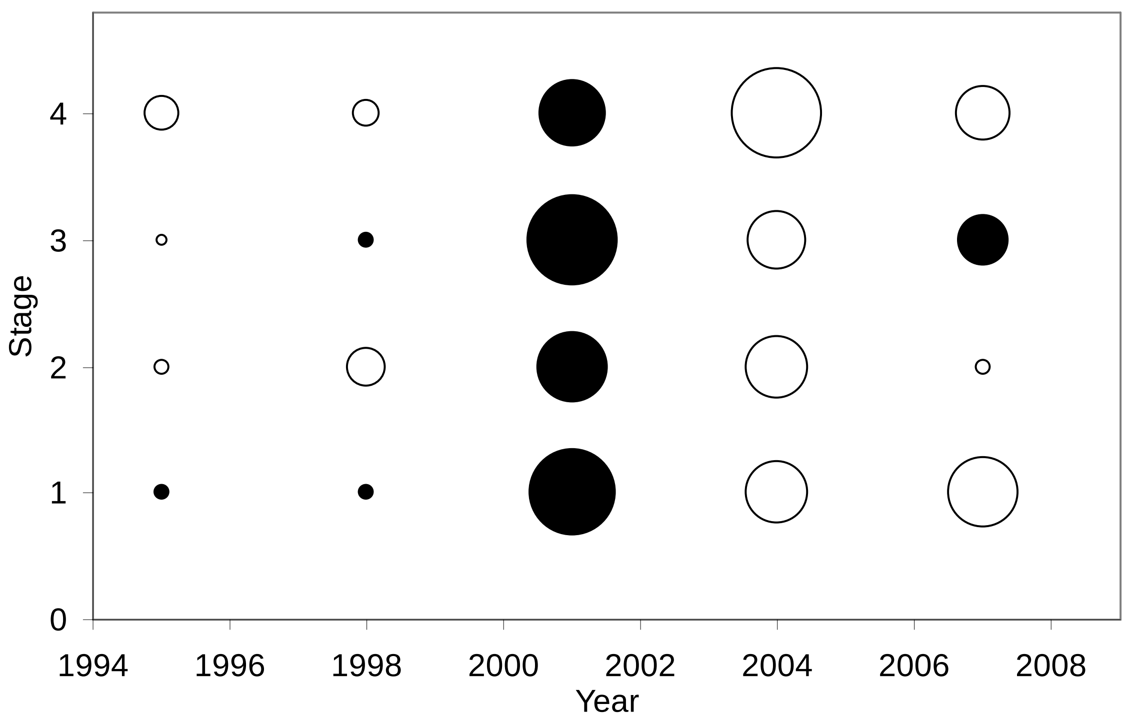


Figure 11. Residuals of the catch-survey analysis with scenario (1) of fixed both M=0.18 and Q=1. Upper plot is for trawl survey and lower plot is for pot survey. Stages 1-4 are prerecruit-2s, prerecruit-1s, recruits and postrecruits. Solid circles are positive residuals, and open circles are negative residuals.

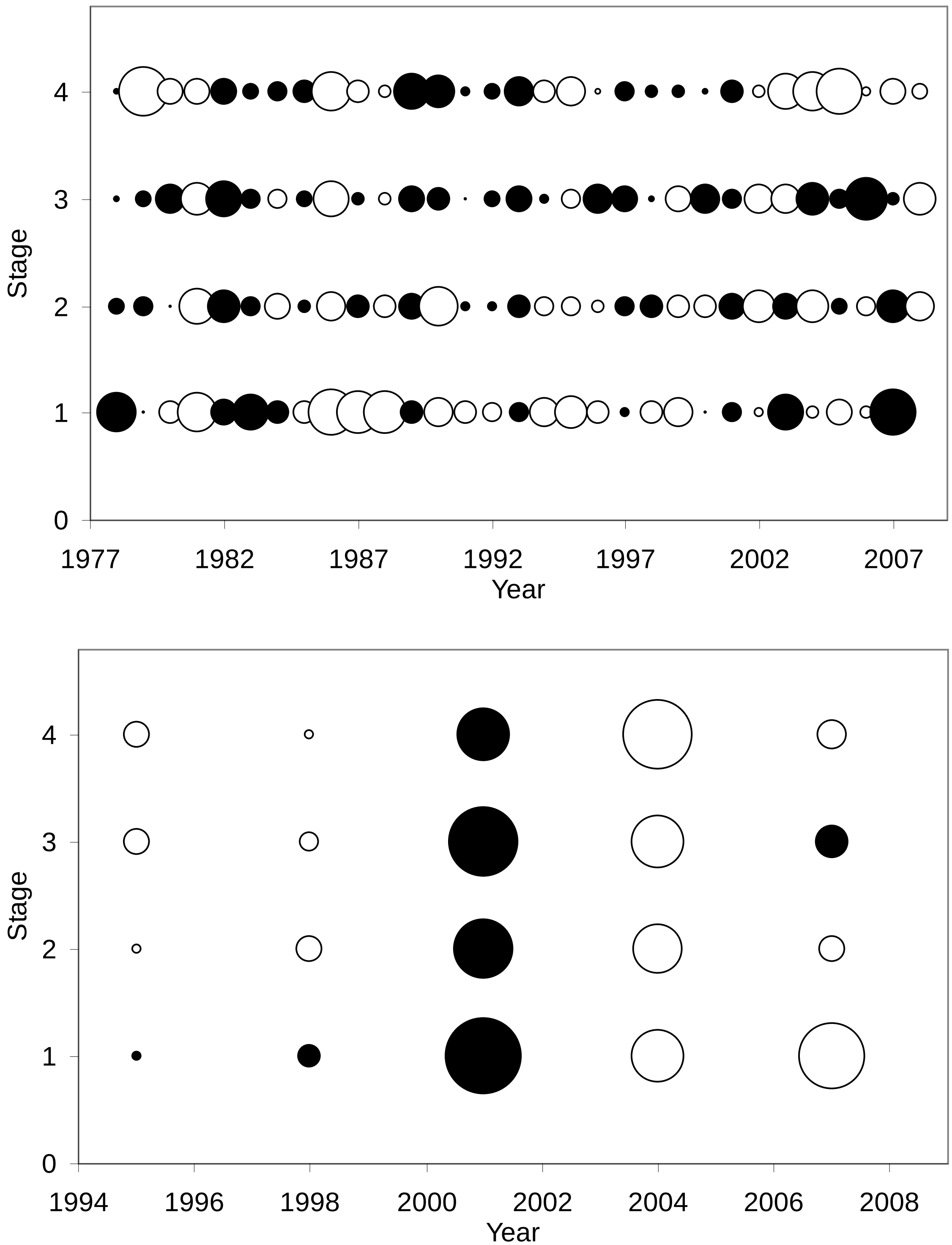
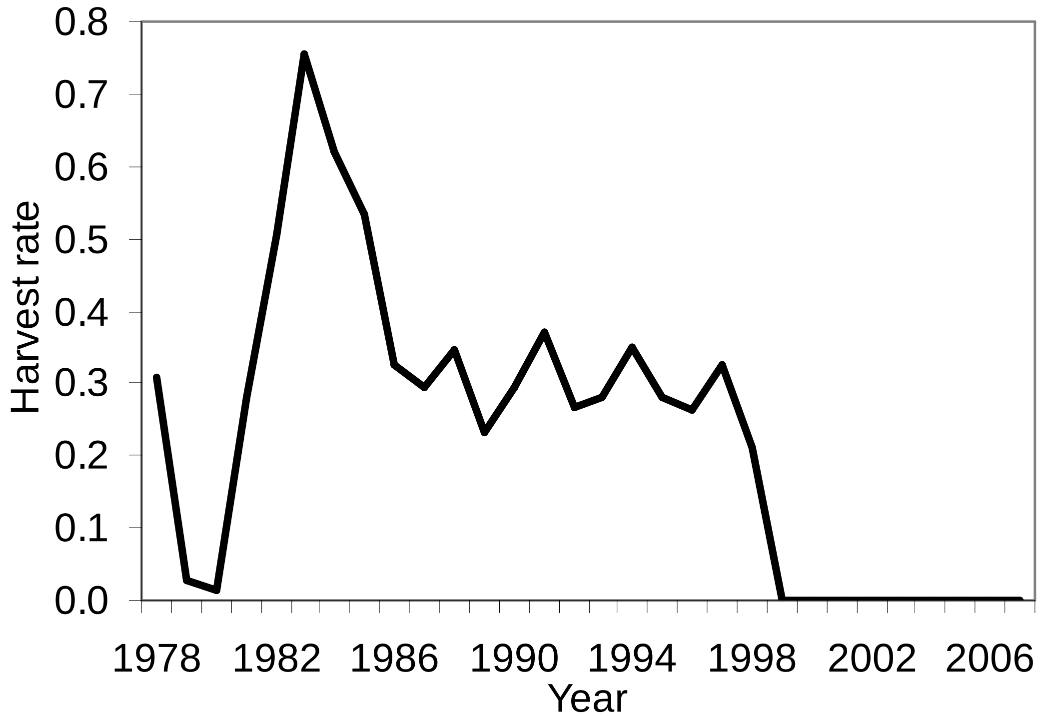


Figure 12. Residuals of the catch-survey analysis with scenario (2) of fixed *Q*=1 and estimating *M*. Upper plot is for trawl survey and lower plot is for pot survey. Stages 1-4 are prerecruit-2s, prerecruit-1s, recruits and postrecruits. Solid circles are positive residuals, and open circles are negative residuals.



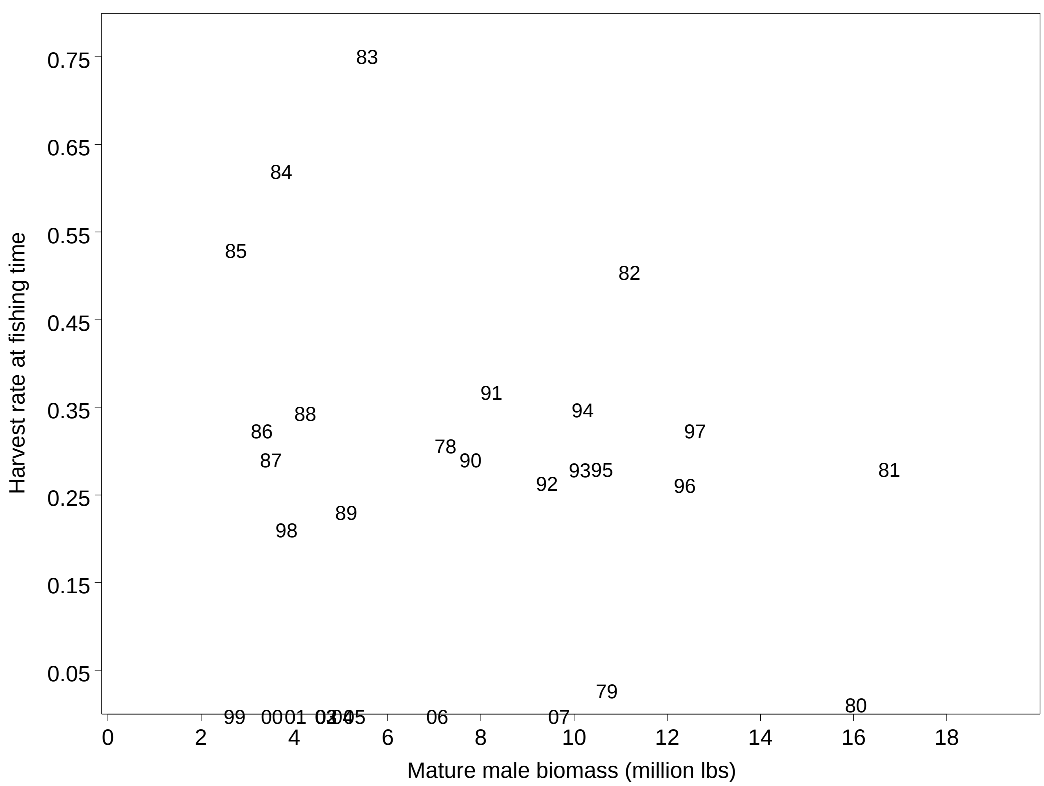


Figure 13. Estimated harvest rates (upper plot) and relationship between harvest rate and mature male biomass (lower plot) of St. Matthew Island blue king crab with scenario (1) of fixed *M*=0.18 and *Q*=1.0.

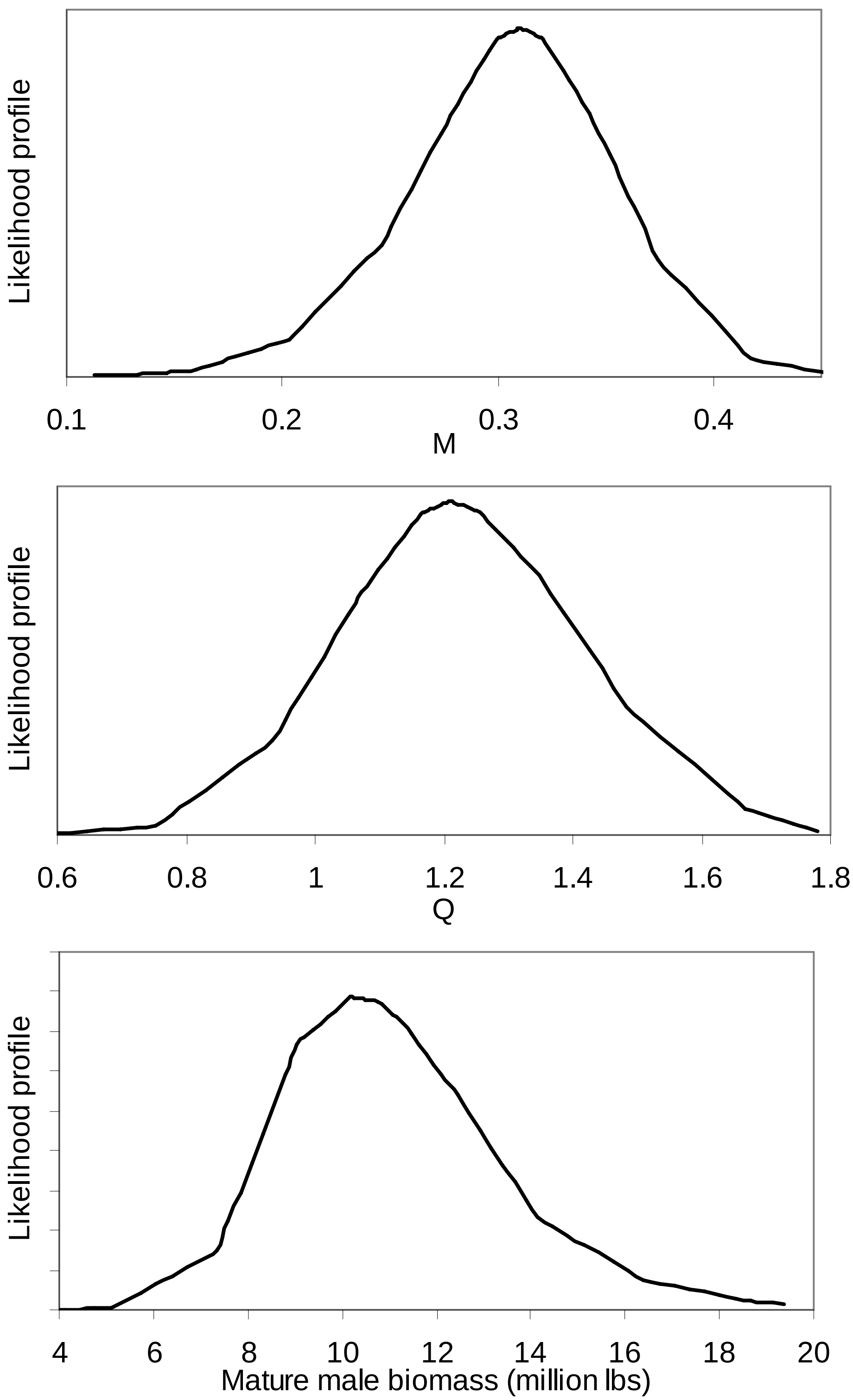
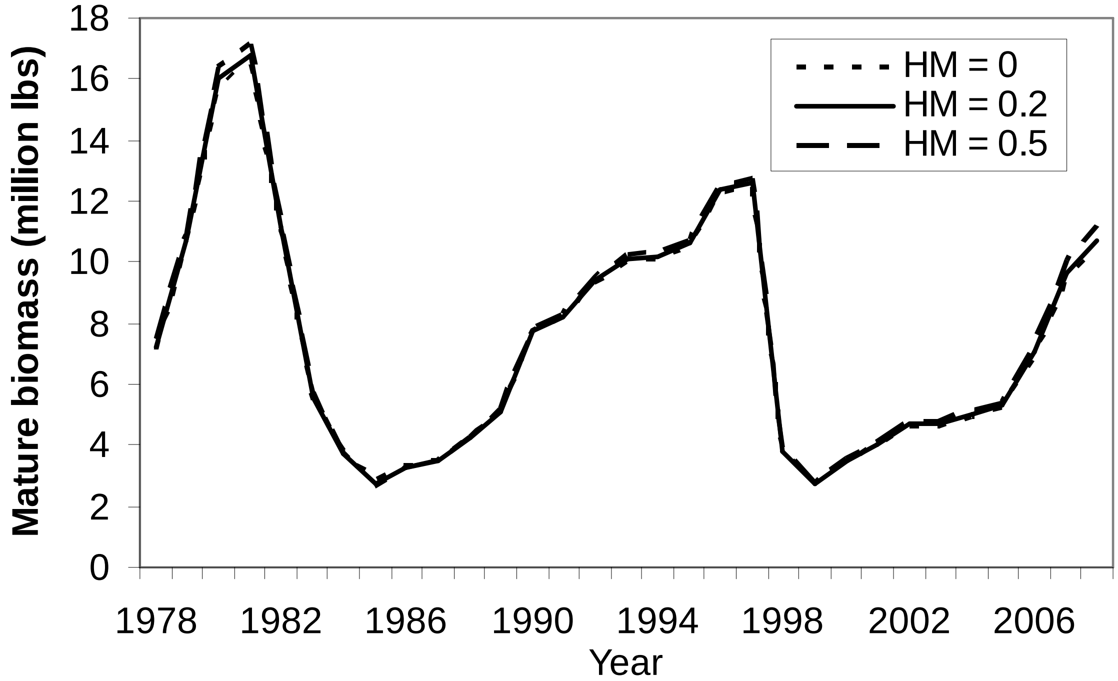


Figure 14. Likelihood profiles of estimated natural mortality (*M*) with a fixed trawl survey catchability (*Q*=1) (scenario 2), estimated trawl survey catchability with a fixed *M* (=0.18) (scenario 3), and estimated mature male biomass on Feb. 15, 2009 with fixed *M* =0.18 and *Q* = 1 and F = 0.18 in 2008 (scenario 1).



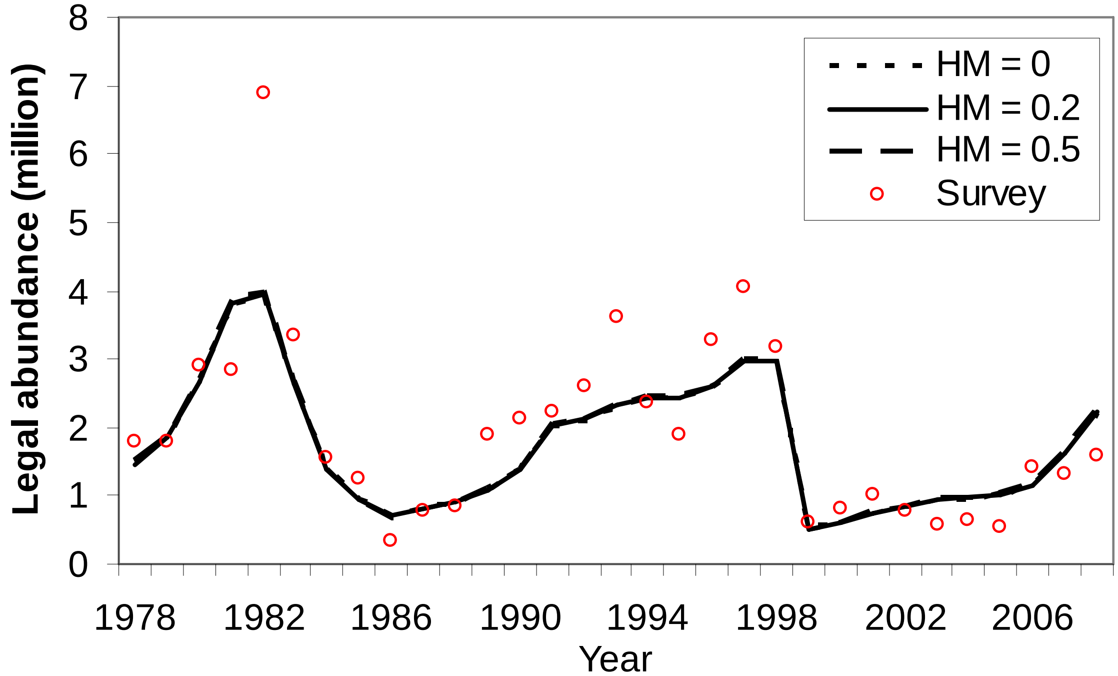
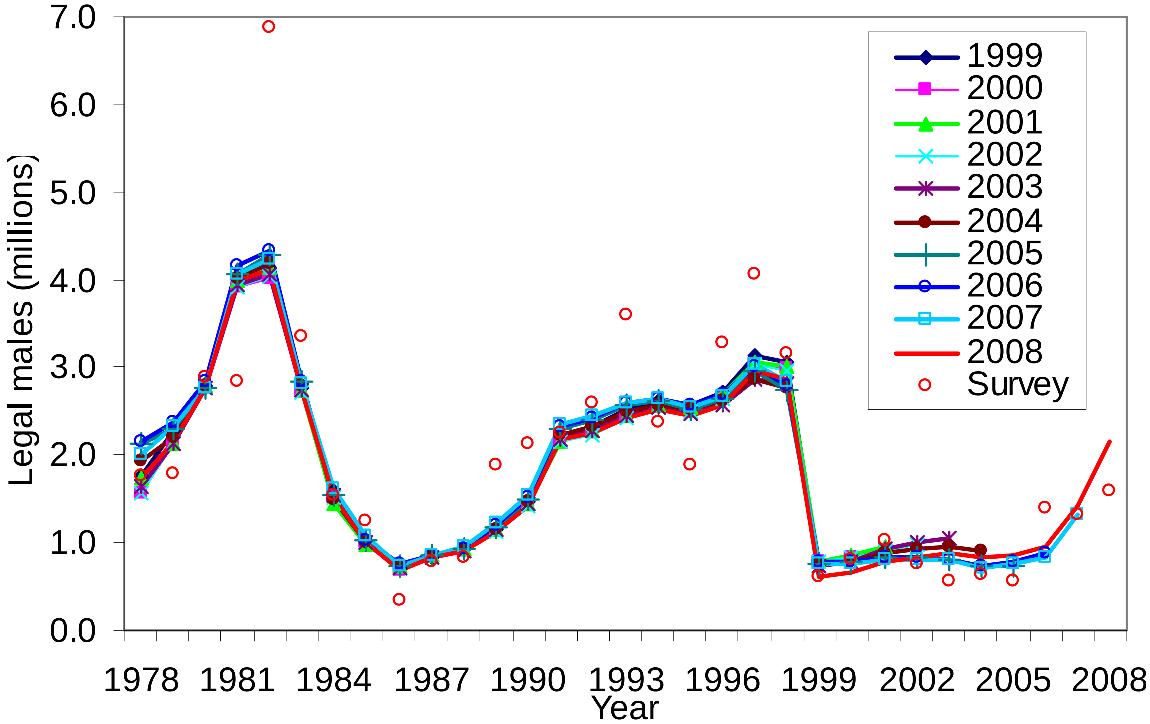


Figure 15. Comparison of estimated mature male biomass (upper plot) and legal male abundance (lower plot) with three levels of handling mortality under scenario (1) of fixed $M = 0.18$ and $Q = 1.0$.



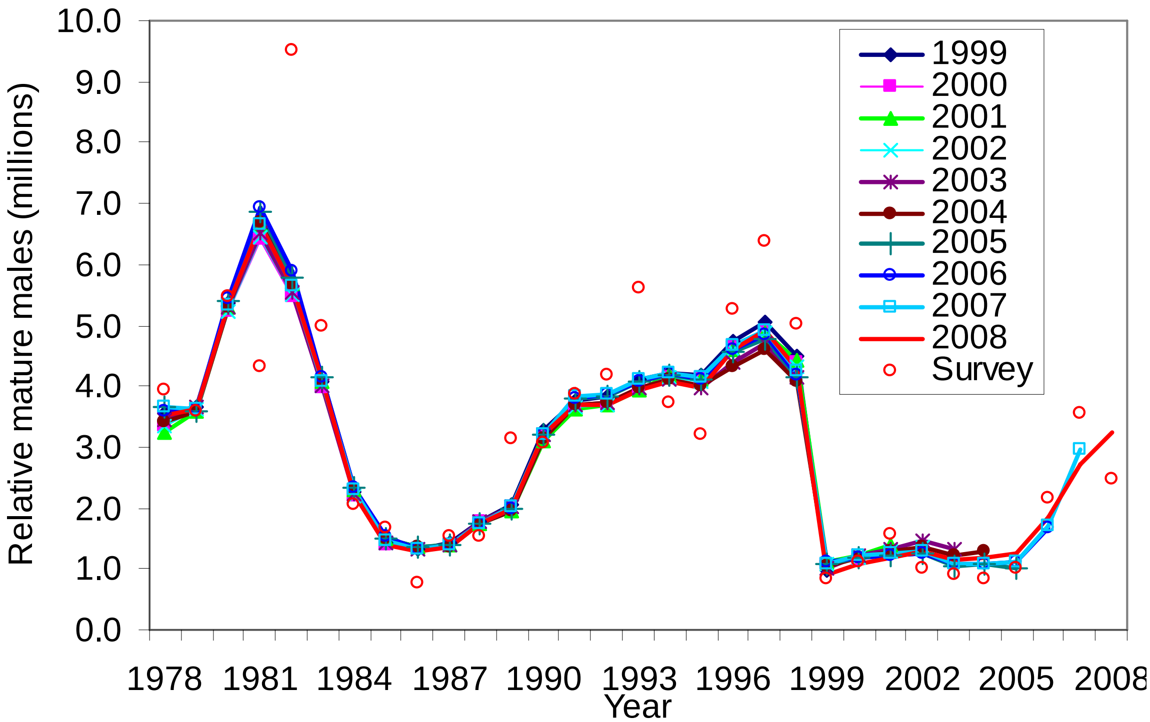
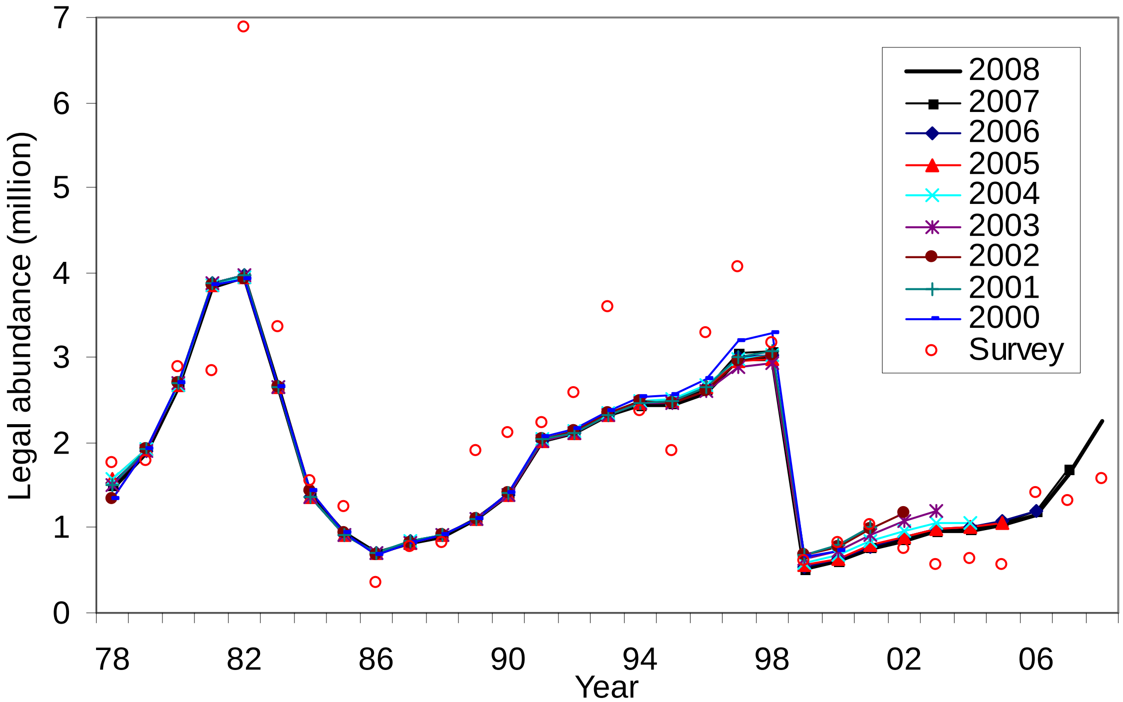


Figure 16. Comparison of estimates of legal male abundance and relative mature male abundance of St. Matthew Island blue king crab with terminal years 1999-2008. The 2008 model was with a fixed *Q*=1.0 and estimating *M* (scenario 2). These are results of historical assessments. Legend shows the year in which the assessment was conducted.



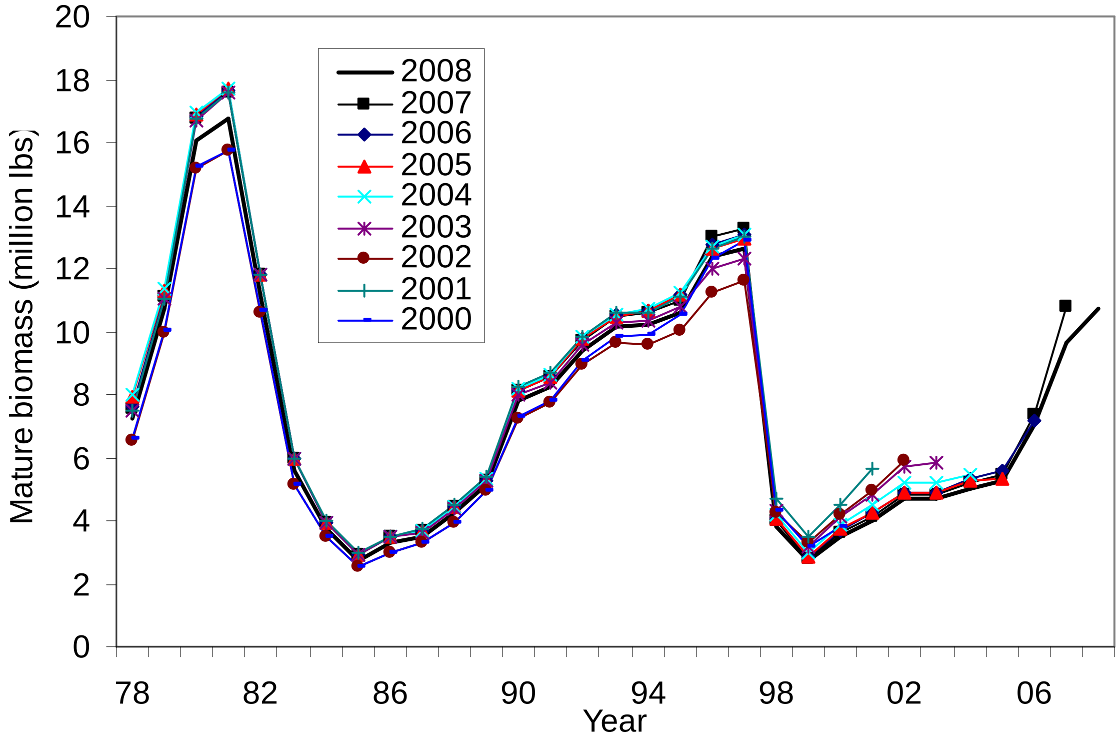
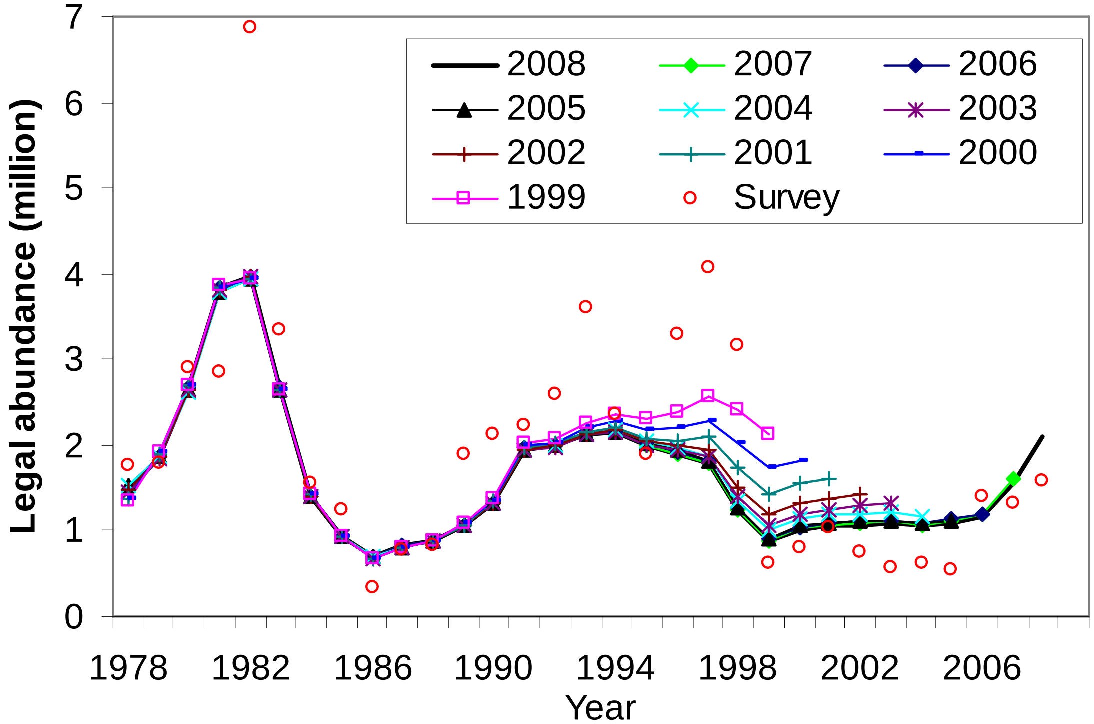


Figure 17. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 2001-2008. These are results of the 2008 model with a fixed *M*=0.18 and *Q*=1.0 (scenario 1). Legend shows the year in which the assessment was conducted.



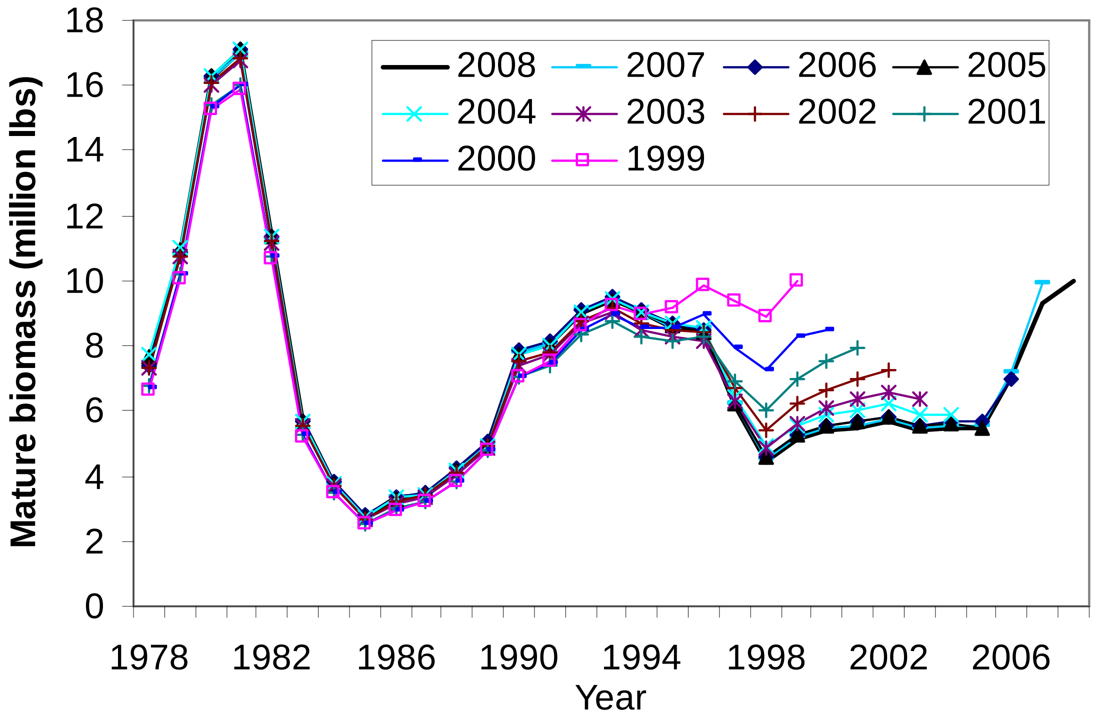


Figure 18. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 1999-2008. These are results of the 2008 model with a fixed *M*=0.18 and *Q*=1.0 (scenario 4). Legend shows the year in which the assessment was conducted.

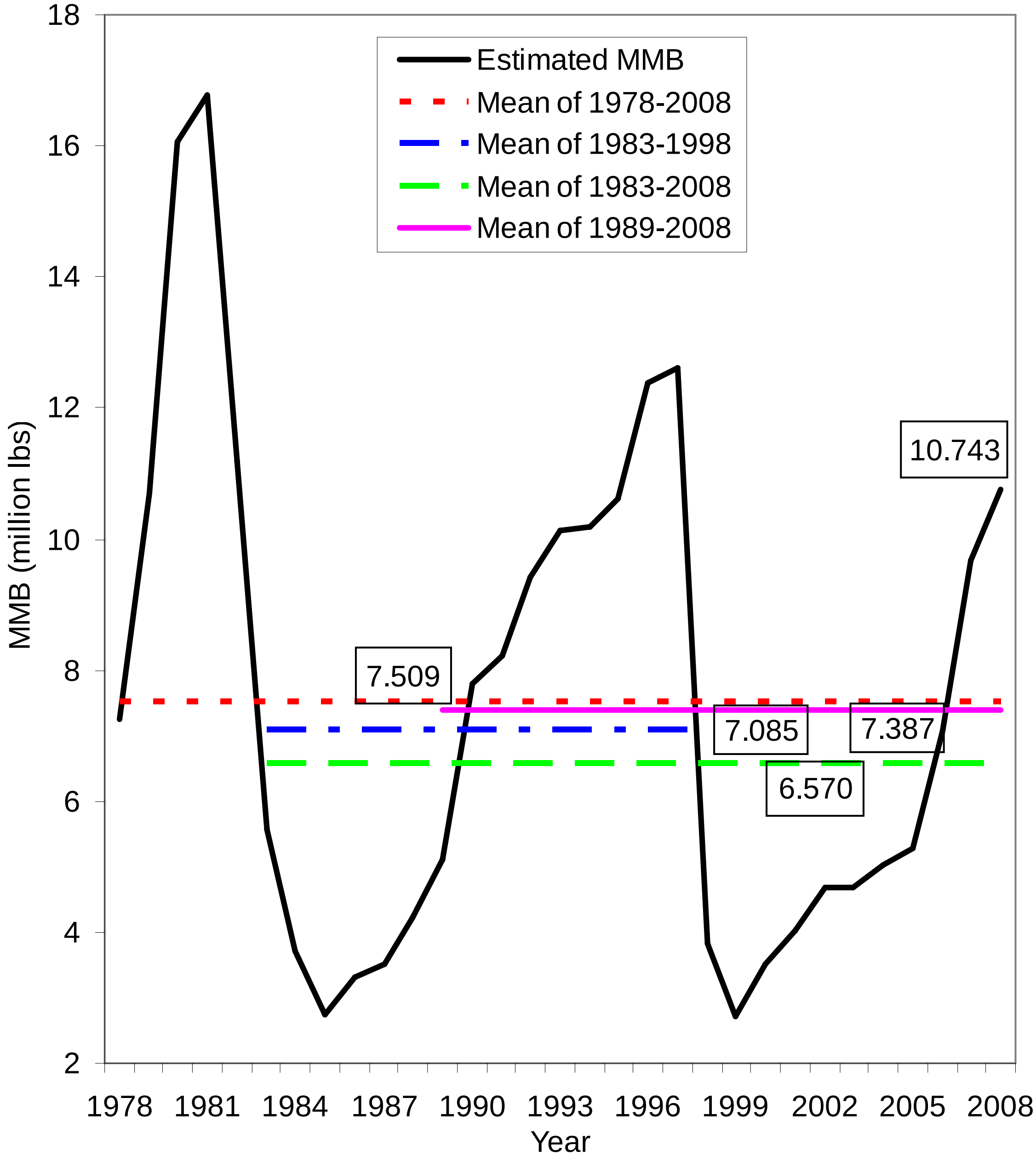


Figure 19. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed *M*=0.18 and *Q*=1.0 (scenario 1). $\gamma = 1$ was used for the 2008 fishery to project mature male biomass in 2008.

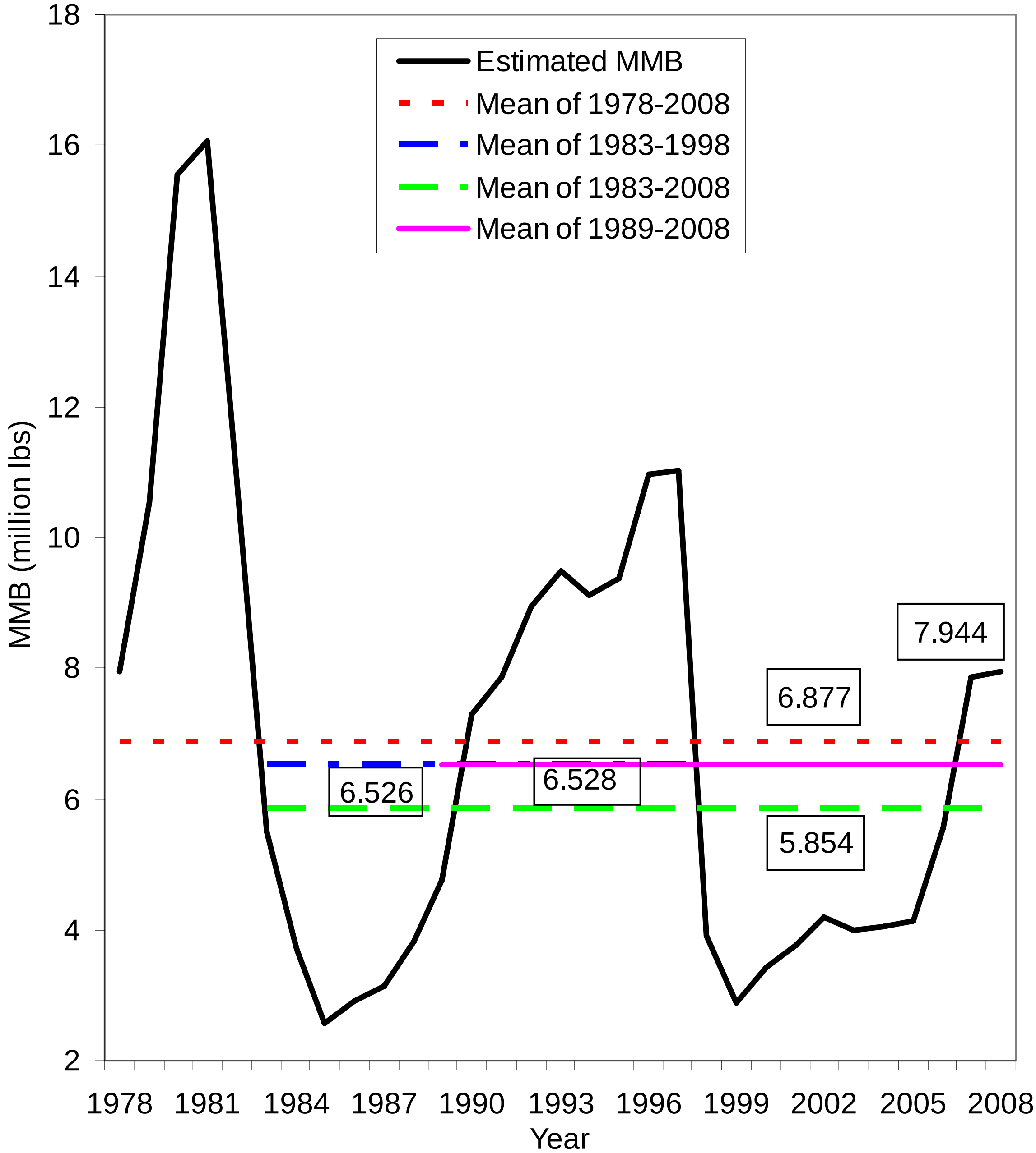


Figure 20. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed Q=1.0 and estimating M (scenario 2). $\gamma = 1$ was used for the 2008 fishery to project mature male biomass in 2008.

Norton Sound Red King Crab Stock Assessment in Fall 2008

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Executive Summary

Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska, support three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. 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 the data from 1976 to 2008 and estimated population abundance in 2008. Estimated abundance and biomass in 2008 are:

Legal males: 1.4932 million crabs.

Mature male biomass: 5.240 million lbs.

Average of mature male biomasses during 1983-2008 was used as the B_{MSY} proxy and due to uncertainty of abundance estimates, γ=1 was used to derive the F_{MSY} proxy. Estimated B_{MSY} proxy, F_{MSY} proxy and retained catch limit in 2008 are:

B_{MSY} proxy = 3.567 million lbs,

F_{MSY} proxy = 0.18,

Retained catch limit: 0.2460 million crabs.

Summary of Major Changes in 2008

1. Historical trawl survey abundance estimates were revised. The original estimates were based on the core area with some survey stations outside of the core area not being used for abundance estimates. The new estimates were based on all sampled areas.
2. Historical harvest and size composition data were re-checked and revised as necessary.
3. Natural mortality was changed from 0.3 to 0.18.
4. Newshell and oldshell length compositions were combined to compute likelihood values.

Response to CPT Comments (from May 2008)

"The team requests that additional information be included in future assessment reports on asymptotic standard errors and selectivity parameters (to indicate which are fixed not estimated). The residual plots as shown are difficult to interpret and should be revised. The team discussed the rationale for using the M value of 0.18 and its basis on laboratory studies. Some team members did not agree with this estimate usage for this stock noting that model information could be used to inform the best estimate. The team recommends exploration of a broader range of models and sensitivity analyses for this stock in the future."

The previous report showed which parameters are estimated and which are fixed. The standard error of estimated parameters can be documented in the report in April 2009. Weights on various data and parameter sensitivities were investigated in Zheng et al (1998) and can be reexamined with alternative models in the future. Alternative M values can be examined in the report in April 2009. Residuals are standardized and re-graphed for improving presentation.

Response to SSC Comments specific to this assessment (from June 2008)

"A new model has been developed for this stock that includes a four-stage catch-survey analysis. There is need for further exploration of this model, in terms of which parameters can be estimated and sensitivity to model specifications. Nevertheless, the SSC agrees with the Plan Team and author that the model is appropriate for determining OFL. ***The SSC concurs with the placement of the stock in Tier 4 but encourages further investigation of whether this stock could be placed in Tier 3.*** *The SSC requests a presentation on this model at the October meeting.*

The SSC also accepts the choices for range of years, but requests that the rationale be elaborated more clearly. Similarly, a rationale for setting gamma equal to 1 needs to be provided."

Evaluation of parameters and Tier replacement will be carried out after fall 2008. The default gamma value of 1 is used in this report and evaluation of alternative gamma values will be carried out when evaluating Tier replacement after fall 2008. Changes to the May 2008 version of this report include:

1. Residuals by size were standardized and re-plotted in Figures 3 and 4 for a better presentation.

2. Objective function values by data components were added to Table 5.

Response to SSC Comments in General (from June 2008)

"General recommendations to all assessment authors for future assessments:

1. *To the extent possible, a consistent format should be used for the assessments; sections that are not relevant to a particular stock should be omitted.*
2. *Each assessment should provide a range of alternatives for the Plan Team and SSC to consider when setting OFLs, for example, alternative model configurations for Tier 1-3 stocks, alternative parameter values where these are highly uncertain and cannot be estimated, or alternative time periods used in Tier 4 and Tier 5 calculations.*
3. *Model-based stock assessments should clearly document all data sources, model equations, the number of parameters, a list of which parameters are estimated in the model, and a list of fixed parameters, and a justification for the selected parameter values.*
4. *The rationale for selecting a specific time period for establishing B_{MSY} proxies based on time series of recruitment (Tier 1-3) or biomass (Tier 4) or for establishing an OFL based on catch histories (Tier 5) should be clearly articulated. Unless compelling reasons exist to choose a different period, the default should be the full time series for which data are available. When alternative time periods are considered, the rationale and the resulting reference points should be presented for consideration by the Plan Team and SSC.*
5. *The crab OFL definitions are designed to provide a guide for defining the best available proxy for MSY when data are insufficient to directly estimate MSY. The guidelines allow gamma (γ) in the formula for computing F_{OFL} under Tier 4 to be set at a value higher or lower than 1. A gamma less than 1 might be justifiable if the available biomass measure includes a large portion of small crab that has not recruited to the fishery. A gamma greater than 1 might be justifiable if the directed fishery can be expected to harvest male crab with carapace widths well above the size at 50% maturity. The SSC agrees with the Plan Team recommendation that* ***future stock assessments should provide analyses to support the choice of gamma****. These analyses could include an exploration of fishery selectivity and a comparison of minimum size limits and size at 50% maturity for male crab. The SSC does not recommend the use of an $F_{35\%}/M$ ratio derived from one stock as a default for gamma on an unrelated stock unless there is a strong rationale for concluding that the fishery is likely to be prosecuted in an identical manner and knowledge of stock status is sufficient to justify the harvest rate.*
6. *To the extent possible, bycatch information should be provided for all stocks included in the SAFE so that stock OFLs can be moved from "retained catch OFL" to "total catch OFL".*
7. *For stocks with an assessment model, the SSC requests that the authors include a table summarizing the fit to data (including number of parameters, likelihood for each data component, etc.).*
8. *The ecosystem considerations sections could be expanded to include information on prey and predator composition in a consistent format (e.g., pie charts similar to the groundfish assessments). A discussion of seabird predation on crab would be a useful addition. We note that seabirds feed on larval through juvenile crab, particularly in shallow or nearshore areas, such as the Pribilof Islands. Plankton-feeding birds eat larval crab and juveniles are consumed by seaducks and seabirds, particularly during winter months.*
9. *Each assessment should include figures showing the available time series of catch and survey biomass, in addition to tables, to facilitate comparisons and the selection of appropriate time periods.*

10. *The presentation of recruitment time series should be standardized as to year (examples include year of recruitment to maturity for spawner/recruit data, or perhaps year of hatching; and year of recruitment to legal size for catch data) to clearly illustrate specific cohort strength.*
11. *Assessment authors should provide alternative options for setting OFLs to the Plan Team and the SSC, particularly where there are large uncertainties about correct model structure or parameter estimates."*

The schedule for this fishery is advanced by several months relative to most of the other Bering Sea crab fisheries, such that the SSC's review of the OFL and TAC occurred in June. Therefore, substantive changes to the assessment in response to these review comments will be addressed in the revised assessment in preparation for TAC setting for the summer fishery, to be presented at the May, 2009 crab plan team meeting.

Introduction

Norton Sound Red King Crab (*Paralithodes camtschaticus*) 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 bottom temperatures above 4 ^{o}C. 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. Thus far, no studies have been made on possible stock separation within the putative stock known as Norton Sound red king crab.

The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Soong et al., *in prep*). 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.

Fisheries

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 (July – August) and in winter (December – March) (Banducci et al. 2007).

Summer Commercial Fishery

A large-vessel summer commercial crab fishery existed in the Norton Sound Section from 1977 through 1990. No summer commercial fishery occurred in 1991 because there was no staff to manage the fishery. In 1992, the summer commercial fishery resumed. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Regulation changes and location of buyers resulted in harvest distribution moving eastward in Norton Sound in the mid 1990s. Commercial fisheries history and catch data are summarized in Table 1.

CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with 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 affect the CDQ crab fishery and relaxed closed-water boundaries in eastern Norton Sound and waters west of Sledge Island. At its March 2008 meeting, BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order and could occur 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%.

Data

Available data are summarized in Table 2. National Marine Fisheries Service (NMFS) conducted trawl surveys every 3 years from 1976 to 1991 (Stevens and MacIntosh 1986), and ADF&G conducted four trawl surveys during 1996-2006 (Soong and Banducci 2006). 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 average growth increment of each length class (Table 3) from the length of each soft-shell crab (molting 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 24 winter pot surveys during 1980-2008 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 change in environmental conditions over time and 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 2007 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.

Analytic Approach

Main Assumptions for the Model

A list of main assumptions for the model:

(1) Natural mortality is constant over time and length except for the last length group, which is 20% higher than natural mortality in the other five length groups, and was estimated with a maximum age of 25 and the 1% rule (Zheng 2005).

(2) 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 compositions and pot limits.

(3) Growth is a function of length and does not change over time.

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

(5) A summer fishing season for the directed fishery is short.

(6) Due to lack of data and the time of fishing mainly during summer and early fall, handling mortality is assumed to be zero.

(7) Annual retained catch is measured without error.

(8) Trawl survey catchability is set to be 1.0 for mature males.

(9) Male crabs are mature at sizes ≥94 mm CL.

(10) Length compositions have a multinomial error structure and abundance has a log-normal error structure.

Model Structure

Zheng et al. (1998) developed a length-based model for Norton Sound red king crab. The model is based on length structured model 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:

$$N_{s,l,t+1} = (N_{w,l,t} - C_{w,t} P_{w,n,l,t} - C_{p,t} P_{p,n,l,t}) e^{-0.417 M_l},$$
$$O_{s,l,t+1} = (O_{w,l,t} - C_{w,t} P_{w,o,l,t} - C_{p,t} P_{p,o,l,t}) e^{-0.417 M_l}, \quad (1)$$

where $N_{s,l,t}$ 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, which, for simplicity, we assumed constant (M) for all sizes and shell conditions except for the last length class where M_6 = 1.2 M. 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:

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} [G_{l',l}((N_{s,l',t} + O_{s,l',t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l',t} + P_{s,o,l',t}))m_{l'} e^{-(0.583-y_t)M_l}] + R_{l,t}, \quad (2)$$

where $G_{l',l}$ is a growth matrix representing the expected proportion of crabs molting from length 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, 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:

$$O_{w,l,t} = [(N_{s,l,t} + O_{s,l,t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l,t} + P_{s,o,l,t})](1 - m_l)e^{-(0.583-y_t)M_l}. \quad (3)$$

Males >123 mm CL were grouped together to form the last length class. Sublegal males (<104 mm CL) are not legally retained in the commercial catch but are sorted, discarded, and subject to handling mortality. Due to complexity and lack of data, we did not model handling mortality.

Following Balsiger's (1974) findings, we used a reverse logistic function to fit molting probabilities as a function of length and time:

$$m_l = 1 - \frac{1}{1+e^{-\alpha(\iota-\beta)}}, \quad (4)$$

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:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2). \quad (5)$$

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:

$$R_{1,t} = r R_t, R_{2,t} = (1-r) R_t, \quad (6)$$

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:

$$P_{w,n,l,t} = N_{w,l,t} S_{w,l} L_l / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l],$$
$$P_{w,o,l,t} = O_{w,l,t} S_{w,l} L_l / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l], \quad (7)$$

where L_l is proportion of legal crabs for length class l, estimated from the observer data, and $S_{w,l}$ is winter selectivity for pots for length class l. Based on winter pot survey data, winter selectivities for length classes 3-5 were assumed to be one, and $S_{w,1}$, $S_{w,2}$ and $S_{w,6}$ were estimated as parameters.

The subsistence fishery does not have a size limit, but crabs with size smaller than length class 3 are generally not retained. So, we estimated length compositions of subsistence catch as follow when $l > 2$:

$$P_{p,n,l,t} = N_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}],$$
$$P_{p,o,l,t} = O_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]. \quad (8)$$

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:

$$P_{s,n,l,t} = N_{s,l,t} S_{s,l} L_l / A_t,$$
$$P_{s,o,l,t} = O_{s,l,t} S_{s,l} L_l / A_t, \quad (9)$$

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:

$$S_{s,l} = \frac{1}{1+e^{-\phi(t-\omega)}}. \quad (10)$$

$S_{s,l}$ 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. To correct the bias of the residuals, $S_{s,6}$ was set to $0.6*S_{s,5}$ for the period after 1992. Exploitable abundance was estimated as:

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} L_l]. \quad (11)$$

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:

$$f_t = C_t / [q(A_t - 0.5C_t)]. \quad (12)$$

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:

$$P_{b,n,l,t} = N_{s,l,t} S_{s,l}(1-L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}(1-L_l)],$$
$$P_{b,o,l,t} = O_{s,l,t} S_{s,l}(1-L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}(1-L_l)]. \quad (13)$$

The same selectivity for the summer commercial fishery was applied to the summer pre-season survey, resulting in estimated length compositions for both newshell and oldshell crabs as:

$$P_{sf,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}],$$
$$P_{sf,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]. \quad (14)$$

Estimated length/shell condition compositions of summer pot survey abundance were:

$$P_{sp,n,l,t} = N_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}],$$
$$P_{sp,o,l,t} = O_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}] \quad (15)$$

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, $P_{st,l,t}$.

Parameters Estimated Independently

The following parameters were estimated independently: natural mortality (M_1-M_5=0.18 and M_6=0.216), proportions of legal males by length group, and the growth matrix. Natural mortality is based on an assumed maximum age of 25 and the 1% rule (Zheng 2005). Tagging data were used to estimate mean growth increment per molt and standard deviation for each pre-molt length class (Table 3). The growth matrix was derived from normal distributions generated with estimated mean growth increments per molt and standard deviations (Table 3). Observed growth increments per molt are approximately normally distributed. Proportions of legal males by length group were estimated from the observer data (Table 4).

Parameters Estimated Conditionally

Estimated parameters are listed in Table 5. Selectivities and molting probabilities based on these estimated parameters are summarized in Table 4.

A likelihood approach was used to estimate parameters, which include fishing catchability, parameters for selectivities of survey and fishing gears and for molting probabilities, recruits each year except the first and the last, and total abundance in the first year (Table 5). Under assumptions that measurement errors of annual total survey abundances and summer commercial fishing efforts follow lognormal distributions and each type of length compositions has a multinomial error structure (Fournier and Archibald 1982; Methot 1989), the log-likelihood function is:

$$\sum_{i=1}^{i=6}\sum_{t=1}^{t=n_i}\{K_{i,t}\sum_{l=1}^{l=6}[\hat{P}_{i,l,t}\,ln(P_{i,l,t}+\kappa)]\}-\sum_{i=1}^{i=2}\{W_i\sum_{k=1}^{k=2}\sum_{t=1}^{t=n_i}[ln(\hat{B}_{i,k,t}+\kappa)-ln(B_{i,k,t}+\kappa)]^2\}$$
$$-W_f\sum_{t=1}^{t=32}[ln(\hat{f}_t+\kappa)-ln(f_t+\kappa)]^2-W_R\sum_{t=1}^{t=32}\tau_t^2, \quad (16)$$

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 pre-season survey, 5 for summer fishery, and 6 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; W_i is the weighting factor of annual total survey abundance for data set i; $\hat{B}_{i,k,t}$ 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; $\hat{f}_t$ 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.

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 400 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_i was set as 200 for all survey abundances, W_f was set to be 100, or 50% of W_i, and W_R was set to be 0.01. According to the fishery manager, the 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. Sensitivity of estimated legal abundance to changes in W_i, W_f and maximum effective sample size was investigated.

We estimated parameters with AD Model Builder (Otter Research Ltd. 1994) using the quasi-Newton method to minimize negative likelihood values. To reduce the number of parameters, we assumed that length and shell compositions from the first year (1976) summer trawl survey data approximate 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.

Results

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 2). Estimated fishing effort for the summer commercial fishery was very similar to, but smoother than, observed fishing effort in most years (Figure 2). This close fit between the observed effort and the model effort, which is calculated from catch and abundance data, indicates that the CPUE of the summer commercial fishery is closely associated with the estimated legal abundance.

The residuals of length compositions were generally large, except for the summer pot survey (Figures 3 and 4). 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 1986, and (2) residuals of length class 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 both summer trawl and pot surveys were very close to each other; both 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 5). Due to lack of commercial fishing, the abundance in the late 1970s was close to 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 slightly downward trend from 1983 to 1993. Estimated recruitment was strong during the recent years (Figure 5; Table 5). High harvest rates (>25%) from the summer fishery occurred from 1979 to 1981, and since then estimated harvest rates have been below 20% (Figure 6). Estimated harvest rates during the last 10 years were below 15% (Figure 6).

Standard deviations of estimated parameters and abundances were artificially small except for those of recruitment estimates. Coefficients of variation for recruitment estimates were up to 71%, whereas coefficients of variation for other parameters and legal crab abundance estimates were below 11%. Such small standard deviations may partially be caused by the assumptions made in the model and a small number of survey abundances available to estimate catchabilities of the commercial fishing gear. AD Model Builder may also underestimate the standard deviations.

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. Zheng et al. (1998) assumed M = 0.3. With the low *M* value in this report, the model would not fit the shell condition data very well. We combined all shell condition data in this report. Increasing *M* from 0.18 to 0.22 would result in the best fit of the data (Figure 7). Estimates of legal male abundance and mature male biomass in 2008 decreased from *M* = 0.18 to *M* = 0.22, increased until *M* = 0.26 and then decreased again when *M* continued to increase (Figure 7).

Retrospective Analyses

Two kinds of retrospective analyses are presented in this report: (1) historical results and (2) the 2008 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 2008 to be baseline values, we can also evaluate how well the model has done in the past. The 2008 model results are based on leaving one-year 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 2008 (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 2001, 2002, 2003, and 2007 were very close to those made in 2008 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. The complete 2006 results were available and compared with those made in 2008 (Figure 8). Despite additional data and changes in the model fitting, estimated legal male abundance and mature male biomass were very close except during 2004-2006 (Figure 8).

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 2008 model includes leaving out data as well as one-year-ahead projection. The model performed very well except the estimates in the early 2000s and mid 2000s made with terminal years 2001, 2002, 2004, 2005 and 2006 (Figure 9). Like the historical results, the years with a large difference were without a trawl survey one year earlier. The average relative error from 2000 to 2007 was 25.7% for estimated legal male abundance and 28.0% for estimated mature male biomass.

The large projection errors were mainly due to data conflicts between the trawl survey and the winter pot survey. 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 and 2006 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.

Overfishing Limits for 2008

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. 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: 1976-2008, 1980-2008 and 1983-2008 (Figure 11).

Besides B_{MSY} proxy, a γ value is also needed to be determined. NPFMC (2007) sets the default γ for Tier 4 king crab stocks to be the ratio of $F_{35\%}$ to M based on the results of Bristol Bay Red king crab. This ratio is 1.844 (0.332/0.18) from the 2008 assessment results of Bristol Bay red king crab. Because Norton Sound red king crab occur at the edge of the distributional range for this species and historically the harvest rates were lower than those in Bristol Bay, we consider Norton Sound red king crab to sustain a lower exploitation rate than Bristol Bay red king crab. Therefore, we evaluated two γ values that are lower than the ratio of $F_{35\%}$ to M for setting overfishing limits for 2008: $\gamma = 1$ and $\gamma = 1.5$.

Estimated B_{MSY} proxy:

Based on average during 1976-2008: 4.328 million lbs,

Based on average during 1980-2008: 3.513 million lbs,

Based on average during 1983-2008: 3.567 million lbs.

Estimated F_{MSY} proxy:

$\gamma = 1$: 0.18,

$\gamma = 1.5$: 0.27.

Estimated mature male biomass in 2008 was 5.240 million lbs (Figure 12), 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 1983-2008 is appropriate for B_{MSY} proxy. Because a trawl survey was conducted only every three or four years, abundance estimates are very uncertain. Therefore, a conservative γ (=1) should be used to set the overfishing limits.

With B_{MSY} proxy = 3.567 million lbs, F_{MSY} proxy = 0.18 (γ=1), B = 5.240 million lbs in 2008, legal male abundance = 1.4932 million crabs or 4.1162 million lbs in 2008, the overfishing limits for retained catch in 2008 are 0.2460 million crabs or 0.6781 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.

Acknowledgments

We thank Doug Woodby, Shareef Siddeek, and James Menard of ADF&G for reviewing the earlier draft of this report. The study was funded, in part, by cooperative agreement from the National Oceanic and Atmospheric Administration (NOAA). The views expressed are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2007.

Year	Guidline Harvest Level (lbs) [b]	Legal Male Population Est. No. crab (millions)	lbs [b]	Commercial Harvest (lbs) [a,] Open Access	CDQ	Total Number (incl. CDQ) Vessels	Permits	Landings	Total Number of Registered	Pulls	Total Exvessel Price/lb	Total Fishery Value (millions $)	Season Length Days	Dates
1977	[c]	1.7	5.1	0.52		7	7	13	[c]	5,457	0.75	0.229	60	[c]
1978	3.00			2.09		8	8	54	[c]	10,817	0.95	1.897	60	6/07-
1979	3.00	0.8	2.4	2.93		34	34	76	[c]	34,773	0.75	1.878	16	7/15-
1980	1.00	1.9	5.7	1.19		9	9	50	[c]	11,199	0.75	0.890	16	7/15-
1981	2.50	1.2	3.6	1.38		36	36	108	[c]	33,745	0.85	1.172	38	7/15-
1982	0.50	0.9	2.7	0.23		11	11	33	[c]	11,230	2.00	0.405	23	8/09-
1983	0.30			0.37		23	23	26	3,583	11,195	1.50	0.537	3.8	8/01-
1984	0.40			0.39		8	8	21	1,245	9,706	1.02	0.395	13.6	8/01-
1985	0.45	1.1	3.3	0.43		6	6	72	1,116	13,209	1.00	0.427	21.7	8/01-
1986	0.42			0.48		3	3	[c]	578	4,284	1.25	0.600	13	8/01- [d]
1987	0.40			0.33		9	9	[c]	1,430	10,258	1.50	0.491	11	8/01-
1988	0.20	1.0	3.0	0.24		2	2	[c]	360	2,350	[c]	[c]	9.9	8/01-
1989	0.20			0.25		10	10	[c]	2,555	5,149	3.00	0.739	3	8/01-
1990	0.20			0.19		4	4	[c]	1,388	3,172	[c]	[c]	4	8/01-
1991	0.34	1.3	3.9			No Summer Fishery								
1992	0.34			0.07		27	27	[c]	2,635	5,746	1.75	0.130	2	8/01-
1993	0.34			0.33		14	20	208	560	7,063	1.28	0.430	52	7/01- [e]
1994	0.34			0.32		34	52	407	1,360	11,729	2.02	0.646	31	7/01-
1995	0.34			0.32		48	81	665	1,900	18,782	2.87	0.926	67	7/01-
1996	0.34	0.5	1.5	0.22		41	50	264	1,640	10,453	2.29	0.519	57	7/01- [f]
1997	0.08			0.09		13	15	100	520	2,982	1.98	0.184	44	7/01- [g]
1998	0.08			0.03	0.00	8	11	50	360	1,639	1.47	0.041	65	7/01- [h]
1999	0.08	1.6	4.8	0.02	0.00	10	9	53	360	1,630	3.08	0.073	66	7/01- [i]
2000	0.33	1.4	4.2	0.29	0.01	15	22	201	560	6,345	2.32	0.715	91	7/01- [j]
2001	0.30	1.3	3.8	0.28	0.00	30	37	319	1,200	11,918	2.34	0.674	97	7/01- [k]
2002	0.24	1.0	3.1	0.24	0.01	32	49	201	1,120	6,491	2.81	0.729	77	6/15- [l]
2003	0.25	1.0	3.1	0.25	0.01	25	43	236	960	8,494	3.09	0.823	68	6/15- [m]
2004	0.35	1.6	4.4	0.31	0.03	26	39	227	1,120	8,066	3.12	1.063	51	6/15- [n]
2005	0.37	1.7	4.8	0.37	0.03	31	42	255	1,320	8,867	3.14	1.264	73	6/15- [o]
2006	0.45	1.6	4.5	0.42	0.03	28	40	249	1,320	8,695	2.26	1.021	68	6/15- [n]

[a] Deadloss included
[b] Millions of pounds.
[c] Information not
[d] Fishing actually began 8/12.
[e] Fishing actually began 7/8.
[f] Fishing began 7/9 due to fishers'
[g] First delivery was made 7/10.
[h] First delivery was made
[i] The season was extended 24 hours
[j] Open access (OA) closed 8/29. CDQ
[k] OA closed 9/1. CDQ opened from
[l] OA opened 7/1 - 8/6. CDQ opened 6/15-6/28 and
[m] OA opened 7/1 - 8/13. CDQ opened 6/15-6/28 and
[n] CDQ opened 6/15-6/28. OA opened 7/1 to the end
[o] OA opened 7/1 - 8/15. CDQ opened 6/15-

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	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, 89-91,93,95-00,02-08	Proportion by length and shell condition
Summer preseason survey	95	Proportion by length and shell condition
Summer commercial fishery	76-90,92-07	Catch, effort, and prop. by length and shell condition
Observer data	87-90,92,94	Proportion by length and shell condition
Winter commercial fishery	76-08	Catch
Subsistence fishery	76-08	Catch
Tagging data	80-91	Mean and standard deviation of growth increment

Table 3. Means and standard deviations (SD) of growth increments per molt and 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 1980 to 1991.

Pre-molt	Growth Increment (mm)		Post-molt Length Class					
Length Class	Mean	STDEV	74-83	84-93	94-103	104-113	114-123	124+
74-83	14.50	3.344	0.01	0.54	0.45	0	0	0
84-93	14.50	3.344	0	0.01	0.54	0.45	0	0
94-103	14.09	2.685	0	0	0.01	0.58	0.41	0
104-113	13.35	2.795	0	0	0	0.01	0.65	0.35
114-123	11.35	2.192	0	0	0	0	0.03	0.97
124+	11.35	2.192	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 93-07	All Years
1	74 - 83	0.00	0.90	0.80	0.80	0.30	0.20	1.00
2	84 - 93	0.00	1.00	0.80	1.00	0.47	0.33	0.87
3	94 - 103	0.15	1.00	1.00	1.00	0.67	0.52	0.67
4	104 - 113	0.92	1.00	1.00	1.00	0.86	0.75	0.43
5	114 - 123	1.00	1.00	1.00	1.00	1.00	1.00	0.23
6	>123	1.00	1.00	1.00	0.31	1.00	0.60	0.10

Table 5. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab. Recruits R and N_{76} are in million crabs. Total number of free parameters: 49.

Parameter	Value	Parameter	Value	Data Component	Neg.Likelihood Value
N_{76}	5.5809	q_1	1.6031E-05	Trawl immat. indices	67.080
R_{76}	NA	q_2	1.5464E-05	Trawl mat. indices	342.684
R_{77}	0.0002	r	0.6098	Pot immat. indices	40.071
R_{78}	0.0002	α	0.0891	Pot mat. indices	122.201
R_{79}	0.2302	β	103.6272	Total effort	434.185
R_{80}	1.0515	$S_{st,1}$	0.9000	Trawl length compos.	2258.730
R_{81}	0.4078	$S_{st,2}$	1.0000	Pot length compos.	2569.830
R_{82}	0.7891	$S_{sp,1}$	0.8000	Winter length compos.	3819.950
R_{83}	0.9727	$S_{sp,2}$	0.8000	Summer length compos	7059.130
R_{84}	0.5390	$S_{w,1}$	0.8000	Pre-fishery length com.	310.742
R_{85}	0.2422	$S_{w,2}$	1.0000	Observed length comp.	553.780
R_{86}	0.5243	$S_{w,6}$	0.3078	Recruitment deviation	1.398
R_{87}	0.5319	ϕ_1	0.0670	Total	17579.781
R_{88}	0.4257	ω_1	95.6887		
R_{89}	0.2806	ϕ_2	0.0571		
R_{90}	0.1877	ω_2	114.8584		
R_{91}	0.1616				
R_{92}	0.1105				
R_{93}	0.1540				
R_{94}	0.5161				
R_{95}	0.4221				
R_{96}	0.4208				
R_{97}	1.0182				
R_{98}	0.0488				
R_{99}	0.0865				
R_{00}	0.9034				
R_{01}	0.4955				
R_{02}	0.7407				
R_{03}	0.1574				
R_{04}	0.4004				
R_{05}	1.6180				
R_{06}	0.8356				
R_{07}	0.9548				

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 1976-2008.

Year	Total (>73 mm)	Matures (>93 mm)	Legals (>103 mm)	MMB
1976	5.5950	4.8633	3.6343	11.1457
1977	4.7563	4.5394	3.9143	11.6665
1978	3.7666	3.7233	3.4686	10.4654
1979	2.5652	2.5602	2.4744	7.6627
1980	1.5171	1.3030	1.2784	4.0644
1981	1.9494	0.9051	0.8164	2.7715
1982	1.6774	0.9771	0.5529	2.3229
1983	2.0616	1.1714	0.7871	2.7925
1984	2.4954	1.3396	0.8962	3.1743
1985	2.4505	1.6313	1.0678	3.8162
1986	2.1310	1.7093	1.2405	4.1490
1987	2.1131	1.5324	1.2423	3.9522
1988	2.1582	1.4976	1.1951	3.9342
1989	2.1156	1.5430	1.2063	4.0540
1990	1.9338	1.5263	1.2154	4.0564
1991	1.7163	1.4419	1.2002	3.9386
1992	1.5521	1.3349	1.1640	3.7867
1993	1.3608	1.2025	1.0716	3.5094
1994	1.1585	0.9762	0.8798	2.9122
1995	1.3308	0.8015	0.7060	2.3931
1996	1.4001	0.8486	0.6197	2.2927
1997	1.4867	0.9522	0.6767	2.4408
1998	2.1417	1.0552	0.7756	2.6931
1999	1.8071	1.4417	0.9492	3.4912
2000	1.5652	1.4343	1.1562	3.7195
2001	2.0398	1.1703	1.0437	3.2667
2002	2.0635	1.3304	0.9632	3.4547
2003	2.3162	1.4502	1.0671	3.7056
2004	1.9891	1.6018	1.1632	4.0449
2005	1.9151	1.4695	1.1994	3.8891
2006	2.9711	1.3422	1.0972	3.6225
2007	3.1046	1.8316	1.1431	4.4005
2008	3.3649	2.1733	1.4932	5.2397

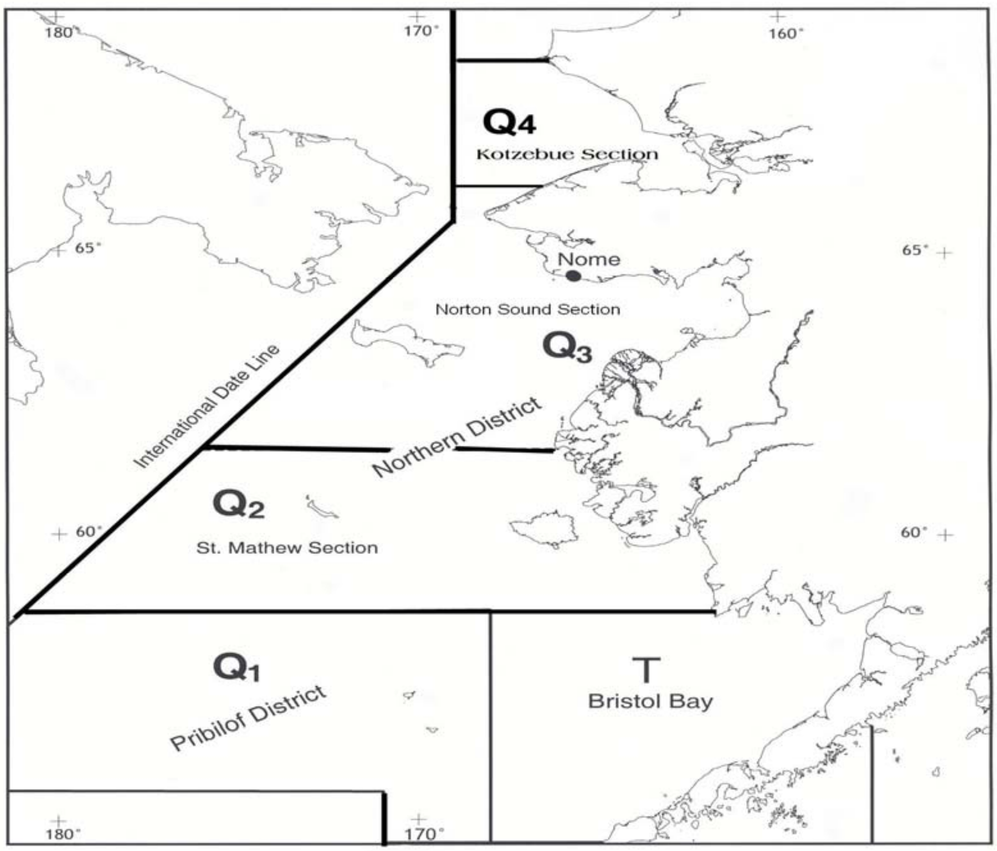


Figure 1. King crab fishing districts and sections of Statistical Area Q.

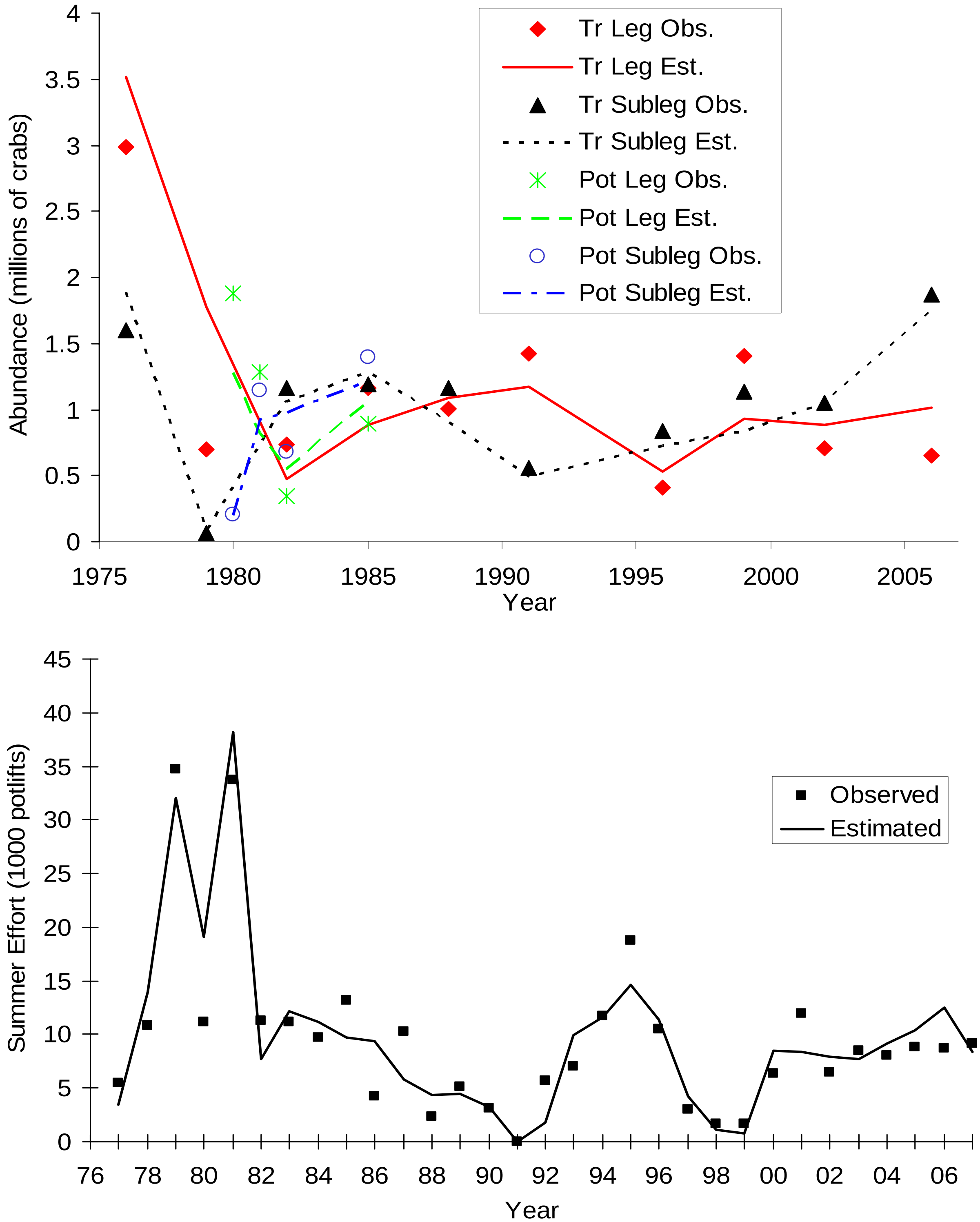


Figure 2. Comparison of observed and estimated Norton Sound red king crab abundances (legal and sublegal males) by summer trawl and pot surveys (upper plot) and observed and estimated summer fishing efforts (lower plot). "Tr" is trawl, "Leg" is legal, "Obs." is observed or survey catchable abundance, and "Est." is estimated catchable abundance. Catchable abundance is equal to population abundance times survey selectivities.

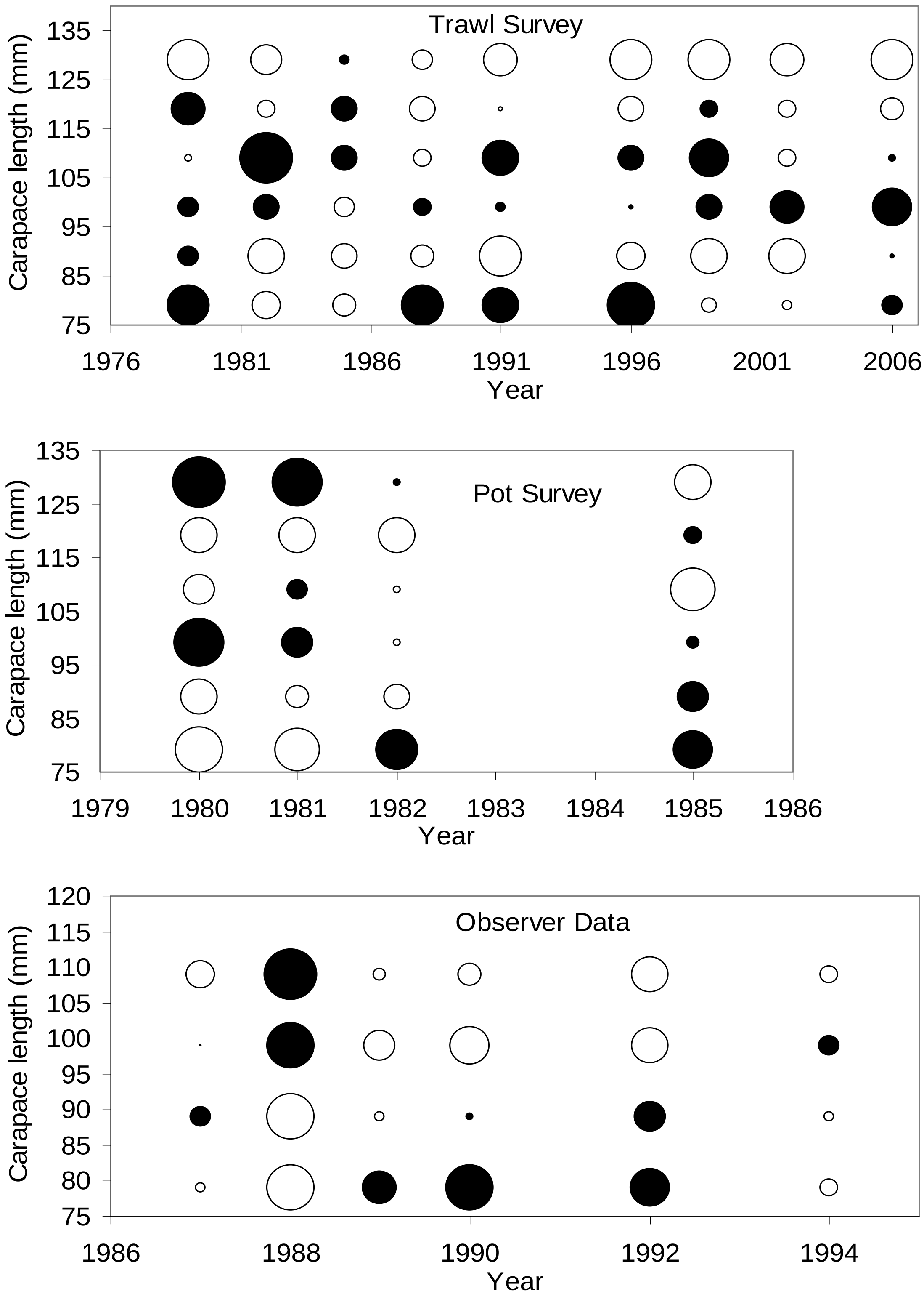
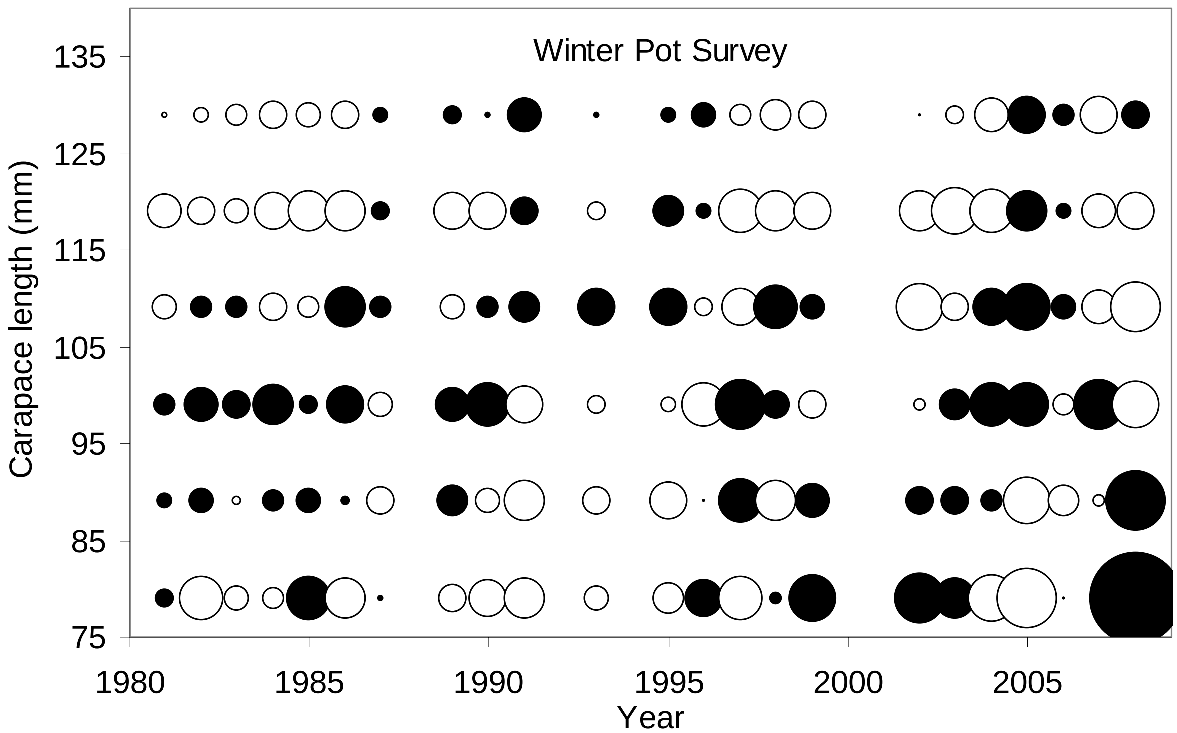


Figure 3. Residuals of length compositions by year for summer trawl and pot surveys and observer data for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.



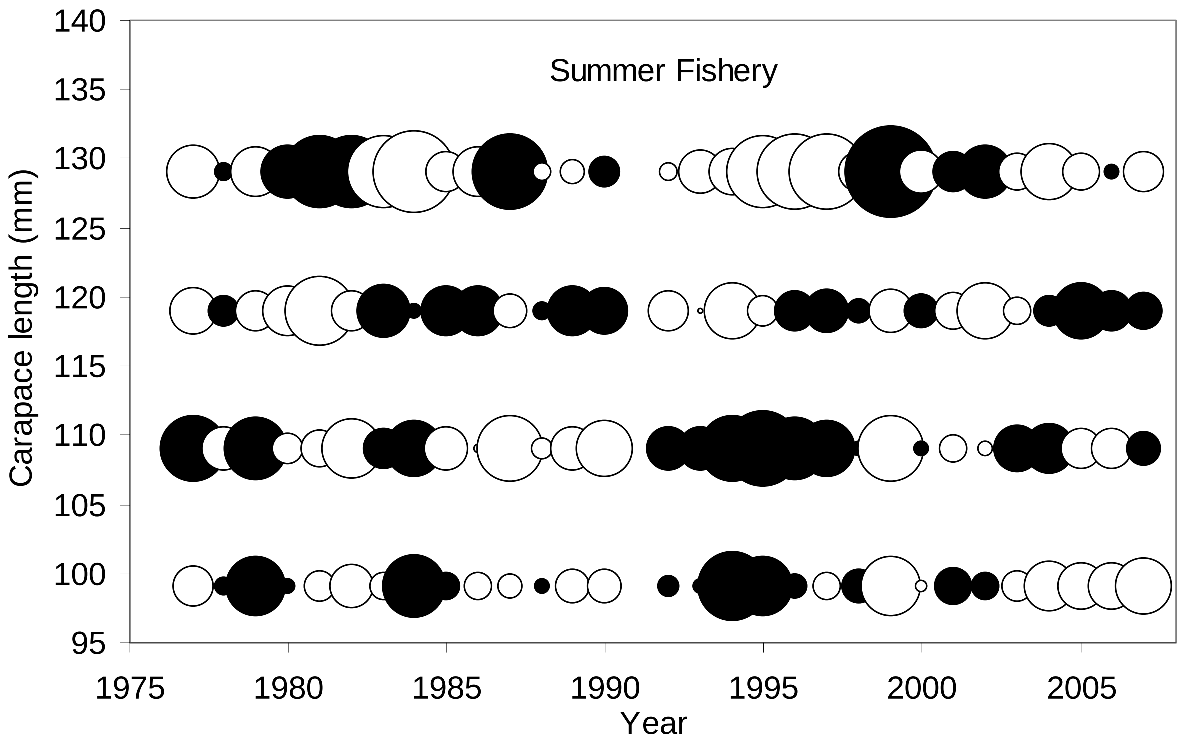


Figure 4. Residuals of length compositions by year for winter pot surveys and summer fishery for Norton Sound red king crab. Solid circles are positive residuals, and open circles are negative residuals.

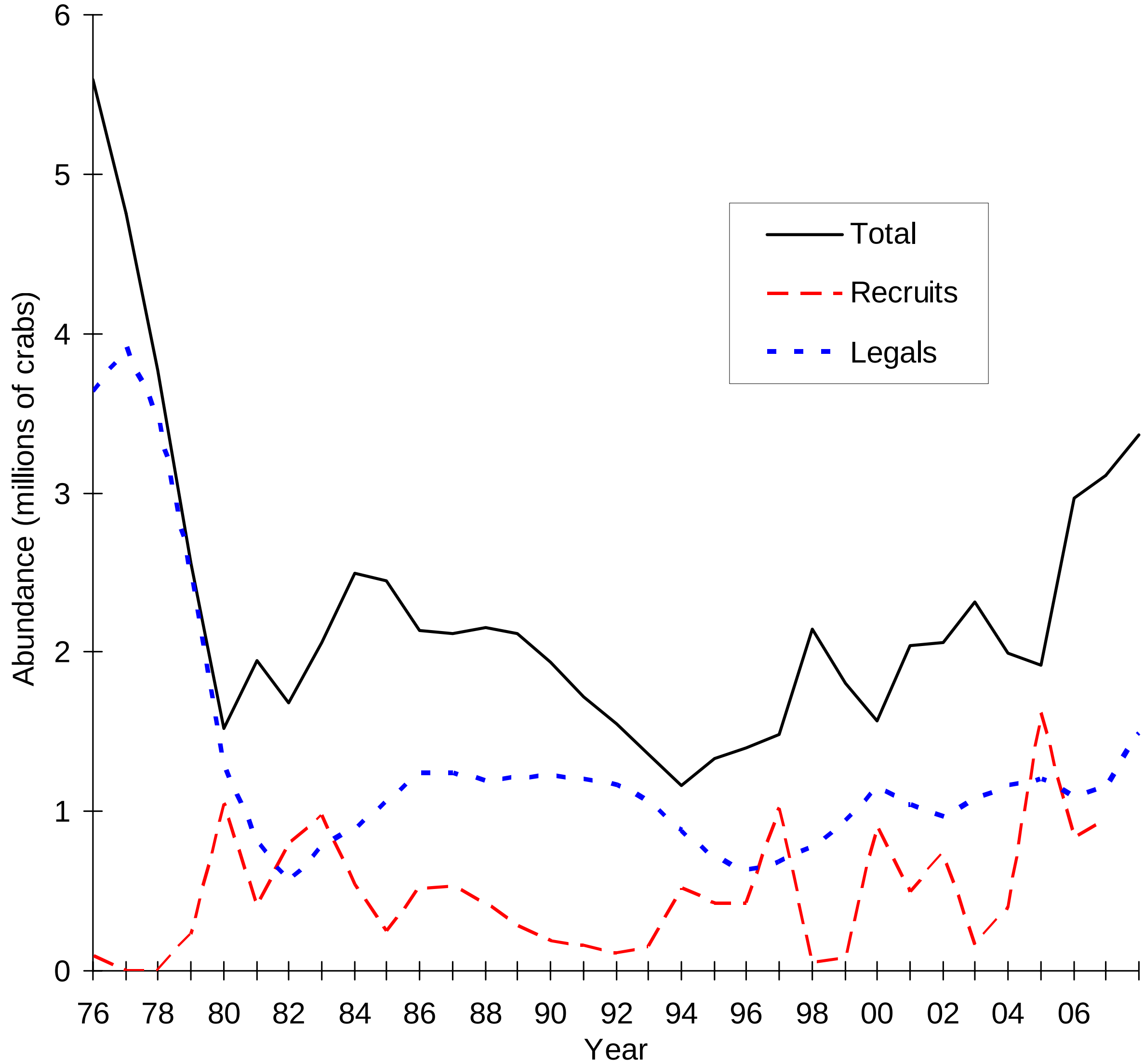
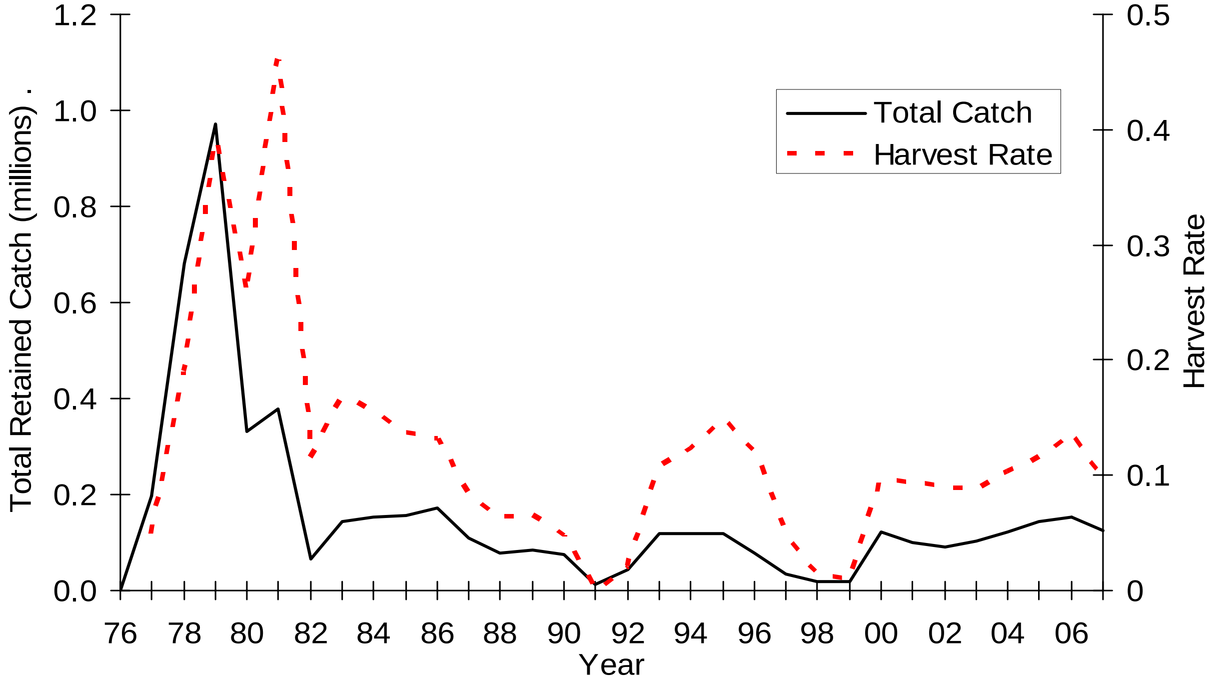


Figure 5. Estimated total (crabs>73 mm CL) and legal male abundances and recruits from 1976 to 2008.



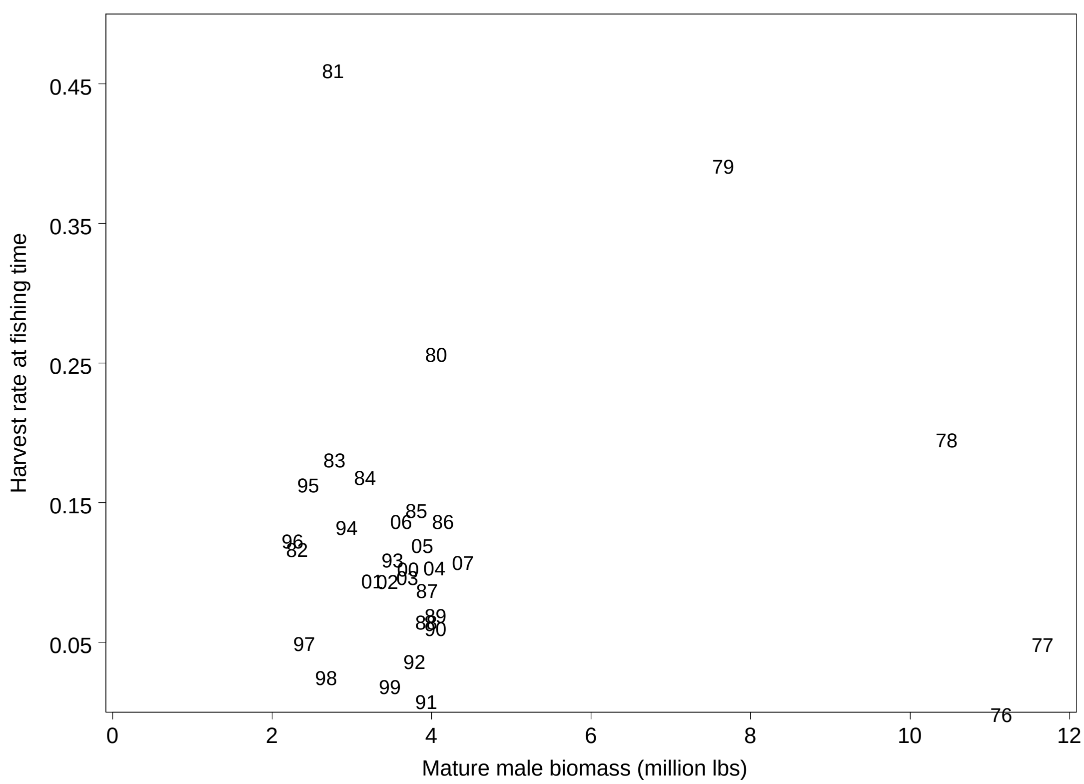


Figure 6. Total retained catches and harvest rates (upper plot) and relationship between harvest rates and mature male biomass (lower plot) of Norton Sound red king crab from July 1, 1976 to June 30, 2008.

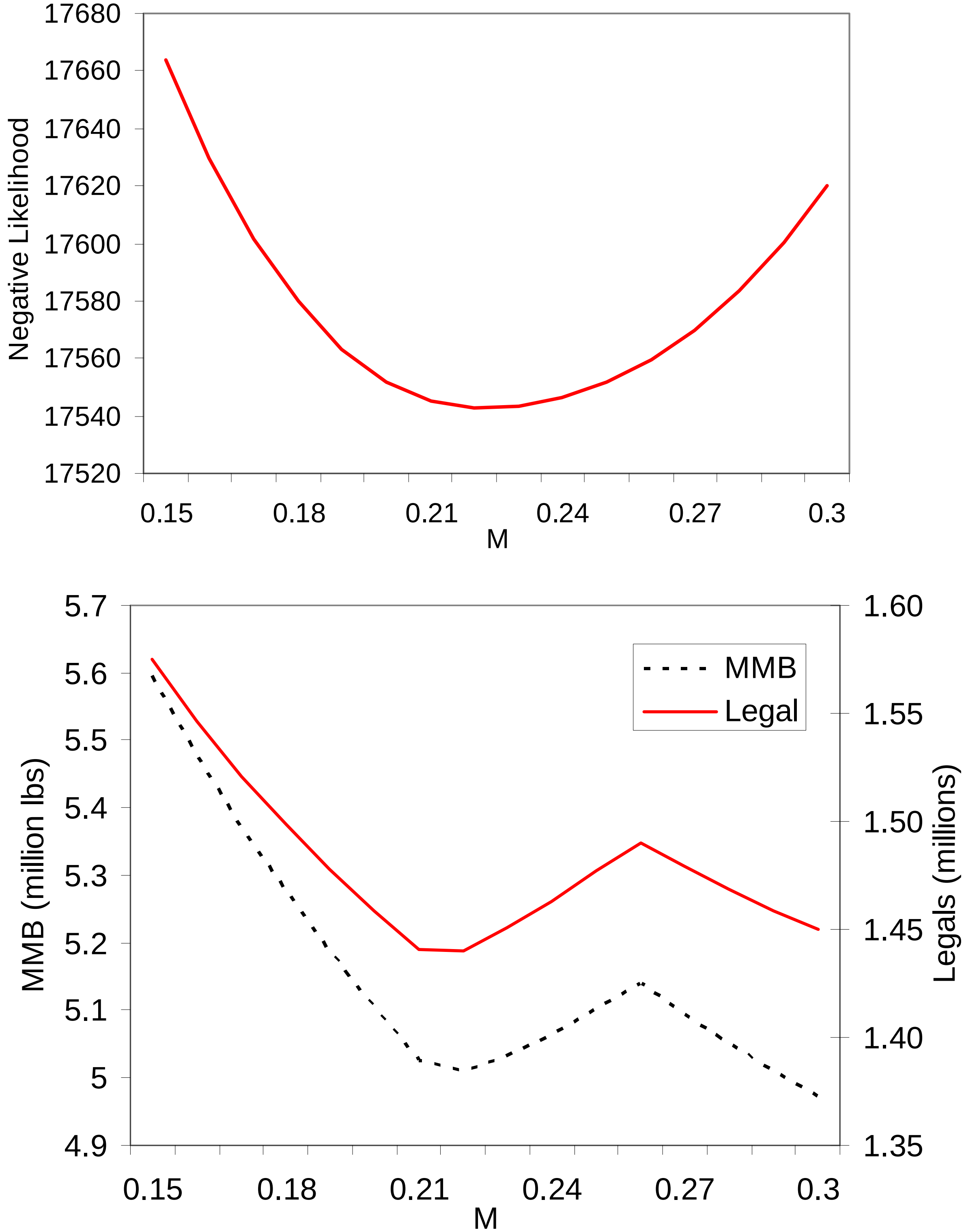
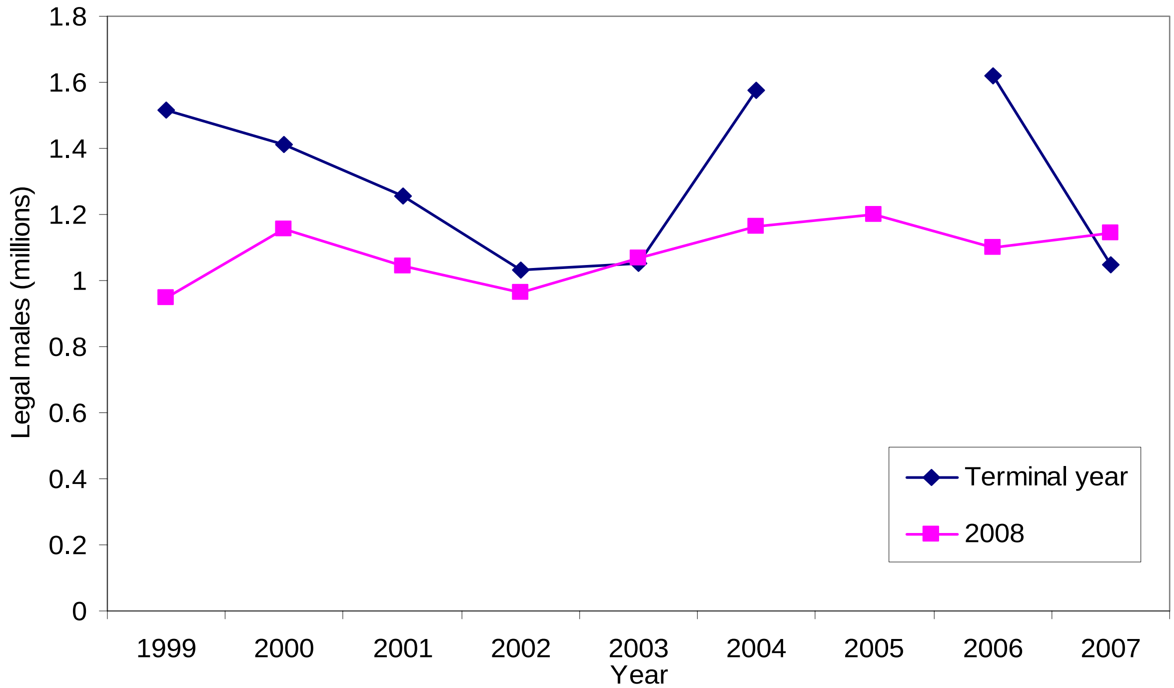


Figure 7. Likelihood profile for natural mortality and estimated legal abundance and mature male biomass in 2008 under different natural mortality values.



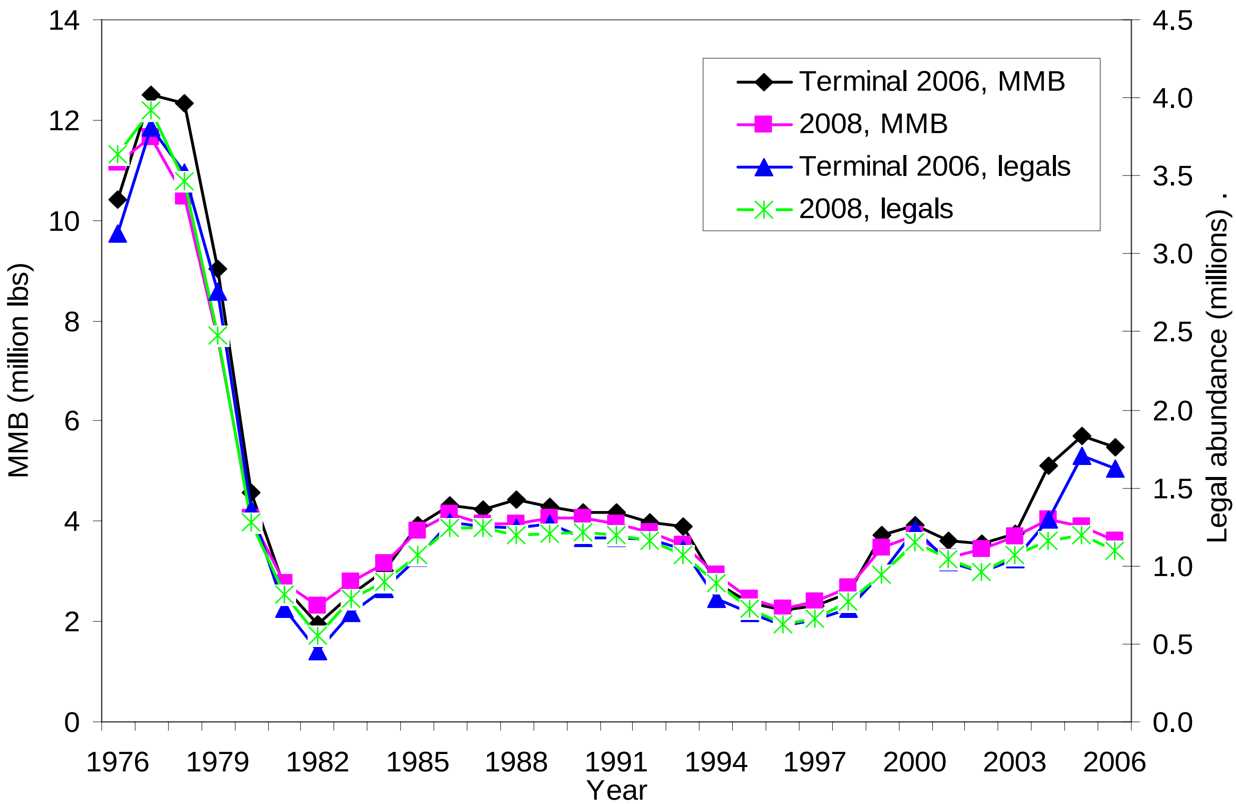
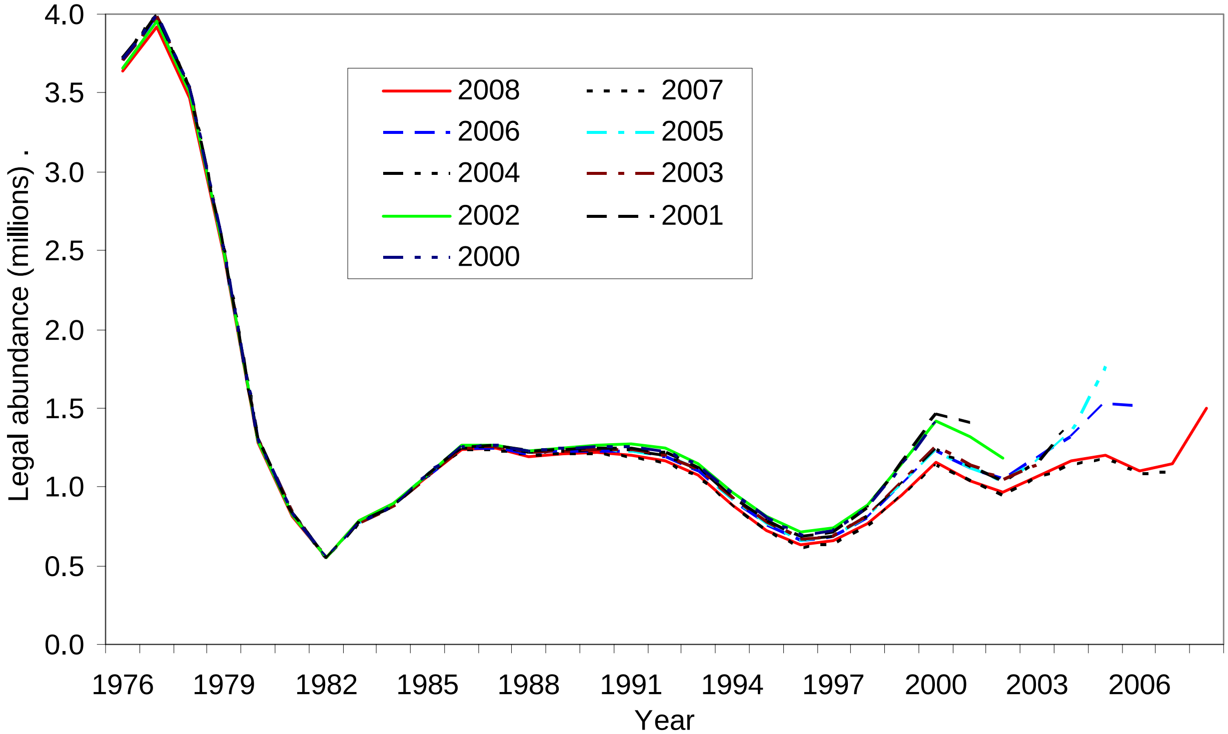


Figure 8. Comparison of estimates of legal male abundance (upper plot) of Norton Sound red king crab with terminal years 1999-2008 and legal abundance and mature male biomass (lower plot) with terminal years of 2006 and 2008. These are results of historical assessments. Legend shows the year in which the assessment was conducted.



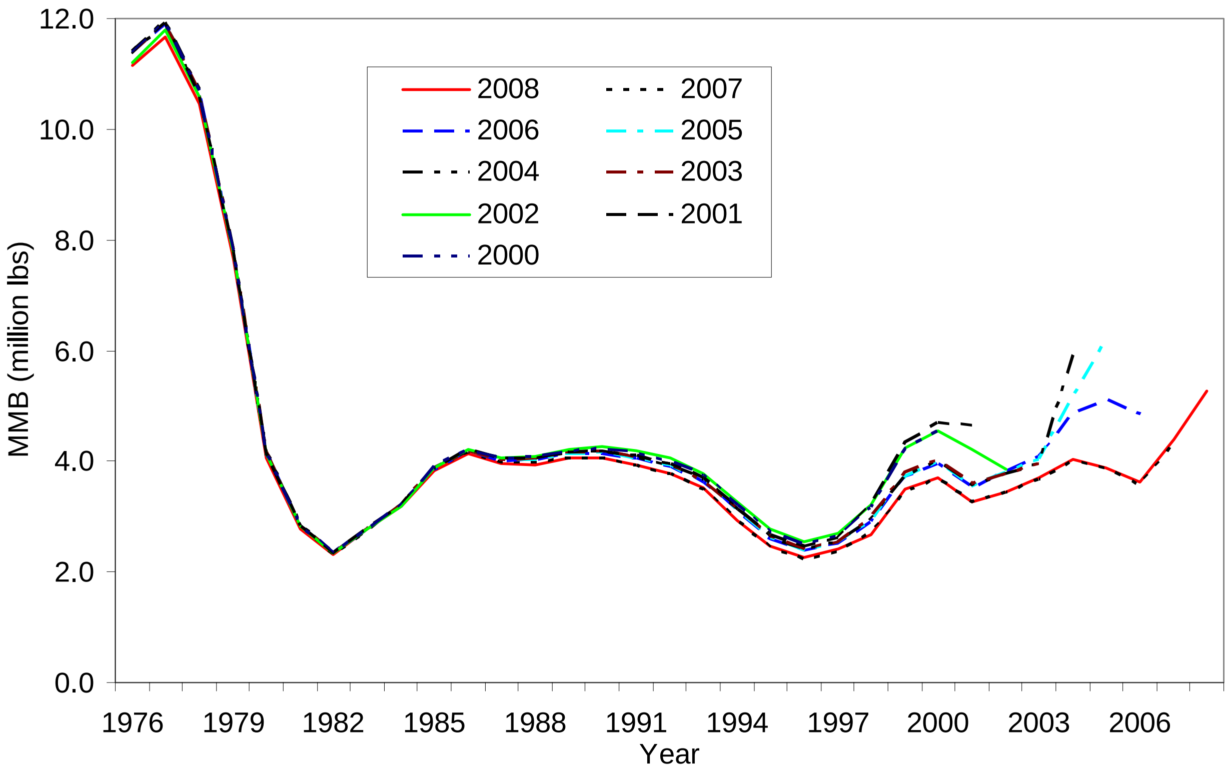


Figure 9. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of Norton Sound red king crab from 1976 to 2008 made with terminal years 2000-2008. These are results of the 2008 model. Legend shows the year in which the assessment was conducted.

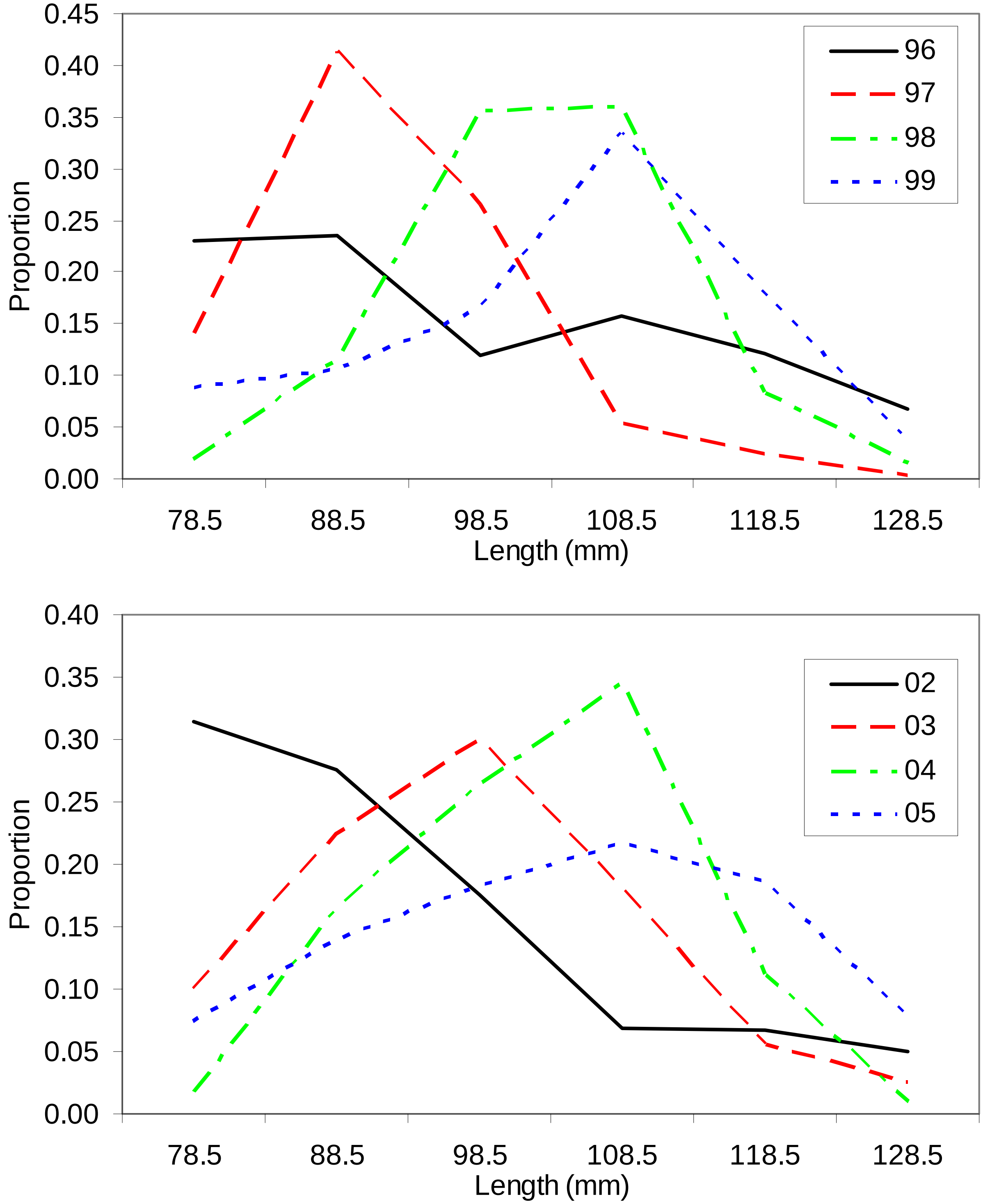


Figure 10. Length frequency of newshell crabs from the winter survey during two periods: 1996-1999 and 2002-2005.

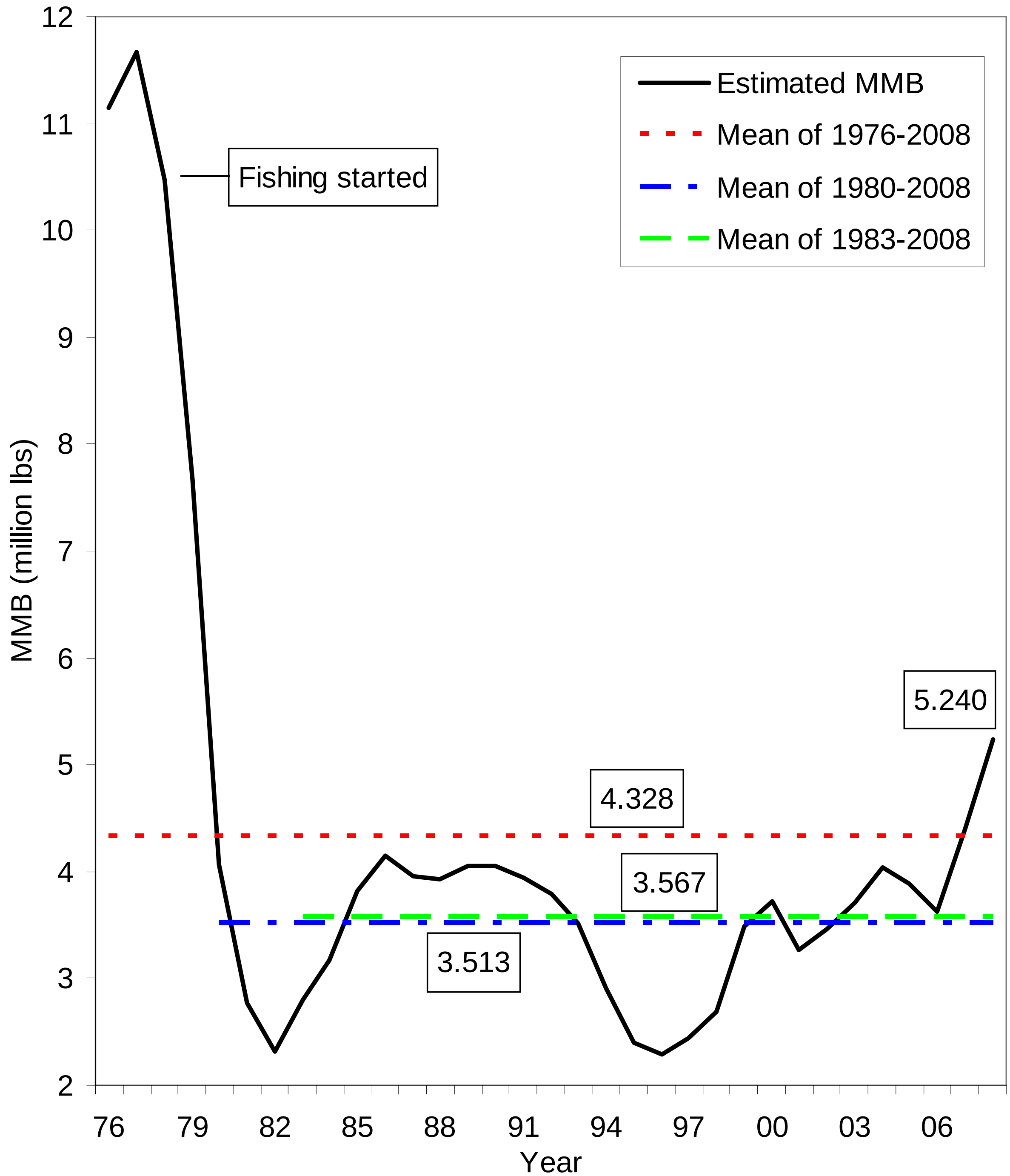


Figure 11. Comparison of estimated mean mature male biomasses during different periods of Norton Sound red king crab.

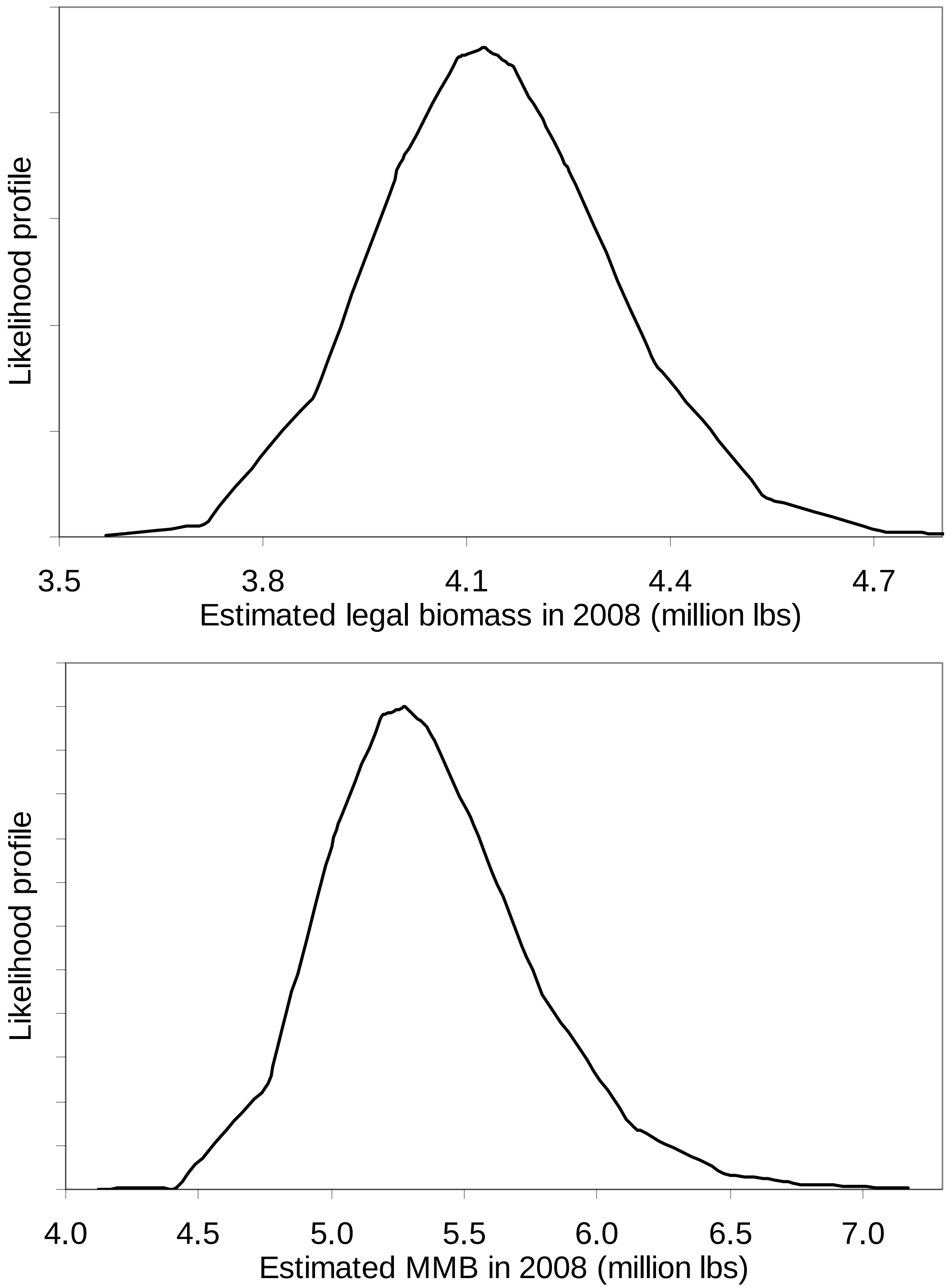


Figure 12. Likelihood profiles for estimated legal male biomass and mature male biomass in 2008.

Aleutian Islands Golden King Crab

Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak, 29 August 2008

Executive Summary

Stock: Golden king crab/Aleutian Islands

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 catch = 11,875,811 pounds), but average harvests dropped sharply from the 1989/90 to 1990/91 season and average harvests for the period 1990/91–1995/96 was 6,930,627 pounds. Management towards a formally established 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, and the GHL (or TAC, since the 2005/06 season) has remained at 5.7 million pounds through the ongoing 2007/08 season. Average retained catch for the period 1996/97–2006/07 was 5,633,236 pounds. Retained catch in the last completed season, 2006/07 was 5,262,342 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; CPUE increased markedly in the 2005/06 with the advent of the Crab Rationalization program. Non-retained catch of sublegal and female golden king crabs during the fishery as decreased relative to the retained catch and in absolute numbers since the mid-1990's.

Data and assessment: There is no assessment model in use for this stock. Available data are from fish tickets (retained catch numbers, retained catch weight, and pot lifts by 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), and recovery data from tagged crabs released during the triennial pot surveys. These data are available through the 2006/07 season and the 2006 triennial pot survey.

Unresolved problems and major uncertainties: Most of the available data are obtained from the fishery which targets legal-size (≥6" carapace width) males and trends in the data can be affected by changes in fishery practices as well as changes in 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.

Reference points: This stock is recommended for Tier 5 stock due to the lack of biomass estimates. BMSY and MSST are not estimated and OFL is defined as "the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007b).

Stock biomass: Estimates of stock biomass are not available.

Recruitment: 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.

Exploitation status: Estimates of fishing mortality are not available.

Management performance: The fishery was managed with a GHL/TAC of 5.9-million pounds during 1996/97–1997/98 and 5.7-million pounds during 1998/99–2006/07. Over the period 1996/97–2005/06 the average retained catch has been 2% below the average GHL/TAC. 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). Estimated weight of discarded bycatch (sublegal and female golden king crabs) 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). Estimated weight of discarded bycatch was reduced to 2,523,737 pounds in the 2005/06 and 2,573,040 pounds in 2006/07 season, representing <50% of the retained catch in each of those two seasons.

Forecasts: No forecasts of catch and biomass are available.

Decision table: Not available.

Recommendations: It has been suggested that use of an assessment model that has been in development would allow for this stock to be moved to Tier 4 (NPFMC 2007b); use of an assessment model would provide focus for establishing research and data collection priorities.

Summary of Major Changes

The revisions to this chapter as it appeared in the May 2008 Draft SAFE are limited to correcting spelling and formatting errors and removing chapter sections that are not relevant to this stock. Specifically this chapter is not updated to include 2007/08 fishery data that became available between the May 2008 and September 2008 CPT meetings or to reflect the SSC's June 2008 recommendation to change to the OFL recommended by the CPT in May 2008. The 2008/09 OFL is not under review at the September 2008 Crab Plan Team (CPT) meeting, because the 2008/09 fishery season for this stock opened on 15 August 2008 under the OFL recommended by the SSC at their June 2008 meeting. [Note: The "Final recommended OFL" given in this draft is that recommended by the CPT at their May 2008 meeting, not that subsequently recommended by the SSC in June 2008. At the June 2008 meeting the SSC recommended that a 2008/09 OFL equal to 9,178,438 pounds of retained catch (determined on the basis of the average retained catch from the time period, 1985/86–1995/96).]

Introduction

Scientific name: *Lithodes aequispinus* J. E. Benedict, 1895

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).

Commercial fishing for golden king crabs in the Aleutian Islands Area typically occurs at depths of 100–300 fathoms (183–549 m; Table 1); average depth of pots fished in the Aleutian Islands Area during the 2005/06 season was 183 fathoms (335 m) for the area east of 174° W longitude and 177 fathoms (324 m) for the area east of 174° W longitude (Barnard and Burt 2007).

Description of management unit(s) and spatial and seasonal management measures
From Failor-Rounds (2008, page 4; 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).

Formerly, the Aleutian Islands king crab populations had been managed using the Adak and Dutch Harbor Registration Areas, which had been divided at 171° W longitude since the 1984/85 season (Figure 2), but from the 1996/97 season to present the fishery has been managed using a division at 174° W longitude (Figure 1; Failor-Rounds 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 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). 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.

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.

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 the 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; personnel communication).

Description of life history characteristics relevant to stock assessments

The following review on molt timing and reproductive cycle is adapted with some additions 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 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.

Fishery

Description of the directed fishery

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).

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).

The following is historical review of the Aleutian Islands golden king crab fishery is from Failor-Rounds (2008, pages 9–13):

> The golden king crab fishery in the Aleutian Islands has never failed to open due to low stock abundance, making it unique among Westward Region king crab fisheries. Golden king crabs inhabit depths greater than where other commercially exploited king crabs are typically found (Blau et al. 1996). The depths and steep bottom topography of the inter-island passes inhabited by golden king crabs necessitate the use of longline rather than single-pot gear. No other major king crab fisheries in Alaska exist where longline pot gear is the only legal gear type.
>
> Historically, golden king crabs were taken as incidental harvest during red king crab fisheries in the Adak (Area R) and Dutch Harbor (Area O) Registration areas. One landing of golden king crabs was reported from the Adak Area during the 1975/76 season, but directed fishing for golden king crabs did not occur in either management area until the 1981/82 season (ADF&G 1984). From the 1981/82 season until the 1996/97 season, the golden king crab resource in the Aleutian Islands was harvested in separate directed fisheries occurring in the Adak and Dutch Harbor Registration areas.
>
> During the 1981/82 season, 14 vessels landed 1.2 million pounds of golden king crabs in 76 deliveries from the Adak Area. By the following season, harvest had reached 8.0 million pounds with 99 vessels participating in the fishery. Between 1981 and 1995, an average of 49 vessels participated in the Adak golden king crab fishery, harvesting an average of 6.9 million pounds annually. Peak harvest in the Adak Area fishery occurred during the 1986/87 season when 12.9 million pounds of golden king crabs were harvested for an exvessel value of $37.6 million. No stock assessment of the golden king crab population was performed in the Adak Area, and initially the fishery was managed based on size, sex, and season restrictions. Catches were monitored inseason (ADF&G 1999a) and after the initial fishery, harvest levels were set based on harvest expectations generated from catch in prior seasons (ADF&G 1983). The majority of golden king crabs harvested in the Adak Area were taken in the North Amlia and Petrel Bank Districts; however, significant harvest also occurred in the remainder of the Western Aleutian District.
>
> From the 1981/82 season to the 1995/96 season, the average weight of golden king crabs harvested in the Adak Area fishery declined from 5.5 to 4.2 pounds and CPUE declined

from 10 to five legal crabs per pot lift. In July 1985, the BOF adopted a regulation reducing the minimum legal size for golden king crabs from 6.5 to 6.0 inches in carapace width (CW). Decreasing the legal size for golden king crabs in this area resulted in an expected decrease in average weight of legal crabs harvested after 1985/86 and increased catch during the 1985/86 and 1986/87 seasons. This regulation change did not, however, reverse the trend of slowly declining catch rates in the area west of 171° W long.

Initial catches of golden king crabs in the Dutch Harbor Area were similar to those observed in the Adak Area fishery (ADF&G 1984). Harvest was incidental to the red king crab fishery and effort in the fishery only increased as red king crab stocks decreased in abundance. Six vessels harvested approximately 116,000 pounds of golden king crabs during the 1981/82 Dutch Harbor red king crab season. The following season, 49 vessels participated in the directed golden king crab fishery, harvesting 1.2 million pounds. Between 1981 and 1995, an average of 18 vessels harvested approximately 1.5 million pounds of golden king crabs annually. Peak golden king crab harvest in the Dutch Harbor Area occurred during the 1995/96 season when 2.0 million pounds were harvested for an exvessel value of $5.2 million. The Dutch Harbor Area harvest was primarily from the Islands of Four Mountains and Yunaska Island area.

In general, the average weight of golden king crabs harvested in the Dutch Harbor Area declined during the period from 1981 to 1995, ranging from a high of 7.6 pounds during the 1983/84 season to 4.1 pounds during the 1992/93 season. In 1984, the BOF adopted an ADF&G staff proposal to lower the legal size for golden king crabs in the Dutch Harbor Area from 6.5 inches to 6.0 inches CW, which would have affected average weight, and to establish the area as a permit fishery. CPUE has slowly declined throughout the history of this fishery, reaching a peak of 14 legal crabs per pot during the 1984/85 season and declining to 6 crabs during the 1994/95 season. The golden king crab stock in the Dutch Harbor Area was not surveyed for abundance prior to 1991 and the fishery was managed based on a historical average catch of 1.5 million pounds annually (ADF&G 1999a).

At its March 1996 meeting, the BOF chose to restructure management of king crabs in the Aleutian Islands. Formerly, the Aleutian Islands king crab populations had been managed using the Adak and Dutch Harbor Registration Areas that were established for red king crab fisheries. However, during the 1970s and 1980s, red king crab fisheries declined in the Aleutian Islands while the golden king crab fishery gained increasing importance. Consequently, the BOF felt that king crab management areas in the Aleutian Islands should be re-designated to more accurately reflect current golden king crab stock distribution and patterns in fishing effort. The BOF, therefore, elected to replace 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 in the areas east and west of 174° W long. as two distinct stocks. It also stipulated that a conservative management plan be initiated and that all vessels registered for the fishery continue to carry an onboard observer for all of their fishing activities.

In 1996, when the initial golden king crab fishery in the new king crab Registration Area O occurred, GHLs were established at 3.2 million pounds for the area east of 174° W long., and 2.7 million pounds for the area west of 174° W long. Compared to the combined Adak and Dutch Harbor Area fisheries from prior years, there was reduced effort and harvest during the 1996/97 fishery. Eighteen vessels harvested 5.9 million pounds, down from 28 vessels taking 6.9 million pounds in 1995/96. This reduction in effort was likely due to the departure of vessels for the 1996 Bristol Bay red king crab season, which re-opened to commercial fishing for the first time since 1993. The eastern portion of Area O closed by emergency order on December 25, with a harvest of 3.3 million pounds, while the western portion was open for the entire registration year with a harvest of 2.6 million pounds.

During the 1996/97 fishery, the CPUE east of 174° W long. was six legal crabs per pot and the average weight was 4.5 pounds per crab. Most fishing effort was concentrated in the area around Yunaska Island and the Islands of Four Mountains with some effort in the Seguam and Amukta Pass areas. In the portion of Area O west of 174° W long., fishery performance was six legal crabs per pot pull with an average weight of 4.2 pounds per crab. Most harvest occurred between Amchitka Pass and Buldir Island. The 1996/97 golden king crab fishery in the Aleutian Islands had an estimated exvessel value of $12.5 million.

Since the 1996/97 season, effort and harvest in the Aleutian Islands east of 174° W long. have remained relatively stable. During the 1997/98 season, 15 vessels harvested 3.5 million pounds in an 84-day season. CPUE averaged seven legal crabs per pot lift and harvested crabs averaged 4.5 pounds each. The fishery west of 174° W long. has experienced greater variability in catch and effort. During the 1997/98 season, eight vessels participated in the fishery and harvested 2.4 million pounds. The GHL west of 174° W long. was not reached and the fishery was not closed. The fleet averaged seven legal crabs per pot lift with landed crabs averaging 4.3 pounds each. The 1997/98 Aleutian Islands golden king crab fishery had an exvessel value of $12.5 million.

Prior to the 1998/99 season, the Aleutian Islands golden king crab GHL east of 174° W long. was reduced from 3.2 million pounds to 3.0 million pounds. Fishery performance trends and data from tag recoveries indicated that the 200,000 pound GHL reduction for the area east of 174° W long. was necessary in order to comply with the overfishing definition specified in the Fishery Management Plan (FMP) for the king and Tanner crab fisheries of the Bering Sea and Aleutian Islands (NPFMC 1998).

The 1998/99 fishery east of 174° W long. was similar to the prior two fisheries. Fourteen vessels registered and harvested 3.2 million pounds in a 68-day season. The catch rate was nine legal crabs per pot lift with landed crabs averaging 4.4 pounds each. West of 174° W long., effort declined significantly from the prior two seasons. A fleet of three vessels harvested 1.7 million pounds, or 63% of the GHL. The fleet averaged 12 legal crabs per pot lift with landed crabs averaging 4.1 pounds each. The 1998/99 fishery had an exvessel value of $9.3 million, the lowest in 14 years.

In July 1999, the BOF adopted a regulation to move the Registration Area O golden king crab fishery from September 1 to August 15 in order to accommodate fishers that participate in both the golden king and Bristol Bay red king crab (BBRKC) fisheries. The BBRKC fishery opening date had been moved from November 1 to October 15, which reduced the amount of fishing time available to the golden king crab fleet prior to the Bristol Bay opening. The change in opening date for Area O was designed to provide adequate fishing time for the golden king crab fleet to harvest the GHL east of 174° W long., prior to the opening of the BBRKC fishery.

In 2000/01, the fishery east of 174° W long. continued the stable trend seen in the previous four years. Fifteen vessels registered and harvested 3.1 million pounds. The

CPUE was 10 legal crabs per pot, with a 4.5-pound average weight per crab. West of 174° W long., a fleet of 12 vessels harvested 2.9 million pounds. The CPUE was seven legal crabs per pot, while the average weight per crab was 4.1 pounds. With an exvessel value of just under $19.5 million, the 2000/01 season was the most valuable golden king crab fishery in six years.

These stable trends continued through the 2003/04 fishery. In the area east of 174° W long., since the 2001/02 season, 18 to 19 vessels participated and harvested an average of 2.99 million pounds per year. The CPUE and average weight have remained relatively stable with an average of 11 to 12 crab per pot lift and legal males averaging 4.4 to 4.6 pounds. In the area west of 174° W long., six to nine vessels harvested an average of 2.69 million pounds per year. Legal males averaged 4.0 pounds and in 2001/02 and 2002/03 CPUE has averaged seven crabs per pot lift. Catch rates rose during the 2003/04 fishery when average CPUE increased to 10 legal crabs per pot lift.

The number of vessels fishing and the average number of pots per vessel in the eastern portion of the Aleutian Islands golden king crab fishery remained fairly constant from the 1994/95 season to the 2004/05 season. In the western portion of the Aleutian Islands golden king crab fishery, there has been a decrease in the number of vessels registered per season with a dramatic increase in the number of pots registered per vessel. With the adoption of longline gear in 1986, vessels became more specialized in fishing for golden king crabs and were able to more efficiently operate gear. In recent years, with shorter Bristol Bay red king and Bering Sea snow crab *Chionoecetes opilio* fisheries, longline vessels that also fish in the Bering Sea have increased their effort in the Aleutian Islands. While the total number of vessels registered has remained relatively low since the early 1990s, the amount of time relative to other crab fisheries that these vessels spend fishing in the Aleutian Islands has increased, resulting in shorter golden king crab fisheries. The expansion of processing facilities in Adak has also contributed to the shorter seasons, especially in the western Aleutians. Vessels could deliver closer to the fishing grounds, saving approximately a week in transit time for each delivery. The implementation of Crab Rationalization in 2005 decreased participation further with the consolidation of quota onto fewer vessels. Under rationalization the season is open from August 15 to May 15 of the following year.

The 2005/06 season was the first Aleutian Islands golden king crab fishery to be prosecuted under the Crab Rationalization program. The following summary of changes to management of the fishery that resulted from the Crab Rationalization program is from Failor-Rounds (2002, page 14):

Crab Rationalization introduced regulatory changes in the Aleutian Islands golden king crab fishery. The historic GHL has been changed to a Total Allowable Catch (TAC). Qualified participants are issued IFQ shares which they may harvest at any time while the season is open. Harvesters may now use gear cooperatively, transporting and fishing another vessel's gear if registered to do so. Additionally, observer coverage requirements have been decreased. Prior to rationalization, vessels harvesting golden king crab in the Aleutian Islands were required to carry an observer during 100% of their fishing activities. 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).

Also 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 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.

The following summary of the 2006/07 Aleutian Islands golden fishery season is from Failor-Rounds (2008, pages 9–13):

> The 2006/07 Aleutian Islands golden king crab fishery opened by regulation at 12:00 NOON August 15 with a TAC of 5.7 million pounds (5.13 million pounds IFQ, 0.57 million pounds CDQ); 3.0 million pounds of which was apportioned to the area east of 174° W long. and further subdivided between the IFQ (2.7 million pounds) and CDQ (300,000 pounds) fisheries, and 2.7 million pounds apportioned to the area west of 174° W long. further subdivided into the IFQ (2.43 million pounds) and Adak Community Allocation (ACA) fishery (270,000 pounds). This was the second season under rationalization regulations, including the CDQ fishery for golden king crab, and the ACA fishery. Seven vessels participated in the IFQ fishery and landed 4.69 million pounds. The fleet averaged 23 legal crabs per pot lift, the same as the prior season, and landed crabs averaged 4.5 pounds each which is slightly higher than the 2005/06 season.
>
> *East of 174° W long.*
> With the implementation of crab rationalization, the golden king crab fleet has been reduced to less than half of the pre-rationalization fleet size. A total of six vessels participated in the Aleutian Islands golden king crab commercial fishery east of 174° W long. The fleet registered 8,150 pots, or 1,358 pots per vessel, only 92% of the overall pots registered during the 2005/06 fishery and on average 7% more pots registered per vessel as compared to the 2005/06 fishery. Weekly harvest peaked mid-September. Most fishing effort was concentrated around Yunaska Island, Islands of Four Mountains, and in Seguam and Amukta Passes. Catch rates tended to be highest in Amukta and Seguam Passes, with the most productive grounds yielding up to 36 legal crabs per pot lift, compared to 29 crabs per pot lift in this area the previous season. The average catch rate for the entire eastern portion was 24 crabs per pot lift, down slightly from 25 crabs per pot lift the previous season. The average weight of legal crabs was 4.6 pounds, the same as the 2005/06 season, with the largest crabs encountered around Seguam Island.
> The IFQ fleet harvested 2.69 million pounds of golden king crabs during the season. Four shore-based processors in Dutch Harbor, one shore-based processor in Akutan, and one catcher-processor processed golden king crabs from the eastern Aleutian Islands. Exvessel price paid for live, whole crabs averaged $1.77 per pound, leading to a fishery value of $4.71 million, a decrease of $1.77 million from the 2005/06 fishery.
>
> *West of 174° W long.*
> A total of three vessels participated in the IFQ fishery west of 174° W long. The fleet registered 6,000 pots, an average of 2,000 pots per vessel, 25% more pots overall than were registered in the 2005/06 season, and 25% more pots per vessel than the 2005/06

season. Weekly harvest peaked in early November. Fishing effort was concentrated around the Delarof Islands, Amchitka Pass and the Petrel Bank. Weekly catch rates ranged from ten to 54 crabs per pot lift and averaged 20, down from 21 crabs per pot lift the previous season. The average weight of legal crab was 4.3 pounds, an increase from the 2005/06 season average weight of 4.2 pounds.

The fleet harvested 2.00 million pounds of golden king crab. Golden king crabs were purchased and processed by one catcher-processor, one floating processor and by three shore-based processors, one in Adak and two in Dutch Harbor. Exvessel price averaged $1.33 per pound for live, whole crabs, yielding a total fishery value of $2.64 million, well below the previous 5-years' average fishery value of $8.03 million.

Although the TACs set for the Aleutian Islands golden king crab fishery for the areas east and west of 174° W longitude remained the same as for the pre-rationalized fishery since the 1998/99 season, there have been changes noted in fishery practices since the first rationalized fishery. With the implementation of crab rationalization fleet size has decreased, though average pots deployed per vessel has increased substantially. Only 8 vessels participated in the 2005/06 season and only 7 vessels participated in the 2006/07 season, whereas 15–22 vessels participated annually during the 1996/97–2004/05 seasons (Failor-Rounds 2008). In the eastern Aleutian Islands, the average number of pots deployed per vessel during rationalized golden king crab fisheries has nearly doubled compared to the number of pots utilized per vessel pre-rationalization (ADF&G 2008, Table 2). Average pot soak time for both the eastern Aleutian Islands and western Aleutian Islands golden king crab fisheries has increased considerably from the pre-rationalization level (through 2004/05) to the first rationalized 2005/06 fishery, and then lowered slightly during the second rationalized season in 2006/07 (ADF&G 2008, Table 3).

The 2007/08 Aleutian Islands golden king crab fishery opened on 15 August 2007 with a TAC of 3.0-million pounds for the area east of 174° W longitude (2.7-million pounds allocated to IFQ holders and 0.3-million pounds allocated to the CDQ fishery) and a TAC of 2.7-million pounds of the area west of 174° W longitude (2.43-million pounds allocated to IFQ holders and 0.27-million pounds allocated to the ACA fishery). As of April 8, 2008 (http://www.fakr.noaa.gov/ram/daily/cratland.pdf, Prepared: APR-08-08 06:46), 100% of the 2007/08 IFQ allocation for the area east of 174° W longitude has been harvested (2,690,377 pounds out of the 2,700,00 pounds allocated to IFQs) and 81% of the 2007/08 IFQ allocation for the area west of 174° W longitude has been harvested (1,974,167 pounds out of the 2,430,000 pounds allocated to IFQs).

In response to a proposal from Industry, the Alaska Board of Fisheries, during their March 2008 meeting, took action to set in regulation TACs for the Aleutian Islands golden king crab fishery of 2.835-million pounds for the area west of 174° W longitude and of 3.15-million pounds for the area east of 174° W longitude. The new regulations will not become effective until the 2008/09 season.

Information on bycatch and discards

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, Coleman, and Salmon 2008). During the 1988/89–1994/95 seasons observers were required only on vessels processing golden king crabs at sea, including catcher-processor vessels. 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, 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.

A summary of the information obtained by observers on bycatch and discards during the Aleutian Islands golden king crab fishery is provided in annual reports (e.g., Barnard and Burt 2007). Estimates of the weight of bycatch (discarded non-retained) golden king crabs during the Aleutian Islands golden king crab fishery and other Aleutian Islands crab fisheries are reported under the section "DATA: Total catch, partitioned by strata used in the assessment model, if any," below.

Summary of historical catch distributions
Table 4 provides the time series of GHLs/TACs, retained catch, estimated discard, and estimated total catch (estimated discard mortality and retained catch). No handling mortality rate for the Aleutian Islands golden king crab fishery was discussed by the Crab Plan Team during development of Amendment 24. However, as handling mortality rates of 10%, 20%, 30% were discussed for the Bristol Bay red king fishery and handling mortality rates of 25%, 40%, 50%, and 60% were discussed for the eastern Bering Sea snow crab fishery (NPFMC 2007b), we provide total catch estimates for assumptions of handling mortality rates of 10%, 20%, 30%, 40%, 50%, and 60%. Tables 5 and 6 provide the same time series separately for the areas east and west of 174° W longitude. Data sources for retained and non-retained (discard) catch are provided under the section "DATA."

Data

Total catch
Harvest history for the Aleutian Islands golden king crab fishery (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) by fishery season from the 1981/82 season through the 2006/07 season is provided in Table 7; data are from fish ticket database summaries produced by ADF&G Dutch Harbor during March 2008. The size limit for golden king crabs has been 6" CW for the entire Aleutian Islands Area since the 1985/86 season and the areas east and west of 174° W longitude have been managed with separate GHLs or TACs since the 1996/97 season. Harvest history for the Aleutian Islands golden king crab fishery (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) for the area east of 174° W longitude by fishery season from the 1985/86 season through the 2006/07 season is provided in Table 8; data are from fish ticket database summaries produced by ADF&G Dutch Harbor during March 2008. Harvest history for the Aleutian Islands golden king crab fishery (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) for the area west of 174° W longitude by fishery season from the 1985/86 season through the 2006/07 season is provided in Table 9; data are from fish ticket database summaries produced by ADF&G Dutch Harbor during March 2008. Because the Aleutian Islands golden king crab fishery was managed separately for the areas east and west of 171° W longitude during the 1985/86–1995/96 seasons, we also provide the annual harvests during 1985/86–2006/07 for the areas east of 171° W longitude, between 171° W longitude and 174° W longitude, and west of 174° W longitude are provided in Table 10.

Observer data collected since the 1996/97 season on size distribution and estimated catch numbers of non-retained catch (provided by D. Barnard, ADF&G, 20 July 2007 and 7 April 2008) were used to estimate the weight of non-retained catch of legal male, sublegal male, and female golden king crabs during commercial fisheries by season through the 2006/07 season according to the methods and parameters provided in Section 3.4 of NPFMC 2007b. Estimates of the weight of non-retained catch of golden king crabs by sex-size class for the total Aleutian Islands and for the areas east and west of 174° longitude, 1996/97–2006/07, are provided and compared with weight of retained catch in Tables 11–13. Although most of the non-retained catch of golden king crabs is attributable to the golden king crab fishery, some incidental catch of golden king crabs may occur in the Aleutian Islands triangle Tanner crab *Chionoecetes angulatus*, eastern Aleutian Islands and Adak grooved Tanner crab *C. tanneri*, eastern Aleutian Islands Tanner crab *C. bairdi*, Adak red king crab *Paralithodes camtschaticus*, and eastern Aleutian Islands and Adak scarlet king crab *Lithodes couesi* fisheries; the contribution of those fisheries to weight of non-retained golden king crabs is included in Table 11a. Estimates of the bycatch during groundfish fisheries, 2003–2007, is provided in Table 11b.

Catch at length

The size (carapace length, CL, mm) distribution of retained legal male golden king crabs from the Aleutian Islands golden king crab fishery sampled prior to processing at-sea and dockside by observers and ADF&G catch samplers by season, 1996/97–2006/07, are provided in Table 14. Tables 15 and 16 provide the data for the fisheries east and west of 174° W longitude separately.

Survey numbers at length

Data on catch per unit effort of golden king crabs by sex-size class during triennial ADF&G pot surveys, 1997–2006 are provided in Table 17.

Fishing effort

The time series of fishing effort (pot lifts) are provided in Tables 7–9.

Sample sizes for length samples

Sample sizes for length samples from the fishery by season and area (entire Aleutian Islands Area and the areas east and west of 174° W longitude) are provided in Tables 14–16.

Independently-Estimated Life-History Parameters

Length at age

There is no length-at-age relationship established for golden king crab.

Growth per molt

Growth per molt and probability of molt was 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 (Tables 18–22).

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 (Figure 5):

$$P(\text{molt}) = \exp(17.930 - 0.129*CL)/[1 + \exp(17.930 - 0.129*CL)].$$

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 (Figure 6):

$$P(\text{molt to legal size}) = 1 - \exp(15.541 - 0.127*CL)/[1 + \exp(15.541 - 0.127*CL)].$$

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).

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 intermit period were estimated from those observations (Paul and Paul 2001a); those results are not provided here.

Weight at length or weight at age
Parameters for estimating weight (g) from carapace length (CL, mm) of Aleutian Islands golden king crabs are provided in Table 23.

Natural mortality rate:
Estimates of natural mortality and some information pertaining to life span have been obtained using data from recoveries of golden king crabs tagged and released by ADF&G in the Aleutian Islands Area in 1991 (Blau and Pengilly 1994), 1997 (Blau, Watson, and Vining 1998), 2000 (Watson and Gish 2002), 2003 (Watson 2004), and 2006 (Watson 2007). Using data on tag recoveries during commercial fisheries through 2000 of males tagged in 1991 and 1997, Siddeek et al (2002) provide estimates of M = 0.375, M = 0.484, and M = 0.573. The longest period between tag release and tag recovery recorded to date for an Aleutian Island golden king crab is approximately 8 years (from 10 August 1997 to 10 October 2005); that animal was tagged and released as a 93-mm CL male. The longest period between tag release and tag recovery recorded to date for an Aleutian Island golden king crab tagged and released as a legal-size male is slightly more than 4 years (from 26 July 2003 to 3 September 2007; L. J. Watson, Fishery Biologist, ADF&G, Kodiak; personnel communication).

Parameters governing maturity schedule:
Males: Carapace length (CL) at maturity for male golden king crabs in three areas within Aleutian Islands Area has been estimated by Otto and Cummiskey (1985) using Somerton's (1980) method of estimating the intersection point of lines estimated to fit two phases of growth in height of the right chela relative to CL:

- Eastern Bering Sea south of 54°14' N latitude: 130.0-mm CL (SD = 4.0 mm)
- Bowers Ridge: 108.6-mm CL (SD = 2.6 mm)
- Seguam Pass: 120.8-mm CL (SD = 2.9 mm).

Paul and Paul (2001b) studied mating success of male golden king crabs collected from Prince William Sound. The two smallest males studied (95-mm CL and 99-mm CL) could not induce females to ovulate. The smallest male examined that fertilized a female (a 101-mm CL male) fertilized a clutch in which only 71% of the eggs initiated division. In almost all of the clutches fertilized by hardshell males ≥107-mm CL, ≥90% of the eggs initiated division.

Females: Otto and Cummiskey (1985) estimated CL at maturity for female golden king crabs in three areas within the Aleutian Islands Area as the estimated CL at which 50% of females are mature (SM50; as evidenced by presence of clutches of eggs or empty):

- Eastern Bering Sea south of 54°14' N latitude: 110.7-mm CL (SD = 0.8 mm)
- Bowers Ridge: 106.4-mm CL (SD = 0.5 mm)
- Seguam Pass: 113.2-mm CL (SD = 0.3 mm).

Blau and Pengilly (1994) estimated percent mature (as evidenced by presence of clutches of eggs or empty) as a function of CL for female golden king crabs in two areas within the Aleutian Islands Area according to a logistic regression (with parameters β_0 and β_1) and estimated the CL at which 50% of females are mature (SM50):

- Aleutian Islands between 170° W longitude and 171° W longitude (near Yunaska I)
  - Logistic regression parameters:
    - $_0$ = -15.558 (95% CI: -19.123 – -11.992)
    - $_1$ = 0.142 (95% CI: 0.111 – 0.173)

        - SM50 = 109.6-mm CL (95% CI: 106.7 mm to 112.6 mm)
    - Aleutian Islands between 171° W longitude and 172° W longitude (near Amukta I)
        - Logistic regression parameters:
            - $_0$ = -28.273 (95% CI: -30.181 – -26.308)
            - $_1$ = 0.264 (95% CI: 0.246 – 0.282)
        - SM50 = 107.0-mm CL (95% CI: 106.6 mm to 107.5 mm)

TIER 5 OFL BACKGROUND ANALYSIS

An assessment model for Aleutian Islands golden king crab is in development (Siddeek et al. 2005). However, that model has not yet been used for annual stock assessment and biomass estimation. Hence, as of this writing, this stock should remain in Tier 5. 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 the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007b). Additionally, NPFMC (2007b) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, [should] be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." This section provides background for considering the appropriate time period for estimating OFL.

<u>Time periods for averaging the retained catch</u>. Two time periods have been previously suggested 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 there was no TAC or GHL established for the entire Aleutian Islands Area prior to the 1996/97 season (see "Description of the directed fishery", 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 to date (Table 4).]

Aside from those considerations the following changes in management measures by season are also important for considering the period to estimate the OFL from the average retained catch:

Season	Change in management measure
1984/85	• Decrease in minimum size limit from 6.5" to 6.0" for the Dutch Harbor Area (i.e., the area east of 171° W longitude)
1985/86	• Decrease in minimum size limit from 6.5" to 6.0" for the Adak Area (i.e., the area west of 171° W longitude)
1996/97	• Aleutian Islands golden king crab management restructured to manage the area east of 174° W longitude separate from the area west of 174° W longitude; previously divided at 171° W longitude (Dutch Harbor and Adak Areas) o 3.2-million pound GHL for the area east of 174° W longitude o 2.7-million pound GHL for the area west of 174° W longitude
1998/99	• GHL for area east of 174° W longitude reduced to 3.0-million pounds
2005/06	• First fishery under crab rationalization program

The changes in size limit that occurred in 1984 and 1985 support using only data from after the 1984/85 season; the 1985/86 season was the first season that the entire Aleutian Islands Area was managed using the current 6.0" CW minimum size limit.

The change in management that occurred with the restructuring of management beginning with the 1996/97 season is also important for determining the period over which to average the retained catch. Prior to the 1996/97 season the former Adak Area (west of 171° W longitude) was managed essentially under a "size-sex-season" policy with no management towards a specified GHL, whereas the former Dutch Harbor area (east of 171° W longitude) was managed on the basis of fishery performance with the historic average landings providing an informal GHL (B. Failor-Rounds, ADF&G, July 17, 2007 memorandum). Beginning with the 1996/97 season management was based on a GHL (or TAC) established for the areas east and west of 174° W longitude; 3.2-million pounds for the area east of 174° W longitude and 2.7-million pounds for the area west of 174° W longitude. The 3.2-million pound GHL for the area east of 174° W longitude was arrived at by doubling the 1.6-million pound average harvest of the previous five seasons (1991/92–1995/96); more recent fish ticket runs show that the average harvest for the area east of 171° W longitude during 1991/92–1995/96 was actually 1.5-million pounds. The 2.7-million pound GHL for the area west of 174° W longitude was determined by the average harvest for the five seasons, 1990/91–1994/95 (data for the complete 1995/96 season for the area west of 174° W longitude was not available when the 1996/97 GHL was established). The reduction in the GHL for the area east of 174° W longitude from 3.2-million pounds to 3.0-million pounds beginning with the 1998/99 season will also have a slight influence on average harvests. The effect of those management measures instituted at the beginning of the 1996/97 season have resulted in a decrease in the annual harvests for the Aleutian Islands Area, relative to the entire period 1985/86–1995/96 and to the more recent 1990/91–1995/96 seasons (Tables 7–9, Figure 7). That reduction in harvest relative to the 1990/91–1995/96 seasons is attributable to a reduction in the harvest reported from the area east of 174° W longitude (Figure 7), which is, in turn, attributable to a reduction in the harvest reported from the area between 171° W longitude and 174° W longitude (Table 10; see also Figure 3 and Figure 4).

The change of management to a rationalized fishery beginning with the 2005/06 season has a small effect on the time series of harvests in that the TACs, unlike GHLs, cannot be exceeded; in fact, reportedly due to problems finding processors with available quota shares, the harvest did not attained the TAC in the 2005/06 and 2006/07 seasons, particularly during the 2006/07 in the area west of 174° W longitude (Tables 4–6). The change to a rationalized fishery also resulted in changes in fishery practices (see "Description of the directed fishery" and Tables 2–3), which are a consideration when using fishery performance data or other fishery data to judge the condition of the stock.

Fishery performance data and available observer and pot survey data should be examined prior to determining the time period that is "representative of the production potential of the stock" and provides "the required risk aversion for stock conservation and utilization goals" for estimating OFL. Annual season average weights of landed crabs may give some idea of recruitment trends, although those average weights may also be influenced by changes in fishery practices (e.g., use of escape mechanisms and soak times; see "Description of the directed fishery"). We examine these data for three periods: 1985/86–1995/96, 1996/97–2004/05, and 2005/06–2006/07.

<u>The pre-GHL/TAC period, 1985/86–1995/96</u>. Catch per pot lift (number of retained legal males; CPUE) in the entire Aleutian Islands Area showed a declining trend during 1985/86–1995/96 that accompanied the declining trend in harvest (Table 7, Figure 8). That trend is also shown within each of the areas east of 174° W longitude (Table 8, Figure 9) and west of 174° W longitude (Table 9, Figure 9). 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 7, Figure 10) and for each of the areas east and west of 174° W longitude (Tables 8–9, Figure 11).

Average retained catch for the period 1985/86–1989/90 was 11,875,811 pounds. Harvests dropped sharply from the 1989/90 to 1990/91 season (from 12,022,052 pounds to 6,590,362 pounds) and average retained catch for the period 1990/91–1995/96 was 6,930,627 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. Given that, as well as considering average retained catch over the period 1985/86–1995/96 as an estimate of OFL, the average retained catch over the period 1987/88–1995/96 should also be considered because it excludes the two years with the highest retained catch in the history of the fishery.

The GHL and pre-rationalization period, 1996/97–2004/05. Since the 1996/97 season, catches have stabilized with management of the fishery to a pre-season GHL/TAC and CPUE has increased steadily from the 1996/97 season through the 2004/05 season for the entire Aleutian Islands Area and within the areas east and west of 174° W longitude (Tables 7–9, Figure 8, Figure 9). The CPUE for the entire Aleutian Islands Area increased from 6.0 crabs per pot lift in 1996/97 to 14.2 in 2004/05; between 1996/97 and 2004/05, CPUE increased from 6.5 crabs per pot lift to 14.3 in the area east of 174° W longitude and from 6.1 crabs per pot lift to 12.1 in the area west of 174° W longitude. The trend in increasing CPUE over this period would be consistent with an increase in legal male abundance since the mid-1990’s. For the entire Aleutian Islands Area and within the areas east and west of 174° W longitude, average weights of landed crabs during the 1996/97–1997/98 seasons were comparable to those of the 1985/86–1986/87 seasons, but then declined into the 2001/02–2004/05 seasons (Tables 7–9, Figure 10, Figure 11). The decline in average weights after the 1997/98 season could be indicative of increase in recruitment to legal size during the late 1990’s and early 2000’s that was responsible for the increase in CPUE over this period. Average weights continued to decline through the 2004/05 season in the area west of 174°W longitude, whereas average weights increased between the 2001/02 and 2004/05 seasons in the area east of 174°W longitude.

Observer data and, for the area east of 174° W longitude only, survey data from this period can also be used to give some assessment of the relative contribution of new recruits to legal-size crabs during this period. Classifying legal male golden king crabs as “recruits” is difficult due to the asynchronous, aseasonal molting of golden king crabs and the difficulties in consistently scoring shell condition of golden king crabs and relating those scores to time since the last molt (see “Description of life history characteristics relevant to stock assessments”). Instead we will only summarize data on the proportion of “recruit-sized” legal males among the legal males. Watson et al. (2002) estimated an average per molt increment of 15-mm CL from recoveries of eastern Aleutian Islands male golden king crabs tagged and released at sizes of 91–183-mm CL and Blau and Pengilly (1994) and Blau et al. (1998) estimated the CL at which 50% of male crabs are legal sized (6" CW) to be 135–137-mm CL. Hence we will use “legal-sized males ≤150-mm CL” as the definition of “recruit-sized legal males.” The percentage of legal-size males that were recruit-sized was estimated from pot lifts sampled by observers during the 1996/97 seasons through the 2006/07 season for each of the areas east and west of 174° W longitude. Additionally the percentage of legal-size males that were recruit-sized was estimated for the area east of 174° W longitude using data from the ADF&G pot survey performed in the area between 170° 21' and 171° 33' W longitudeduring 1997, 2000, 2003, and 2006. Not surprisingly, within each area east and west of 174° W longitude the annual average weight of landed crabs over 1996/97–2006/07 is negatively correlated with the annual percent recruit-sized legal males among the legal males in pot lifts sampled by observers (r = -

0.76 for the area east of 174° W longitude and r = -0.83 for the area west of 174° W longitude) and trends in annual percent recruit-sized legal males are generally consistent with trends in average weights of landed crabs. For the area east of 174° W longitude the percent recruit-sized males in fishery pots sampled by observers increased slightly from 67% in the 1996/97 season to 69–71% in the 1997/98–2002/03 seasons and then declined steadily in subsequent seasons to 63% in the 2004/05 season; that percentage increased from 76% in the 1997 survey to 82% in the 2000 survey and declined to 72% in the 2003 survey (Figure 12). For the area west of 174° W longitude the percent recruit-sized males in fishery pots sampled by observers showed a general increasing trend from 73–74% in the 1996/97–1997/98 seasons to 77–81% in the 2002/03–2004/05 seasons.

Trends in the CPUE of incidentally captured sublegal males and females can also be assessed using the data from pot sampled by at-sea observers for the areas east and west of 174° W longitude. Among the sublegal males, males estimated to molt to legal size within the next year are referred to as "pre-recruit-1 males." Following Blau and Pengilly (1994) and Blau et al. 1997), we define pre-recruit-1 males as sublegal males ≥121-mm CL (see also Watson et al. 2002). Whereas CPUE of legal males increased during 1996/97–2004/05 in the area east of 174° W longitude, CPUE of sublegal males and females tended to decrease from the peak values of 19 sublegal males and 15 females per pot lift in the 1998/99 season to 11 sublegal males and 8 females per pot in 2004/05 (Figure 13). Although the estimated CPUE of sublegal males during the fishery east of 174° W longitude showed a declining trend since the late 1990s, the CPUE of pre-recruit-1 males remained stable over the years (Figure 13); the decrease in CPUE of sublegal males in the fishery east of 174° W longitude is due to decreases in the CPUE of sublegal males <121 mm CL. In the area west of 174° W longitude, CPUE of sublegal males was, with the exception of a peak value of 15 crabs per pot lift in the 1998/99 season, relatively stable, showing a weak increasing trend from the 1999/00 season (8 crabs per pot lift) through the 2004/05 season (11 crabs per pot lift; Figure 14). That variation in CPUE of sublegal males is largely attributable to pre-recruit-1 males (Figure 14). CPUE of females in the area west of 174° W longitude has also been relatively stable with the exception of the 1998/99 season (15 crabs per pot lift), showing only a weak decreasing trend from 1996/97 (12 crabs per pot lift) to 2004/05 (9 crabs per pot lift; Figure 14).

Data from triennial pot surveys (1997, 2000, 2003, 2006) in a limited area east of 174° W longitude (between 170° 21' and 171° 33' W longitude) is also available for inspecting trends in survey CPUE. The trend in CPUE of legal males during the triennial survey within the period 1996/97–2004/05 is not consistent with the trend in fishery CPUE for the area east of 174° W longitude. Although CPUE during the 1997, 2000, and 2003 surveys is somewhat stable in terms of absolute numbers (ranging only from 2.9 to 4.7 crabs per pot lift), the CPUE actually decreased from the 1997 through the 2003 surveys; the CPUE of legal males in the 2003 survey was 62% of that for the 1997 survey (Table 17). Additionally, survey CPUE of sublegal males declined from 49.7 crabs per pot lift in 1997 to 11.9 in the 2003 and survey CPUE of females declined from 58.6 crabs per pot lift in 1997 to 10.5 in 2003 (note, however, that the survey CPUE of sublegal males and females can be greatly affected by occasional large catches of small juvenile males and females).

Data on tag recovery rates of legal males tagged during the triennial survey are also available for inspection relative to stock trends in the area east of 174° W longitude. The number of crabs harvested in the 1997/98, 2000/2001, and 2003/04 seasons east of 174° W longitude in comparison to the relative changes in survey CPUE (the number harvest in the 2003/04 season was 83% of that harvested in the 1997/98 season, whereas the CPUE of legal males in the 2003 survey was 62% of that for the 1997 survey; Table 8, Table 17). However, recovery rates during commercial fisheries of legal males tagged during the surveys have not increased over this period, but have actually decreased: in the 1997/98 season, 20.4% of legal males tagged in 1997 were recovered; 20.0% of legal males tagged in 2000 were recovered during the 2000/01 season; and only 10.5% of the legal males tagged in 2003 were recovered during the 2003/04 season (Watson 2004). Variation in the geographic distribution of tag releases among survey years and variation in the geographic distribution of fishery effort among seasons may account for the some of the variation in tag recovery rates by season. For example, tag recovery rates during the 2003/04 season varied among the release locations of legal males tagged during the 2003 survey, with generally higher recovery rates for those crabs tagged and released at locations east of 171^{o} W longitude (Pengilly 2005). Legal males tagged and released in 2003 at locations east of 171^{o} W longitude were recovered during the 2003/2004 fishery at a rate of 16.1% as compared to a rate of 3.4% for those tagged and release at locations west of 171^{o} W longitude. Nonetheless, the decreasing trend in tag recovery rates suggests that legal male abundance did not decrease between 1997 and 2003 at the rate indicated by the decrease in survey CPUE and that abundance of legal males may have increased over that period, consistent with the trend in fishery CPUE.

Weight of discarded bycatch golden king crabs has been estimated from size-sex frequency distribution in the non-retained catch in pot lifts sample by observers (Tables 4–6). Weight of discarded bycatch 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). Total catch weight (retained catch weight plus by catch mortality weight) during this period for the entire Aleutian Islands Area and for each of the areas east and west of 174° W longitude has also be estimated using observer data and a range of assumed values for handling mortality (*hm*) of discarded bycatch (Tables 4–6). Although the effects of the total catch weight on the stock will depend on the true value of *hm*, it is notable that estimated total catch weight decreased during the period 1996/97–2004/05 under all scenarios for *hm*, both in absolute terms and relative to the retained catch (Figure 15, Figure 16).

In summary, during the 9-season period 1996/97–2004/05 there was little variation in retained catch (ranging from 4.942-million pounds to 6.019-million pounds), making the Aleutian Islands fishery the most stable and consistently-producing fishery among the BSAI FMP crab fisheries. However, other information on the stock condition during this period is incomplete and often conflicting. Fishery CPUE of legal males has increased in both the areas east and west of 174° W longitude during this period whereas survey CPUE of legal males in the triennially surveyed portion of the area west of 174° has decreased. A declining trend in tag-recovery rates is consistent with an increasing trend in legal male abundance. Observer data on fishery CPUE of pre-recruit-1 sublegal males and data on the percentage of legal males that are recruit-size provide no evidence for a large recruitment of legal males. Given all data sources together for the period 1996/97–2004/05, the abundance of legal males may have grown steadily from the late 1990s through the 2004/05 season with stable recruitment of legal males adding to surviving legal males. Although it unclear whether the decrease in bycatch of sublegal males and females relative to the catch of legal males during this period is due to changes in fishery practices or to population trends, that decrease has resulted in a decrease in the total catch (retained catch plus handling mortality) weight during this period.

<u>The TAC and rationalized fishery period, 2005/06–2006/07</u>. Harvests in 2005/06–2006/07 decreased only slightly relative to the average for the period 1996/97–2004/05, whereas fishery CPUE increased markedly to values of 20 crabs per pot or more (Tables 7–9, Figure 8, Figure 9). The increase in CPUE was not accompanied by a decrease in average weight of landed crabs (Figure 10, Figure 11) or an increase in the percentage of legal males that were recruit-sized (Figure 12); in fact, average weight of landed crabs increased and the percent of legal males that were recruit-sized decreased. Hence the large increase in fishery CPUE that has accompanied rationalization cannot be explained by a large recruitment of legal males. The increase in CPUE is likely due largely to changes in fishery practices that have accompanied the rationalization of the fishery (see "Description of the directed fishery").

In the 2006 pot survey within the area east of 174° W longitude, CPUE of legal males also increased from the 2003 value towards the value for the 1997 survey (Table 17). Nonetheless, survey CPUE of sublegal males and females remained low in 2006 relative to 1997 and 2000 (Table 17). Of the legal males tagged in 2006 7.4% were recovered during the 2006/07 season. Most of the tags recovered during the fishery are recovered by observers and after the 2004/05 season, observer coverage declined from 100% coverage to 66.5% coverage during the 2005/06 season (i.e., observers were not on vessels at times during which 33.5% of the retained catch was captured). That reduction in observer coverage influenced the tag recovery rate during the 2006/07 season relative to previous years when observer coverage was 100%. Adjusting for the reduction in observer coverage, the 7.4% recovery rate in the 2006/2007 season would be comparable to a recovery rate of 10–11% in a season with 100% coverage. The adjusted rate is comparable to the recovery rate during the 2003/04 season, but is half the rate for the 1997/98 and 2000/01 seasons. Given the number of crabs harvested in the 1997/98, 2000/01, 2003/04, and 2006/07 seasons east of 174° W longitude, the tag recovery rates suggest that abundance of legal males in 2006/07 was comparable to that in 2003/04 and higher than that in 1997/98 and 2000/01.

Estimated weight of non-retained bycatch in the 2005/06 season and 2006/07 season was markedly lower than in previous seasons (2,523,737 pounds in 2005/06 and 2,573,040 in 2006/07; Tables 4–6). Due to thatreduction in incidental catch of sublegal males and females relative to retained legal males (Figure 13, Figure 14), estimated total catch (retained plus handling mortality) weights in the 2005/06–2006/07 season are at the lowest value for the time series of estimates (Tables 4–6, Figure 15, Figure 16); even under the assumption *hm* = 60%, estimated total catch weight is only approximately 27–29% greater than the retained catch weight during 2005/06–2006/07. Again, however, it is uncertain how much that reduction can be attributed to changes in fishery practices as opposed to changes in the stock.

Projections and Harvest Alternatives

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:

- OFL = "The average retained catch from a time period determined to be representative of the production potential of the stock"

Specification of FOFL , OFL, the upper bound on Ftarget, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring:

- Estimated OFLs estimated as average retained catch (pounds) for seven different candidate time periods are provide in the table below.

Time period	Number of seasons	OFL (= average retained catch, pounds)
1981/82–2006/07	26	7,261,516
1985/86–2006/07	22	7,405,837
1987/88–2006/07	20	6,772,773
1990/91–2006/07	17	6,091,139
1996/97–2006/07	11	5,633,236
1985/86-1999/00	15	8,233,663
1985/86–1995/96	11	9,178,438
1987/88–1995/96	9	8,165,540
1990/91–1995/96	6	6,930,627

- Original recommendation: average of 1985/86–2006/97 retained catch = 7,405,837 pounds.
- Final recommendation: average of 1990/91–1995/96 retained catch = 6,930,627 pounds.

List of standard harvest scenarios and description of projection methodology

- Standard harvest scenario is that retained catch will be ≤TAC under rationalized fishery
- The actual retained catch and GHL/TAC for the entire Aleutian Islands Area and for each of the areas east and west of 174° W longitude (Tables 4–6) are compared graphically in Figure 17 and Figure 18. Over the period 1996/97–2005/06 the average retained catch has been 2% below the average GHL/TAC. By season, retained catch has been as much as 13% below the GHL/TAC (1998/99 season) and as much as 6% above the GHL/TAC.

Data gaps and research priorities

The process of development and annual use of an assessment model to estimate spawning biomass will identify data gaps and research priorities.

Summary

Parameter	Value
M	Default = 0.18
Tier	5
Recommended value of OFL	6,930,627 pounds (retained catch)

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Table 1. Relative frequency distribution (percentage) of depths of pot lifts sampled during the 2005/06 Aleutian Islands golden king crab fishery east and west of 174° W longitude (from Barnard and Burt 2007).

Depth (fm)	East of 174°W longitude (n=1,190)	East of 174°W longitude (n=1,370)
<76	0.1%	0.1%
76-100	6.5%	1.6%
101-125	16.0%	6.9%
126-150	15.7%	20.9%
151-175	15.6%	26.2%
176-200	8.4%	16.9%
201-225	8.8%	13.7%
226-250	8.2%	9.2%
251-275	11.8%	2.9%
276-300	6.9%	0.9%
>300	2.1%	0.6%

Table 2. Average pots deployed per vessel in the eastern and western Aleutian Islands golden king crab fishery from the 2000/01 to the 2006/07 seasons (from ADF&G 2008).

Fishery Season	Eastern Aleutian Islands Average Pots / Vessel	Western Aleutian Islands Average Pots / Vessel
2000/01	707	743
2001/02	680	943
2002/03	623	1,038
2003/04	695	1,190
2004/05	693	1,230
Average	**680**	**1,029**
2005/06*	1,232	1,600
2006/07*	1,358	2,000
Average	**1,295**	**1,800**

* Rationalized season

Table 3. Average soak times in hours and days in the eastern and western Aleutian Islands golden king crab fishery from the 2000/01 to the 2006/07 seasons (from ADF&G 2008).

Fishery Season	Eastern Aleutian Islands		Western Aleutian Islands	
	Soak Time (hours)	Soak Time (days)	Soak Time (hours)	Soak Time (days)
2000/01	110.9	4.6	230.2	9.7
2001/02	105.6	4.4	294.9	12.3
2002/03	97.7	4.1	290.6	12.1
2003/04	97.0	4.0	321.6	13.4
2004/05	88.2	3.7	278.9	11.6
Average	**99.9**	**4.2**	**283.2**	**11.8**
2005/06*	340.2	14.2	580.9	24.2
2006/07*	277.8	11.6	456.3	19.0
Average	**309.0**	**12.9**	**518.6**	**21.6**

*Rationalized season

Table 4. Annual guideline harvest level (GHL, 1996/97–2004/05) or total allowable catch (TAC, 2005/06–2006/07) for retained catch (pounds), actual retained catch (pounds), estimated non-retained discards (pounds), and estimates of total catch (retained catch plus discard mortality; pounds) for the Aleutian Islands golden king crab fishery.

				Total Catch (retained plus discard mortality with assumed handling mortality rate, *hm*)					
Season	Retained GHL/TAC	Retained Catch	Non-retained Discards	*hm*=10%	*hm*=20%	*hm*=30%	*hm*=40%	*hm*=50%	*hm*=60%
1996/97	5,900,000	5,815,772	9,075,548	6,723,327	7,630,882	8,538,437	9,445,991	10,353,546	11,261,101
1997/98	5,900,000	5,945,683	8,692,668	6,814,950	7,684,217	8,553,483	9,422,750	10,292,017	11,161,284
1998/99	5,700,000	4,941,893	7,388,274	5,680,720	6,419,548	7,158,375	7,897,203	8,636,030	9,374,858
1999/00	5,700,000	5,838,788	7,551,570	6,593,945	7,349,102	8,104,259	8,859,416	9,614,573	10,369,730
2000/01	5,700,000	6,018,761	8,901,534	6,908,914	7,799,068	8,689,221	9,579,374	10,469,528	11,359,681
2001/02	5,700,000	5,918,706	6,888,462	6,607,552	7,296,398	7,985,244	8,674,091	9,362,937	10,051,783
2002/03	5,700,000	5,462,455	5,671,318	6,029,587	6,596,719	7,163,850	7,730,982	8,298,114	8,865,246
2003/04	5,700,000	5,665,828	4,973,484	6,163,176	6,660,525	7,157,873	7,655,222	8,152,570	8,649,919
2004/05	5,700,000	5,575,051	4,321,014	6,007,152	6,439,254	6,871,355	7,303,457	7,735,558	8,167,660
2005/06	5,700,000	5,520,318	2,523,737	5,772,692	6,025,065	6,277,439	6,529,813	6,782,186	7,034,560
2006/07	5,700,000	5,262,342	2,573,040	5,519,646	5,776,950	6,034,254	6,291,558	6,548,862	6,806,166
2007/08	5,700,000	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing

Table 5. Annual guideline harvest level (GHL, 1996/97–2004/05) or total allowable catch (TAC, 2005/06–2006/07) for retained catch (pounds), actual retained catch (pounds), estimated non-retained discards (pounds), and estimates of total catch (retained catch plus discard mortality; pounds) for the Aleutian Islands golden king crab fishery in the area east of 174° W longitude.

Season	Retained GHL/TAC	Retained Catch	Non-retained Discards	Total Catch (retained plus discard mortality with assumed handling mortality rate, *hm*) *hm*=10%	*hm*=20%	*hm*=30%	*hm*=40%	*hm*=50%	*hm*=60%
1996/97	3,200,000	3,290,862	4,031,543	3,694,016	4,097,171	4,500,325	4,903,479	5,306,633	5,709,788
1997/98	3,200,000	3,501,055	4,858,067	3,986,862	4,472,668	4,958,475	5,444,282	5,930,089	6,415,895
1998/99	3,000,000	3,247,863	4,776,471	3,725,510	4,203,157	4,680,804	5,158,452	5,636,099	6,113,746
1999/00	3,000,000	3,069,886	3,449,331	3,414,819	3,759,752	4,104,685	4,449,619	4,794,552	5,139,485
2000/01	3,000,000	3,134,079	4,075,231	3,541,602	3,949,125	4,356,648	4,764,171	5,171,694	5,579,218
2001/02	3,000,000	3,178,653	2,610,981	3,439,751	3,700,849	3,961,947	4,223,045	4,484,143	4,745,241
2002/03	3,000,000	2,821,851	2,299,720	3,051,823	3,281,795	3,511,767	3,741,739	3,971,711	4,201,683
2003/04	3,000,000	2,977,055	2,108,319	3,187,887	3,398,719	3,609,551	3,820,383	4,031,215	4,242,047
2004/05	3,000,000	2,886,817	1,483,769	3,035,194	3,183,571	3,331,948	3,480,325	3,628,701	3,777,078
2005/06	3,000,000	2,866,603	832,073	2,949,810	3,033,018	3,116,225	3,199,432	3,282,639	3,365,847
2006/07	3,000,000	2,992,010	1,133,134	3,105,323	3,218,637	3,331,950	3,445,264	3,558,577	3,671,891
2007/08	3,000,000	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing

Table 6. Annual guideline harvest level (GHL, 1996/97–2004/05) or total allowable catch (TAC, 2005/06–2006/07) for retained catch (pounds), actual retained catch (pounds), estimated non-retained discards (pounds), and estimates of total catch (retained catch plus discard mortality; pounds) for the Aleutian Islands golden king crab fishery in the area west of 174° W longitude.

			Non-	Total Catch (retained plus discard mortality with assumed handling mortality rate, *hm*)					
Season	Retained GHL/TAC	Retained Catch	retained Discards	*hm*=10%	*hm*=20%	*hm*=30%	*hm*=40%	*hm*=50%	*hm*=60%
1996/97	2,700,000	2,524,910	4,741,681	2,999,078	3,473,246	3,947,414	4,421,583	4,895,751	5,369,919
1997/98	2,700,000	2,444,628	3,698,153	2,814,443	3,184,259	3,554,074	3,923,889	4,293,704	4,663,520
1998/99	2,700,000	1,694,030	2,611,803	1,955,210	2,216,391	2,477,571	2,738,751	2,999,931	3,261,112
1999/00	2,700,000	2,768,902	4,102,238	3,179,126	3,589,350	3,999,573	4,409,797	4,820,021	5,230,245
2000/01	2,700,000	2,884,682	4,826,303	3,367,312	3,849,943	4,332,573	4,815,203	5,297,833	5,780,464
2001/02	2,700,000	2,740,054	4,277,398	3,167,794	3,595,534	4,023,273	4,451,013	4,878,753	5,306,493
2002/03	2,700,000	2,640,604	3,371,533	2,977,757	3,314,911	3,652,064	3,989,217	4,326,371	4,663,524
2003/04	2,700,000	2,688,773	2,862,862	2,975,059	3,261,345	3,547,632	3,833,918	4,120,204	4,406,490
2004/05	2,700,000	2,688,234	2,837,238	2,971,958	3,255,682	3,539,406	3,823,129	4,106,853	4,390,577
2005/06	2,700,000	2,653,715	1,691,664	2,822,881	2,992,048	3,161,214	3,330,381	3,499,547	3,668,713
2006/07	2,700,000	2,270,332	1,439,906	2,414,323	2,558,313	2,702,304	2,846,294	2,990,285	3,134,276
2007/08	2,700,000	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing

Table 7. Harvest history for the Aleutian Islands golden king crab fishery (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) by fishery season from the 1981/82 season through the 2006/07 season.

Season	Harvest Number[a]	Harvest Pounds[a]	Pot lifts	CPUE[b]	Average Weight[c]
1981/82	242,407	1,319,666	28,263	8.4	5.4
1982/83	1,746,206	9,236,942	179,888	9.4	5.3
1983/84	1,964,772	10,495,045	267,519	7.2	5.3
1984/85	995,453	4,819,347	90,066	10.7	4.8
1985/86	2,811,195	12,734,212	236,281	11.9	4.5
1986/87	3,340,627	14,738,744	433,020	7.7	4.4
1987/88	2,174,576	9,257,005	306,730	7.1	4.2
1988/89	2,488,433	10,627,042	321,927	7.6	4.3
1989/90	2,902,913	12,022,052	357,803	8.0	4.1
1990/91	1,703,251	6,950,362	214,814	7.7	4.1
1991/92	1,847,398	7,702,141	234,857	7.7	4.2
1992/93	1,528,328	6,291,197	203,221	7.4	4.1
1993/94	1,397,530	5,551,143	234,654	5.8	4.0
1994/95	1,924,271	8,128,511	386,593	4.8	4.2
1995/96	1,582,333	6,960,406	293,021	5.2	4.4
1996/97	1,334,877	5,815,772	212,727	6.0	4.4
1997/98	1,350,160	5,945,683	193,214	6.8	4.4
1998/99	1,150,029	4,941,893	119,353	9.4	4.3
1999/00	1,385,890	5,838,788	186,169	7.2	4.2
2000/01	1,410,315	6,018,761	172,790	8.0	4.3
2001/02	1,416,768	5,918,706	168,151	8.3	4.2
2002/03	1,308,709	5,462,455	131,021	9.8	4.2
2003/04	1,319,707	5,665,828	125,119	10.3	4.3
2004/05	1,323,001	5,575,051	91,694	14.2	4.2
2005/06	1,263,339	5,520,318	54,685	22.9	4.4
2006/07	1,178,321	5,262,342	53,065	22.0	4.5

a. Includes deadloss.
b. Catch (number of crabs) per pot lift.
c. Average weight (pounds) of landed crabs, including deadloss.

Table 8. Harvest history for the Aleutian Islands golden king crab fishery (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) for the area east of 174° W longitude by fishery season from the 1985/86 season through the 2006/07 season.

Season	Harvest Number[a]	Harvest Pounds[a]	Pot lifts	CPUE[b]	Average Weight[c]
1985/86	1,400,484	6,514,777	117,718	11.9	4.7
1986/87	1,307,032	5,922,425	155,240	8.4	4.5
1987/88	1,029,424	4,431,745	146,501	7.0	4.3
1988/89	1,169,427	5,148,776	155,518	7.5	4.4
1989/90	1,317,833	5,473,218	155,262	8.5	4.2
1990/91	945,641	3,938,756	106,281	8.9	4.2
1991/92	1,093,983	4,553,550	133,428	8.2	4.2
1992/93	1,118,955	4,606,054	133,778	8.4	4.1
1993/94	832,194	3,328,604	106,890	7.8	4.0
1994/95	1,128,013	4,751,501	191,455	5.9	4.2
1995/96	1,046,780	4,627,487	177,773	5.9	4.4
1996/97	731,909	3,290,862	113,460	6.5	4.5
1997/98	780,610	3,501,055	106,403	7.3	4.5
1998/99	740,011	3,247,863	83,378	8.9	4.4
1999/00	709,332	3,069,886	79,129	9.0	4.3
2000/01	704,702	3,134,079	71,551	9.9	4.5
2001/02	730,030	3,178,653	62,639	11.7	4.4
2002/03	643,886	2,821,851	52,042	12.4	4.4
2003/04	643,074	2,977,055	58,883	10.9	4.6
2004/05	637,536	2,886,817	34,848	18.3	4.5
2005/06	623,971	2,866,603	24,569	25.4	4.6
2006/07	650,587	2,992,010	26,195	24.8	4.6

a. Includes deadloss.
b. Catch (number of crabs) per pot lift.
c. Average weight (pounds) of landed crabs, including deadloss.

Table 9. Harvest history for the Aleutian Islands golden king crab fishery (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) for the area west of 174° W longitude by fishery season from the 1985/86 season through the 2006/07 season.

Season	Harvest Number[a]	Harvest Pounds[a]	Pot lifts	CPUE[b]	Average Weight[c]
1985/86	1,410,711	6,219,435	118,563	11.9	4.4
1986/87	2,033,595	8,816,319	277,780	7.3	4.3
1987/88	1,145,152	4,825,260	160,229	7.2	4.2
1988/89	1,319,006	5,478,266	166,409	7.9	4.2
1989/90	1,585,080	6,548,834	202,541	7.8	4.1
1990/91	757,610	3,011,606	108,533	7.0	4.0
1991/92	753,415	3,148,591	101,429	7.4	4.2
1992/93	409,373	1,685,143	69,443	5.9	4.1
1993/94	565,336	2,222,539	127,764	4.4	3.9
1994/95	796,258	3,377,010	195,138	4.1	4.2
1995/96	535,553	2,332,919	115,248	4.7	4.4
1996/97	602,968	2,524,910	99,267	6.1	4.2
1997/98	569,550	2,444,628	86,811	6.6	4.3
1998/99	410,018	1,694,030	35,975	11.4	4.1
1999/00	676,558	2,768,902	107,040	6.3	4.1
2000/01	705,613	2,884,682	101,239	7.0	4.1
2001/02	686,738	2,740,054	105,512	6.5	4.0
2002/03	664,823	2,640,604	78,979	8.4	4.0
2003/04	676,633	2,688,773	66,236	10.2	4.0
2004/05	685,465	2,688,234	56,846	12.1	3.9
2005/06	639,368	2,653,715	30,116	21.2	4.2
2006/07	527,734	2,270,332	26,870	19.6	4.3

Table 10. Harvest history for the Aleutian Islands golden king crab fishery (pounds of crabs landed) for the areas east of 171° W longitude, between 171° W longitude and 174° W longitude, and west of 174° W longitude by fishery season from the 1985/86 season through the 2006/07 season.

Season	East of 171° W long.	171° W long to 174° W long.	West of 174° W long.
1985/86	1,709,453	4,805,324	6,219,435
1986/87	1,869,180	4,053,245	8,816,319
1987/88	1,388,983	3,042,762	4,825,260
1988/89	1,546,113	3,602,663	5,478,266
1989/90	1,852,249	3,620,969	6,548,834
1990/91	1,699,675	2,239,081	3,011,606
1991/92	1,516,779	3,036,771	3,148,591
1992/93	1,404,452	3,201,602	1,685,143
1993/94	915,460	2,413,144	2,222,539
1994/95	1,750,481	3,001,020	3,377,010
1995/96	1,993,980	2,633,507	2,332,919
1996/97	2,617,750	673,112	2,524,910
1997/98	1,748,178	1,752,877	2,444,628
1998/99	1,562,267	1,685,596	1,694,030
1999/00	1,785,602	1,284,284	2,768,902
2000/01	1,324,687	1,809,392	2,884,682
2001/02	1,770,138	1,408,515	2,740,054
2002/03	1,751,219	1,070,632	2,640,604
2003/04	1,772,776	1,204,279	2,688,773
2004/05	1,567,849	1,318,968	2,688,234
2005/06	1,556,720	1,309,883	2,653,715
2006/07	1,216,389	1,775,621	2,270,332
Average: 1985/86–1995/96	1,604,255	3,240,917	4,333,266
Average: 1996/97–2006/07	1,697,598	1,390,287	2,545,351
Average: 1985/86–2006/07	1,650,926	2,315,602	3,439,308

Table 11a. Weight (in pounds) of retained legal males and estimated weight of non-retained legal male, non-retained sublegal male, and non-retained female Aleutian Islands golden king crabs during commercial crab fisheries by season for the 1996/97–2006/07 seasons. All non-retained catch occurred during the commercial Aleutian Islands golden king crab fishery unless noted.

	Retained	Non-retained			
Season	Legal Male	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

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 11b. Estimated annual weight (pounds) of discarded bycatch of Aleutian Islands golden king crabs (all sizes, males and females) during groundfish fisheries (all gear types and fisheries pooled) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 2003–2007 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office, 31 March 2008).

Year	541	542	543	Total
2003	82,695	10,153	1,315	94,163
2004	39,086	928	454	40,468
2005	5,728	2,461	5,677	13,865
2006	23,564	9,848	1,140	34,552
2007	212,515	5,472	3,217	221,203
Average	72,718	5,772	2,360	80,850

Table 12. Weight (in pounds) of retained legal males and estimated weight of non-retained legal male, non-retained sublegal male, and non-retained female golden king crabs during the commercial Aleutian Islands golden king crab fishery east of 174° longitude by season for the 1996/97–2006/07 seasons.

	Retained	Non-retained			
Season	Legal male	Legal male	Sublegal male	Female	Total
1996/97	3,290,862	0	2,099,555	1,931,988	4,031,543
1997/98	3,501,055	0	2,536,029	2,322,039	4,858,067
1998/99	3,247,863	34,358	2,976,521	1,765,592	4,776,471
1999/00	3,069,886	40,284	2,048,481	1,360,567	3,449,331
2000/01	3,134,079	17,720	2,501,540	1,555,971	4,075,231
2001/02	3,178,653	14,199	1,648,759	948,023	2,610,981
2002/03	2,821,851	25,535	1,315,071	959,113	2,299,720
2003/04	2,977,055	20,009	1,200,043	888,268	2,108,319
2004/05	2,886,817	19,555	919,950	544,263	1,483,769
2005/06	2,866,603	84,334	509,375	238,363	832,073
2006/07	2,992,010	92,819	567,443	472,872	1,133,134

Table 13. Weight (in pounds) of retained legal males and estimated weight retained legal males and weight of non-retained legal male, non-retained sublegal male, and non-retained female golden king crabs during the commercial Aleutian Islands golden king crab fishery west of 174° longitude by season for the 1996/97–2006/07 seasons.

	Retained	Non-retained			
Season	Legal	Legal	Sublegal male	Female	Total
1996/97	2,524,910	0	2,022,619	2,719,062	4,741,681
1997/98	2,444,628	0	1,592,503	2,105,650	3,698,153
1998/99	1,694,030	6,967	1,326,885	1,277,951	2,611,803
1999/00	2,768,902	23,592	1,881,796	2,196,850	4,102,238
2000/01	2,884,682	17,712	2,280,887	2,527,704	4,826,303
2001/02	2,740,054	12,343	2,138,480	2,126,575	4,277,398
2002/03	2,640,604	16,086	1,798,270	1,557,177	3,371,533
2003/04	2,688,773	18,861	1,463,856	1,380,145	2,862,862
2004/05	2,688,234	56,545	1,591,573	1,189,121	2,837,238
2005/06	2,653,715	56,159	969,226	666,279	1,691,664
2006/07	2,270,332	26,771	695,861	717,274	1,439,906

Table 14. Carapace length (CL, mm) frequency distribution from biological measurements of retained golden king crabs sampled by season during the 1996/97 through 2006/07 Aleutian Islands golden king crab fishery (data from ADF&G shellfish observer database, Dutch Harbor, 7 April 2008).

CL (mm)	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07
<130	68	73	25	25	26	15	16	10	4	5	4
130	78	78	35	42	42	28	16	20	14	5	2
131	108	137	58	63	57	45	38	23	22	12	11
132	258	256	147	151	132	107	106	65	76	35	27
133	377	438	279	265	209	170	231	137	99	57	39
134	617	657	439	395	346	292	391	180	215	128	106
135	796	1,005	628	581	569	461	496	334	381	228	177
136	957	1,236	778	638	660	546	698	427	460	282	201
137	1,265	1,470	1,190	1,095	981	840	999	569	566	452	330
138	1,429	1,874	1,228	1,253	1,051	1,019	972	730	718	476	410
139	1,358	1,747	1,119	1,214	951	985	889	611	574	456	389
140	1,827	2,056	1,597	1,525	1,532	1,168	1,246	1,039	959	687	544
141	1,408	1,951	1,279	1,377	1,151	1,109	1,039	696	793	646	554
142	1,649	2,251	1,599	1,744	1,400	1,307	1,341	1,051	956	767	651
143	1,673	2,227	1,623	1,656	1,249	1,278	1,480	924	1,002	772	763
144	1,558	1,912	1,306	1,497	1,145	1,276	1,113	840	809	661	565
145	1,458	2,067	1,442	1,538	1,487	1,266	1,224	1,028	943	756	674
146	1,288	1,792	1,226	1,279	1,049	992	1,001	758	746	627	590
147	1,453	1,766	1,371	1,567	1,269	1,169	1,190	923	826	694	618
148	1,358	1,695	1,251	1,410	1,042	1,122	944	783	693	661	642
149	1,055	1,412	844	1,131	876	897	882	568	571	572	505
150	1,135	1,458	1,083	1,091	1,142	890	864	728	609	585	510
151	905	1,266	788	896	799	717	626	502	455	520	458
152	919	1,252	912	1,053	893	879	766	592	504	581	563
153	863	1,134	753	819	742	671	594	477	395	443	530
154	799	972	566	735	664	587	672	427	405	423	445
155	696	840	577	635	792	538	502	405	398	411	446
156	585	824	514	545	530	419	353	318	300	335	363
157	566	742	475	570	581	427	452	323	317	323	397
158	489	659	428	527	496	391	262	280	213	283	333
159	445	611	308	398	375	295	221	178	208	254	290

(continued)

Table 14. page 2 of 2.

CL (mm)	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07
160	449	588	337	383	469	261	250	255	229	247	267
161	334	451	241	305	281	236	180	135	142	196	269
162	351	447	273	335	334	236	197	166	182	195	283
163	353	433	222	294	318	231	136	123	134	145	254
164	305	361	178	213	246	206	131	162	122	136	169
165	242	350	180	183	258	173	116	142	126	145	201
166	188	279	122	161	179	112	86	78	71	94	153
167	221	297	142	157	216	160	100	88	80	110	174
168	221	250	118	125	143	126	71	74	77	75	131
169	142	176	107	101	110	83	60	56	52	74	103
170	173	183	105	76	152	86	59	60	74	76	110
171	104	137	70	71	104	52	49	38	46	58	94
172	112	150	72	59	95	65	57	52	28	65	81
173	96	137	54	48	88	48	22	29	34	62	73
174	82	95	44	23	61	38	22	30	41	43	61
175	56	92	51	31	61	41	25	18	11	52	53
176	43	95	21	29	41	20	17	17	11	29	35
177	53	55	33	21	37	18	10	12	11	32	33
178	50	67	20	20	34	17	13	8	13	18	26
179	37	47	8	15	22	12	7	20	1	12	24
180	34	35	11	10	27	18	6	8	7	13	10
>180	59	135	55	33	75	44	16	30	19	51	71
Total	33,145	42,718	28,332	30,408	27,589	24,189	23,254	17,547	16,742	15,065	14,812

Table 15. Carapace length (CL, mm) frequency distributions from biological measurements of retained golden king crabs sampled by season during the 1996/97 through 2006/07 Aleutian Islands golden king crab fishery east of 174° W longitude (data from ADF&G shellfish observer database, Dutch Harbor, 7 April 2008).

CL(mm)	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07
<130	46	25	9	8	11	3	3	2	0	0	0
130	10	16	7	9	7	8	3	0	1	0	0
131	23	26	22	21	11	6	3	3	5	1	0
132	48	24	46	40	28	17	23	6	16	4	2
133	50	84	69	82	39	30	44	20	23	4	2
134	93	151	104	96	69	59	52	23	41	8	5
135	118	225	182	142	103	79	70	41	67	20	14
136	139	246	196	196	144	112	91	76	61	28	26
137	157	246	304	265	184	121	147	75	84	38	32
138	181	324	289	316	202	181	151	74	101	38	39
139	194	302	278	288	196	160	177	83	107	41	39
140	244	342	435	336	304	190	227	132	154	68	43
141	220	328	341	284	243	199	185	105	128	61	42
142	245	373	413	311	310	228	229	136	166	95	76
143	242	415	386	345	262	233	220	131	148	73	68
144	243	363	333	305	242	218	193	124	146	83	56
145	241	318	373	292	248	229	221	148	155	78	75
146	232	319	332	263	211	175	177	142	129	85	62
147	235	291	393	284	273	207	221	146	148	99	68
148	246	311	300	220	204	220	184	115	127	62	79
149	166	261	262	184	166	175	194	116	114	89	73
150	179	264	309	197	169	175	170	138	134	93	69
151	171	262	280	163	166	184	154	98	116	85	62
152	152	199	279	175	162	177	164	104	86	92	66
153	147	205	192	144	131	140	118	79	81	53	63
154	137	182	166	123	130	133	122	88	99	78	59
155	133	142	177	115	120	132	116	76	109	61	60
156	133	144	178	100	91	115	83	83	63	78	36
157	109	150	129	103	89	100	89	85	89	61	39
158	95	113	146	91	108	97	79	55	60	52	42
159	92	108	107	82	57	77	75	32	63	45	27

(continued)

Table 15. page 2 of 2.

CL(mm)	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07
160	82	133	153	78	76	70	92	52	69	50	38
161	72	90	111	57	60	61	57	33	45	37	32
162	76	91	106	65	58	59	59	34	57	44	39
163	63	83	75	63	53	61	45	26	37	19	39
164	55	43	70	53	47	49	46	26	23	19	27
165	52	56	72	42	38	44	32	22	30	33	22
166	30	46	54	39	36	31	33	22	20	19	18
167	40	56	65	33	29	31	39	18	37	23	20
168	45	29	58	31	28	37	29	13	16	13	24
169	32	42	53	30	13	22	23	16	16	18	20
170	48	30	40	25	18	24	20	11	20	11	12
171	36	21	39	22	15	18	16	5	13	12	6
172	21	22	30	19	10	17	26	11	7	18	10
173	20	14	29	16	14	9	7	10	9	16	13
174	22	15	26	6	9	8	8	8	10	9	10
175	16	11	23	8	12	14	7	3	3	15	4
176	14	13	9	7	4	2	8	3	2	8	3
177	18	6	18	9	3	4	2	1	2	2	4
178	11	10	10	7	9	4	5	3	1	6	5
179	10	9	4	7	2	3	3	3	0	1	5
180	7	7	7	3	4	5	2	0	0	2	0
>180	14	6	25	8	10	14	7	9	2	15	10
Total	5,505	7,592	8,114	6,208	5,228	4,767	4,551	2,865	3,240	2,063	1,685

Table 16. Carapace length (CL, mm) frequency distributions from biological measurements of retained golden king crabs sampled by season during the 1996/97 through 2006/07 Aleutian Islands golden king crab fishery west of 174° W longitude (data from ADF&G shellfish observer database, Dutch Harbor, 7 April 2008).

CL (mm)	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07
<130	22	36	16	17	7	12	13	3	4	3	3
130	68	56	28	33	20	20	12	17	13	5	2
131	85	90	36	42	27	39	35	18	17	11	11
132	210	202	101	111	73	90	83	51	57	28	25
133	327	294	210	182	106	138	179	109	69	52	37
134	524	426	335	295	175	228	317	132	160	112	98
135	678	639	446	436	338	380	407	260	303	200	157
136	818	813	582	437	333	427	559	308	386	238	170
137	1,108	1,018	886	819	537	710	798	412	461	396	296
138	1,248	1,283	939	927	588	829	770	583	592	421	367
139	1,164	1,196	841	913	519	819	674	445	447	381	342
140	1,583	1,431	1,162	1,172	905	971	957	793	783	568	491
141	1,188	1,348	938	1,081	643	903	800	489	639	541	501
142	1,404	1,521	1,186	1,419	740	1,074	1,057	817	754	630	567
143	1,431	1,508	1,237	1,289	669	1,041	1,171	693	829	663	686
144	1,315	1,244	973	1,181	626	1,051	871	604	632	544	500
145	1,217	1,475	1,069	1,233	958	1,031	937	761	761	623	583
146	1,056	1,208	894	1,006	612	811	772	517	590	504	513
147	1,218	1,243	978	1,270	732	960	910	667	659	543	542
148	1,112	1,138	951	1,180	587	896	716	585	546	560	554
149	889	971	582	937	531	714	646	379	437	440	426
150	956	1,003	774	888	763	710	653	498	461	450	418
151	734	860	508	727	470	532	440	330	324	389	382
152	767	895	633	870	547	698	564	404	398	443	484
153	716	795	561	664	441	529	453	337	306	359	454
154	662	653	400	608	414	453	511	278	289	315	362
155	563	582	400	514	556	406	361	279	278	313	366
156	452	581	336	442	321	303	253	173	228	221	295
157	457	507	346	463	379	323	335	191	223	243	329
158	394	452	282	433	302	294	171	184	150	209	251
159	353	419	201	313	255	217	133	108	136	188	243

(continued)

Table 16. page 2 of 2.

CL (mm)	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07
160	367	394	184	300	316	191	144	160	155	169	208
161	262	303	130	247	168	175	114	76	89	141	224
162	275	304	167	265	204	177	125	98	118	139	229
163	290	296	147	227	200	168	84	69	91	119	201
164	250	279	108	154	145	157	77	104	90	98	128
165	190	260	108	141	179	129	79	91	92	103	168
166	158	194	68	118	114	81	50	31	45	57	129
167	181	218	77	120	150	128	54	53	43	81	145
168	176	192	60	91	82	88	41	50	60	57	100
169	110	120	54	68	73	59	31	30	33	49	79
170	125	135	65	51	117	62	39	38	51	62	93
171	68	100	31	47	64	34	26	13	27	42	82
172	91	108	42	40	65	47	28	28	18	44	66
173	76	93	25	30	60	39	14	11	23	44	54
174	60	75	18	17	39	30	13	8	24	33	50
175	40	70	28	23	34	27	15	9	8	35	47
176	29	76	12	19	26	18	8	4	6	20	29
177	35	42	15	9	22	14	5	5	8	29	28
178	39	53	10	13	21	13	6	3	10	12	21
179	27	31	4	6	19	9	2	8	1	11	17
180	27	28	4	4	17	13	4	6	7	11	9
>180	45	120	30	19	50	29	8	10	17	33	56
Total	27,640	29,378	20,218	23,911	16,339	19,297	17,525	12,330	12,948	11,982	12,618

Table 17. Catch per unit effort (CPUE; number of crabs per pot lift) of legal males, sublegal males, and females in the 1997–2006 ADF&G Aleutian Islands golden king crab triennial pot survey for 61 stations fished in common over all four surveys (data from Watson 2007; 62 stations were fished in common over all four surveys, but data from one of those stations – station 12 – was not included due to excessive soak time and inability to sample entire catch in 2006 survey).

Survey Year	Legal Males	Sublegal Males	Females
1997	4.7	49.7	58.6
2000	3.1	30.7	32.7
2003	2.9	11.9	10.5
2006	4.3	11.9	17.2

Table 18. Mean and standard deviation (S.D.) of estimated growth in carapace length (mm) from a single molt by shell condition and legal status at release for male golden king crabs tagged and released in the Yunaska Island area of the Aleutian Islands, Alaska, July-August 1997 and recovered during subsequent commercial fishery seasons 0–4, 12–15, 24–27, 36-38 and 12–38 months after release (from Watson et al. 2002).

		Shell condition at release								
Months After		New shell			Old shell			All shell conditions		
Release	Statistic	Sublegal	Legal	All	Sublegal	Legal	All	Sublegal	Legal	All
0–4	N	3	8	11	0	1	1	3	9	12
	Mean	19.7	10.0	12.6	-	11	11	19.7	10.1	12.5
	S.D.	3.51	3.63	5.66	-	-	-	3.51	3.41	5.42
12–15	N	232	62	294	4	5	9	236	67	303
	Mean	14.6	13.9	14.5	12.5	13.2	12.9	14.6	13.9	14.4
	S.D.	2.71	3.43	2.88	2.38	2.39	2.26	2.71	3.35	2.87
24–27	N	148	42	190	0	2	2	148	44	192
	Mean	14.2	14.9	14.4	-	13.0	13.0	14.2	14.8	14.3
	S.D.	3.29	2.03	3.06	-	4.24	4.24	3.29	2.13	3.07
36–38	N	25	8	33	0	0	0	25	8	33
	Mean	15.4	15.8	15.5	-	-	-	15.4	15.8	15.5
	S.D.	3.13	1.98	2.87	-	-	-	3.13	1.98	2.87
12–38	N	405	112	517	4	7	11	409	119	528
	Mean	14.5	14.4	14.5	12.5	13.1	12.9	14.5	14.4	14.5
	S.D.	2.96	2.93	2.95	2.38	2.61	2.43	2.96	2.92	2.95

Table 19. Mean and standard deviation (S.D.) of estimated growth in carapace length (mm) from two molts for male golden king crabstagged and released in the Yunaska Island area of the Aleutian Islands, Alaska, July-August 1997 and recovered during the commercial fishery 12–15, 24–27, 36–38, and 12–38 months after release (from Watson et al. 2002).

Months after release		Legal Status at Release		
		Sublegal	Legal	All
12–15	N	2	0	2
	Mean	25.0	-	25.0
	S.D.	1.41	-	1.41
24–27	N	34	0	34
	Mean	30.1	-	30.1
	S.D.	2.73	-	2.73
36–38	N	48	1	49
	Mean	31.3	36	31.4
	S.D.	3.39	-	3.42
12–38	N	84	1	85
	Mean	30.6	36	30.7
	S.D.	3.26	-	3.29

Table 20. Percent by shell condition and legal status at release of male golden king crabs tagged and released in the Yunaska Island area of the Aleutian Islands, Alaska, July-August 1997 and recovered during the commercial fishery 0–4, 12–15, 24–27, and 36–38 months after release that were estimated to have not molted (% Not), to have molted once (% One), or to have molted twice (% Two) prior to recovery (from Watson et al. 2002).

		Shell condition at release								
Months After		New shell			Old shell			All shell conditions		
Release	Statistic	Sublegal	Legal	All	Sublegal	Legal	All	Sublegal	Legal	All
0–4	N	221	520	741	3	34	37	224	554	778
	% Not	98.6	98.5	98.5	100.0	97.1	97.3	98.7	98.4	98.5
	% One	1.4	1.5	1.5	0.0	2.9	2.7	1.3	1.6	1.5
	% Two	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12–15	N	283	184	467	4	6	10	287	190	477
	% Not	17.3	66.3	36.5	0.0	16.7	10.0	17.0	64.7	36.0
	% One	82.0	33.7	63.0	100.0	83.3	90.0	82.3	35.3	63.6
	% Two	0.7	0.0	0.4	0.0	0.0	0.0	0.7	0.0	0.4
24–27	N	187	49	236	0	2	2	187	51	238
	% Not	2.7	14.3	5.1	-	0.0	0.0	2.7	13.7	5.0
	% One	79.1	85.7	80.5	-	100.0	100.0	79.1	86.3	80.7
	% Two	18.2	0.0	14.4	-	0.0	0.0	18.2	0.0	14.3
36–38	N	74	9	83	0	0	0	74	9	83
	% Not	1.3	0.0	1.2	-	-	-	1.3	0.0	1.2
	% One	33.8	88.9	39.8	-	-	-	33.8	88.9	39.8
	% Two	64.9	11.1	59.0	-	-	-	64.9	11.1	59.0

Table 21. Percent by maturity at release of female golden king crabs tagged and released in the Yunaska Island area of the Aleutian Islands, Alaska, July-August 1997 and recovered during the commercial golden king crab fishery 0–4, 12–15, 24–27, and 36–38 months after release that were estimated to have not molted or to have molted at least once prior to recovery (from Watson et al. 2002).

		Maturity Status at Release		
Months After release	Statistic	Immature	Mature	All
0–4	N	13	22	35
	% Not Molted	92.3	100.0	2.9
	% Molted	7.7	0.0	97.1
12–15	N	5	10	15
	% Not Molted	40.0	70.0	60.0
	% Molted	60.0	30.0	40.0
24–27	N	2	9	11
	% Not Molted	0.0	0.0	0.0
	% Molted	100.0	100.0	100.0
36–38	N	0	7	7
	% Not Molted	-	0.0	0.0
	% Molted	-	100.0	100.0

Table 22. Range, mean, and standard deviation (S.D.) of estimated growth in carapace length (mm) for female golden king crabs tagged and released in the Yunaska Island area of the Aleutian Islands, Alaska, July-August 1997 and recovered during the commercial fishery 0–4, 12–15, 24–27, and 36–38 months after release, by maturity status at release and by maturity status at recovery (compiled from pages 178–182 *in* Watson et al. 2002).

		Released immature		Released mature
Months After Release	Statistic	Recovered immature	Recovered mature	Recovered mature
0–4	N	0	1	0
	Range	-	10	-
	Mean	-	10	-
	S.D.	-	-	-
12–15	N	2	1	4
	Range	8–9	11	2–10
	Mean	8.5	11	6.5
	S.D.	0.71	-	3.4
24–27	N	0	2	9
	Range	-	6–8	4–11
	Mean	-	7.0	5.8
	S.D.	-	1.4	2.2
36–38	N	0	0	7
	Range	-	-	3–15
	Mean	-	-	10.1
	S.D.	-	-	3.9

Table 23. Estimated parameters (A and B) for estimating weight (g) from carapace length (CL, mm) of male and ovigerous female Aleutian Islands golden king crabs according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007b).

Parameter	Males	Ovigerous females
A	0.0002988	0.001424
B	3.135	2.781

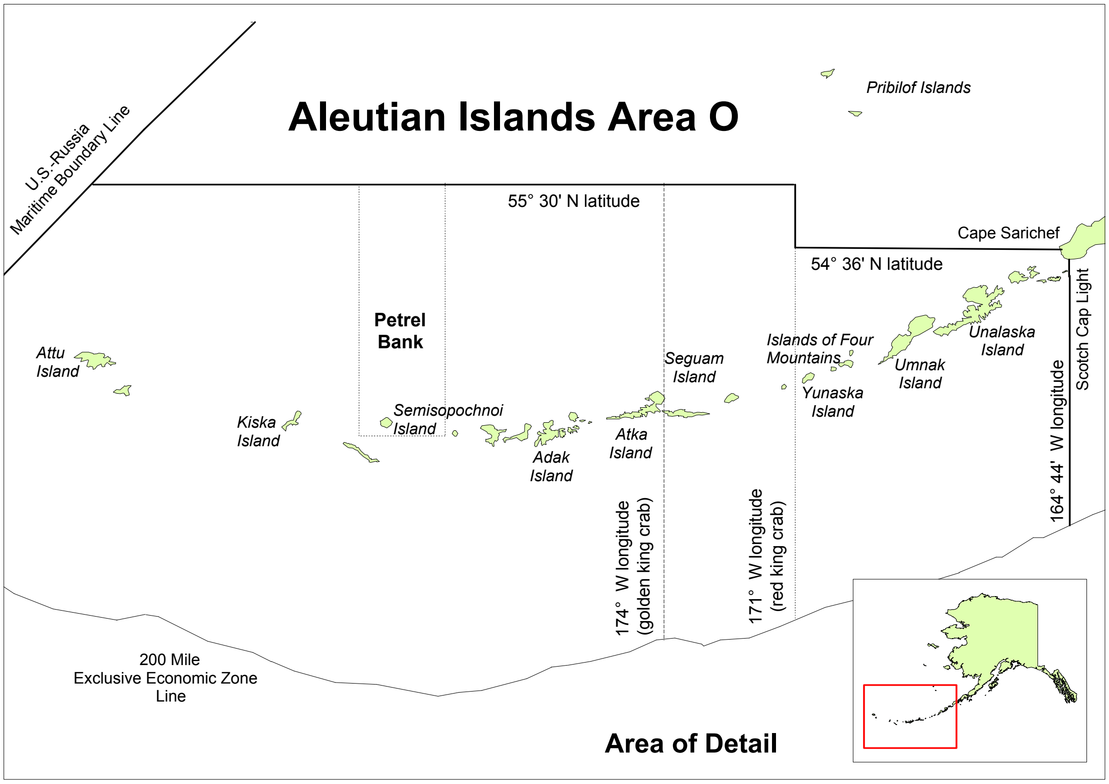


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Failor-Rounds 2008).

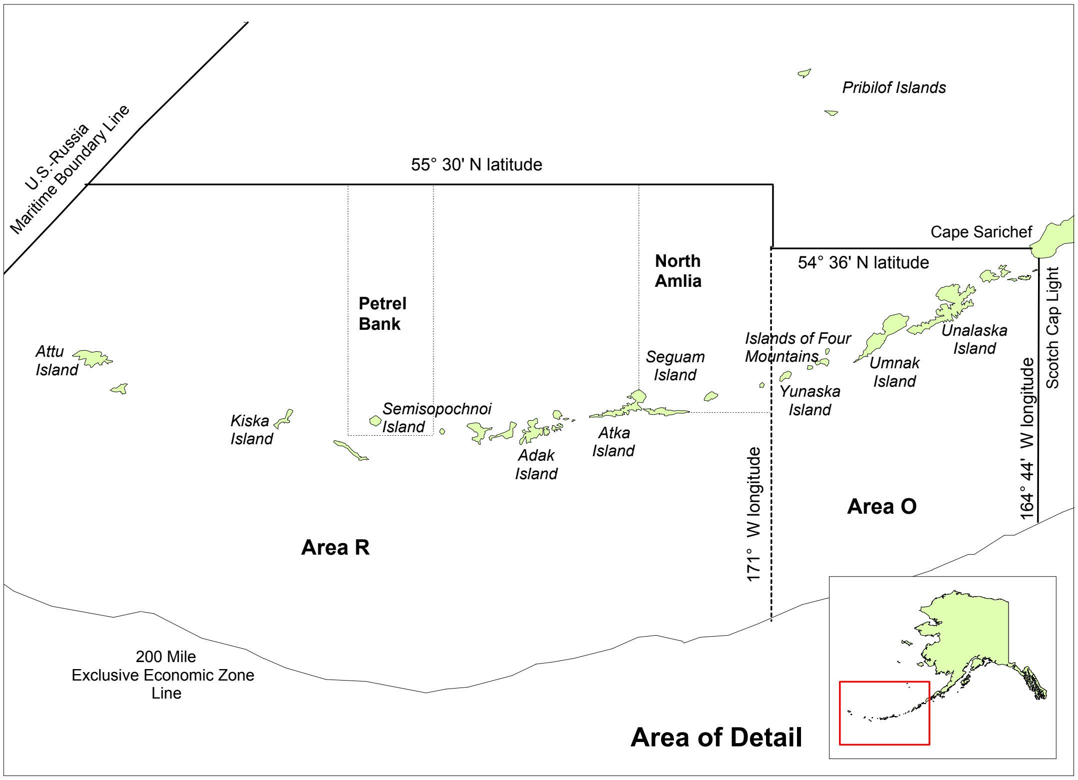


Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85 – 1995/96 seasons (from Failor-Rounds 2008).

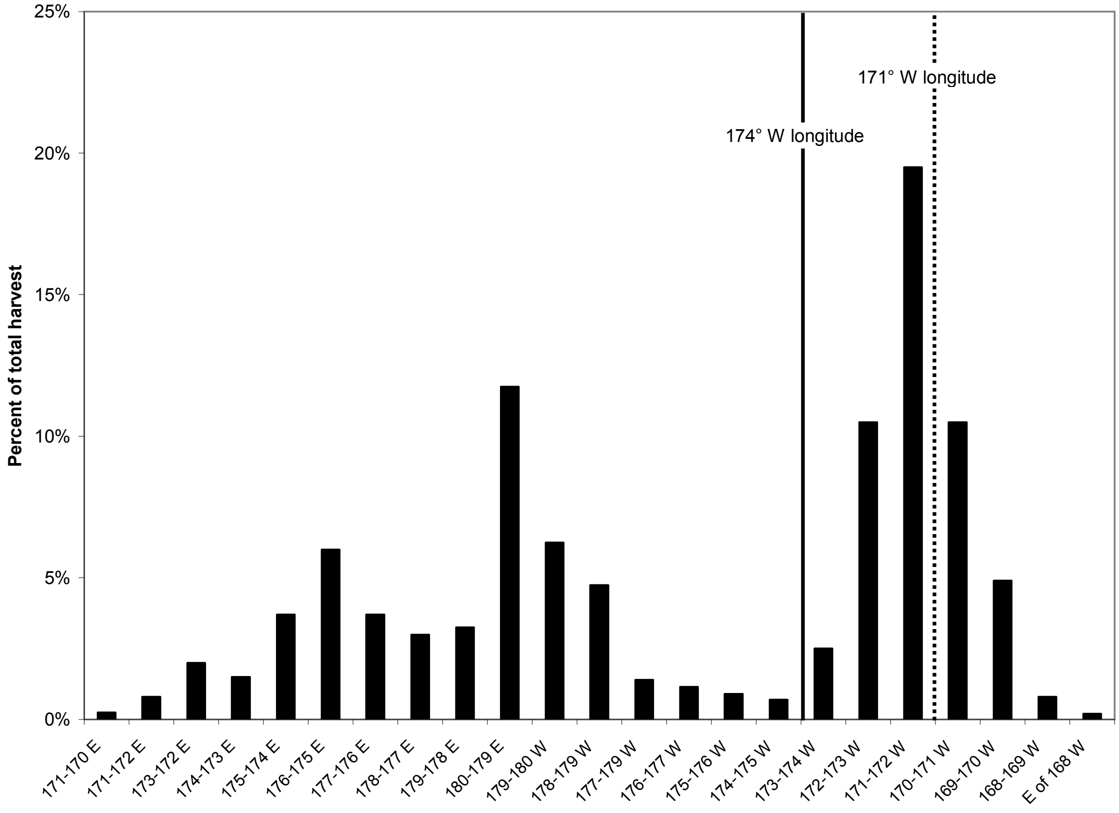


Figure 3. Percent of total 1982–1996 golden king crab harvest by one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude that was used until the end of the 1995/96 season to divide fishery management between the Dutch Harbor Area (east of 171° 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).

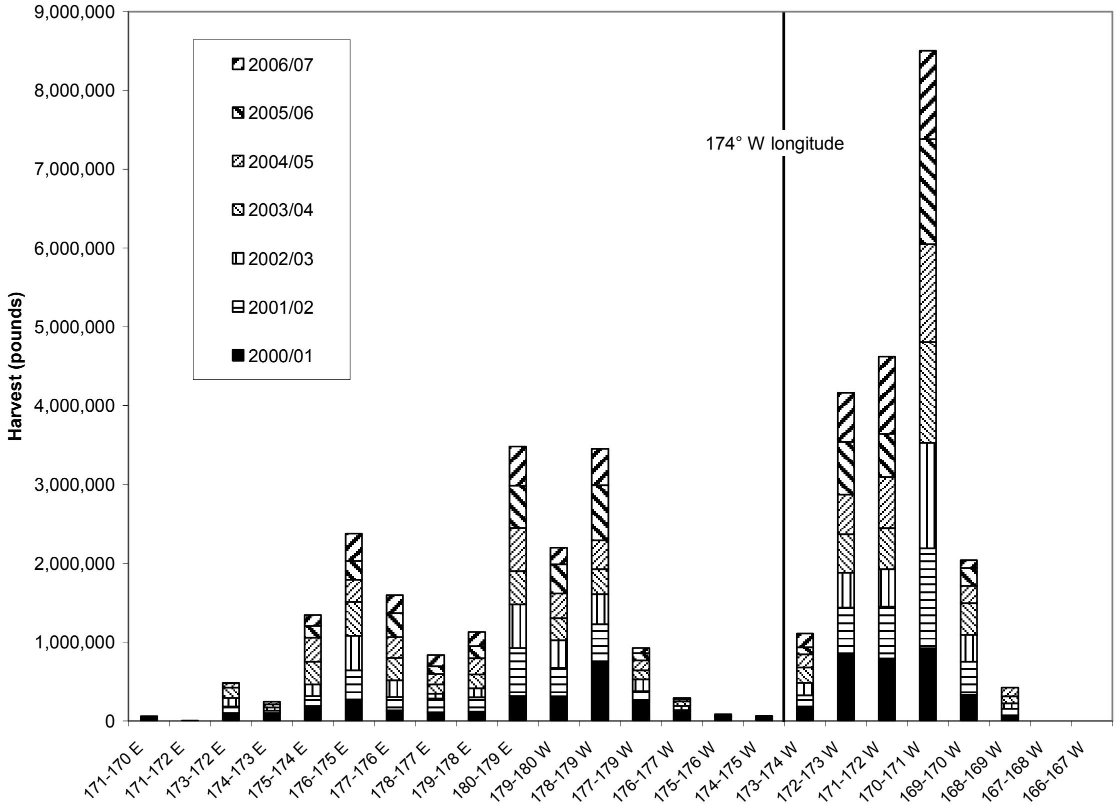


Figure 4. Harvest (pounds) of golden king crabs by one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2006/07 commercial fishery seasons, with solid line denoting the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crabs as separate stocks east and west of 174° W longitude (data from B. Failor-Rounds, Fishery Biologist, ADF&G, Dutch Harbor, 17 July 2007).

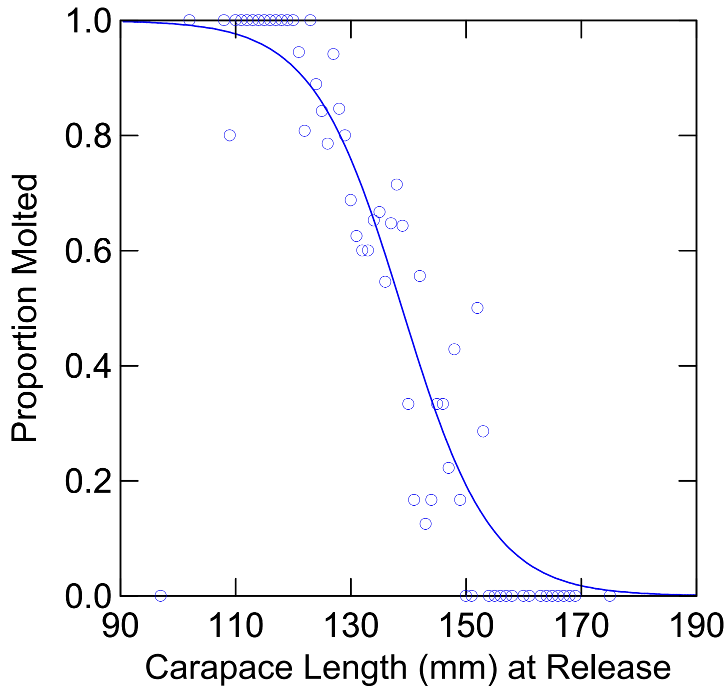


Figure 5. Proportion molting prior to recovery as related to carapace length at release of 487 new-shell male golden king crab tagged and released in the Yunaska Island area of the Aleutian Islands, Alaska, July-August 1997 and recovered 12-15 months later during the 1998/99 commercial golden king crab fishery, with curve showing a logistic regression fit to the data (from Watson et al. 2002).

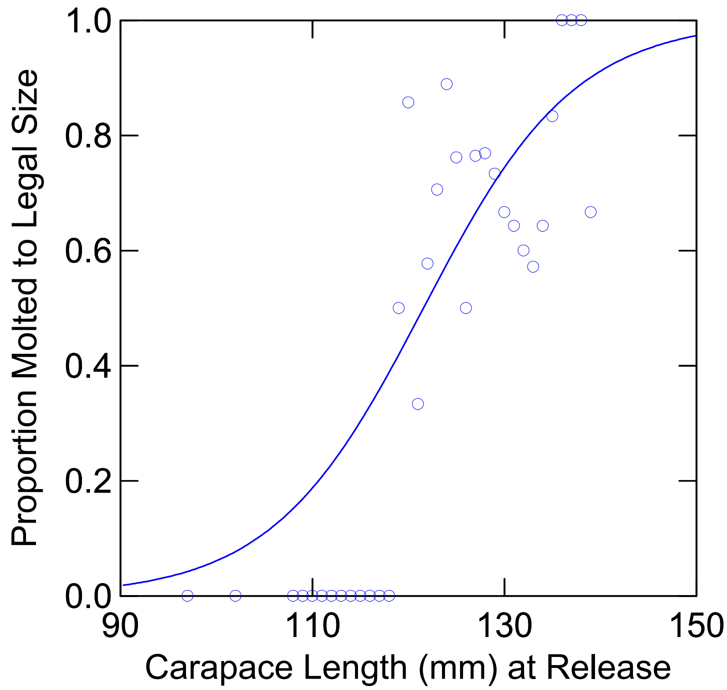


Figure 6. Proportion by carapace length at release of 281 male golden king crabs tagged and released as sublegal new-shell males in Yunaska Island area of Aleutian Islands, Alaska, July-August 1997, that molted to legal size prior to their recovery 12-15 months later during the commercial golden king crab fishery, with curve showing a logistic regression fit to the data (from Watson et al. 2002).

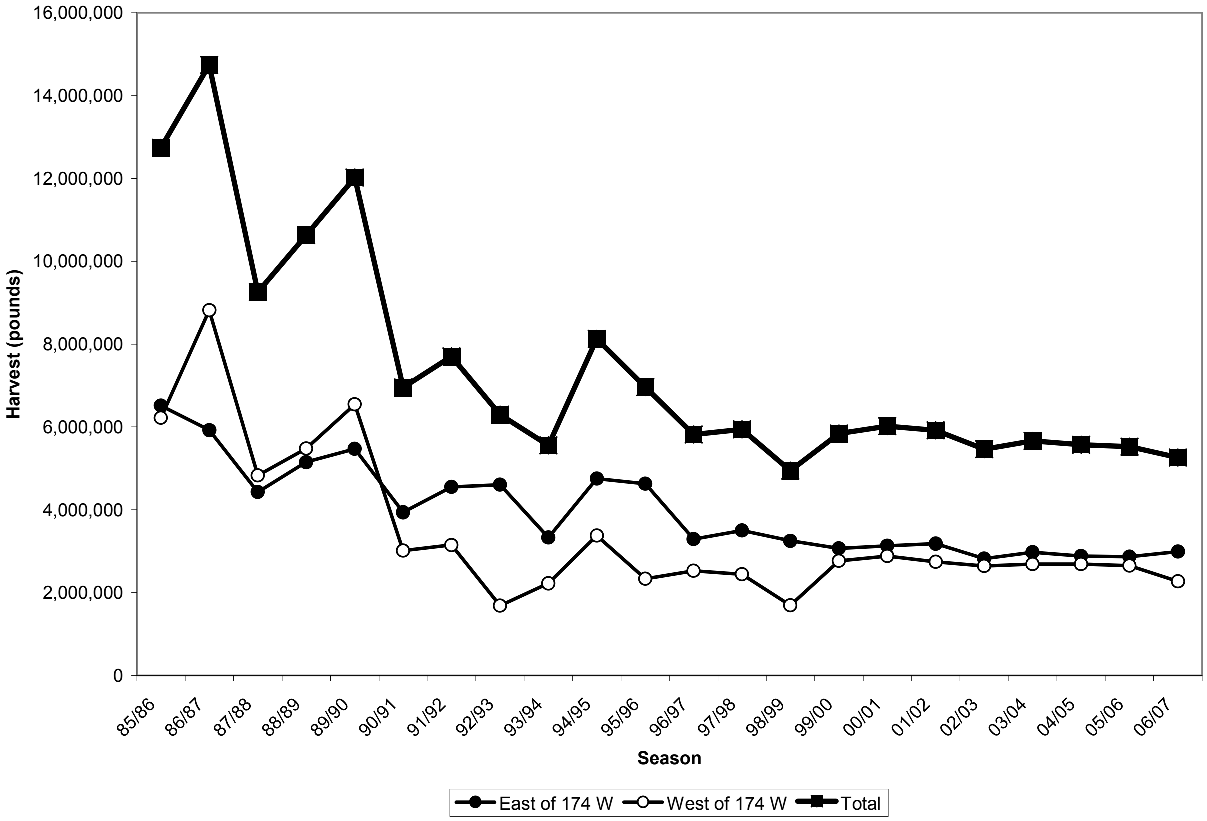


Figure 7. Retained catch (harvest in pounds) in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons for the entire Aleutian Islands Area and for each of the areas east and west of 174° W longitude.

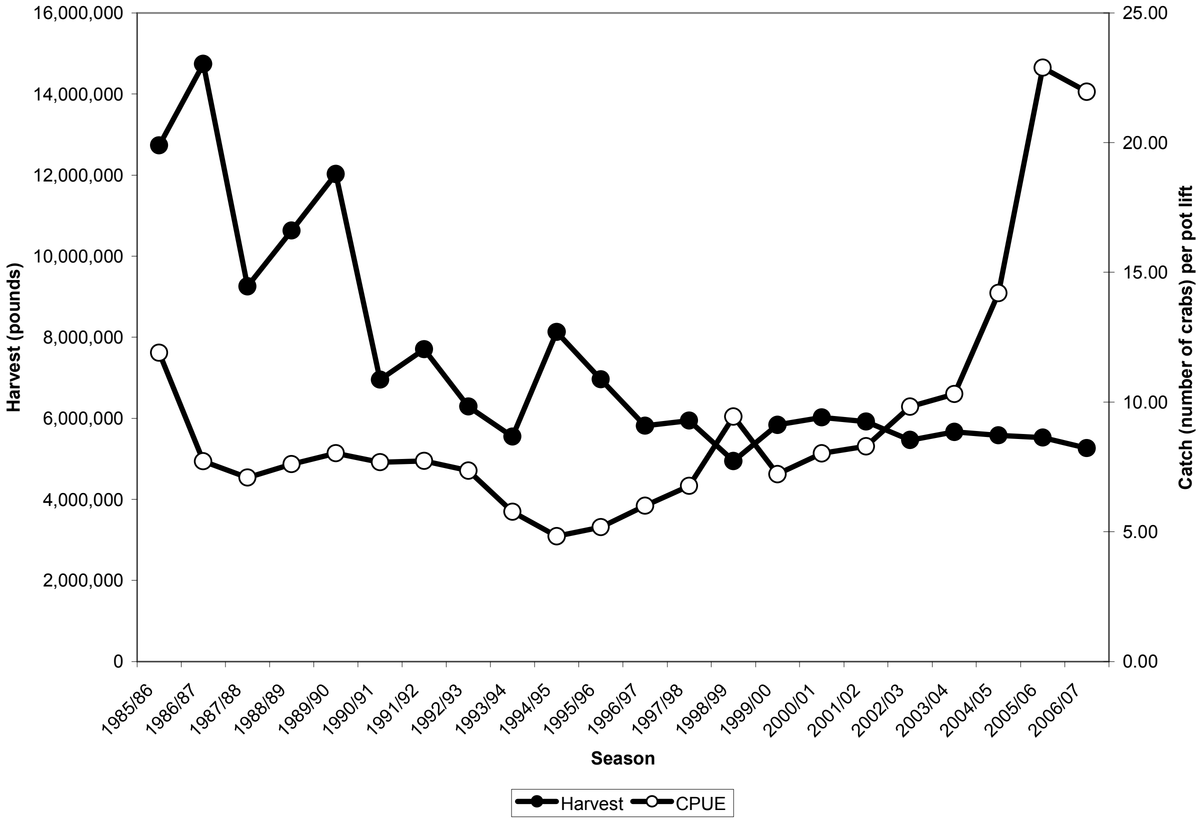


Figure 8. Retained catch (harvest in pounds) and catch (number of retained legal crabs) per pot lift (CPUE) in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons.

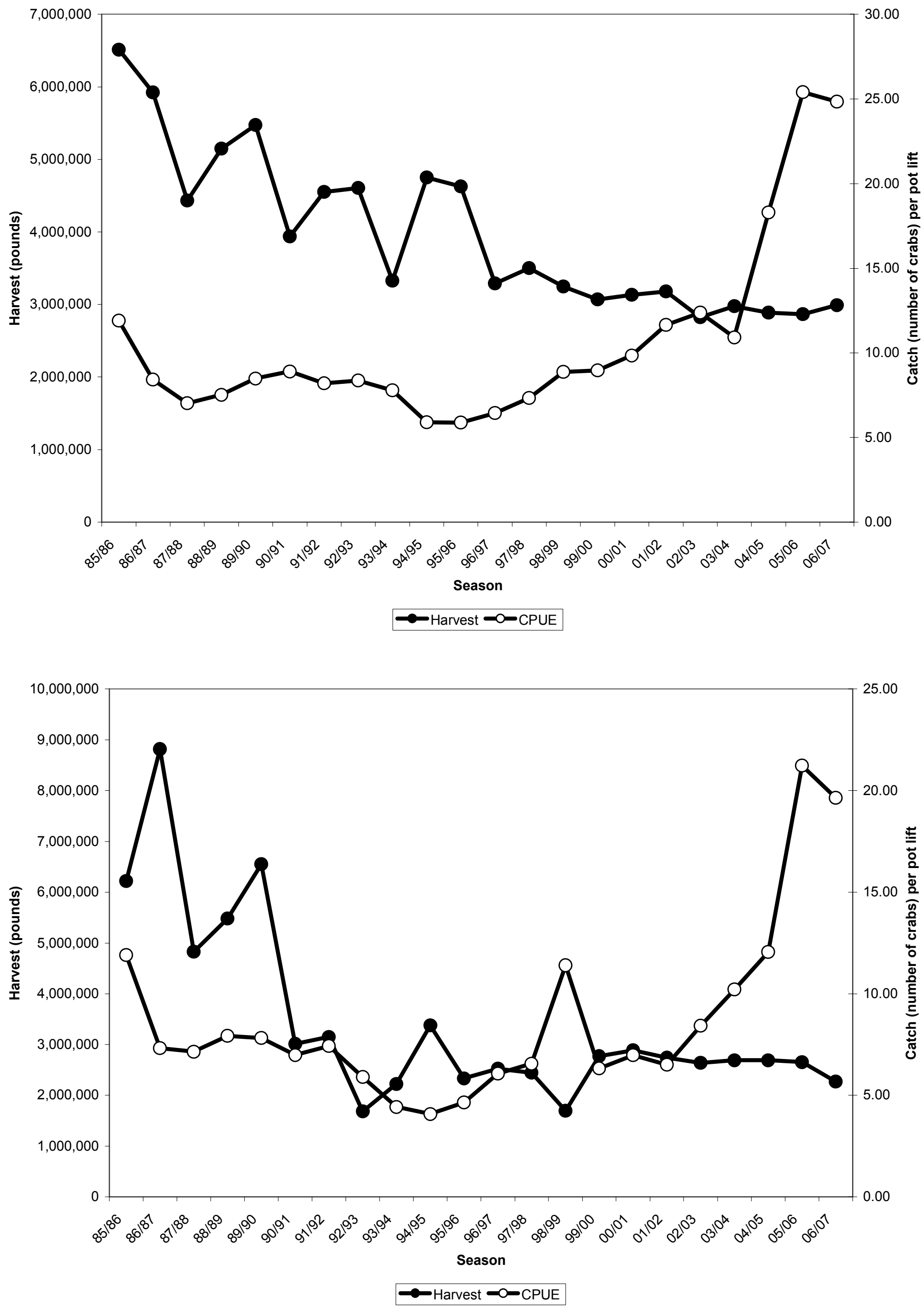


Figure 9. Retained catch (harvest in pounds) and catch (number of retained legal crabs) per pot lift (CPUE) in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons, for the area east of 174° W longitude (top panel) and the area west of 174° W longitude (bottom panel).

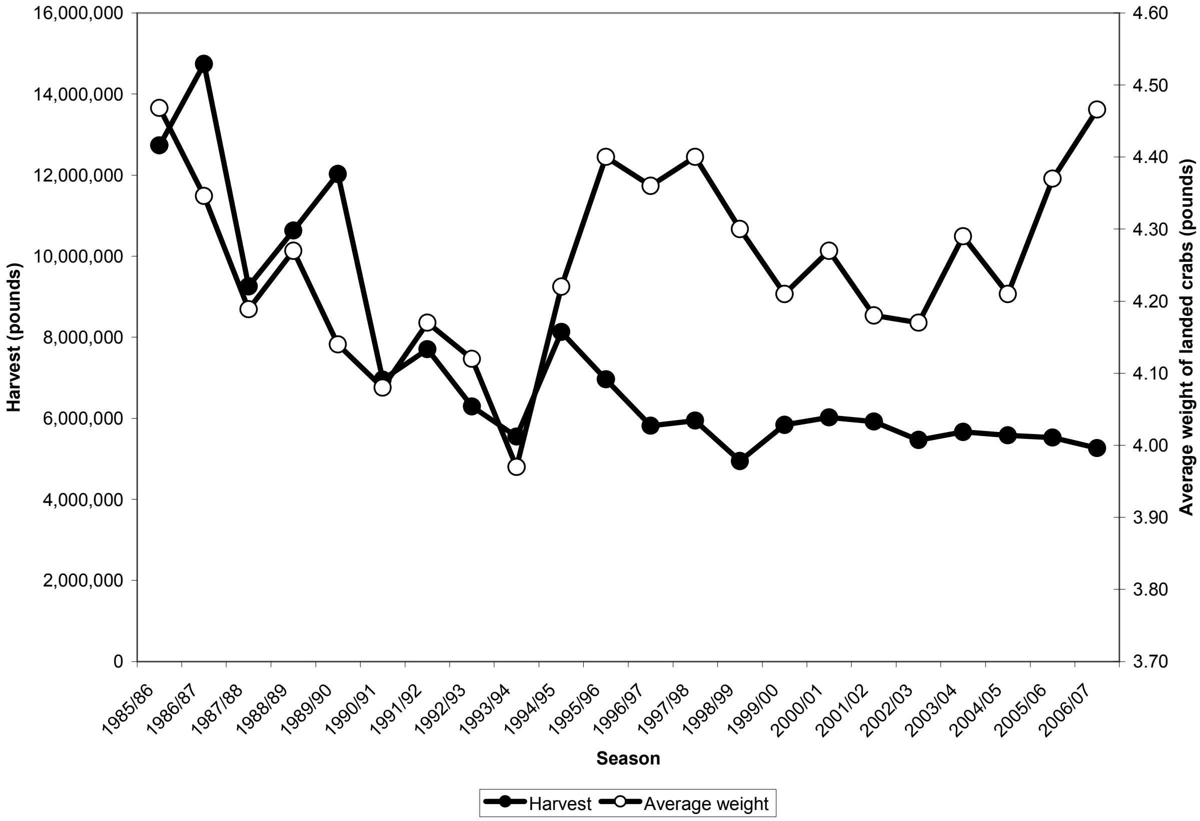


Figure 10. Retained catch (harvest in pounds) and average weight (pounds) of landed crabs in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons.

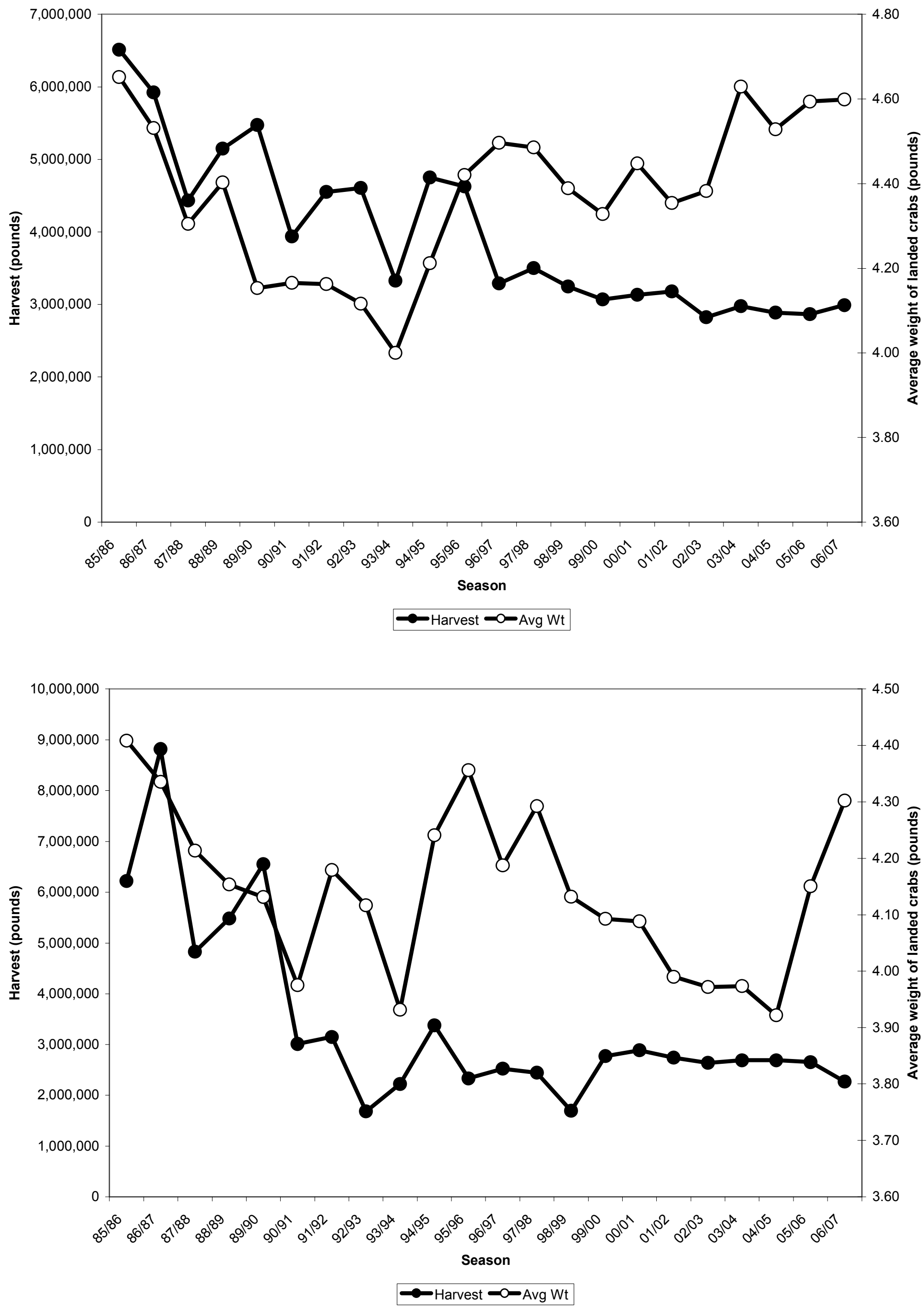


Figure 11. Retained catch (harvest in pounds) and average weight (pounds) of landed crabs in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons, for the area east of 174° W longitude (top panel) and the area west of 174° W longitude (bottom panel).

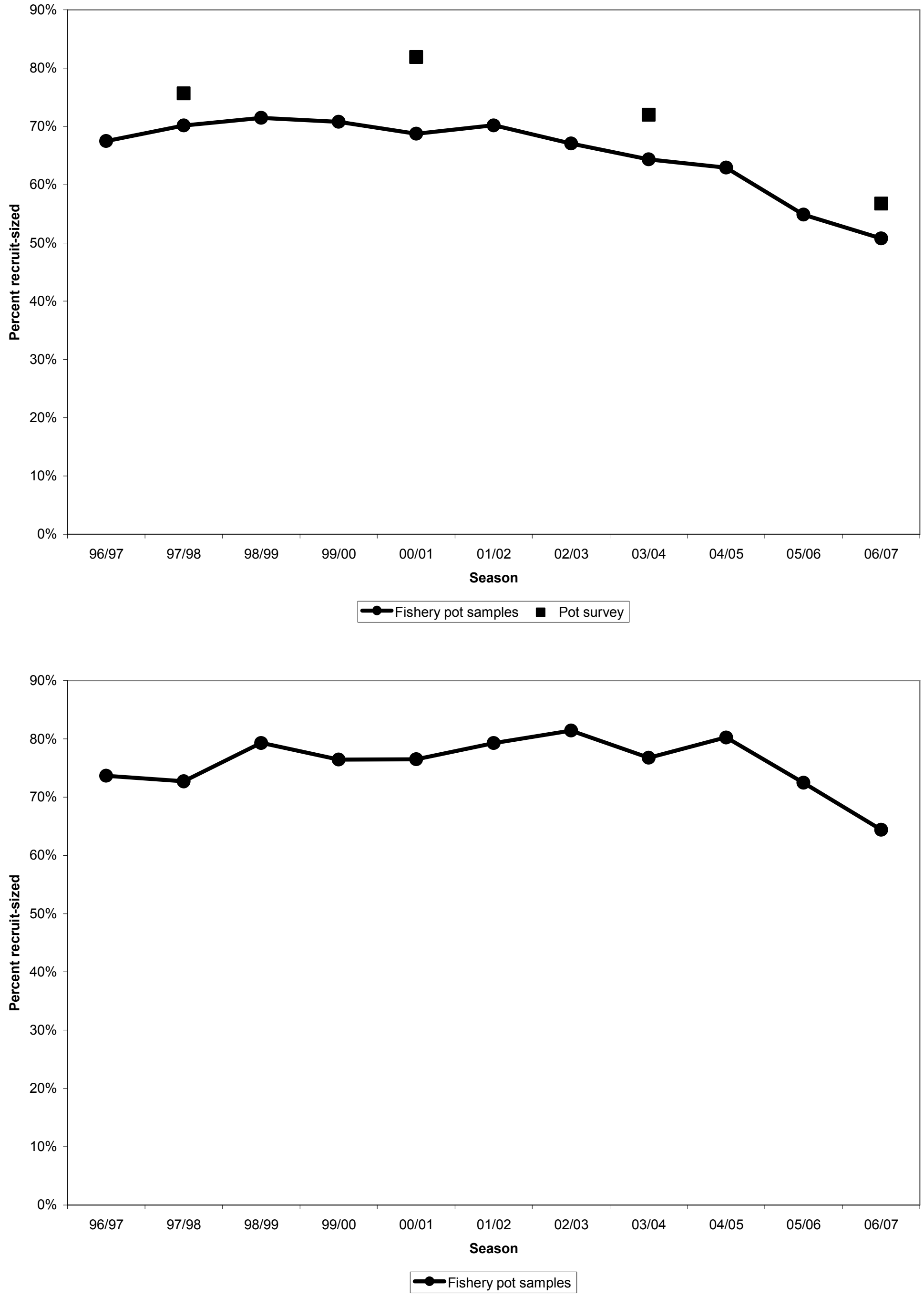
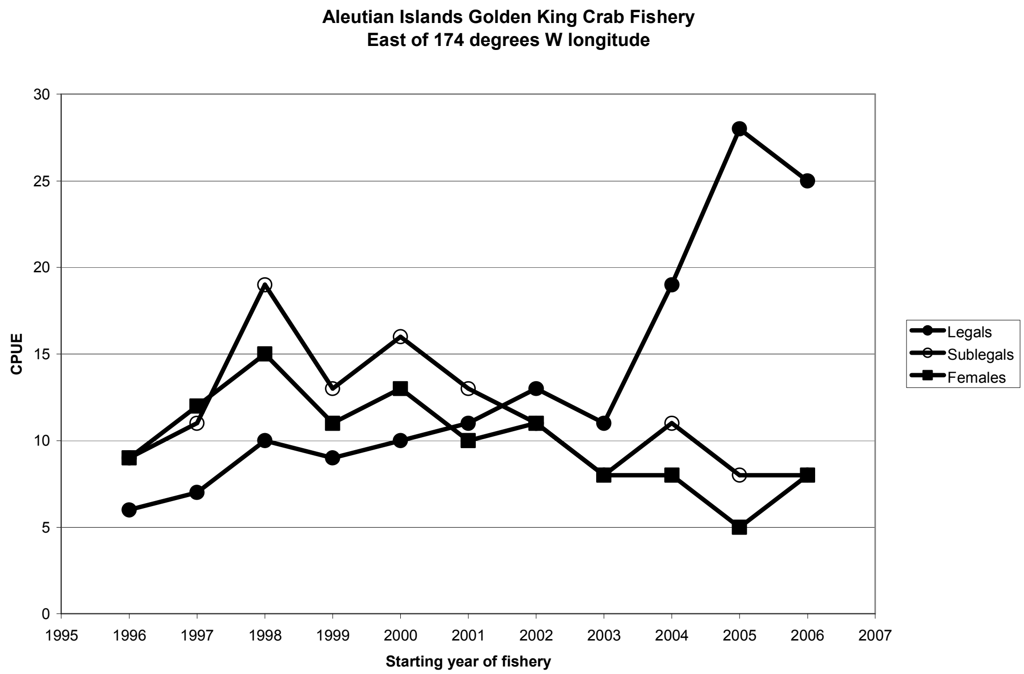


Figure 12. Percent of legal males that were recruit-sized (<151 mm CL) in pots randomly sampled by observers during the Aleutian Islands golden king crab fishery east of 174º W longitude, 1996/97–2006/07, and in pots fished during the triennial ADF&G Aleutian Islands golden king crab pot survey, 1997–2006 (top panel) and in pots randomly sampled by observers during the Aleutian Islands golden king crab fishery west of 174º W longitude, 1996/97–2006/07 (bottom panel).



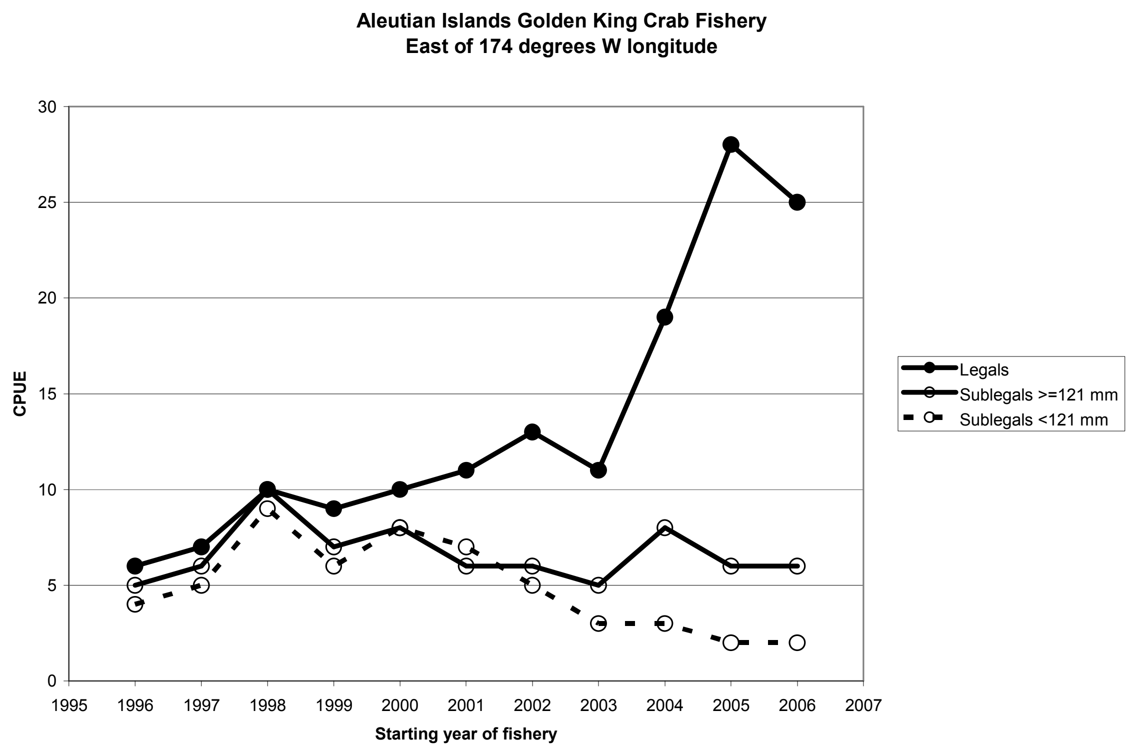
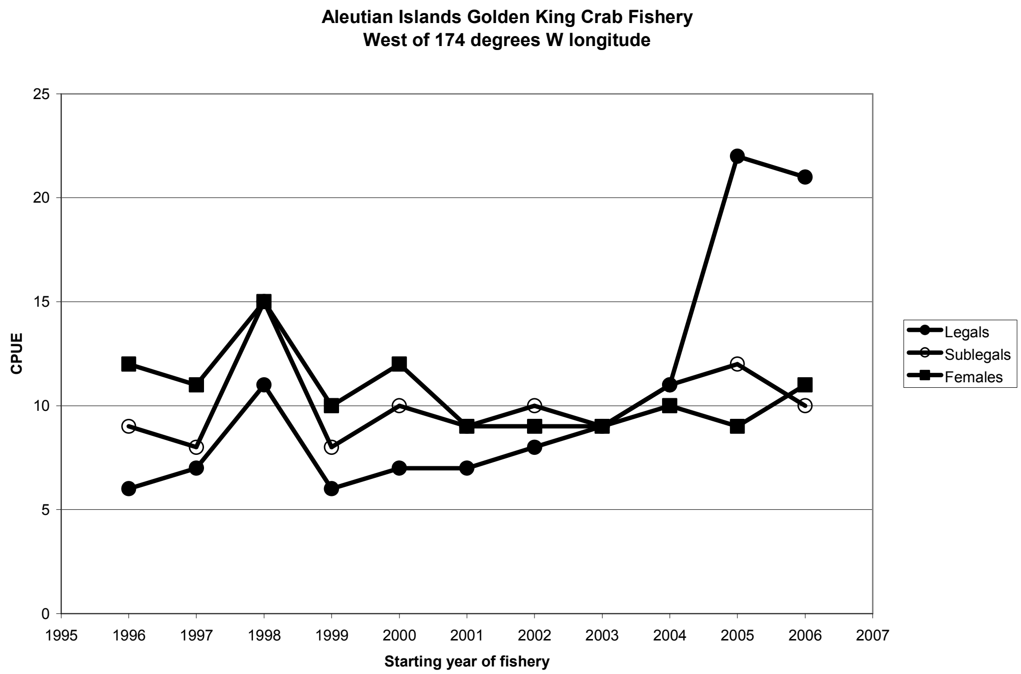


Figure 13. Catch per unit effort of legal males, sublegal males, and females (top panel) and of legal males, sublegal males ≥121 mm CL, and sublegal males <121 mm CL (bottom panel) in the Aleutian Islands golden king crab fishery east of 174º W longitude, 1996/97–2006/07 seasons, as estimated from contents of pots randomly sampled by observers.



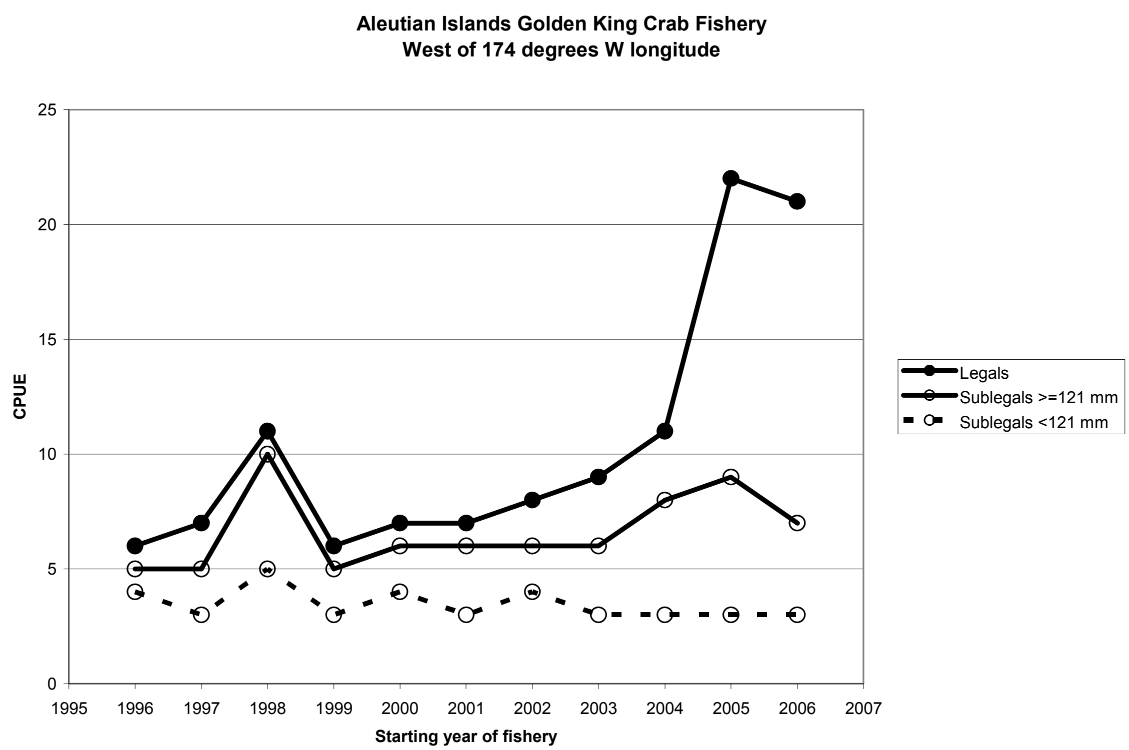


Figure 14. Catch per unit effort of legal males, sublegal males and females (top panel) and of legal males, sublegal males ≥121 mm CL, and sublegal males <121 mm CL (bottom panel) in the Aleutian Islands golden king crab fishery west of 174º W longitude, 1996/97–2006/07 seasons, as estimated from contents of pots randomly sampled by observers.

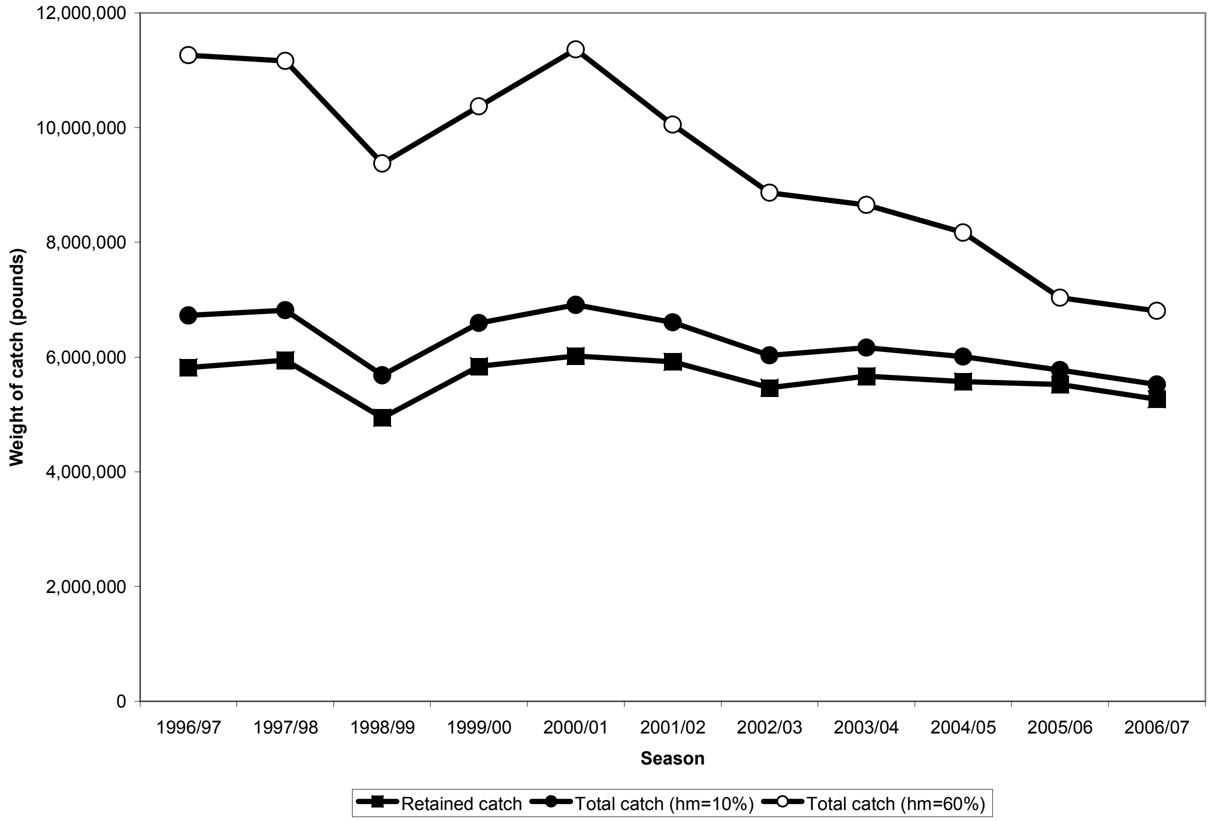


Figure 15. Annual retained catch (pounds) for the 1996/97–2006/07 Aleutian Islands golden king crab fishery compared to total catch (retained catch plus handling mortality of discarded bycatch, pounds) estimated by assuming handling mortality (*hm*) rates of *hm*=10% and *hm*=60%.

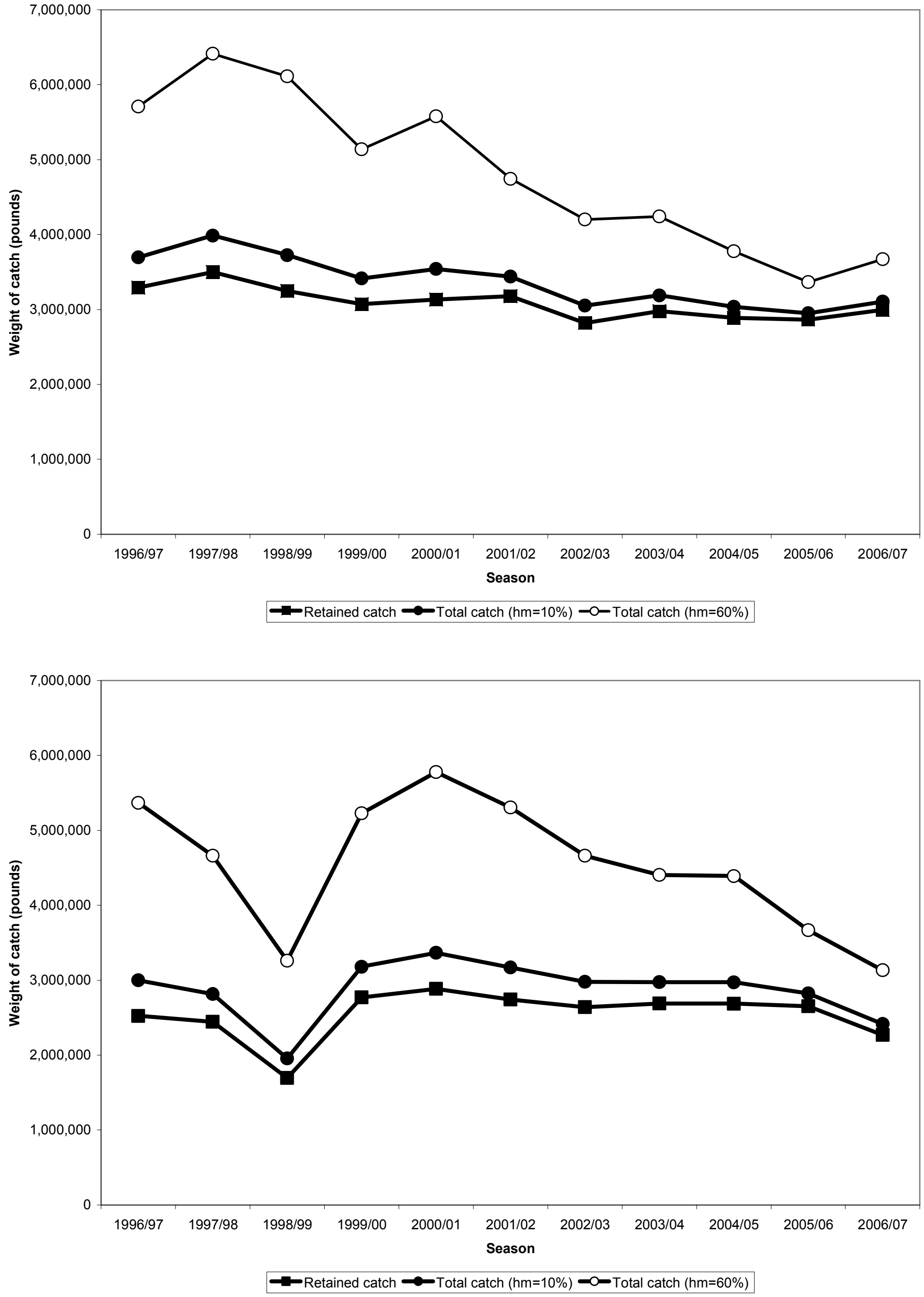


Figure 16. Annual retained catch (pounds) for the 1996/97–2006/07 Aleutian Islands golden king crab fishery in the area east of 174° W longitude (top panel) and in the area west of 174° W longitude (bottom panel) compared to total catch (retained catch plus handling mortality of discarded bycatch, pounds) estimated by assuming handling mortality (*hm*) rates of *hm*=10% and *hm*=60%.

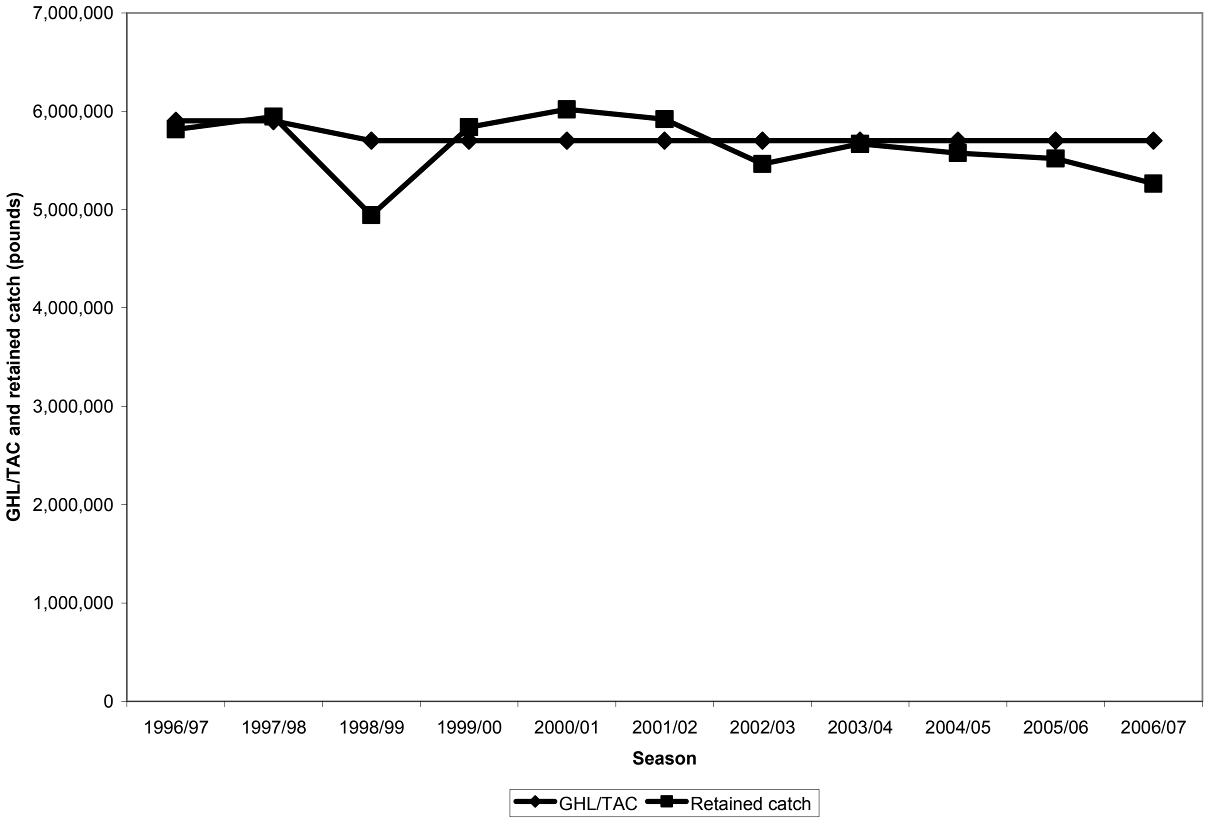
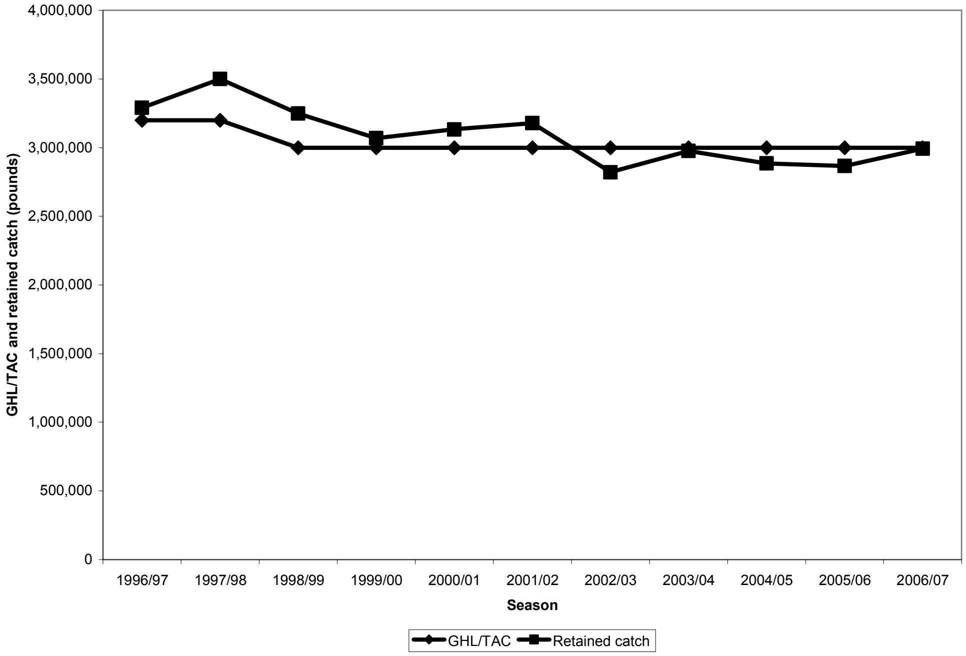


Figure 17. Pre-season GHL (in pounds for the 1996/97–2004/05 seasons) and TAC (in pounds for the 2005/06–2006/07 seasons) compared to the retained catch (pounds) during the 1996/97–2006/07 Aleutian Islands golden king crab fishery.



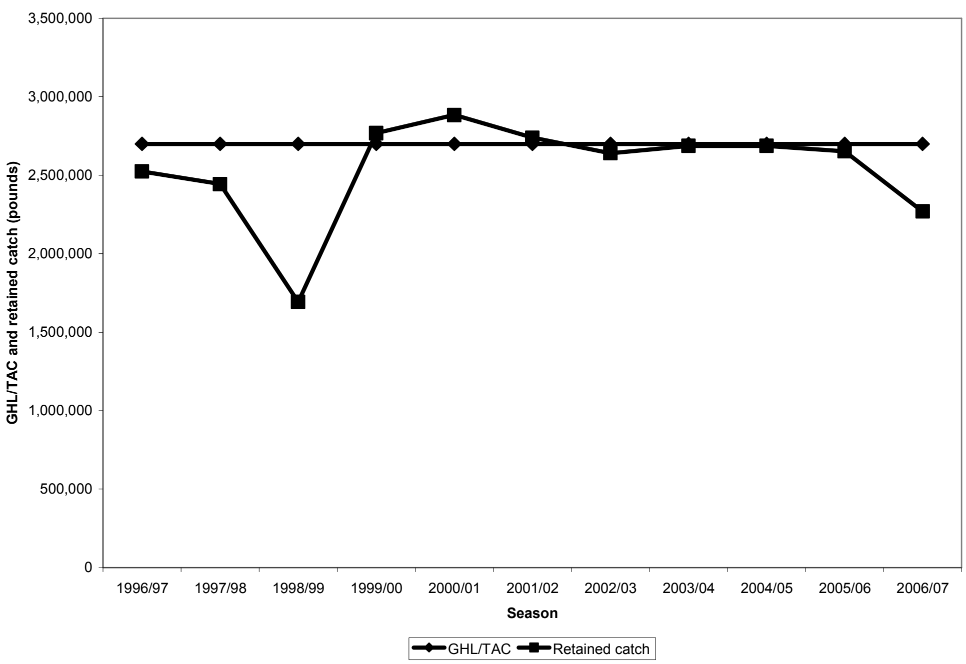


Figure 18. Pre-season GHL (in pounds for the 1996/97–2004/05 seasons) and TAC (in pounds for the 2005/06–2006/07 seasons) compared to the retained catch (pounds) during the 1996/97–2006/07 Aleutian Islands golden king crab fishery in the area east of 174° W longitude (top panel) and in the area west of 174° W longitude (bottom panel).

DRAFT

Aleutian Islands golden king crab (*Lithodes aequispinus*) stock assessment

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Executive Summary

This document describes an assessment of the Aleutian Islands golden king crab (*Lithodes aequispinus*) stocks in the east and the west of 174°W longitude based on an integrated model.

The Aleutian Islands golden king crab stocks contribute to a commercially important male-only fishery. The 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.

Despite its economic importance, the stock has not been surveyed annually, biological data are limited, and assessment models are lacking. An integrated analysis method was developed, which combined commercial catch, triennial pot survey catch-per-unit-effort (CPUE), observer CPUE, and tagging data. The data series used in the current assessment for the area east of 174°W longitude ranges from 1990 to 2007 for catch and catch length frequency, 1990 to 2007 for observer CPUE and length frequency, and 1997-2006 for triennial pot survey CPUE and tag release-recaptures. Data series considered for the area west of 174°W longitude ranges from 1989 to 2007 for catch, catch length frequency, and observer CPUE and length frequency. 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).

Assessment of the eastern stock indicated that male recruit abundance to the fishery peaked in 1996, declined to the lowest level in 2005, and slightly increased thereafter. The trends in legal and mature male biomasses were high during 1990-1998 and declined thereafter. The estimated retained harvest rate has systematically increased since 1996.

Assessment of the western stock showed that male recruit abundance to the fishery peaked in 2003 and slightly declined thereafter. The trends in legal and mature male biomasses were high during 1990-1998 and declined thereafter. The estimated retained harvest rate has systematically increased since 1998.

The integrated model procedure was used to determine the limit harvest level for both the eastern and western stocks under Tier 4, assuming an *M* value of 0.18 (a default value for all king crab stocks, NPFMC 2007). Two options for limit harvest levels are provided below:

East of 174°W longitude stock:

Mean Mature Biomass Calculation Period	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)
1990-2007	1996.0	111.9	2107.9	4.65
1996-2007	2434.5	136.5	2571.0	5.67

West of 174°W longitude stock:

Mean Mature Biomass Calculation Period	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)
1989-2007	1733.7	113.0	1846.7	4.07
1996-2007	2347.8	153.0	2500.8	5.51

Because the 2008/09 fishery is in progress, the selected limit harvest level from the above two options can be provisionally considered for the 2009/10 fishing season with the intention of updating the values in May 2009 once the 2008/09 fishery is completed.

Limited data are available on the groundfish bycatch of golden king crab. The 2007/2008 groundfish bycatch from the region was 122.2 t (0.269 million pounds).

Lack of reliable estimates of important life history parameters, such as *M*, annual biomass, and changes in fishing practices introduce greater uncertainty to biomass estimates and hence the yields. The poor quality of data also restricts investigation of different model scenarios. The model development is ongoing. Following are some research recommendations:

(a) Continue tagging to estimate mortality, growth, movement, and determination of proportion of biomass available for the commercial fishery.
(b) Continue the triennial pot survey to increase the fishery independent data series.
(c) Increase the observer coverage frequency to get estimates of CPUE and biological characteristics based on larger samples.
(d) Investigate appropriate methods to standardize CPUE considering space and time of the fishery.
(e) Investigate the handling mortality.
(f) Investigate the selectivity pattern in the fishery.
Some of the above investigation may be under taken in collaboration with the fishing industry.

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 occupy. 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, triennial pot survey CPUE (restricted to east of 174°W longitude stock), observer CPUE, and tagging data (restricted to east of 174°W longitude stock). The 1990-2007 data series from the area east of 174°W longitude and the 1989-2007 data series from the area west of 174°W longitude were used in the analysis. The model estimates of historical stock and recruit male abundances, harvest rate, 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. 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 male CPUE by length, commercial retained and discarded catch by length, triennial pot survey CPUE by length (restricted to the ES), tagged male release-recaptures associated with the four surveys (1997, 2000, 2003, and 2006), and the mean annual growth increment per molt (Watson et al. 2002) are the primary input data and parameter values for the integrated model. The annual CPUE, retained, and discard catch are listed in Table1 for the ES and in Table 6 for the WS; and the tag release-recapture data are provided in Table 2.

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-

2007 for the ES and for the period 1989-2007 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 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 season. The annual length-specific CPUEs were summed by length to obtain the total CPUE to use in the maximum likelihood function. The annual length specific discard CPUE 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.

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 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.

Four mark-recapture experiments conducted during the surveys in the ES were considered in the analysis to determine a constant natural mortality, *M*, value. Only male release-recapture data were considered (Table 2). The total recovery rate ranged from 11.8% to 22% except for recoveries from the 2006 release, which was 6.4% and for which additional recoveries are expected in the next several years.

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 3 for east the ES and Table 7 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 multinomial length composition, lognormal CPUE, multinomial tag-recaptures (for the ES), lognormal catch biomass, log normal recruit deviation, and a normal natural mortality 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 optimizing function:

a and b: for the molt probability model;

ν, c_1 and d_1: for the total and pot survey selectivity model;

c_2 and d_2: for the retention selectivity model for the period 1990-1998;

c_3 and d_3: for the retention selectivity model for the period 1999-2004;

c_4 and d_4: for the retention selectivity model for the period 2005 onward;

α_r and β_r: for the recruitment distribution model;

R_{90} to R_{08},: total number of male recruits for each year, except the first year;

q_1: pot survey catchability;

q_2: pot fishery catchability for the period 1990-1998;

q_3: pot fishery catchability for the period 1999-2004;

q_4: pot fishery catchability for the period 2005 onward;

F_{89} to F_{07}: full selection fishing mortality for 1989 to 2007;

$F*_{97}$, $F*_{2000}$, $F*_{2003}$, $F*_{2006}$: tagged crab release year additional fishing mortality (to offset non mixing effect);

β: shape parameter of the gamma growth function;

M: natural mortality;

ϕ : tagged population initial survival and a constant reporting rate product;

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 1998, between 1999 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 were the major criteria for model evaluation.

The weights attached to negative log likelihood components for the base optimization were:

- For ES: retained CPUE (λ_r = 20), discard CPUE (λ_d =4), pot survey CPUE (λ_s =1), catch biomass (λ_B =1), recruit deviation (λ_R =3), and natural mortality penalty (λ_M =8).
- For WS: retained CPUE (λ_r = 6), discard CPUE (λ_d =1), catch biomass (λ_B =1), recruit deviation (λ_R =4), and natural mortality penalty (λ_M =8).

The weights were chosen arbitrarily to obtain better fits to observed data. However, values of these weights were reduced by 50% and increased by 50% for sensitivity analysis.

Time varying effective sample sizes (K_t) were used for multinomial 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 10).

Results

Model evaluation

ES:

The time series of predicted versus observed retained, discard, and pot survey CPUEs showed reasonably good fits for the ES (Figure 3a-c). The predicted versus observed tag recaptures also depicted a reasonable fit (Figure 4a). Estimated full selection fishing mortality (*F*) based on only tagging and natural mortality penalty negative log likelihoods, the complete negative log likelihood, and the complete negative log likelihood without the tagging component, showed reasonable agreement for the years during which tagged populations were at large (Figure 4b). The time series of predicted vs. observed retained catch relative length frequency (Figure 5) and discard catch relative length frequency (Figure 6) depicted reasonably good fits for the ES. The profile likelihood of model estimated constant *M* indicated a peak near the 0.144 value (Figure 7).

Negative log likelihood components

M penalty	2.52988
Retained length composition	283.862
Discard length composition	404.172
Retained CPUE	75.745
Discard CPUE	27.9289
Pot survey CPUE	0.128852
Tagging	4586.25
Retained catch biomass	88.3763
Recruitment deviation	2.21801
Total	5471.211

WS:

The time series of predicted versus observed retained and discard CPUEs showed reasonably good fits for the WS (Figure 12a-b). The time series of predicted vs. observed retained catch relative length frequency (Figure 13) and discard catch relative length frequency (Figure 14) depicted reasonably good fits for the WS. The profile likelihood of model estimated constant *M* indicated a peak near the 0.14 value (Figure 15).

Negative log likelihood components

M penalty	2.30274
Retained length composition	249.54
Discard length composition	159.123
Retained CPUE	51.8478
Discard CPUE	7.1678
Retained catch biomass	94.4822
Recruitment deviation	0.16573
Total	564.62927

Parameters estimated conditionally

ES:

Table 4 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 83.1 mm CL (Figure 8a). The fishery retention selectivity curves for the three periods (1990-1998, 1999-2004, and 2005-) systematically increased and 50% selectivity were achieved at 136.2, 141.7, and 96.6 mm CL, respectively (Figure 8b). The catchability in the survey pot gear and the fishery pot gear for the three periods ranged from $4.26*10^{-7}$ to $2.26*10^{-6}$. Fishery catchability has dramatically increased during the latter two periods, perhaps due to increases 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 5. The estimated male recruit abundance to the model peaked in 1996, declined to the lowest level in 2005, and slightly increased thereafter. The recruits entered the model population in the length range 101-110 mm CL (Figure 9a-b). The trends in legal and mature biomasses were high during 1990-1998 and systematically declined thereafter (Figure 10a-b). The estimated retained harvest rate has systematically increased since 1996 (Figure 11).

WS:

Table 8 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 79.5 mm CL (Figure 16a). The fishery retention selectivity curves for the three periods (1990-1998, 1999-2004, and 2005-) systematically increased and 50% selectivity were achieved at 135.5, 140.8, and 137.2 mm CL, respectively (Figure 16b). The catchability ranged from $3.15*10^{-7}$ to $2.08*10^{-6}$ for the fishery pot gear for different periods. Different fishery catchabilities were considered for the time period before 1998, between 1999 and 2004, and 2005 onwards. Fishery catchability has increased during the latter two periods, perhaps due to increases 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 9. The estimated male recruit abundance to the model did not show high variation, peaked in 2003, and declined thereafter (Figure 17a). The recruits entered the model population in the length range 121-171 mm CL (Figure 17b). The trends in legal and mature biomasses were high during 1990-1998 and systematically declined thereafter (Figure 18). The estimated retained harvest rate has systematically increased since 1998 (Figure 19).

Harvest alternatives

ES:

The limit harvest level for the ES under Tier 4, assuming an *M* value of 0.18 (a default value for all king crab stocks, NPFMC 2007), which is equivalent to a γ value of 1.25 with the model estimated *M*, 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. Two options for limit harvest level are provided below:

Mean Mature Biomass Calculation Period	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)
1990-2007	1996.0	111.9	2107.9	4.65
1996-2007	2434.5	136.5	2571.0	5.67

WS:

The limit harvest level for the WS under Tier 4, assuming an M value of 0.18, which is equivalent to a γ value of 1.23 with the model estimated M, were estimated. Two options for limit harvest level are provided below:

Mean Mature Biomass Calculation Period	Retained Limit Catch (t)	Discard Limit Catch (t)	Total Limit Catch (t)	Total Limit Catch (million pounds)
1989-2007	1733.7	113.0	1846.7	4.07
1996-2007	2347.8	153.0	2500.8	5.51

Because the 2008/09 fishery is in progress, the above limit total harvest levels can be provisionally considered for the 2009/10 fishing season with the intention of updating the values in May 2009 once the 2008/09 fishery is completed.

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.

Tag-recapture data in ES indicated the possibility of misclassification of shell condition by onboard observers (Doug Pengilly and Leslie Watson, personal communication, ADF&G, Kodiak). The effect of the possible misclassification of shell condition on the rest of the parameter estimates was minimized by considering the total CPUE (old- and new-shell CPUEs lumped together) from the pot survey and observer samples in the likelihood function.

We used the simple weighted average (weighted by effort) of nominal monthly CPUE (catch in observer samples / number of pot hauls in observer samples) to obtain the annual CPUE. The CPUE can be further standardized for area and time effect to reflect the true stock abundance variation (Starr, 2007).

We formulated the tag-recapture multinomial model incorporating an initial survival parameter to account for initial loss of tagged crabs and a constant under-reporting parameter due to less observer coverage in recent years. These two parameters cannot be separated unless independent experiments are conducted to estimate one of the two or both. Thus, our optimization estimated the product of the two parameters.

The natural mortality was estimated by the model fit, which appears to be slightly low (~ 0.145). 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.

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). 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	0.1442	0.1459
γ	1.25	1.23
Mature male biomass on 15 Feb 2008	23018 t	22848 t
a. Proxy MSY mature male biomass (1990-07 mean (ES),1989-07 mean (WS))	38018 t	42848 t
b. Proxy MSY mature male biomass (1996-07 mean)	32203 t	33384 t
Tier allocation	4(b)	4(b)

Proxy F_{OFL} (1990-07 / 1989-07option)	0.09	0.08
Proxy F_{OFL} (1996-07 option)	0.11	0.11
Limit total catch (1990-07/ 1989-07option)	4.65 mill.pounds	4.07 mill.pounds
Limit total catch (1996-2007 option)	5.67 mill. pounds	5.51 mill.pounds

Limited data are available on the groundfish bycatch of golden king crab. The 2007/2008 groundfish bycatch from the region was 122.2 t (0.269 million pounds) (Gretchen Harrington, NMFS, personal communication).

Acknowledgments

We thank Jim Ianelli and Jack Turnock of Alaska Fisheries Science Center, Seattle, and Mark Maunder of Inter-American Tropical Tuna Commission, La Jolla, for introducing various features of the AD Model Builder software, Andre Punt for review of the model structure, and Doug Woodby of the ADFG, Juneau for review of this and earlier version of the draft report. This study is funded by the FMP Extended Jurisdiction program from the National Oceanic and Atmospheric Administration (NOAA). The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA, any of its sub-agencies, or any of the reviewers.

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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	

Table 2. Tagged male golden king crab releases (sublegal and legal crabs ≥ 85 mm CL) and recaptures east of 174°W longitude.

Release Year	Number of Crabs Released	Percent Total Recovery	Number Recaptured 1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1997	7,660	22.0	834	495	243	88	17	2	1	0	1		
2000	7,779	14.9				727	227	128	52	19	4	2	
2003	6,174	11.8							318	210	100	82	19
2006	5,235	6.4										228	107

Table 3. 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	0.4973
2006/07	0.4973
2007/08	0.4973

Table 4. Estimates of parameters by the base model for the golden king crab data from the ES, 1990-2007.

Parameter	Estimate
a	0.0437
b	83.1442
ν	0.0135
c_1	0.3988
d_1	58.0439
c_2	0.3732
d_2	136.2326
c_3	0.0690
d_3	141.7292
c_4	0.0210
d_4	96.6480
α_r	2.8334
β_r	0.2496
R_{91} to $R_{08,}$ (million crabs)	6.32, 6.54, 6.94, 7.59, 8.66, 10.89, 9.92, 7.54, 6.93, 6.39, 6.08, 5.74, 5.52, 5.44, 5.34, 5.49, 5.62, 6.08
q_1	$4.29*10^{-7}$
q_2	$4.26*10^{-7}$
q_3	$9.84*10^{-7}$
q_4	$2.26*10^{-6}$
F_{90} to F_{07}	0.75, 0.68, 0.15, 0.15, 0.15, 0.75, 0.75, 0.48, 0.55, 0.75, 0.64, 0.26, 0.20, 0.15, 0.17, 0.15, 0.15, 0.15
F^*_{97}, F^*_{2000}, F^*_{2003}, F^*_{2006}	0.08, -0.15, 0.09, 0.05
β	0.4741
M	0.1442
ϕ	0.2568
N_{90} (million crabs)	16.2841
O_{90} (million crabs)	0.0065

Table 5. 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	48,117	49,062
1991	6.3236	49,449	50,539
1992	6.5389	50,297	51,599
1993	6.9415	50,552	52,092
1994	7.5857	50,184	51,993
1995	8.6627	49,292	51,312
1996	10.8879	47,953	50,162
1997	9.9167	46,264	48,625
1998	7.5359	44,324	46,794
1999	6.9326	33,233	32,639
2000	6.3861	31,456	31,340
2001	6.0795	29,723	29,987
2002	5.7374	28,059	28,618
2003	5.5214	26,481	27,265
2004	5.4383	25,000	25,948
2005	5.3417	26,338	26,270
2006	5.4857	24,587	24,794
2007	5.6226	23,018	23,428
2008	6.0783	NA	22,174

Table 6. 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

Table 7. 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, 1989-2007. Data are from ADF&G (2008).

Fishing Season	y_t
1989/90	
1990/01	0.7315
1991/02	0.7315
1992/03	0.7329
1993/04	0.7315
1994/05	0.7315
1995/06	0.7315
1996/07	0.7329
1997/08	0.6699
1998/09	0.6699
1999/00	0.6699
2000/01	0.6466
2001/02	0.5151
2002/03	0.4342
2003/04	0.4041
2004/05	0.3630
2005/06	0.3164
2006/07	0.4973
2007/08	0.4973

Table 8. Estimates of parameters by the base model for the golden king crab data from the WS, 1989-2007.

Parameter	Estimate
A	0.0475
B	79.5397
ν	0.0143
c_1	0.4173
d_1	58.0033
c_2	0.5000
d_2	135.5080
c_3	0.1006
d_3	140.7948
c_4	0.0695
d_4	137.1664
α_r	40.0979
β_r	1.2092
R_{90} to $R_{08,}$ (million crabs)	6.96, 6.98, 6.97, 7.05, 7.10, 7.23, 7.44, 7.64, 7.79, 7.62, 7.69, 7.81, 7.84, 7.95, 7.72, 7.43, 7.30, 7.16, 6.87
q_2	$3.15*10^{-7}$
q_3	$6.89*10^{-7}$
q_4	$2.08*10^{-6}$
F_{89} to F_{07}	0.72, 0.44, 0.15, 0.15, 0.15, 0.15, 0.66, 0.37, 0.15, 0.15, 0.75, 0.64, 0.62, 0.15, 0.15, 0.15, 0.15, 0.15, 0.15
F^*_{97}, F^*_{2000}, F^*_{2003}, F^*_{2006}	0.07, -0.15, 0.09, 0.05
β	0.9744
M	0.1459
N_{89} (million crabs)	18.3239
O_{89} (million crabs)	0.0070

Table 9. 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	64,198	67,033
1990	6.9611	62,797	65,485
1991	6.9837	61,266	63,904
1992	6.9673	59,518	62,144
1993	7.0454	57,520	60,177
1994	7.1027	55,297	57,994
1995	7.2262	52,913	55,634
1996	7.4379	50,417	53,159
1997	7.6444	47,868	50,616
1998	7.7854	45,324	48,057
1999	7.6233	35,378	35,457
2000	7.6934	33,368	33,765
2001	7.8125	31,481	32,133
2002	7.8446	29,722	30,578
2003	7.9473	28,094	29,108
2004	7.7174	26,591	27,726
2005	7.4281	25,443	26,100
2006	7.2957	24,079	24,879
2007	7.1592	22,848	23,760
2008	6.8698	NA	22,735

Table 10. Effective sample sizes, K_t , for fitting relative retained and discarded catch compositions of golden king crab east and west of 174°W longitude. NC = not considered.

Year	East of 174°W longitude		West of 174°W longitude	
	Retained Catch	Discard Catch	Retained Catch	Discard Catch
1989	NC	NC	400	74
1990	300	14	109	16
1991	400	16	133	35
1992	328	24	72	21
1993	28	152*	30	12
1994	49	152*	47	56
1995	105	150	6	400
1996	87	400	78	175
1997	119	357	83	118
1998	128	391	57	77
1999	98	339	68	138
2000	71	132	48	159
2001	73	162	55	139
2002	70	110	49	91
2003	33	101	37	83
2004	51	86	36	75
2005	33	54	34	51
2006	26	41	35	57
2007	46	54	82	57

* = Mean for the entire time series of discarded catch K_t values was substituted for missing observer samples for discarded crab.

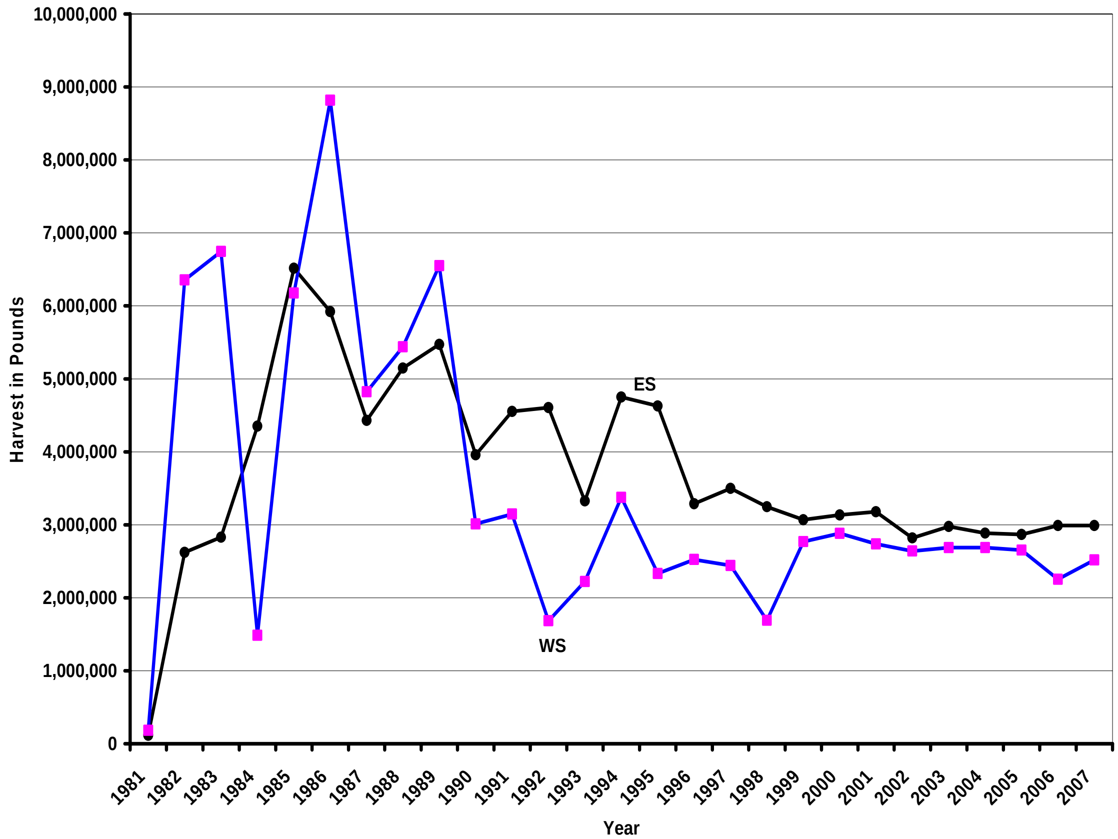

Figure 1. Historical commercial harvest (in pounds) of golden king crab east of 174°W longitude (ES, Eastern Segment) and west of 174°W longitude (WS, Western Segment), 1981-2007.

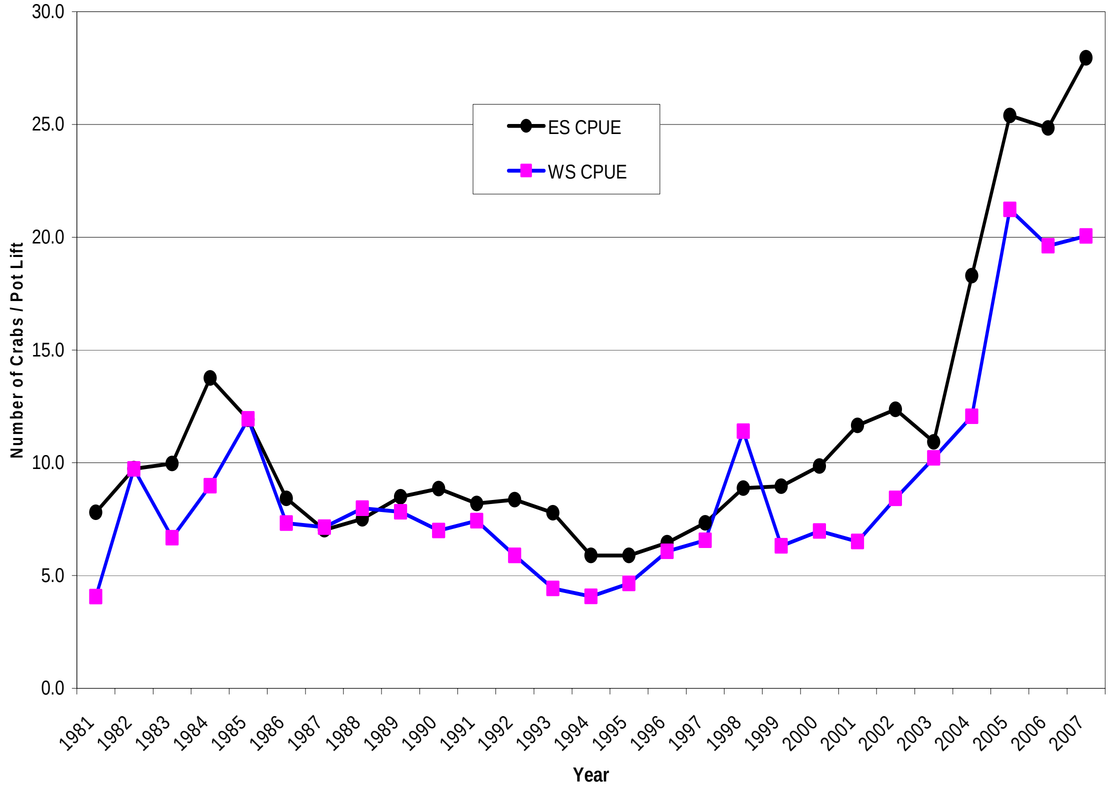

Figure 2. Historical catch-per-unit-effort CPUE (number of crabs per pot lift) in the commercial fishery for golden king crab in the ES and the WS, 1981-2007.

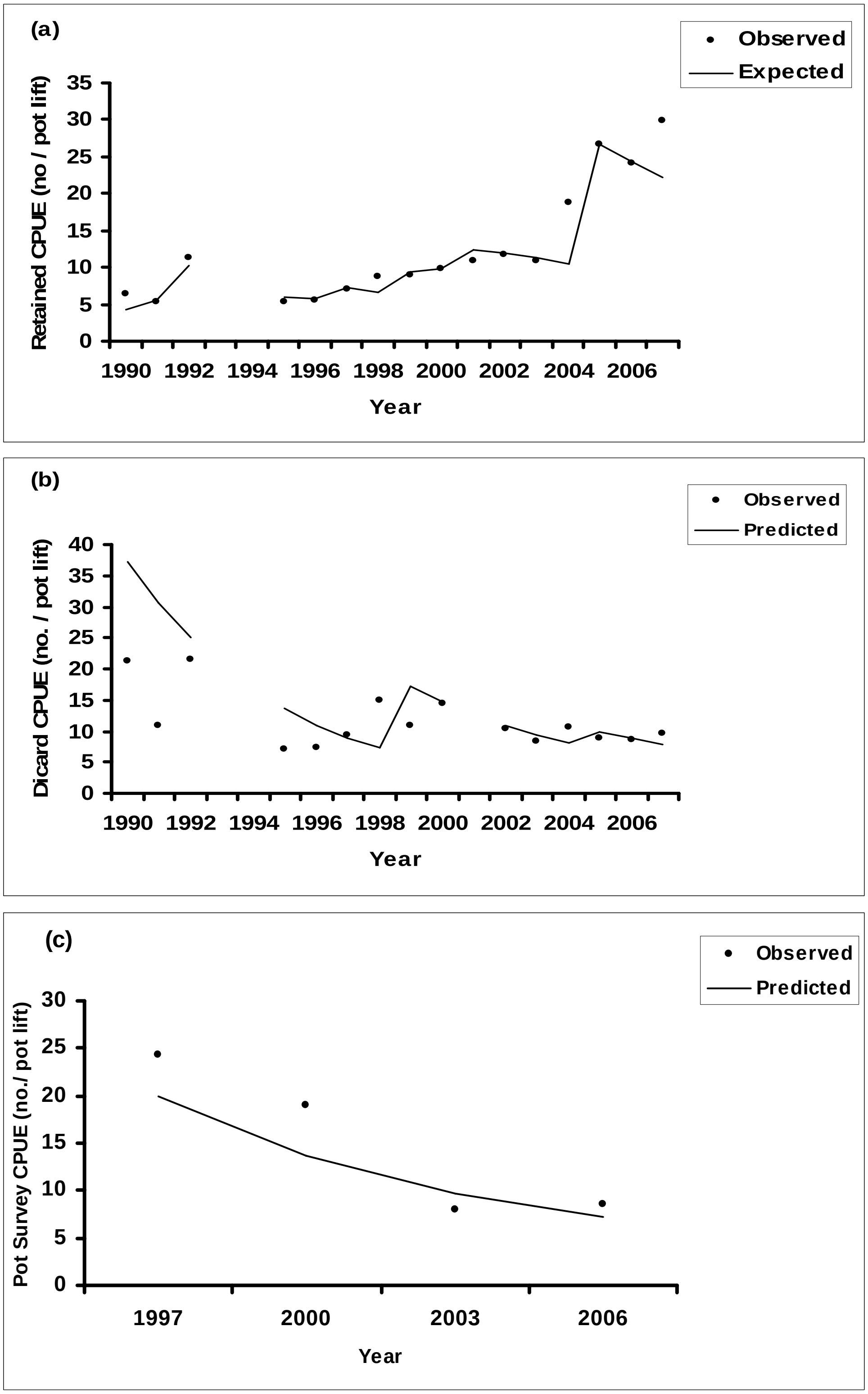

Figure 3. Predicted (line) versus observed (filled circle) (a) retained catch-per-unit-effort (CPUE), (b) discard CPUE, and (c) pot survey CPUE for golden king crab in the ES.

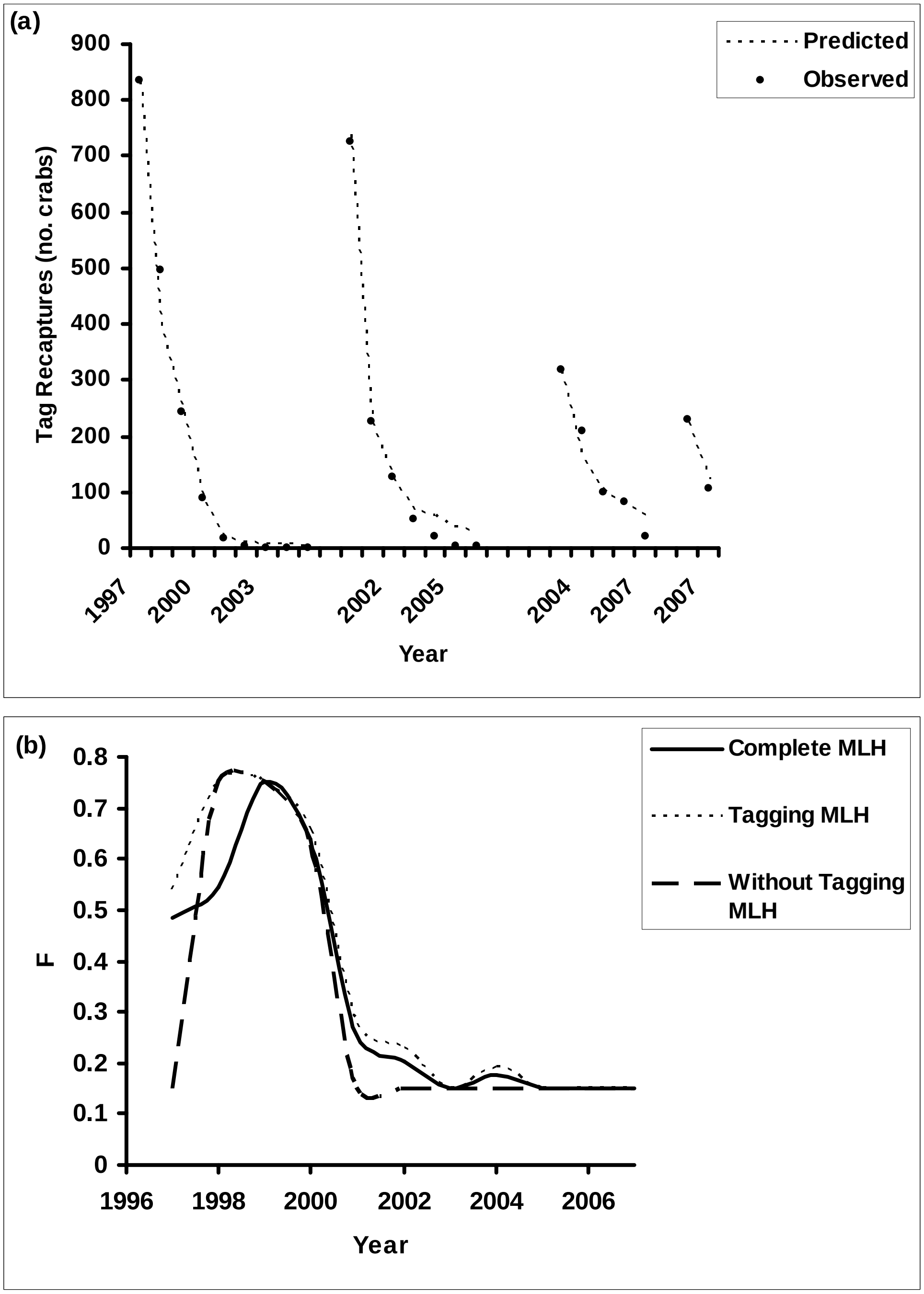

Figure 4. (a) Predicted (line) versus observed (filled circle) annual recaptures of tagged male golden king crab in the ES for the four triennial pot survey releases, 1997-2006. (b) Estimated full selection fishing mortality considering the complete negative log likelihood (line), only natural mortality and tag negative log likelihoods (dotted line), and the full negative log likelihood without tag negative log likelihood (broken line) for the same period.

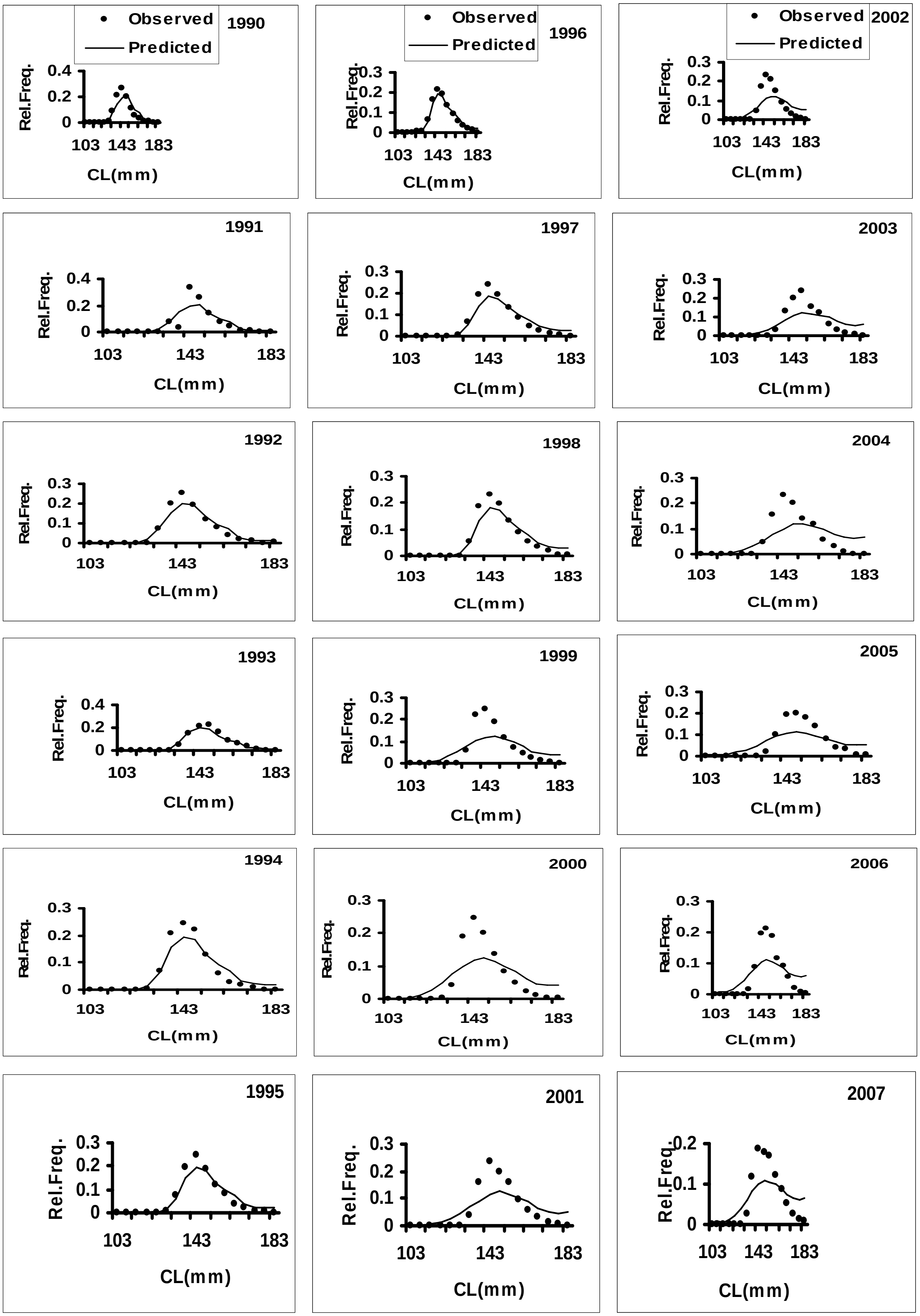

Figure 5. Predicted (line) vs. observed (filled circle) retained catch relative length frequency distributions of golden king crab in the ES, 1990 to 2007.

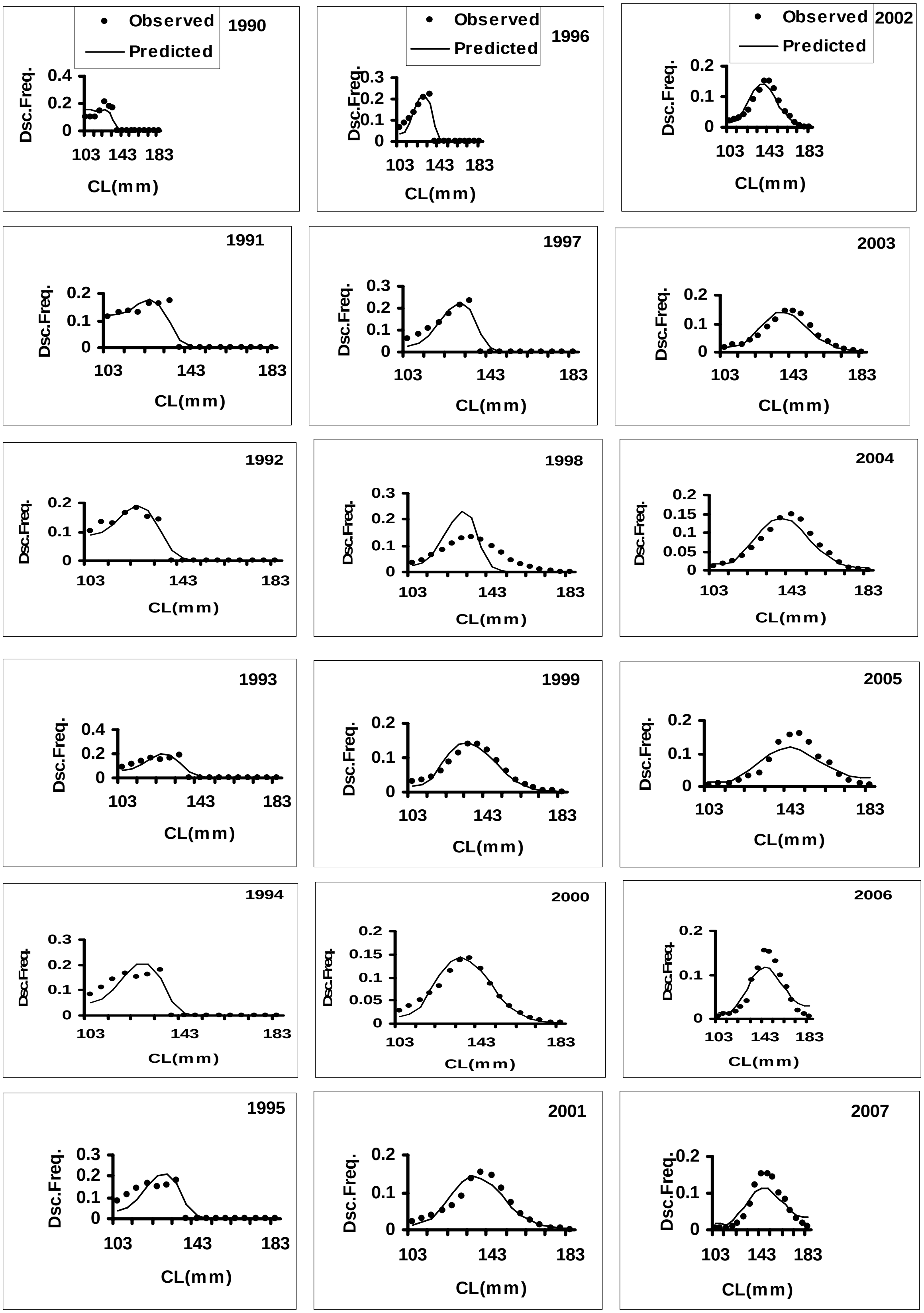

Figure 6. Predicted (line) vs. observed (filled circle) discarded catch relative length frequency distributions of golden king crab in the ES, 1990 to 2007.

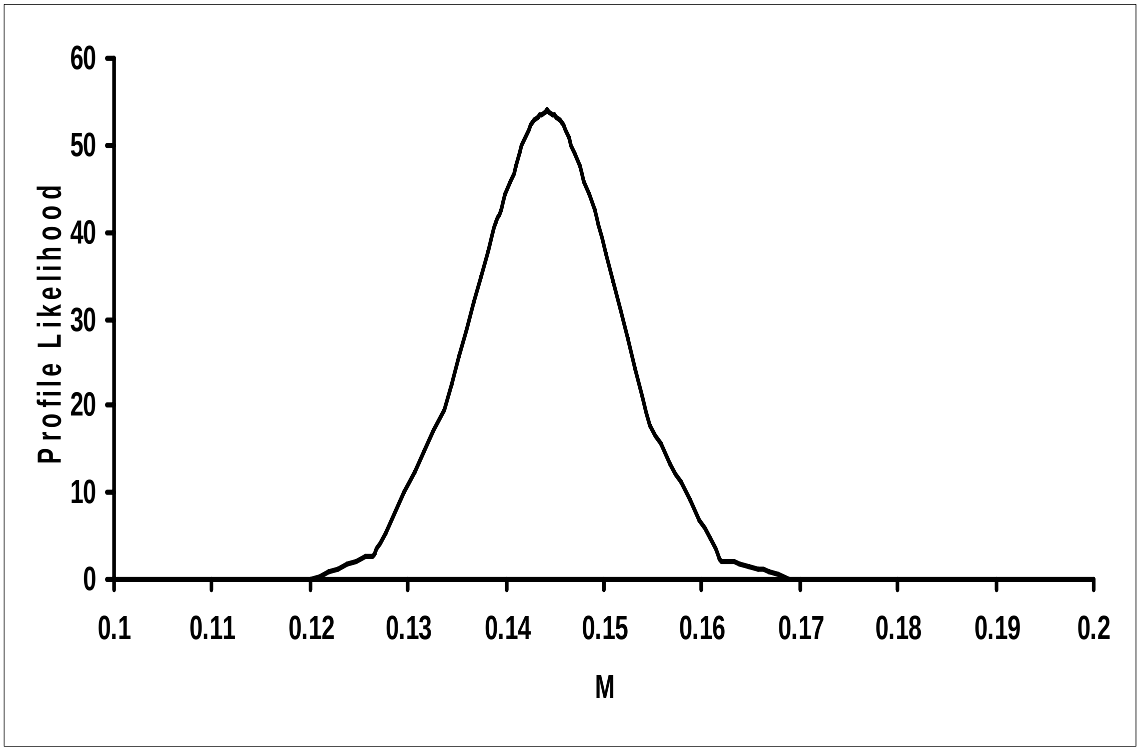

Figure 7. Profile likelihood of estimated natural mortality (*M*) based on 1990-2007 data for ES golden king crab.

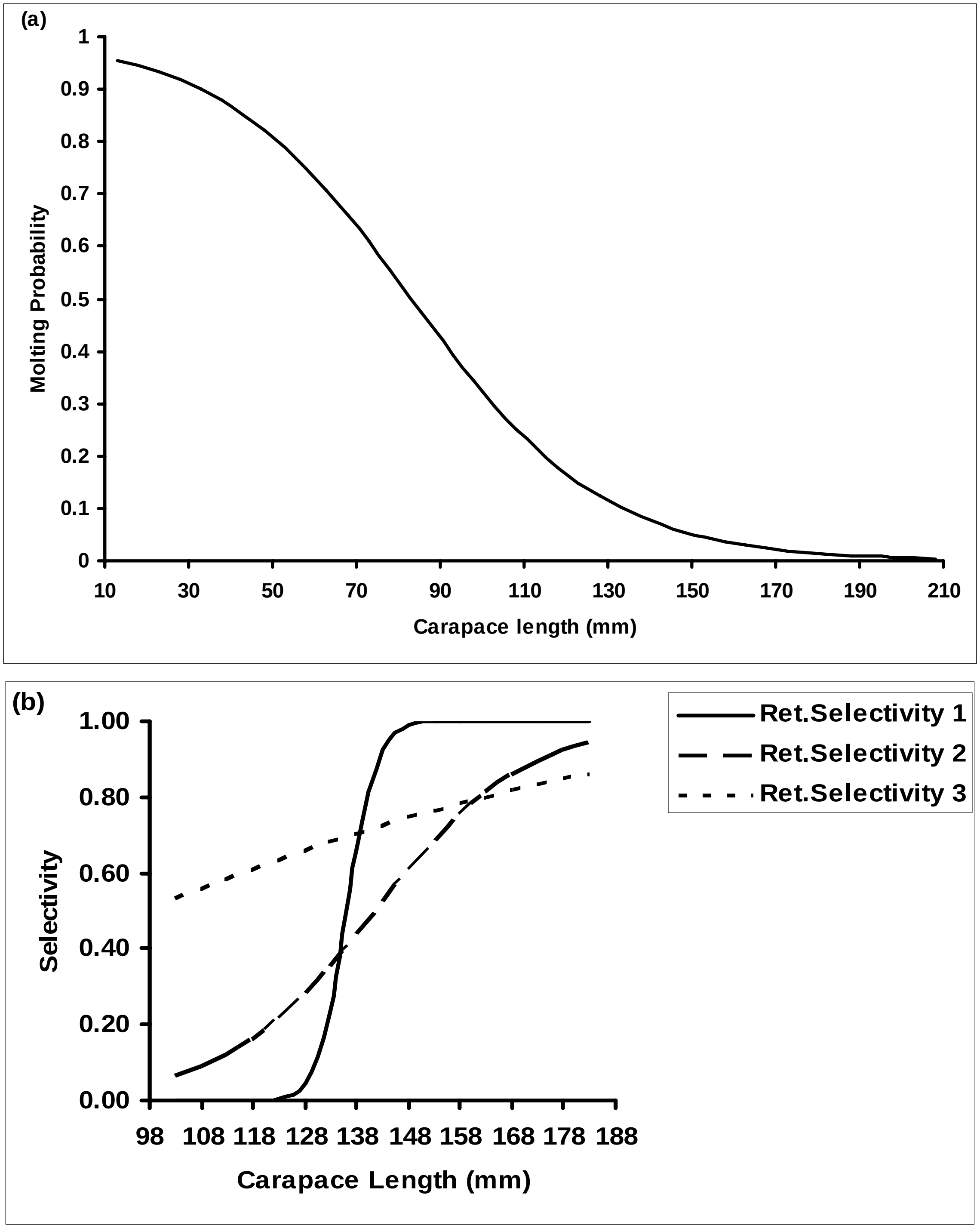

Figure 8. Estimated (a) molt probability and (b) retained selectivities for ES golden king crab. Ret. Selectivity 1 (solid line): retained selectivity curve for the 1990-1998 period; Ret. Selectivity 2 (broken line): retained selectivity curve for the 1999-2004 period; and; Ret. Selectivity 3 (dotted line): retained selectivity curve since 2005.

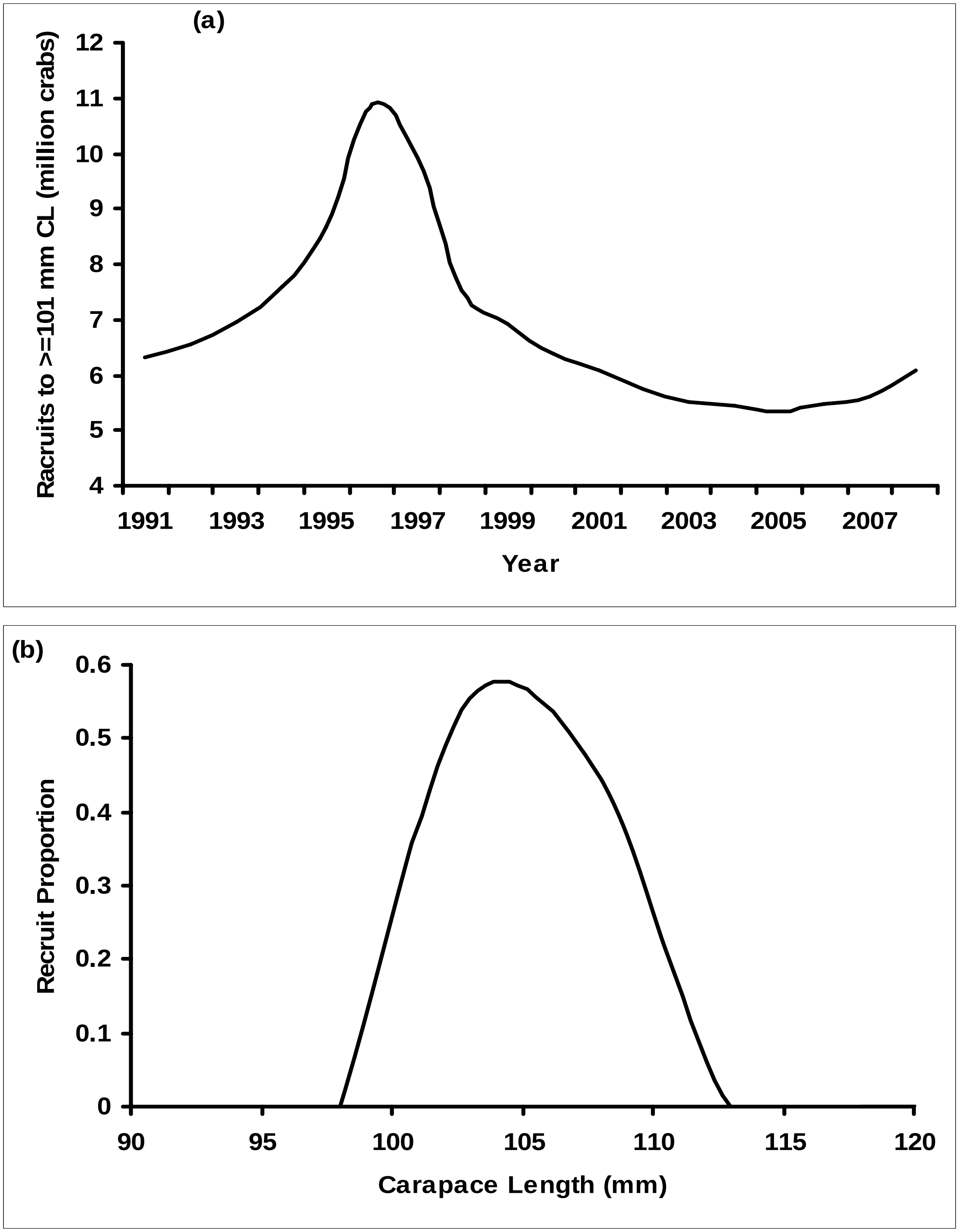

Figure 9. (a) Estimated number of male recruits (millions of crabs ≥ 101 mm CL) to the golden king crab fishery east of 174°W longitude, 1991-2008; and (b) recruit distribution to different length intervals.

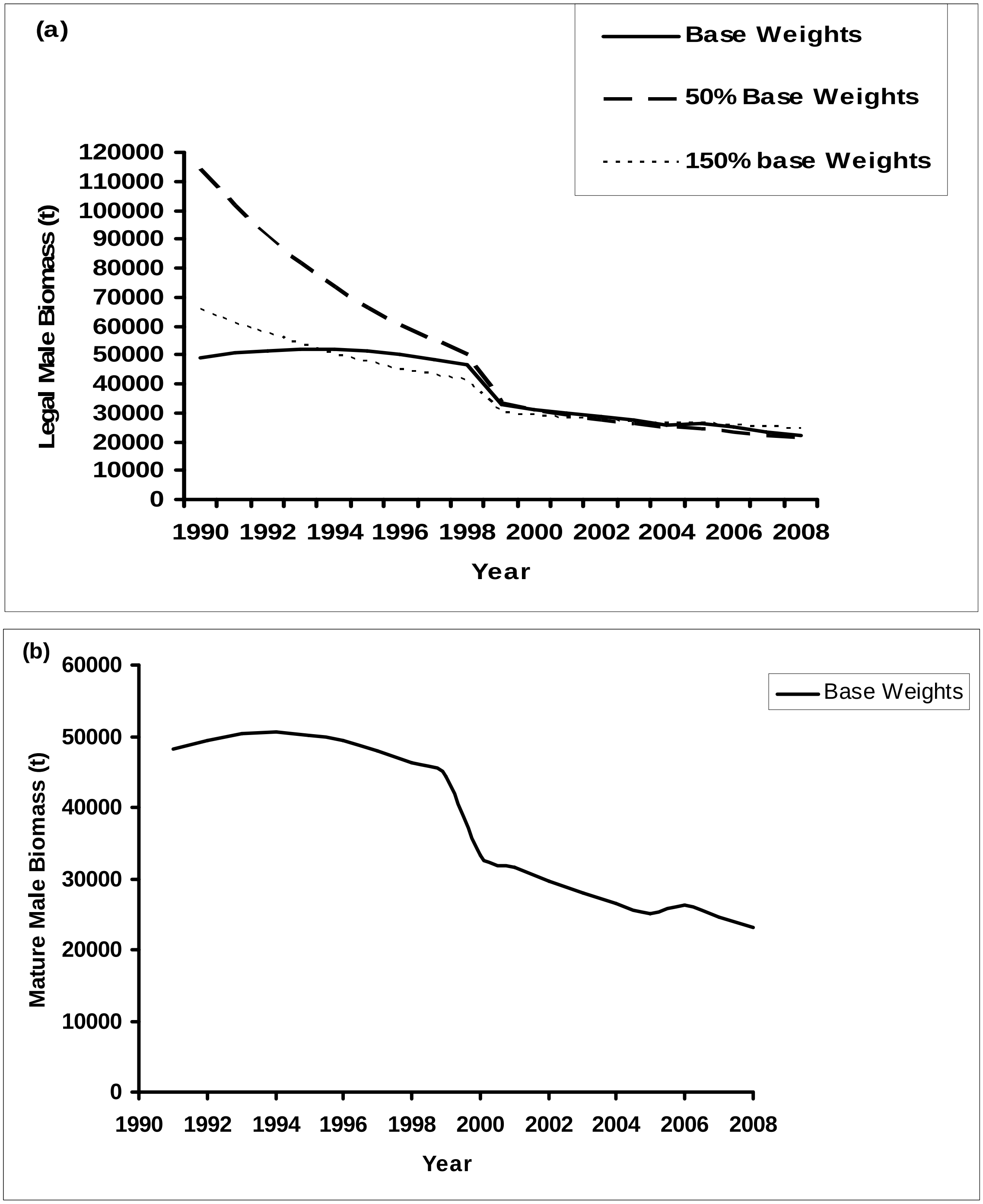

Figure 10. (a) Trends in available golden king crab legal male biomass (t) in the ES, 1990-2008 for different combinations of weights applied to the negative log likelihood components. Trend for the base weights is in solid line; trend for the 50% of the base weights is in broken line; and trend for the 150% of the base weights is in dotted line. (b) Trend in available golden king crab mature male biomass (t) in the ES, 1991-2008 for the base weights applied to the negative log likelihood components. Legal male crabs are ≥ 136 mm CL and mature male crabs are ≥ 121 mm CL.

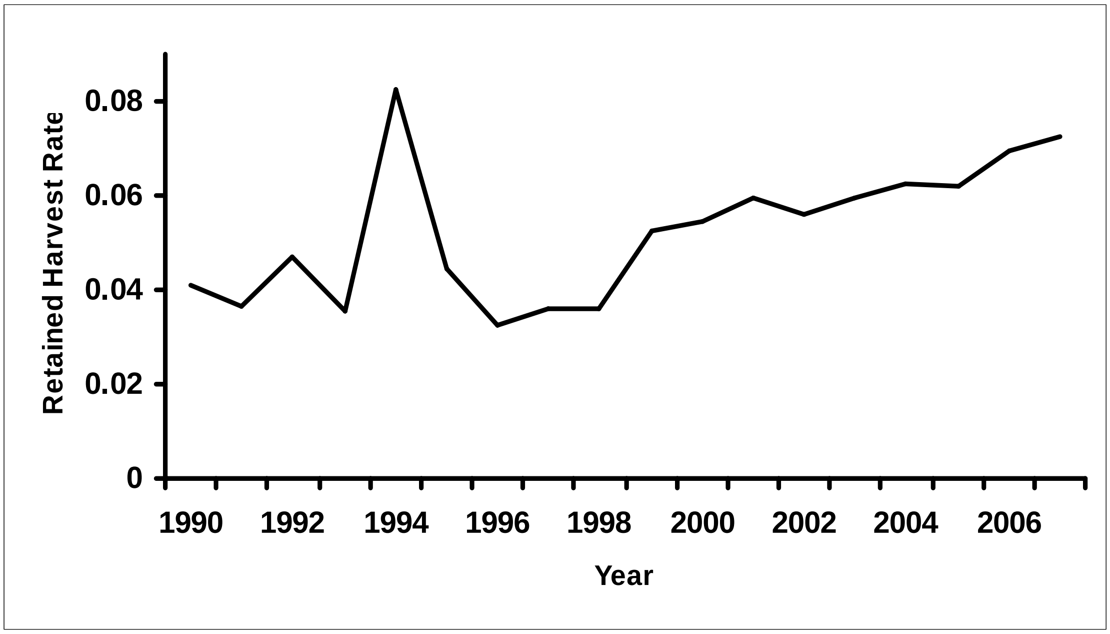

Figure 11. Trend in retained harvest rate of golden king crab in the ES, 1990-2007.

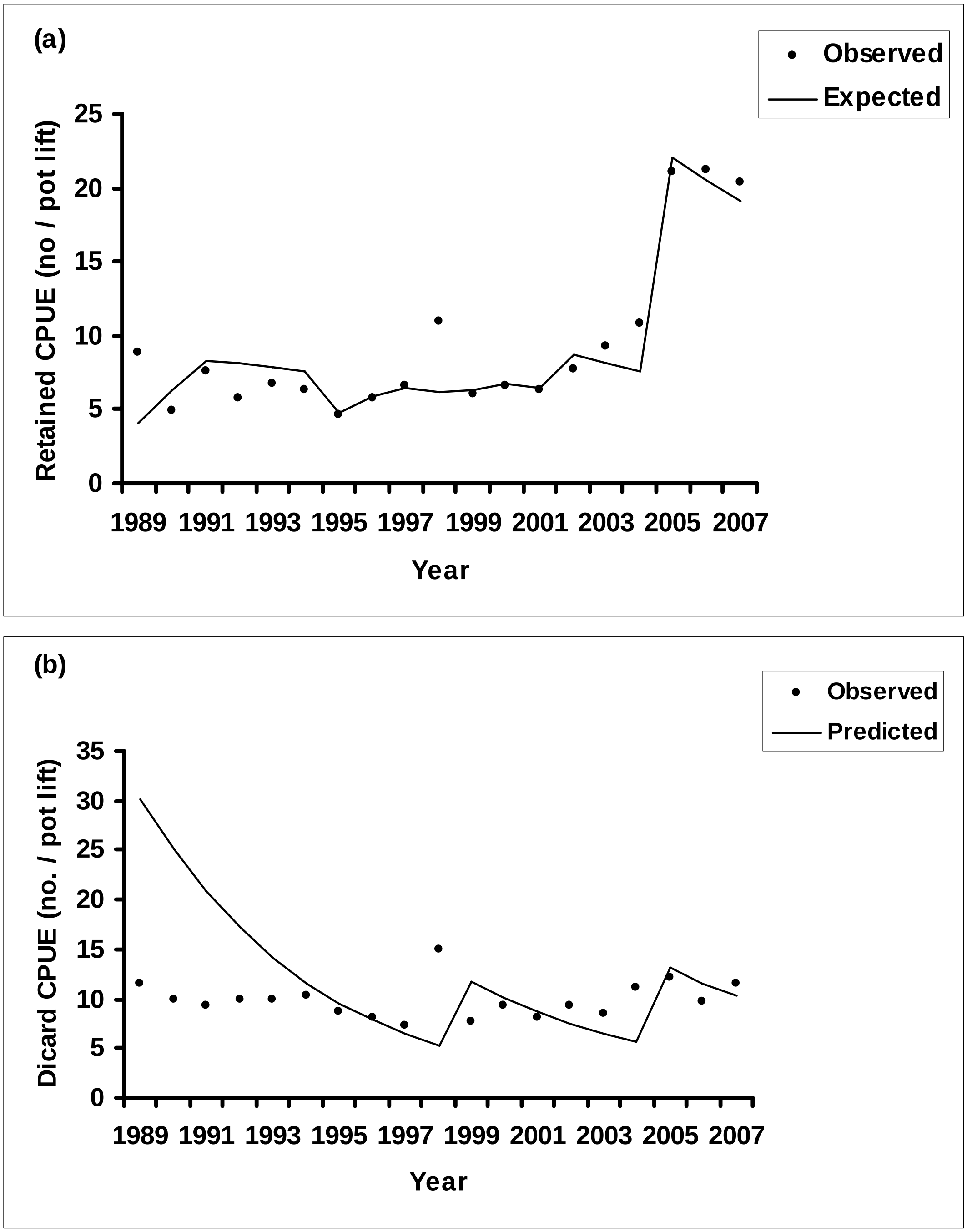

Figure 12. Predicted (line) versus observed (filled circle) (a) retained catch-per-unit-effort (CPUE) and (b) discard CPUE for golden king crab in the WS.

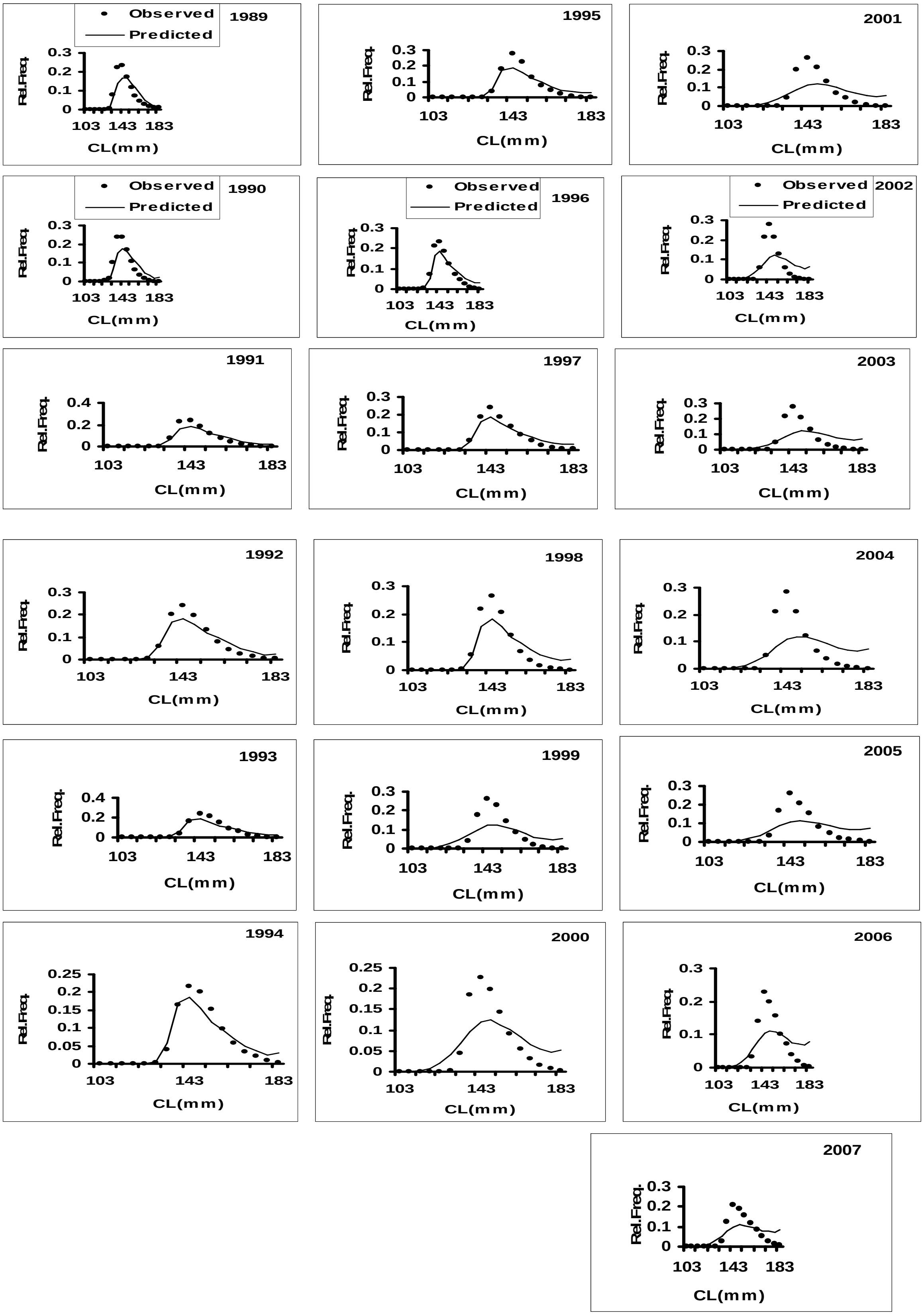

Figure 13. Predicted (line) vs. observed (filled circle) retained catch relative length frequency distributions of golden king crab in the WS,1989 to 2007.

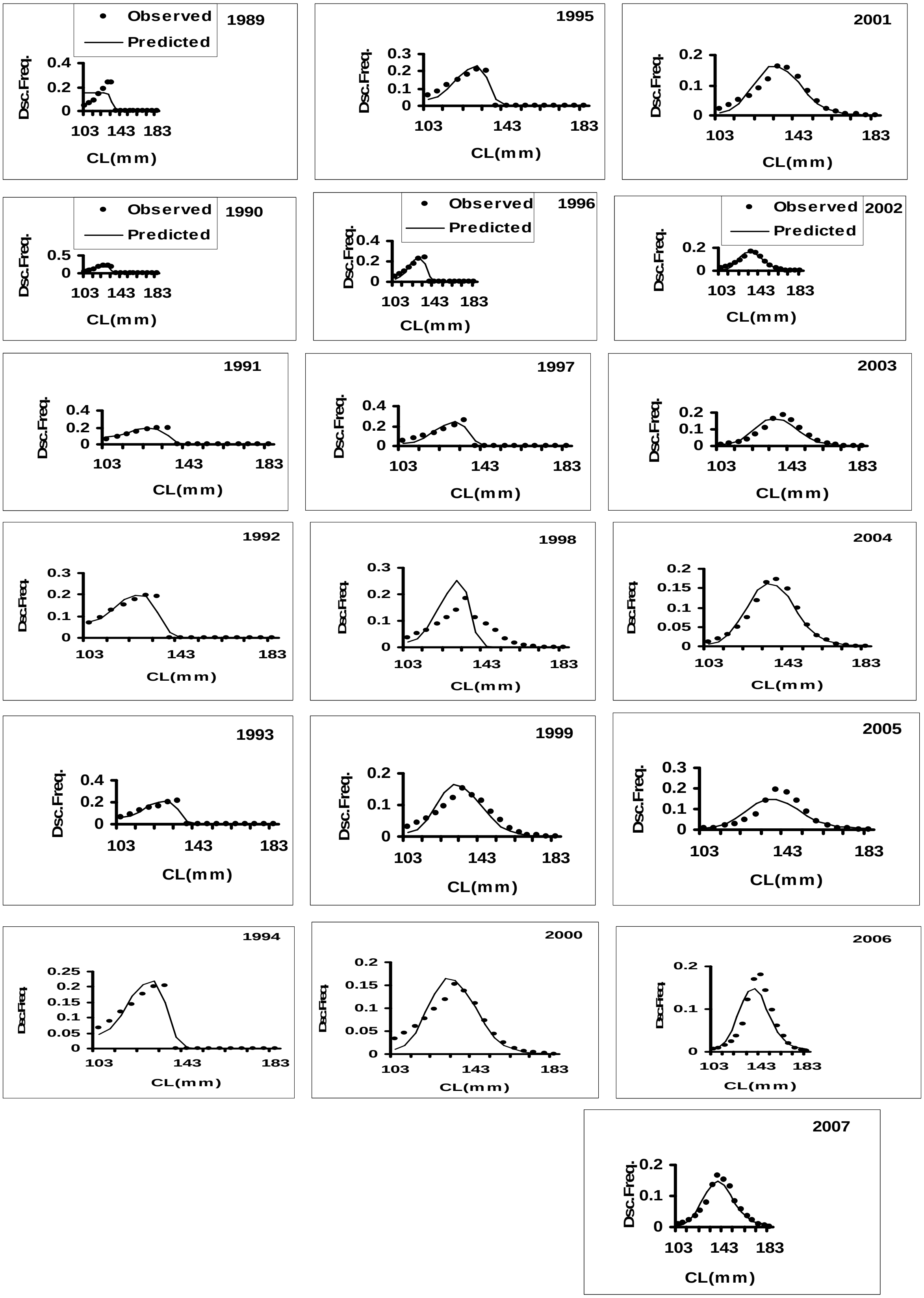

Figure 14. Predicted (line) vs. observed (filled circle) discarded catch relative length frequency distributions of golden king crab in the WS,1989 to 2007.

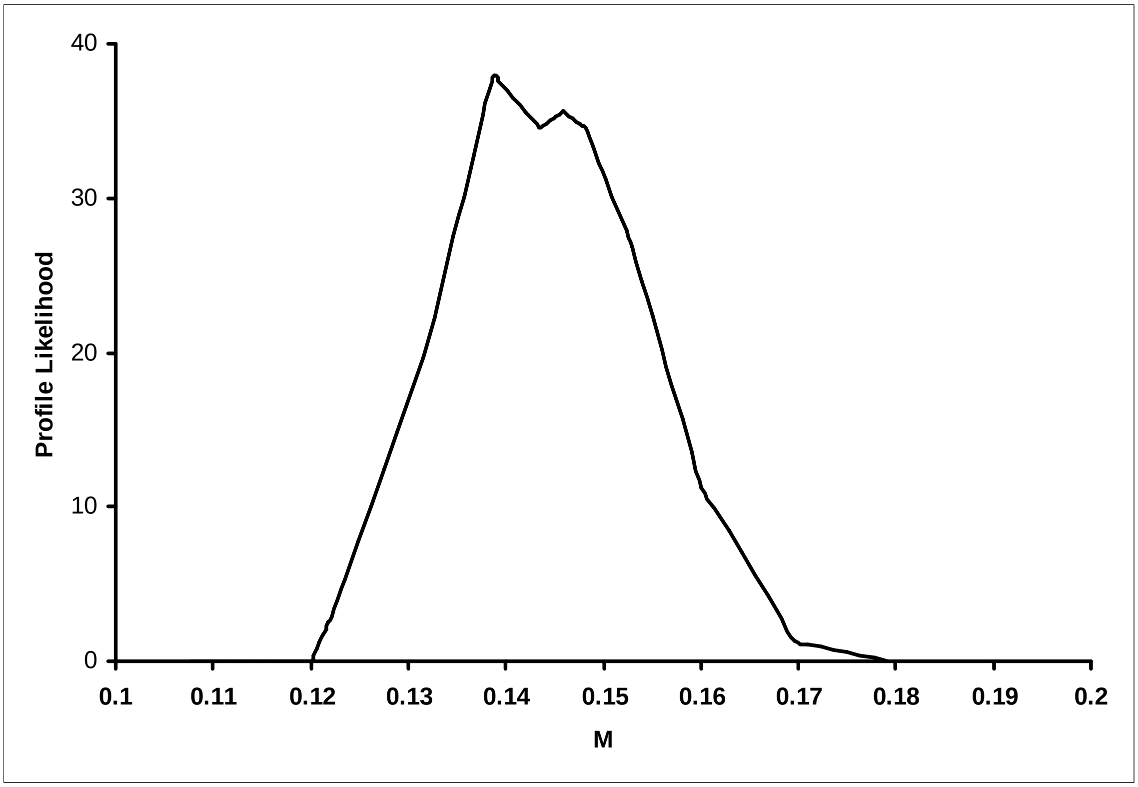

Figure 15. Profile likelihood of estimated natural mortality (*M*) based on 1989-2007 data for WS golden king crab.

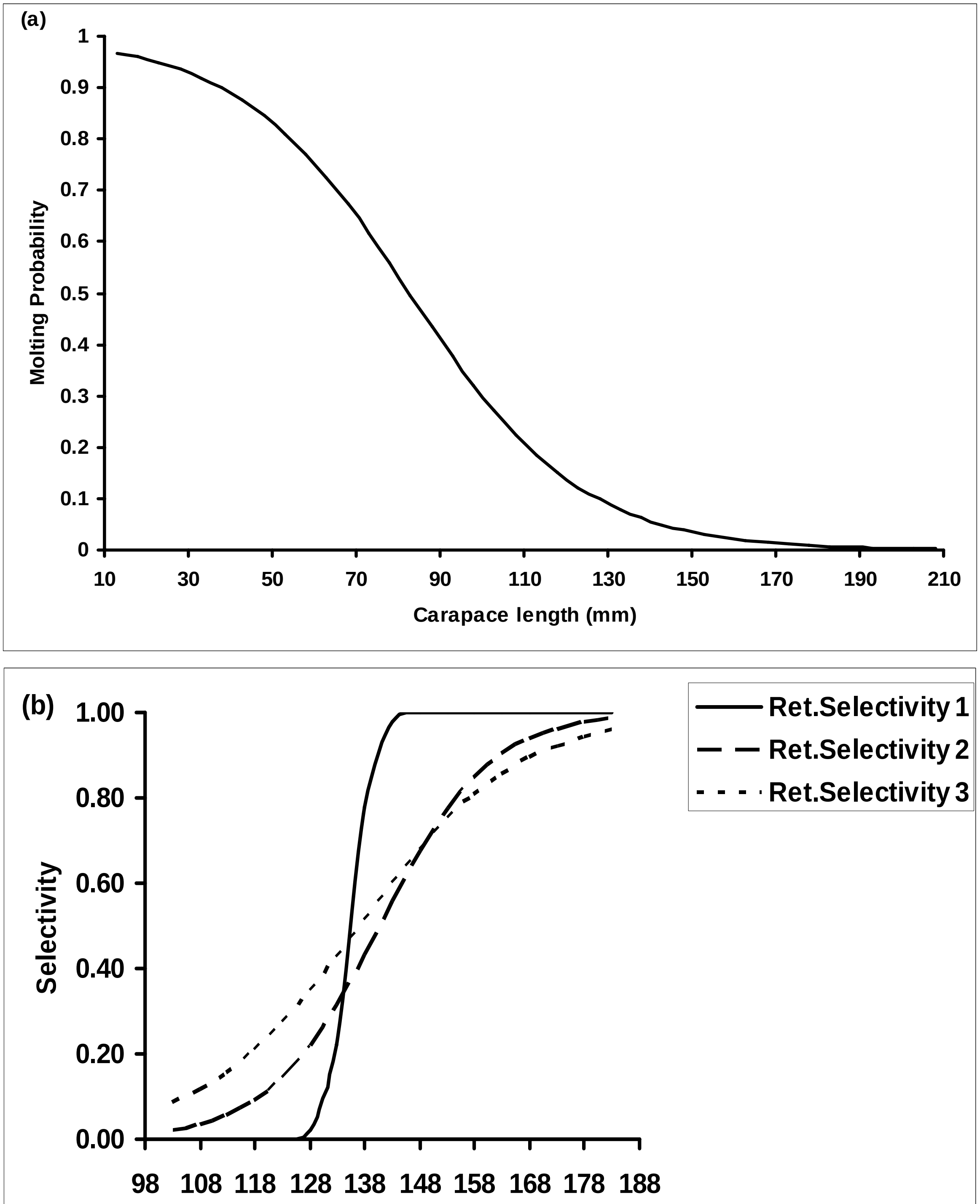

Figure 16. Estimated (a) molt probability and (b) retained selectivities for WS golden king crab. Ret. Selectivity 1 (solid line): retained selectivity curve for the 1990-1998 period; Ret. Selectivity 2 (broken line): retained selectivity curve for the 1999-2004 period; and; Ret. Selectivity 3 (dotted line): retained selectivity curve since 2005.

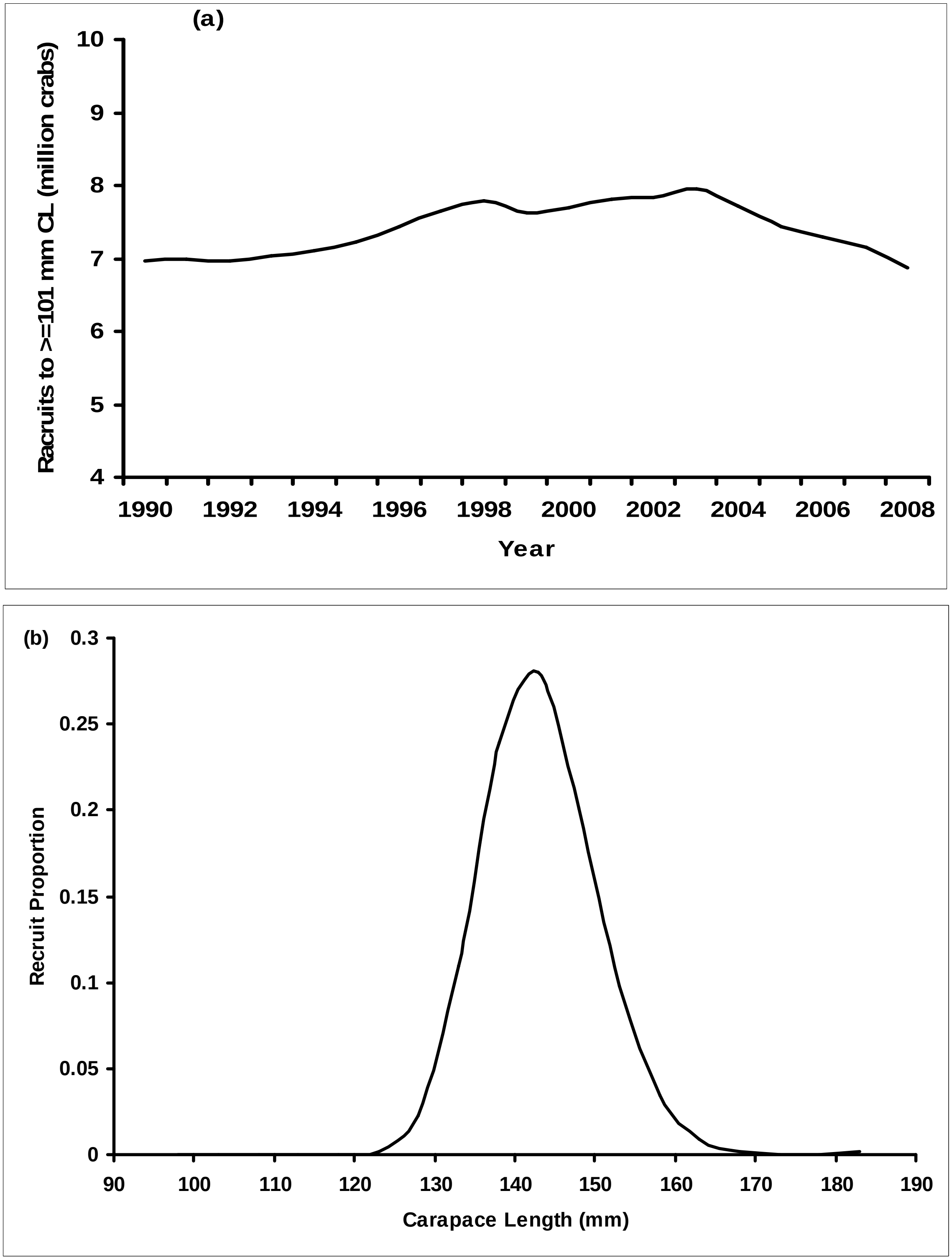

Figure 17. (a) Estimated number of male recruits (millions of crabs ≥101 mm CL) to the golden king crab fishery west of 174°W longitude, 1990-2008; and (b) recruit distribution to different length intervals.

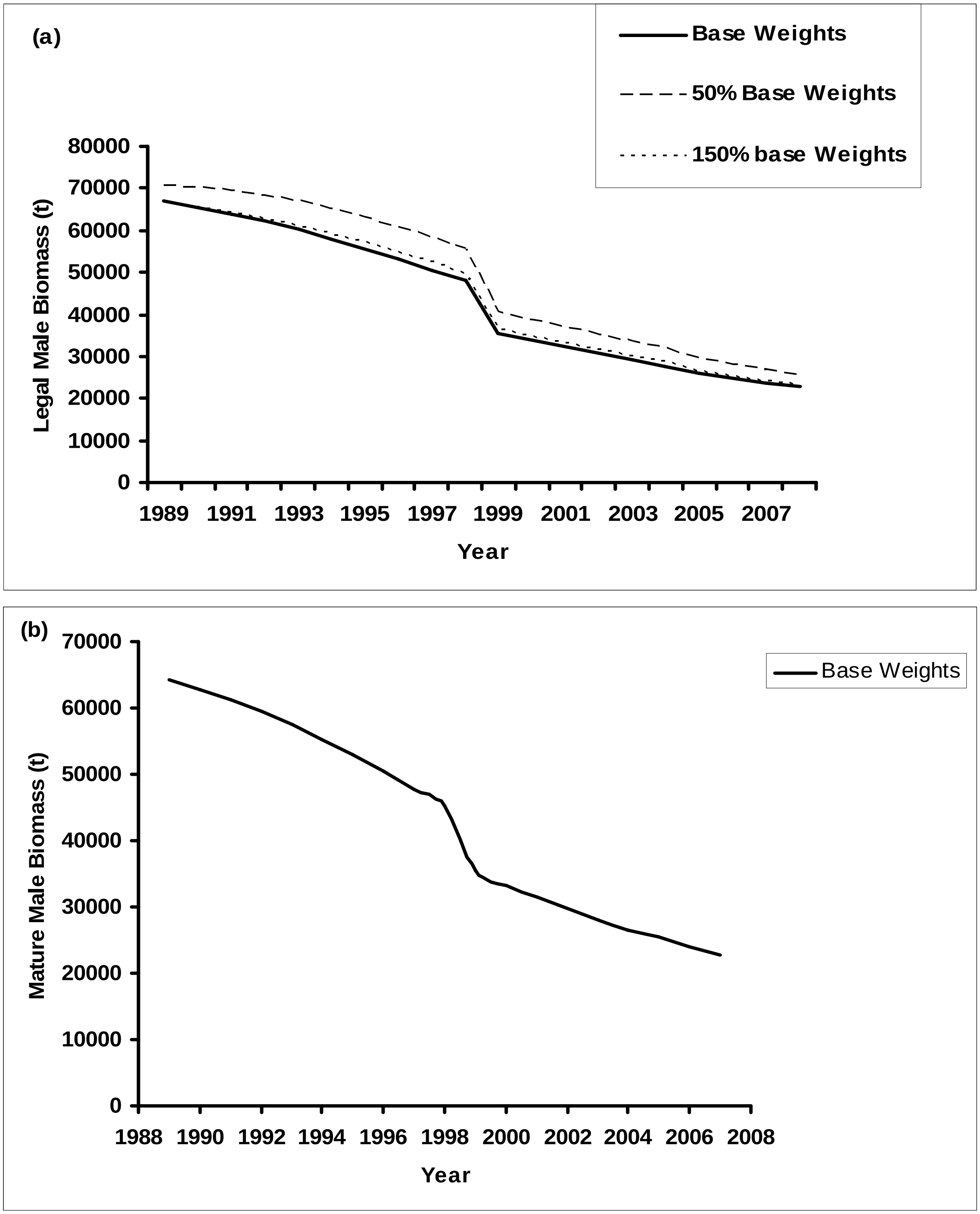

Figure 18. (a) Trends in available golden king crab legal male biomass (t) in the WS, 1989-2008 for different combinations of weights applied to the negative log likelihood components. Trend for the base weights is in solid line; trend for the 50% of the base weights is in broken line; and trend for the 150% of the base weights is in dotted line. (b) Trend in available golden king crab mature male biomass (t) in the WS, 1990-2008 for the base weights applied to the negative log likelihood components. Legal male crabs are ≥ 136 mm CL and mature male crabs are ≥ 121 mm CL.

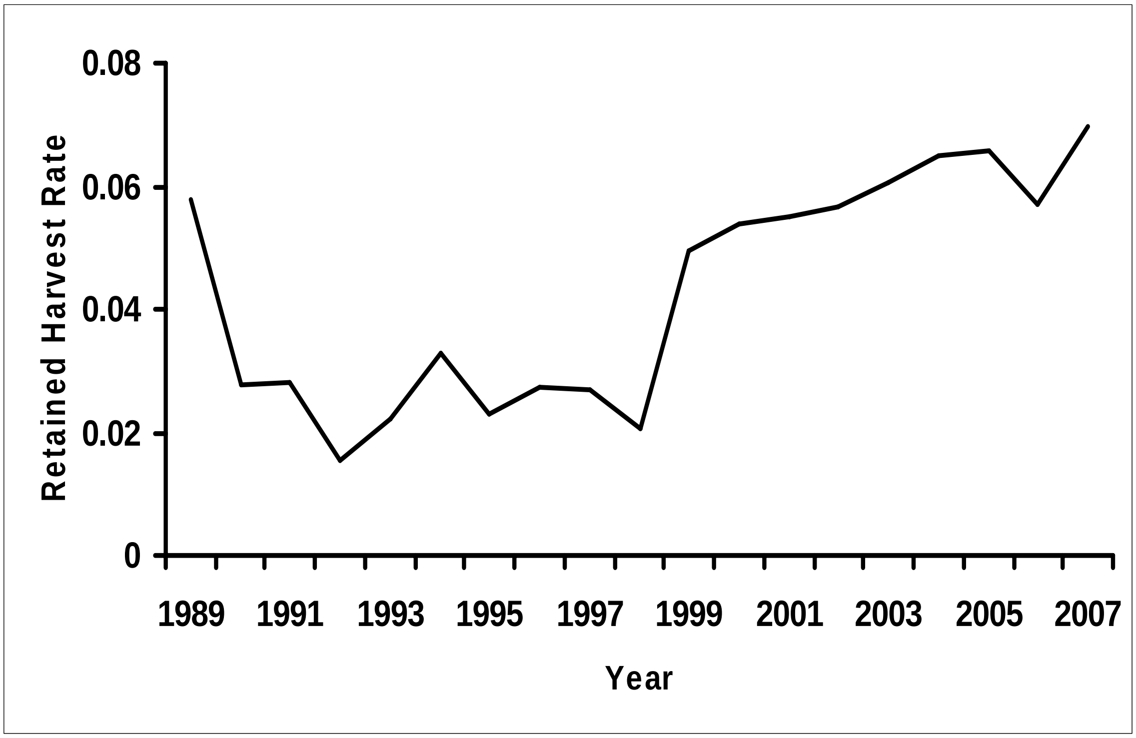

Figure 19. Trend in retained harvest rate of golden king crab in the WS, 1989-2007.

Appendix A: Integrated model

The molting probability (m_i) for a length class i is

$$m_i = 1 - \frac{1}{1 + e^{-a(i-b)}} \quad (1)$$

where a and b are parameters.

A gamma distribution was selected to describe the variation in growth increment per molt:

$$gamma(x / \alpha_i, \beta) = \frac{x^{\alpha_i - 1} e^{-\frac{x}{\beta}}}{\beta^{\alpha_i} \Gamma(\alpha_i)} \quad (2)$$

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

$$P_{i,\,j} = \frac{\int_{j_1 - \tau_i}^{j_2 - \tau_i} gamma(x / \alpha_i, \beta) dx}{\sum_{j=1}^{n} \int_{j_1 - \tau_i}^{j_2 - \tau_i} gamma(x / \alpha_i, \beta) dx} \quad (3)$$

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.

The total number of annual recruits (parameter R_t) to the size range 101–185 mm CL was distributed to different length intervals (i) by a fixed proportion (P''_i):

$$R_{i,t} = R_t P''_i \quad (4)$$

where ,

$$P_i'' = \frac{\int_{i_1}^{i_2} gamma(x/\alpha_r, \beta_r)dx}{\sum_{i=1}^{n}\int_{i_1}^{i_2} gamma(x/\alpha_r, \beta_r)dx} \qquad (5)$$

where x is the length, α_r and β_r are parameters, i_1 and i_2 are lower and upper limits of the receiving length interval i, and n is the total number of receiving length intervals.

Because only a portion of the stock is available for exploitation, the total fishery and survey selectivity (s_i^T) were modeled by a logistic function with an additional availability parameter, v:

$$s_i^T = \frac{v}{1+e^{-c_k(i-d_k)}} \qquad (6)$$

where c_k and d_k are parameters with k = 1 and i is the crab size.

Pot fishery retention selectivity (s_i^r) was also modeled as a logistic function:

$$s_i^r = \frac{1}{1+e^{-c_k(i-d_k)}} \qquad (7)$$

where c_k and d_k are parameters and i is the crab size. Three selectivity with three catchability (q_k) parameters (k = 2, 3, 4) were used to describe the fishery removal during 1990-1998, 1999-2004, and 2005-2006 periods. A separate q_k (k = 1) was considered for the standard pot gear used in the survey.

Initial year (1989 for WS and 1990 for ES) stock abundance was modeled as

$$N_{i,1} = N_1 p_i^N \qquad (8)$$

$$O_{i,1} = O_1 p_i^O \qquad (9)$$

where N_1 and O_1 are respective total new-shell and old-shell initial abundance parameters and p_i^N and O_i^O are respective relative size frequencies in size class i. The annual abundances by size and shell condition for other years were modeled considering growth, mortality, and recruitment:

$$N_{j,t+1} = \sum_{i}^{j}[(N_{i,t} + O_{i,t})e^{-M} - (C_{i,t} + D_{i,t})e^{(y_t-1)M}]m_i P_{i,j} + R_{j,t+1} \quad (10)$$

$$O_{j,t+1} = [(N_{j,t} + O_{j,t})e^{-M} - (C_{j,t} + D_{j,t})e^{(y_t-1)M}](1 - m_j) \quad (11)$$

where $N_{j,t}$ and $O_{j,t}$ 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*; $C_{j,t}$ and $D_{j,t}$ are fishery retained and discard dead total catches (20% discard death rate was used) 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.

Total catch-per-unit-effort in year *t* was estimated as

$$C\hat{P}UE_t^T = q_k[\sum_{j}^{n}\{s_j^T(N_{j,t} + O_{j,t})e^{-y_t M} - 0.5(\hat{C}_{j,t} + \hat{D}_{j,t})\}] \quad (12)$$

where *n* is the number of length classes and the ^ sign refers to predicted value.

The predicted retained and discarded dead catches were estimated as

$$\hat{C}_{j,t} = (N_{j,t} + O_{j,t})e^{-y_t M}(1 - e^{-F_t s_j^T s_j^r}) \quad (13)$$

$$\hat{D}_{j,t} = 0.2\,(N_{j,t} + O_{j,t})e^{-y_t M}(1 - e^{-F_t s_j^T (1-s_j^r)}) \quad (14)$$

Retained catch-per-unit-effort in year *t* was estimated as

$$C\hat{P}UE_t^r = q_k[\sum_{j}^{n}\{s_j^T s_j^r(N_{j,t} + O_{j,t})e^{-y_t M} - 0.5(\hat{C}_{j,t} + \hat{D}_{j,t})\}] \quad (15)$$

Assuming that $CPUE_t^r$ have log normally distributed measurement errors, the weighted negative log likelihood for the retained catch-per-unit-effort data is

$$LL_r = \lambda_r \times 0.5 \frac{\sum_t \{\log(C\hat{P}UE_t^r + c) - \log(CPUE_t^r + c)\}^2}{\sigma_r^2} \quad (16)$$

where λ_r is the weight, c is a small constant (0.001), σ_r^2 is the variance of retained catch-per-unit-effort.

Discard catch-per-unit-effort, $CPUE_t^d$, in year t was the difference between the total and retained catch-per-unit effort. The weighted negative log likelihood for discard catch-per-unit-effort data, LL_d, is similar to equation (16) with discard weight (λ_d), catch-per-unit-effort, and variance replacing the corresponding retained values.

Pot survey $CPUE_t^s$ in year t was estimated as

$$C\hat{P}UE_t^s = q_k \sum_j^n s_j^T (N_{j,t} + O_{j,t}) \tag{17}$$

The weighted negative log likelihood for pot survey catch-per-unit-effort data, LL_s, is similar to equation (16) with survey weight (λ_s), catch-per-unit-effort, and variance replacing the corresponding retained values.

Retained catch length composition $L_{j,t}^r$ in year t was computed as

$$\hat{L}_{j,t}^r = \frac{s_j^T s_j^r (N_{j,t} + O_{j,t})}{\sum_j^n s_j^T s_j^r (N_{j,t} + O_{j,t})} \tag{18}$$

Retained length composition is assumed to be multinomial and the negative log likelihood is

$$LL_{rL} = -\sum_t \sum_{j=1}^n K_t L_{j,t}^r \{\log(\hat{L}_{j,t}^r + c) - \log(L_{j,t}^r + c)\} \tag{19}$$

where K_t is the effective sample size.

Discard catch length composition $L_{j,t}^d$ in year t was computed as

$$\hat{L}_{j,t}^d = \frac{s_j^T (1 - s_j^r)(N_{j,t} + O_{j,t})}{\sum_j^n s_j^T (1 - s_j^r)(N_{j,t} + O_{j,t})} \tag{20}$$

Negative log likelihood, LL_{dL}, for discard length composition is similar to equation (19) with discard effective sample size and length composition replacing the corresponding retained values.

Catch biomass in year *t* was estimated assuming pulse fishery

$$\hat{Y}_t = \sum_{j}^{n} (N_{j,t} + O_{j,t}) e^{-y_t M} (1 - e^{-F s_j^T s_j^r}) w_j \qquad (21)$$

where w_j is the mean weight for class *j* crabs.

Assuming that Y_t have log normally distributed measurement errors, the weighted negative log likelihood for the catch biomass data is

$$LL_B = \lambda_B \sum_t \{\log(\hat{Y}_t + c) - \log(Y_t + c)\}^2 \qquad (22)$$

where λ_B is the weight.

Number of tag returns TR_t^k in year *t* from release *k* was predicted as

$$T\hat{R}_t^k = \phi N_k e^{-\sum_{tt}^{t-1} Z_{tt} - T_k M} (1 - e^{-F_t \bar{s}_t}) \qquad (23)$$

where ϕ is the tagged population initial reduction parameter (initial survival*a constant reporting rate), N_k is the number of tagged crabs released in k th experiment, $Z_{tt} = F_{tt} + M$ in year *tt*, F_t is instantaneous fishing mortality in year *t*, and $\bar{s}_t$ is mean selectivity in year *t*. An additional fishing mortality (F_t^*) is included for the year of release to account for non-mixing of tagged crabs with untagged crabs. Mean selectivity was estimated as

$$\bar{s}_t = \frac{\sum_{j=1}^{n} s_j^T s_j^r (N_{j,t} + O_{j,t})}{\sum_{j=legal\ size}^{n} s_j^T (N_{j,t} + O_{j,t})} \qquad (24)$$

Assuming multinomial recapture probability, the negative log likelihood function for tag recaptures is

$$LL_{TR} = -\log[\prod_k \frac{(\phi N_k)!}{(\prod_{t=1}^{T} TR_t^k!)\,(\phi N_k - \sum_{t=1}^{T} TR_t^k)!}(1-\frac{\sum_{t=1}^{T}\hat{TR}_t^k}{\phi N_k})^{(\phi N_k - \sum_{t=1}^{T} TR_t^k)} \prod_{t=1}^{T}(\frac{\hat{TR}_t^k}{\phi N_k})^{TR_t^k}] \qquad (25)$$

where T is the last tag returns year.

Assuming lognormal distribution of annual recruitment, the weighted negative log likelihood is

$$LL_R = \lambda_R \sum_t \{\log(R_t) - \log(\overline{R})\}^2 \qquad (26)$$

where $\overline{R}$ is the mean recruitment parameter and λ_R is the recruitment weight.

A penalty function for M was added to the overall likelihood. Assuming a normal distribution with a 25% coefficient of variation about a mean ($\overline{M}$), assumed to be 0.18 (NPFMC 2007), the weighted negative log likelihood is

$$LL_M = \lambda_M \times 0.5\frac{(M-\overline{M})^2}{\sigma_M^2} \qquad (27)$$

where $\sigma_M^2 = \overline{M}^2 CV^2$.

Thus, the total negative log likelihood for minimization is

$$f = LL_r + LL_d + LL_s + LL_{rL} + LL_{dL} + LL_B + LL_{TR} + LL_R + LL_M \quad . \qquad (28)$$

Following quantities were computed from the estimated parameters:

Vulnerable legal male biomass at the survey time in year t is

$$LM_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r (N_{j,t} + O_{j,t})\, w_j \qquad (29)$$

Mature male biomass on 15 February spawning time (NPFMC 2007) in the following year is

$$MM_t = \sum_{j=mature\ size}^{n} s_j^T s_j^r \{(N_{j,t} + O_{j,t})e^{-y'M} - (C_{j,t} + D_{j,t})e^{-(y_t - y')M}\}\, w_j \qquad (30)$$

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 was applied to compute F':

(a) If $MM_t \geq M\overline{M}$, $F' = \gamma M$

(b) If $MM_t < M\overline{M}$ and $MM_t > 0.25M\overline{M}$,

$$F' = \gamma M \frac{(\frac{MM_t}{M\overline{M}} - \alpha)}{(1-\alpha)} \qquad (31)$$

(c) If $MM_t \leq 0.25M\overline{M}$, $F' = 0$

where γ is a constant multiplier of M, α is a parameter, and $M\overline{M}$ 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 MM_t is depended on the intervening retained and discard catch (i.e., MM_t is estimated after the fishery), an iterative procedure was used using equations (30) and (31) with retained and discard catch predicted from equations (13) and (14). The next year limit harvest catch was estimated using equations (13) and (14) with the estimated F' value.

Pribilof Islands Golden King Crab

2008 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak, 20 August 2008

Executive Summary

Stock: Golden king crab/Pribilof Islands

Catches: The domestic fishery developed in 1982. Since then, participation in the fishery has been sporadic and annually retained catch has been variable, from 0 pounds in the seven years that no vessels participated (1984, 1986, 1990–1992, 2006–2007) 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 has ranged from 19-thousand to 49-thousand pounds annually during 2000–2005, whereas discarded bycatch during Bering Sea groundfish fisheries has ranged from 700 to 3,000 pounds annually during 2003–2007.

Data and assessment: There is no survey and no assessment model in use for this stock. Available data are from fish tickets (including retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date), size-frequency data from samples of landed crabs, at-sea observer data from pot lifts sampled during crab fisheries (including date, location, soak time, catch composition, size, sex, and reproductive condition of crabs, etc.), and data on bycatch during groundfish fisheries. However, much of the directed fishery data are confidential due to low numbers of participating vessels or processors.

Unresolved problems and major uncertainties: Stock abundance and size composition within the stock is unknown and has not been estimated; knowledge on stock distribution is poor.

Reference points: The assessment author recommended that this stock be managed as a Tier 5 stock at the May 2008 Crab Plan Team (CPT) meeting; the CPT (at their May 2008 meeting) and the SSC (at their June 2008 meeting) concurred with that recommendation. For Tier 5 stocks BMSY and MSST are not estimated and OFL is defined as "the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). The assessment author made no recommendation on the OFL to the CPT at the May 2008 meeting, but the CPT recommended defining the OFL as the average retained catch during the time period 1993–1999, which is equal to 174,206 pounds (retained catch). The SSC concurred with that recommendation at their June 2008 meeting.

Stock biomass: Estimates of stock biomass are not available.

Recruitment: Between 2002 and 2005, the average size of legal male golden king crab taken during the commercial fishery has decreased while CPUE has increased, suggesting that strong recruitment to the legal male portion of the stock has recently occurred.

Exploitation status: Estimates of fishing mortality are not available. No landings were reported for the directed fishery in 2006 and 2007.

Management performance: The fishery has been managed with a GHL of 150,000 pounds since 2000. During 2000–2002 the retained catch was within 15% of the GHL.

Forecasts: No forecasts of catch and biomass are available.

Decision table: Not available.

Recommendations: This stock was recommended for management as a Tier 5 stock by the assessment author and the CPT in May 2008; the SSC concurred in June 2008. OFL was recommended as 174,206 lbs of retained catch (equal to the average retained catch during the time period, 1993-1999) by the CPT in May 2008 with concurrence of SSC in June 2008. The SSC recommended in June 2008 that future assessments provide data for considering a total-catch OFL (as opposed to a retained-catch OFL).

Responses to SSC Comments

At their June 2008 meeting, the SSC reviewed the May 2008 draft of this SAFE chapter and the recommendations made in May 2008 by the assessment author and the CPT. Recommendations from the SSC specific to management of this stock or to this SAFE chapter are listed below followed by the response from the author.

1. Manage this stock as a Tier 5 stock.
    - The author agrees with this recommendation; it follows the recommendation of the CPT at their May 2008 meeting.
2. OFL=174,206 lbs of retained catch (equal to the average retained catch during the time period, 1993-1999).
    - The author made no recommendation on the OFL to the CPT at their May 2008 meeting; this recommendation by the SSC follows the May 2008 recommendation of the CPT exactly.
3. Include data to support a total-catch OFL for inclusion in the next year's assessment.
    - The draft of this chapter in the May 2008 Draft Crab SAFE did include data on bycatch from crab and groundfish fisheries. In next year' s report the author will consolidate tables on catch and bycatch to allow for easier inspection of data and consideration of a total catch OFL for this stock. However, it should be noted that there are only two years (2001 and 2002) that estimates of retained catch and bycatch are both available and non-confidential. Consideration of a total-catch OFL for this stock will also involve consideration of the variety of fisheries in which bycatch can occur and the lack of estimates of the handling mortality rates for golden king crabs in those fisheries.

Recommendations from the SSC on assessments in general that have application to this SAFE chapter are listed below followed by the response from the author.

4. Omit sections from chapter that are not relevant to this stock.
    - Sections that are not relevant to this stock and chapter have been removed (e.g., "Summary of Major Changes," "Model Structure," "Parameters Estimated Conditionally," "Model Evaluation," etc) and section/sub-section headings have been reworded as needed to be more appropriate to this chapter.
5. Provide a range of alternative time periods for the CPT and SSC to consider when setting OFLs.
    - The number of years with fishery data that are not confidential representing seasons with unconstrained fishing (i.e., no GHL) is limited. The average retained catch during a

period limited to fishing seasons that were not constrained by a GHL and during two periods that include seasons that were constrained by a GHL are presented in this draft for examination.

6. Clearly articulate the rationale for selecting a specific time period for establishing an OFL based on catch histories; the default should be the full time series for which data are available, unless compelling reasons exist to choose a different period.
   - Can do. Will do. Did.
7. To the extent possible, bycatch information should be provided in the SAFE in order to move stocks from "retained catch OFL" to "total catch OFL".
   - See response to SSC comment #3, above.
8. Expand ecosystem considerations section to include information on prey and predator composition in a consistent format (e.g., pie charts); a discussion of seabird predation would be a useful addition.
   - This chapter contains no section on ecosystem considerations. Realistically, a section on ecosystem considerations section for this unsurveyed, remote, and poorly-known stock is a long ways away. Presently, priority effort should be towards gaining and presenting data on stock distribution, abundance, and dynamics. However, any information provided to the author on ecosystem considerations (e.g., predators and prey) for this stock would be included in future chapters.
9. Include figures showing available time series of catch (in addition to tables) to facilitate comparisons of appropriate time periods.
   - A graph of the time series of retained catch has been added to this draft.

Introduction

Scientific name: *Lithodes aequispinus* J. E. Benedict, 1895

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).

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 2001 fishery (the most recently prosecuted fishery for which fishery data are not confidential) was 214 fathoms (391 m; Table 1).

Description of management units and spatial and/or seasonal management measures
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 79–80) 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.

By State of Alaska regulation (5 AAC 34.910 (b) (3)), male golden king crab may be taken from January 1 through December 31 only under conditions of a permit issued by the commissioner.

<u>Evidence of stock structure</u>
We are aware of no data for evaluating stock structure within this stock.

<u>Description of life history characteristics relevant to stock assessments</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 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.

Fishery

Description of the directed fishery

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)).

The following historical review of the Pribilof District golden king crab fishery is from Bowers et al. (2008, pages 84–85):

> Golden king crabs *Lithodes aequispina* are found in commercial concentrations in only a few deep canyons in the Bering Sea and have never sustained large harvests when compared to other Bering Sea king crab fisheries. As with many other crab fisheries in the Bering Sea, the fishery for golden king crabs was pioneered by foreign fishing fleets. A domestic fishery developed during the 1982/83 season after the Alaska Board of Fisheries (BOF) directed ADF&G to regulate fishing for golden king crabs in the Pribilof District by emergency order. By the 1984 season, BOF directed ADF&G to manage the Area Q golden king crab fishery under authority of a commissioner's permit that allowed the fishery to develop and expand into new areas.
>
> The first domestic harvest of golden king crabs in the Bering Sea occurred in June of 1982 when two vessels fished in the Pribilof District. Effort increased to 10 vessels during the following season with a harvest of nearly 70,000 pounds. The size limit for golden king crabs in the Pribilof District was reduced from six and one-half inches to five and one-half inches in 1983. Subsequently, effort in the Pribilof District peaked during the 1983/84 season when 50 vessels harvested 856,000 pounds of golden king crabs. From 1984 to 1992, no more than two vessels participated each year in the fishery. Since the 1983/84 season, harvest has not exceeded 350,000 pounds annually. The Pribilof District golden king crab fishery reached a maximum exvessel value of just over $1.1 million in 1995, and the highest price fishers received per pound was $3.99 in 1994. During the last nine years in the Pribilof District fishery an average of five vessels have annually harvested an average of 166,000 pounds. CPUE has averaged seven legal crabs per pot lift with an average weight of 4.0 pounds. Most harvest in the Pribilof District has occurred in the area immediately to the south of the Pribilof Islands.

At the March 1993 meeting, BOF developed pot limits for all king crab fisheries in the Bering Sea. Current pot limits in the Pribilof District are set at 40 pots for vessels 125 feet or less in length and 50 pots for vessels greater than 125 feet in length.
In 2000, the Pribilof District golden king crab fishery opened with a GHL of 150,000 pounds, which was 50,000 pounds less than the 1999 harvest level. This adjustment better complies with guidelines outlined in the FMP for the king and Tanner crab fisheries of the Bering Sea and Aleutian Islands and is based on the average harvest from 1983 to 1997. Seven vessels harvested 127,000 pounds in 2000. The GHL was not reached; thus the fishery remained open until the end of the year. In 2001, six vessels harvested 146,000 pounds and the fishery was closed by emergency order.

The golden king crab fishery in the Bering Sea is managed using inseason catch reports provided by processors and observers. Fishing is restricted to depths of 100 fathoms or greater. Starting in 2001, 100% observer coverage was required for each vessel registered for the fishery to provide fishery and biological data that has not previously been available. In addition, vessel logbooks issued with the commissioner's permit provide location of fishing operations, effort, and estimates of bycatch that supplement data collected by observers. Primary bycatch species include non-retained golden king crabs, Pacific halibut *Hippoglossus stenolepis*, Pacific cod *Gadus macrocephalus* and snow crabs.

The 2002 fishery opened January 1 with a GHL of 150,000 pounds, and closed by emergency order on May 14. The total harvest was 150,434 pounds. CPUE averaged six legal crabs per pot lift, a decrease from the CPUE of eight legal crabs per pot during the 2001 fishery. Landed crabs averaged 4.3 pounds per crab, the same as the 2001 season. The 2002 Pribilof District golden king crab fishery had a total fishery value of $438,000, which was $9,000 more than the 2001 fishery value.

The 2003 Pribilof District golden king crab fishery opened on January 1 with a GHL of 150,000 pounds. Three vessels registered for the fishery and began fishing in late March. A fourth vessel registered in April but did not fish. Because only two processors participated in the fishery, most harvest information is confidential. The majority of the harvest in 2003 occurred south of Saint George Island near Pibilof Canyon.

Five vessels registered for the 2004 Pribilof District golden king crab fishery. Fishing effort began in late February and the fishery was closed by emergency order on March 12. Most of the 2004 harvest information is confidential because only two processors purchased the harvest. Catch rates during the 2004 fishery were among the highest on record and the fishery was the shortest ever at approximately three weeks in duration. Most of the 2004 harvest occurred immediately to the south of Saint George Island in the vicinity of the Pribilof Canyon.

Four vessels participated in the 2005 Pribilof District golden king crab fishery, however harvest information is confidential because only two processors purchased the harvest. The entire GHL was not taken in 2005, therefore the fishery was open until December 31, 2005.

No vessels registered to fish for Pribilof Islands golden king in 2006 and 2007.

The Pribilof Islands golden king crab fishery is not included in the Crab Rationalization program.

<u>Information on bycatch and discards</u>

Information on bycatch and discards during the Pribilof Islands golden king crab fishery and other Bering Sea crab fisheries is obtained by observers deployed on fishing vessels by the State of Alaska shellfish observer program (Schwenzfeier et al. 2008). 2001 was the first year observers were deployed in Bering Sea golden king crab fisheries (Neufeld and Barnard 2003) and 100% observer coverage is required in this fishery (Scwhenzfeier et al. 2008). A summary of the information obtained by observers on bycatch and discards during the Pribilof Islands golden king crab fishery is provided in annual reports (e.g., Barnard and Burt 2006); however, much of the data on this fishery in those reports are confidential due to low participation of vessels or processors. Estimates of bycatch of golden king crabs in reporting areas 513, 517, and 521 provided by NMFS (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office, 31 March 2008) are used to estimate the bycatch of the Pribilof Islands stock.

<u>Summary of historical catch distributions</u>

A total catch weight (retained catch plus handling mortality of discards) was not estimated because of the variety of fisheries in which bycatch can occur and the lack of accepted handling mortality rates for golden king crabs in those fisheries. Catch data that includes estimates of both the retained catch and the discarded bycatch of Pribilof Islands golden king crabs are limited to only the few recent years that observers were required during the directed fishery and to those years that the directed fishery data are not confidential. Table 2a provides the time series of GHLs, weight of the retained catch during the directed fishery, and estimated weight of discarded bycatch during crab fisheries for 2001–2005. Most of the bycatch of Pribilof Islands golden king crabs occurs during the directed fishery, when prosecuted. Table 2b provides estimates of golden king crab bycatch during groundfish fisheries in reporting area 513, 517, and 521 during 2003–2007. Weight of discarded bycatch during groundfish fisheries averages about 4% of the weight of the discarded bycatch during crab fisheries.

The actual retained catch and GHL for the Pribilof Islands golden king crab fishery for 2000–2002 is compared graphically in Figure 2; in other years there was either no GHL established or the retained catch data are confidential. Over the period 2000–2002 the average retained catch has been as much as 15% below the GHL (2000) and as much as 0.3% above the GHL (2002).

Table 3 provides the longer history of retained-catch weights during 1981–2007; see Figure 3 for a graphical presentation.

Data

<u>Survey data</u>

There is no survey for Pribilof Islands golden king crabs.

<u>Total catch</u>

Harvest history for the Pribilof Islands golden king crab fishery (number of vessels, number of landings, number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs, average carapace length of landed crabs) by fishery season from the 1981/82 season through 2006 is provided in Table 3.

Collection of observer data on size distribution and estimated catch numbers of non-retained catch collected began in the Pribilof Islands golden king crab fishery in 2001. Those data, combined with observer data from the the eastern Bering sea snow crab fishery and the Bering sea grooved Tanner crab fishery were used to estimate the annual weight of non-retained catch of golden king crabs during commercial crab fisheries from 2001–2005 (provided by D. Barnard, ADF&G, 20 July 2007).

Catch at age or 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 Table 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.

Fishing effort
The time series of fishing effort (pot lifts) are provided in Table 3.

Sample sizes for length samples
Sample size for the length sample from the 2002 fishery is provided in Table 4.

Independently-Estimated Life-History Parameters

Length at age
There is no length-at-age relationship established for golden king crab.

Growth per molt
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.

Weight at length or weight at age
Parameters for estimating weight (g) from carapace length (CL, mm) of Pribolof Islands golden king crabs are provided in Table 5.

Natural mortality rate:
The default natural mortality rate assumed for king crab species by NPFMC (2007) is M =0.18. There are no estimates of natural mortality pertaining specifically to Pribilof Islands golden king crabs. Using data on tag recoveries of golden king crabs in the Aleutian Islands commercial fisheries, Siddeek et al (2002) provide an estimate of M = 0.38 as the most plausible among various estimates.

Parameters governing the maturity schedule:

- Males: Carapace length (CL) at maturity for male golden king crabs in the Bering Sea has been estimated by Otto and Cummiskey (1985) using Somerton's (1980) method of estimating the intersection point of lines estimated to fit two phases of growth in height of the right chela relative to CL:
    - Central Bering Sea (north of 54°14' N and south of 58°31' Nlatitude): 107.0-mm CL (SD = 4.6 mm)

  Paul and Paul (2001b) studied mating success of male golden king crabs collected from Prince William Sound. The two smallest males studied (95-mm CL and 99-mm CL) could not induce females to ovulate. The smallest male examined that fertilized a female (a 101-mm CL male) fertilized a clutch in which only 71% of the eggs initiated division. In almost all of the clutches fertilized by hardshell males ≥107-mm CL, ≥90% of the eggs initiated division.

- Females: Otto and Cummiskey (1985) estimated CL at maturity for female golden king crabs in three areas within the Aleutian Islands Area as the estimated CL at which 50% of females are mature (SM50; as evidenced by presence or absence of clutches of eggs):
    - Central Bering Sea (north of 54°14' N and south of 58° 31' N latitude): 99.9-mm CL (SD = 0.2 mm)

Background and Analysis for Tier-5 OFL and Recommended OFL

No assessment model for the Pribilof Islands golden king crab stock exists and none is in development; hence this stock is recommended to 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" (NPFMC 2007). Additionally, NPFMC (2007) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." This section provides background for considering the appropriate time period for estimating OFL.

Time periods for averaging the retained catch.
NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof Islands golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching during the 1976/77 "regime shift" and growth to legal size. With regard to excluding data from years 1985 to 1992 and years after 1999, NPFMC (2007) states, "The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than 10% of the average or the GHL was set below the previous average catch."

With regard to the period 1985–1992, it should also be noted that for four of those years (1985, 1987–1989) the retained catch is confidential and for the other four years (1986, 1990–1992) there were no landings from the fishery (Table 3, Figure 3). With regard to using years after 1999, it should be noted that for three of the years (2003–2005) the retained catch is confidential, for two of the years (2006 and 2007) there were no landings from the fishery, and for the remaining three years (2000–2002) the retained catch is from fisheries which were managed for the first time to a GHL of 150,000 pounds.

Recent observations on stock status
Bowers et al. (2008, pages 85–86) offered the following recent observations on stock status:

> The golden king crab population in the Pribilof District is not surveyed and no estimate of abundance has been made. There are no plans to survey this population, nor has a formal harvest strategy been developed. Population size is believed to be limited by the amount of available habitat in the Pribilof District. The fishery is currently managed using a GHL set from the long-term average harvest. Data collected by onboard observers in conjunction with data from the landed catch are used to annually evaluate the status of the stock. Since 2002, the average size of legal male golden king crab taken during the commercial fishery has decreased while CPUE has increased suggesting that strong recruitment to the legal male portion of the stock has recently occurred.

<u>Computations of average retained catch as estimate of OFL</u>.

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 five completed seasons since the 2002, fishery data for three of the seasons are confidential and there was no fishery effort in the remaining two seasons. Hence the author recommends that years after the 2002 fishery season not be included in any computation of average retained catch weight as a measure of OFL. Average retained catch 1993–2002 was 164,297 pounds. The 1993–2002 period includes the 2000–2002 seasons, which were each constrained by a GHL of 150,000 pounds. The average retained catch during the "pre-GHL" seasons of 1993–1999 was 174,206 pounds. The average retained catch during the 2000–2002 seasons, which were constrained by the GHL of 150,000 pounds, was 141,176 pounds. See Table 6.

<u>Recommended OFL</u>**.**

- The assessment author made no recommendation on the OFL for this stock to the CPT at their May 2008 meeting.
- At their May 2008 meeting, the CPT recommended that the OFL be set as a retained catch of 174,206 pounds (the average annual retained catch during the 1993–1999 seasons). The recommendation was based on the 1993–1999 seasons representing a period that the fishery was developed but unconstrained by a GHL.
- At their June 2008 meeting, the SSC concurred with the CPT's recommendation and recommended that the OFL be set as a retained catch of 174,206 pounds. The recommendation was based on the 1993–1999 seasons representing a period that the fishery was developed but unconstrained by a GHL.

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Table 1. Mean CPUE by depth for 1,497 bycatch samples taken during the 2002 Pribilof Islands golden king crab fishery. (from Barnard and Burt 2004).

Depth	Percent of Sampled Pots	Catch per sampled pot			
		Legal	Sublegal	Female	Total
101-110	0.2	0	0	0	0
111-120	0.5	0.6	0.3	0	0.9
121-130	1.4	3.4	0.1	0	3.6
131-140	4.9	5.7	0.5	0.1	6.3
141-150	10.8	5.8	1.3	0.6	7.7
151-160	10.8	6.6	2.6	1.0	10.2
161-170	7.3	8.7	2.7	1.1	12.6
171-180	4.9	8.1	4.7	3.4	16.3
181-190	9.6	10.4	10.3	5.6	26.3
191-200	4.2	8.6	8.3	4.0	20.8
201-210	3.1	11.2	3.6	4.2	19.0
211-220	1.9	10.2	1.8	2.1	14.1
221-230	2.1	8.0	1.3	0.9	10.2
231-240	1.0	6.3	1.3	1.1	8.7
241-250	2.5	4.4	1.4	0.6	6.4
251-260	2.2	6.8	2.1	1.3	10.2
261-270	5.1	6.1	2.9	2.5	11.4
271-280	5.3	5.9	3.9	3.4	13.2
281-290	5.5	7.2	2.1	1.5	10.7
291-300	2.7	6.9	1.2	1.1	9.2
301-310	2.7	11.4	3.3	2.1	16.8
311-320	3.6	11.3	2.2	0.6	14.2
321-330	3.4	10.2	1.9	0.4	12.5
331-340	3.6	8.9	1.6	0.4	10.9
341-350	0.1	0	2.0	0	2.0
351-360	0.3	0.3	0.3	0	0.5
361-370	0.1	0	0	0	0
371-380	0.1	0	0	0	0

Table 2a. Annual guideline harvest level (GHL) for retained catch (pounds), actual retained catch (pounds), and estimated non-retained discards (pounds) for the Pribilof Islands golden king crab fishery, 2001–2005. There were no landings of Pribilof Islands golden king crab during 2006–2007. Non-retained catch includes bycatch during the Pribilof Islands golden king crab fishery, the eastern Bering Sea snow crab fishery, and the Bering Sea grooved Tanner crab fishery (bycatch weight estimates were provided by D. Barnard, ADF&G, 20 July 2007).

Year	GHL	Retained catch	Non-retained discards
2001	150,000	145,876	42,054
2002	150,000	150,434	42,223
2003	150,000	Confidential	49,118
2004	150,000	Confidential	30,266
2005	150,000	Confidential	18,659

Table 2b. Estimated annual weight (pounds) of discarded bycatch of golden king crabs (all sizes, males and females) during groundfish fisheries (all gear types and fisheries pooled) in reporting areas 513, 517, and 521, 2003–2007 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office, 31 March 2008).

Year	513	517	521	Total
2003	12	988	145	1,144
2004	1	605	93	699
2005	4	365	601	970
2006	1	2,762	204	2,968
2007	25	1,887	251	2,162
Average	9	1,321	259	1,589

Table 3. Harvest history for the Pribilof Islands golden king crab fishery from the 1981/82 season through the 2006; no effort and landings occurred in 2007.

	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	0				NO LANDINGS				

[a]Deadloss included.
[b]In pounds.
[c]Number of legal crabs per pot lift.
[d]Carapace length in millimeters.
NA = Not available.
Confidential = Less than three vessels or processors participated in the fishery.

Table 4. Carapace length (CL, mm) frequency distribution from biological measurements of retained golden king crabs sampled by season during the 2002 Pribilof Islands golden king crab fishery (data from ADF&G shellfish observer database, Kodiak, April 2008).

CL (mm)	Count	CL (mm)	Count
116	1	151	10
117	0	152	21
118	1	153	19
119	1	154	18
120	1	155	15
121	2	156	14
122	5	157	14
123	4	158	18
124	11	159	14
125	11	160	11
126	18	161	12
127	13	162	5
128	24	163	12
129	12	164	8
130	22	165	12
131	15	166	10
132	22	167	10
133	18	168	12
134	29	169	3
135	32	170	9
136	18	171	1
137	25	172	5
138	29	173	4
139	20	174	3
140	33	175	1
141	21	176	0
142	33	177	2
143	26	178	1
144	29	179	0
145	23	180	2
146	18	181	0
147	20	182	0
148	20	183	0
149	18	184	0
150	30	185	0
		186	0
		187	1
		Total	872

Table 5. Estimated parameters (A and B) for estimating weight (g) from carapace length (CL, mm) of male and ovigerous female golden king crabs according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007).

Parameter	Males	Ovigerous females
A	0.0002988	0.001424
B	3.135	2.781

Table 6. Average annual retained catch (pounds) in the Pribilof Islands golden king crab fishery during the periods 1993–2002, 1993–1999, and 2000–2002.

Time Period	Average retained catch (pounds)
1993–2002[a]	164,297
1993–1999	174,206
2000–2002[a]	141,176

a. The 2000–2002 seasons were constrained by a GHL of 150,000 pounds.

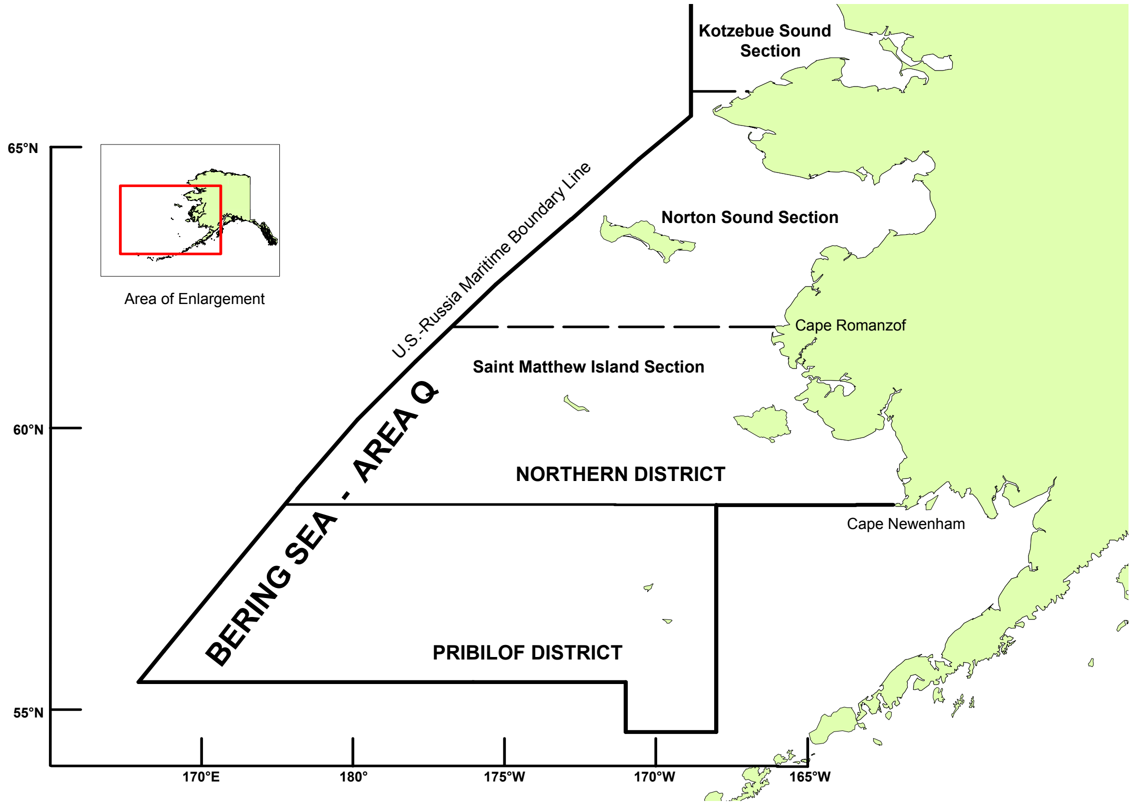

Figure 1. King crab Registration Area Q (Bering Sea) (from Bowers et al. 2008).

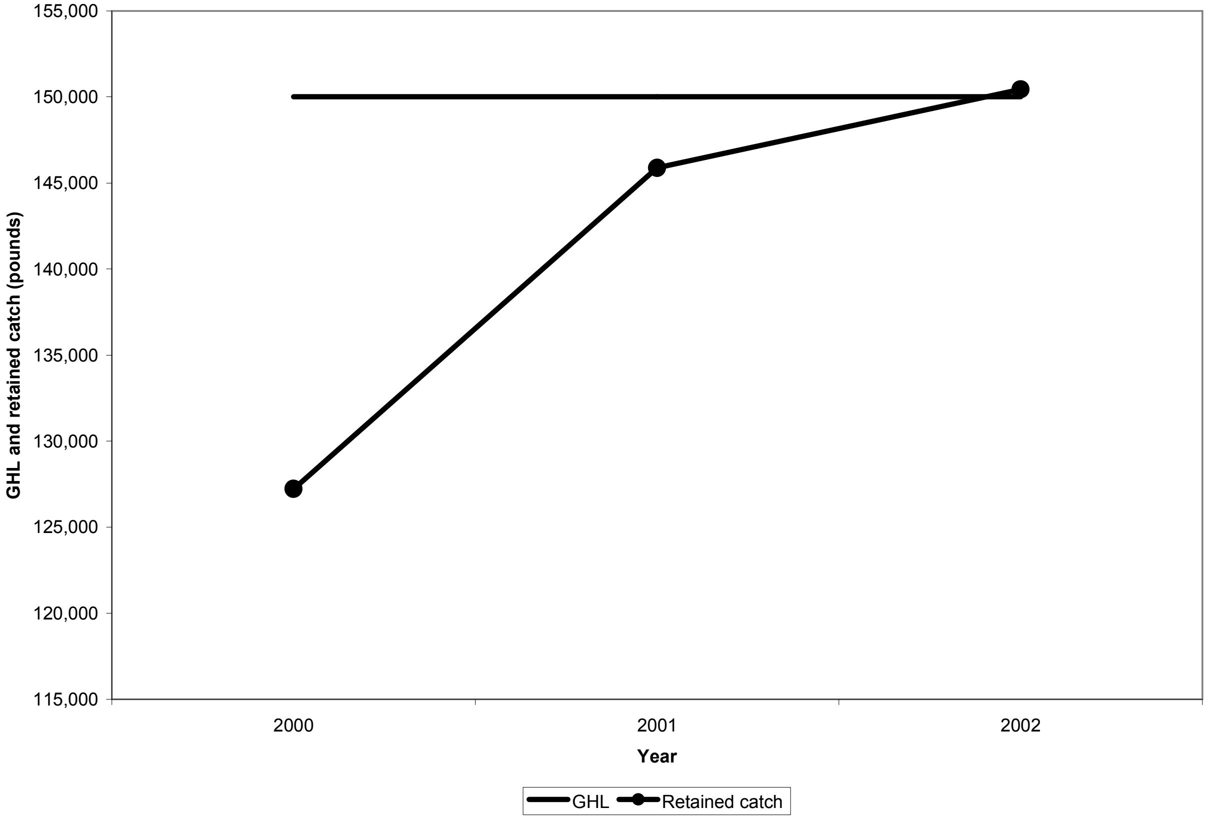

Figure 2. Pre-season GHL (pounds) compared to the retained catch (pounds) during 2000–2002 Pribilof Islands golden king crab fishery.

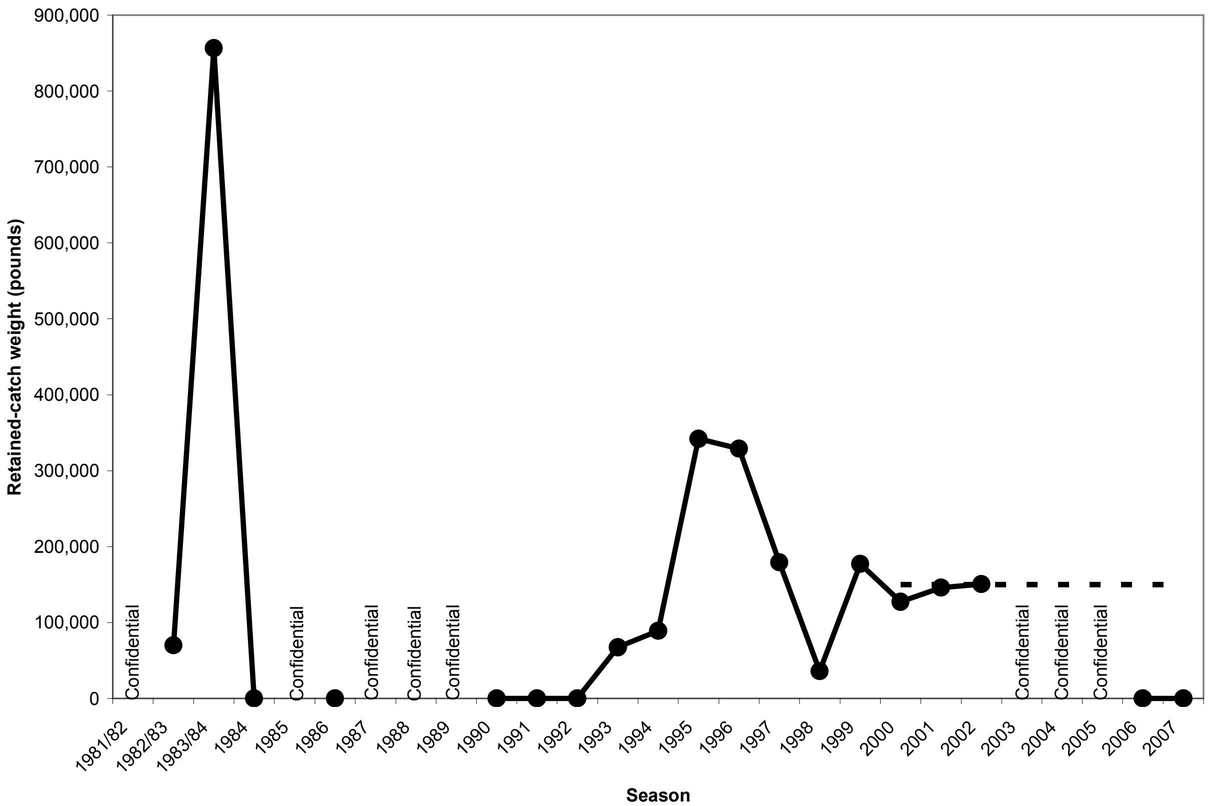

Figure 3. Retained catch (pounds; filled circles and solid line) during the 1981/82 through 2007 Pribilof Islands golden king crab fishery seasons, as compared to the 150-thousand pound GHL established for the fishery during the 2000–2007 seasons (dashed line).

Adak Red King Crab

2008 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak, 22 August 2008

Executive Summary

Stock: Red king crab/Adak (Aleutian Islands, west of 171° W longitude)

Catches: The domestic fishery has been prosecuted since 1961 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 943-thousand pounds, but the retained catch during the 1995/96 season was only 39-thousand pounds. During the 1995/96 through 2007/08 seasons, the fishery was opened only occasionally. There was an exploratory fishery with a low GHL in 1998/99, three commissioner's permit fisheries in limited areas during 2001 and 2002 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 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 506-thousand pounds (2002/03) and 479-thousand pounds (2003/04). The fishery has been closed 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 non-retained catch during the 1996/97–2006/07 seasons has been low (<50-thousand pounds in crab fisheries and <50-thousand pounds in groundfish fisheries); the average total annual bycatch (i.e., in crab and groundfish fisheries combined) from 1996 through the 2007/08 season is estimated to be 25-thousand pounds. During 2002 and 2003, the estimated bycatch in the crab and groundfish fisheries was <20% of the retained catch in the 2002/03 and 2003/04 seasons.

Data and assessment: There is no assessment model in use for this stock. Available data are from fish tickets (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date) through the 2007/08 season, size-frequency data from samples of landed crabs, at-sea observer data from pot lifts sampled in the directed fishery and the Aleutian Islands golden king crab fishery (includingdate, location, soak time, catch composition, size, sex, and reproductive condition of crabs) during 1996/97–2007/08, data on bycatch in groundfish fisheries within areas 541, 542, and 543 during 1996-2007 and 2007/08, data from two ADF&G-Industry pot surveys during 2001 in the Petrel Bank area (north of 51° 45' N latitude and between 179° W longitude and 179° W longitude), data from an ADF&G-Industry survey in the vicinity of Adak, Atka, and Amlia Islands (between 172° W longitude and 179° W longitude), and data from an ADF&G pot survey during 2006 in the Petrel Bank area.

Unresolved problems and major uncertainties: 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.

Reference points: This stock is recommended for placement in Tier 5; the CPT concurred with this recommendation in May 2008, as did the SSC in June 2008. For Tier 5 stocks B_{MSY} and MSST are not estimated and OFL is defined as "the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Although the CPT recommended in May 2008 that the OFL for 2008/09 be set at 26,287 pounds of bycatch only (representing the estimated average annual bycatch for the period 1996–2007), the SSC recommended in June 2008 that the OFL be set at 464,762 pounds of retained catch (representing the average retained catch over the time period 1985/86–2007/08). See SSC comment #1, under "Responses to SSC Comments," below.

Stock biomass: Estimates of stock biomass are not available.

Recruitment: Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. The fishery was closed at 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) provided no evidence of strong recruitment.

Exploitation status: The directed fishery has been closed since the end of the 2003/04 season; there is some bycatch in the golden king crab fishery (average per year = 6,724 pounds for 1996/97–2007/08) and groundfish fisheries (average per year = 13,173 pounds for 1996-2007 and 2007/08).

Management performance: The fishery was only managed strictly towards a preseason GHL in the 2002/03 and 2003/04 seasons. The GHL for both of those seasons was set at 500,000 pounds and the retained catch was within 1% of the GHL in the 2002/03 season and was within 4% of the GHL in the 2003/04 season. Estimated weight of discarded bycatch of red king crabs during those two seasons (including that attributable to the Aleutian Islands golden king crab fishery and to the groundfish fisheries in areas 541, 542, and 543) was less than 20% of the retained catch. The directed fishery has been closed since the end of the 2003/04 season. The fishery area west of 179° W longitude has been regulated under the BSAI Crab Rationalization program since 2005.

Forecasts: No forecasts of catch and biomass are available.

Decision table: Not available.

Recommendations: This fishery has a long history, with the domestic fishery dating back to 1961. However, much of the data on this stock prior to the early-mid 1980s is difficult to retrieve and analyze. Changes in definitions of fishery statistical areas over the history of the fishery also make it difficult to assess geographic trends in effort and catch over much of the fishery's history. An effort to compile all written documentation on the stock and fishery, to enter all existing fishery, observer, survey, and tagging data into a database that allows for analyses of all data from the stock through the history of the fishery would be very valuable. See also "Reference Points," above, for recommendations concerning OFL.

Responses to SSC Comments

At their June 2008 meeting, the SSC reviewed the May 2008 draft of this SAFE chapter and the recommendations made in May 2008 by the CPT. Recommendations from the SSC specific to management of this stock or to this SAFE chapter are listed below followed by the response from the author.

1. Manage this stock as a Tier 5 stock with the OFL for 2008/09 set at the average retained catch over the time period 1985/86–2007/08, or 464,762 pounds.
    - The author and the CPT in May 2008 recommended that the stock be managed as a Tier 5 stock, but the author made no recommendation on the OFL level to the CPT at their May 2008 meeting. Due to the apparent current low level of the stock and the lack of retained

catch data from unconstrained fisheries in the last 12 seasons (many of which were closed due to conservation concerns), the assessment author could not recommend a time period for averaging retained catch to estimate OFL. However, four candidates for OFL, estimated as average retained catch for four different time periods from within 1985/86–2007/08, were presented and discussed in the May 2008 draft of this chapter. The CPT in May 2008 recommended a bycatch-only OFL of 26,287 pounds, representing the estimated average annual bycatch for the period 1996–2007. The SSC recommended the OFL be set as the average retained catch over the period 1985/86–2007/08 (464,762 pounds) because that period, "includes periods of high and low catches, including periods when the fishery was closed because of conservation concerns," and because "these catches likely reflect fluctuations in stock abundance and the average retained catch should be a more appropriate proxy for long-term average production potential than a proxy based on bycatch only" (page 15 of the Draft Report of the Scientific and Statistical Committee to the North Pacific Fishery Management Council, June 2-4, 2008). The author notes that evidence is presented in this SAFE chapter (results of a recent survey and trends in catch and bycatch) that the stock may not have the potential for production in 2008/09 at the level of the long-term average. For example, a graph of the retained catch during 1984/85–2007/08 (added to this chapter at the request of the SSC; see comment 7, below), clearly shows a declining trend in retained catch from 1985/86 through 2007/08; i.e., the period of high catches was 1985/86–1993/94, whereas the period of low catches and of season closures because of conservation concerns was 1994/95–2007/08. Given that trend, the long-term average annual retained catch over 1985/86–2007/08 may not provide the best measure of production potential for 2008/09. Regardless of the OFL established, the author notes that the State of Alaska has stated its intention to manage the rationalized portion of the Adak area red king crab fishery in a precautionary manner, including keeping the fishery closed in the absence of stock assessment data that would indicate rebuilding of the population.

2. Explore the possibility of using a biomass dynamics (production) model to assess this stock, if the large observed changes in the distribution of the fishery can be adequately addressed.
    - The author recognizes the value of the recommendation and accepts it as a long-term goal for assessment of this stock.

Recommendations from the SSC on assessments in general that have application to this SAFE chapter are listed below followed by the response from the author.

3. Omit sections from chapter that are not relevant to this stock.
    - Sections that are not relevant to this stock and chapter have been removed (e.g., "Summary of Major Changes," "Model Structure," "Parameters Estimated Conditionally," "Model Evaluation," etc) and section/sub-section headings have been reworded or re-arranged as needed to be more appropriate to this chapter.
4. Clearly articulate the rationale for selecting a specific time period for establishing an OFL based on catch histories; the default should be the full time series for which data are available, unless compelling reasons exist to choose a different period.
    - See SSC comment #1, above.
5. To the extent possible, bycatch information should be provided in the SAFE in order to move stocks from "retained catch OFL" to "total catch OFL".
    - The draft of this chapter in the May 2008 Draft Crab SAFE included data on bycatch from crab fisheries through the 2006/07 seasons and groundfish fisheries through 2007. Information on bycatch has been updated to include bycatch estimates for the crab and groundfish fisheries during the 2007/08 season. In next year' s report the author will consolidate tables on catch and bycatch to allow for easier inspection of data and consideration of a total catch OFL for this stock. Consideration of a total-catch OFL for

this stock will also involve consideration of the variety of fisheries in which bycatch can occur and the estimates of the handling mortality rates for red king crabs in those fisheries.

6. Expand ecosystem considerations section to include information on prey and predator composition in a consistent format (e.g., pie charts); a discussion of seabird predation would be a useful addition.
   - This chapter contains no section on ecosystem considerations. Realistically, a section on ecosystem considerations section for this unsurveyed, remote, and poorly-known stock is a long way away. Presently, priority effort should be towards gaining and presenting data on stock distribution, abundance, and dynamics. However, any information provided to the author on ecosystem considerations (e.g., predators and prey) for this stock would be included in future chapters.
7. Include figures showing available time series of catch (in addition to tables) to facilitate comparisons of appropriate time periods.
   - The draft of this chapter in the May 2008 Draft Crab SAFE included separate graphs of the time series of retained catch during 1985/86–1995/96 and of that for during 1996/97–2006/07; that choice apparently made sense to the author at the time that the May 2008 draft was prepared, but the reasoning behind that is now a little sketchy. A graph of retained catch for the period 1984/85–2007/08 is included in the present draft.

Introduction

<u>Scientific name</u>: *Paralithodes camtschaticus*, Tilesius, 1815

<u>Description of general distribution</u>
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; Table 1); 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).

<u>Description of management units and spatial and/or seasonal management measures</u>
Although the Adak Registration Area is no longer defined in Stateregulation, 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 Failor-Rounds (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 (Figure 2). The geographic boundaries of the Adak red king crab stock are defined 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.

The Adak Area red king crab fishery west of 179° W longitude is managed 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 and remains open-access (Failor-Rounds 2008; but see below for restrictions on vessels in state waters between 172° W longitude and 179° W longitude).

The following area closures have been applied to the red king crab fishery in the Adak Area:

- The 1998/99 season for red king crab in the Adak Area was open east of 179° W longitude and west of 179° E longitude, but was closed between 179° W longitude and 179° E longitude.
- ADF&G-Industry pot surveys for red king crabs were conducted in January—March 2001 and November 2001 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; Failor-Rounds 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; Failor-Rounds 2008). 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"; Failor-Rounds 2008). The remaining area in the Adak Area was closed to commercial red king crab fishing during the 2003/04 season.

By State of Alaska regulation (5 AAC 34.610 (a)):

> The commissioner may open and close, by emergency order, a season for male red king crab [in the Aleutian Islands Registration Area O] beginning 12:00 noon, October 15 and ending no later than 11:59 p.m. February 15.

Additionally, by State of Alaska regulation (5 AAC 34.610 (d)):

> During a fishing season opened under (a) of this section in the waters of Alaska [in the Aleutian Islands Registration Area O] between 172° W. long. and 179° W. long., the commissioner may issue a permit only to a vessel 90 feet or less in overall length, to fish for red king crab.

<u>Evidence of stock structure</u>
Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crab originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51° 51' N latitude, 176° 39' W longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)."

We know of no analyses of genetic relationships among red king crab from different locations within the Adak Area. However, given the expansiveness of the Adak Area and the canyons between some islands that are deep (>1,000 m) relative to the depth zone restrictions of red king 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.

<u>Description of life history characteristics relevant to stock assessments</u>
Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crabs fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987, McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen 1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crabs:

> Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season.

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, there is little data on reproductive condition of Adak red king crab females that has 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 October 2002/03 and October 2003/04 red king crab seasons in the Petrel Bank area, 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.

Fishery

<u>Description of the directed fishery</u>

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).

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)).

There is a pot limit of 250 pots per vessel for vessels fishing in the Petrel Bank red king crab fishery in king crab Registration Area O (5 AAC 34.625 (d)).

The following historical review of the red king crab fishery in the Adak Area is from Failor-Rounds (2008, pages 4–6):

> Historically, the red king crab *Paralithodes camtschaticus* resource in the Aleutian Islands was harvested in two registration areas. The Adak Registration Area (Area R) consisted of those waters in the Aleutian Islands west of 171° W long., while the Dutch Harbor Registration Area (Area O) encompassed waters east of 171° W long. In addition, as the fleet moved westward, a third Registration Area (Area S) was established for the waters around Amchitka Island and the Petrel Bank. Area S was created in 1967 and was merged into Area R in 1978. In March of 1996, the Alaska Board of Fisheries (BOF) established the Aleutian Islands king crab Registration Area (Area O) by combining the existing Dutch Harbor and Adak Registration areas. The BOF adopted this change to improve management of the increasingly important golden king crab *Lithodes aequispinus* resource in the Aleutian Islands. Combining the Adak and Dutch Harbor areas was not expected to impact management of red king crabs in the Aleutian Islands.
>
> Domestic fisheries for red king crabs in both the Adak and Dutch Harbor Registration areas began in 1961, with effort and harvest rapidly increasing in both areas. The Adak Area reached a peak harvest of 21 million pounds in 1964/65 [text concerning the Dutch Harbor Registration Area omitted. Note that 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 into the early-1980s, the area west of 179° 15' W longitude began to account for a larger portion of the retained catch (ADF&G 1978, 1983).].
>
> In the late 1970s, GHL ranges were established using a blend of pot survey results and fisheries data. Historic fishery GHLs set in the late 1970s ranged [text concerning the Dutch Harbor Registration Area omitted] from 0.5 million to 3.0 million pounds in Adak. GHLs were often modified inseason based on fishery performance.
>
> Fluctuating harvest levels from one year to the next characterized the fisheries in the Dutch Harbor and Adak areas [text concerning the Dutch Harbor Registration Area omitted]. The Adak fishery remained open through the 1995/96 season when only 39,000 pounds were harvested. After the 1995/96 season the fishery was closed for several years. Portions of the area were opened during the 1998/99, 2000/01, and 2001/02 seasons in order to assess the status of red king crab stocks. In 2002 the Petrel Bank portion of Area O was reopened to commercial fishing with a guideline harvest level (GHL) of 500,000 pounds.
>
> Observers have been required on all crab catcher-processor vessels since 1988 and on catcher vessels targeting red or golden king crabs in the Aleutian Islands since 1995. Observer coverage on golden king crab vessels provides red king crab incidental catch

data from that fishery, although red king crab bycatch in golden king crab gear is minimal due to the limited overlap in distribution of the two species. Observer coverage also provides data on retained and non-retained crabs as well as information related to fishing patterns.

Pot surveys in the western Aleutian Islands conducted from 1975 to 1977 provided catch per unit of effort (CPUE), fecundity, and relative abundance information of red king crabs. [see ADF&G 1978; text concerning the Dutch Harbor Registration Area omitted]. In 1996 and 1997, a catcher-processor vessel was permitted to target red king crabs on the Petrel Bank in conjunction with their directed golden king crab fishing. The goals of this project were to enumerate, tag, and collect biological data from all red king crabs captured and to recapture tagged individuals. During this two-year period, a total of 926 crabs were tagged along the north side of Amchitka Island and along the south side of Semisopochnoi Island. Of the tagged crabs, 440 were legal males and 160 were females; 89% of legal crabs were new shell. Recovery efforts yielded 15 tagged crabs, six of which were legal males. While the tagging was too limited to provide quantitative stock assessment data, it did provide some information related to migration, molting cycle, and seasonal distribution [see Byersdorfer 1998].

In order to assess the status of red king crab stocks in two areas of the Aleutian Islands without recent abundance information, a limited commercial fishery was opened on November 1, 1998 with the provision that crabs not harvested be tagged and released. In addition, vessel operators were required to document all red king crab fishing activities in a pilothouse logbook. East of 179° W long., a GHL of 5,000 pounds was established and west of 179° E long., a GHL of 10,000 pounds was set; these GHLs were set using historic catch information. Closed waters included the Petrel Bank (the area between 179° E long. and 179° W long.). The Alaska Department of Fish and Game (ADF&G) did not open the Petrel Bank area in 1998/99 since prior efforts had provided some population data from that area.

Three vessels registered to harvest red king crabs in the Aleutian Islands during the 1998/99 season, but only one recorded landings. The GHL was not reached in either open area and the fishery was closed by emergency order on July 31, 1999. Observers were required on all vessels participating in the 1998/99 fishery.

In order to gain information on red king crab abundance in the Petrel Bank area, two surveys were conducted in January/February and November, 2001. Due to budget constraints, the surveys were designed so fishers could retain and sell all legal male red king crabs captured to cover survey expenses. The commissioner's permit specified stations to be fished, soak times and effort levels.

Capture of red king crabs from both 2001 surveys in the Petrel Bank area indicated healthy levels of legal males. CPUE for the combined surveys was 28. Survey CPUEs are not directly comparable to previous commercial fishery CPUEs because pot lifts in prior commercial fisheries were not conducted in a systematic manner and may have occurred in different fishing locations. Sublegal male and female CPUE for the combined surveys was two and three, respectively.

Size composition data from the 2001 surveys were comparable to the size composition of catches prior to the 1995/96 fishery closure. The size composition and shell condition data indicated that approximately 61% of the sampled legal-size crabs were post recruits.

Of the crabs sampled 77% were new-shell. Similar to the surveys conducted in the mid-1990s, very few sublegal crabs were captured during the 2001 surveys.

The surveys conducted in 2001 indicated that legal male abundance increased since the fishery was closed, however, red king crab female and sublegal abundance remained low. Given the legal male abundance, a limited commercial fishery on the Petrel Bank was opened during the 2002 and 2003 seasons with a GHL of 500,000 pounds. Based on expected effort, this was considered the minimum GHL that could be managed inseason. Because of the uncertainty in the status of sublegal and female red king crabs and to provide for overall stock protection, ADF&G adopted a management strategy that would close the fishery prior to achieving the GHL if legal male CPUE drops below 10 crabs/pot. Establishing a low GHL with a moderate CPUE threshold level should help prevent the stock from declining to levels seen in the mid-90s. Trends in fishery performance were used to evaluate GHLs and having a defined threshold for closing the fishery permitted clearer understanding of the management strategy.

Thirty-three vessels participated in the 2002 Petrel Bank red king crab fishery. The fleet pulled 3,786 pots, an average of 115 pots per vessel. CPUE for the Petrel Bank was 18 legal crabs per pot lift and the fleet harvested a total of 505,642 pounds. Exvessel price averaged $6.51 per pound and the 2002 Petrel Bank fishery had a total value of over $3.29 million.

During the 2003 Petrel Bank red king crab fishery a total of 479,113 pounds were harvested by 30 vessels in 91 hours. The fleet pulled 5,774 pots and average CPUE was 10 legal crabs per pot lift. Exvessel price averaged $5.14 per pound and the 2003 Petrel Bank fishery had a total value of nearly $2.45 million.

The Petrel Bank red king crab fishery was closed in 2004 and 2005 due to low levels of sublegal crab and females seen in the 2002 and 2003 fisheries, along with the low legal male CPUE seen toward the end of the 2003 fishery.

In 2005 Crab Rationalization was implemented for the major Bering Sea and Aleutian Islands crab fisheries. Western Aleutian Islands red king crab (west of 179° W long.) is included in this program and will have both Individual Fishing Quota (IFQ) and Community Development Quota (CDQ) fisheries when the stock is again open to commercial harvest.

The red king crab fishery in the Adak Area has continued to be closed to commercial fishing through the 2007/08 season since the end of the 2003/04 season.

Failor-Rounds (2008, pages 8–9) reviewed fishery management of red king crab in the Adak Area:

Fishery Management and Stock Status 171° W Longitude to 179° W Longitude

A vessel may not be registered to fish in the commercial red king crab and golden king crab fisheries concurrently between 171° W long. and 179° W long. This red king crab fishery remains open access and was not included in crab rationalization. Regulations do not allow vessels to retain IFQ and non-IFQ species concurrently.

In November of 2002 ADF&G conducted a survey similar in design to the Petrel Bank surveys of 2001 in the area between 172° W long. and 179° W long. The survey area was developed in consultation with industry and focused on areas of historic red king crab abundance in the Adak, Atka, and Amlia Islands areas that have been closed to commercial red king crab fishing since the 1998/99 season and had not been previously surveyed. The survey had a total of 116 stations that were divided between state-waters (56 stations) and federal-waters (60 stations).

Ten vessels conducted 1,085 pot lifts in a total of 61 stations. Survey catches were poor and only four legal males were captured during the entire survey. Due to poor survey catches and high operation costs, many vessels were unable to fulfill their survey commitment and only 34% of the survey was completed. The portion of the survey that was completed indicates that the red king crab stocks around Adak, Atka, and Amlia Islands continue to be severely depressed [see Granath 2003]. Therefore, the department does not expect a commercial red king crab fishery to open in this area in the near future.

Fishery Management and Stock Status West of 179° W Longitude (Petrel Bank)

West of 179° W longitude a vessel may be registered to fish in the commercial red king crab and golden king crab fisheries concurrently; however, only single-line pots may be operated in areas open to red king crab fishing and only longline pots may be operated in areas open to golden king crab fishing. Likewise, red king crab may only be retained from single-line pots and golden king crab may only be retained from longline pots. Golden king crab fisheries in the Aleutian Islands are not restricted by pot limits. In the Petrel Bank red king crab fishery each vessel is restricted to a pot limit of 250 pots.

Shell-condition and size composition data from the 2001, 2002 and 2003 fisheries in the Petrel Bank area indicate that primarily older, post-recruit crabs supported these fisheries. Proportions of sublegal and female red king crabs did not change significantly from the 2001 surveys to the 2002 or 2003 commercial fisheries. Average weight and carapace length (CL) of legal male red king crabs increased from 2001 to 2003. Average weight and CL of legal male red king crabs increased from the surveys to 7.4 pounds and 162 mm in 2002 and up to 8.0 pounds and 168 mm in 2003. A mode of sublegal crab seen in 2003 (centered at 86 – 90 mm CL) is approximately three molts from attaining legal size.

Cumulative fishery CPUE did not drop below the benchmark of 10 during the 2003 fishery, although fish ticket data indicate that the fishery CPUE was 10 crabs per pot. Fishery CPUE climbed during the first 36 hours from 8.5 to 15.0 crabs per pot and steadily dropped for the remainder of the fishery with the exception of the morning of October 28, when most pots had soaked for an additional 12 hours. Compared to the combined survey CPUE of 28 and 2002 fishery CPUE of 18, performance during the 2003 fishery was not promising.

The harvest based approach using only legal-male CPUE as a threshold was developed to help maintain multiple size and age classes on the grounds to promote rebuilding. Using a threshold of legal male CPUE alone does not protect the stock. Because survey catch of sublegal and female crab was low, thresholds were not developed for those stock components. After the 2001 surveys, staff expressed concern about overall stock status. While legal male catch was encouraging, the lack of sublegal and female crab was disappointing. ADF&G now has two additional years of fishery information that have failed to indicate healthy levels of those stock components. Based on fishery performance and the lack of recruitment of legal-sized crabs, it was likely that the fishery would fail to stay above the threshold criteria of 10 crabs per pot if a fishery were prosecuted in 2004. Following the 2003 fishery, ADF&G made the decision to close the Petrel Bank red king crab fishery until the next survey was conducted in the fall of 2006.

A survey was conducted on the Petrel Bank area red king crab stock in November of 2006 [see Gish 2007]. This information was compared to the 2001 industry survey and the 2002 and 2003 commercial fisheries to evaluate current stock status. Because of differences in fishing practices between the 2001 survey, the 2002 and 2003 commercial fisheries, and the 2006 survey, a direct CPUE comparison could not be made. However, legal male red king crab catch rate during the 2006 survey was lower than during the 2001 survey and recent commercial fisheries. The 2006 survey CPUE of legal males was 1.2 crabs per pot from 170 stations fished. Red king crabs captured during the survey were predominately larger, mature-sized male crabs, and the size distribution of surveyed crabs provides no expectation for significant recruitment of legal males in the immediate future. Although males that were estimated to be new recruits to legal size accounted for 36% of the 2006 survey catch of legal crabs, recruitment occurring since the 2001 survey has been insufficient to rebuild legal male abundance to levels of the early 2000s. Spatial distribution of legal males during the 2006 survey decreased from the 2001 survey distribution and was limited to the northwestern portion of the Petrel Bank. Distribution of red king crabs was also restricted relative to harvest location during the last two commercial fisheries. Given the limited distribution and low relative abundance of legal male red king crab on Petrel Bank and the lack of projected recruitment to the legal size class in the near future, a harvestable surplus of red king crab is not currently available.

The implementation of Crab Rationalization designated a portion of the western Aleutian Islands (west of 179° W long.) red king crab fishery as an IFQ fishery. Individual fishing quota shares will allow harvesters to prosecute this fishery at any time during the biological season opening. Prior to rationalization, the overall pot limit in the Western Aleutian Islands red king crab fishery was 1,250 pots to be divided evenly among participants. Currently, regulations stipulate a pot limit of 250 pots per vessel. Observer coverage requirements remain at 100% of fishing activity.

Data

Survey data

Surveys on this stock have 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), the only standardized survey for red king crabs performed by ADF&G was performed in November 2006 and was limited to the Petrel Bank area (Gish 2007). The area surveyed in 2006 by ADF&G and the survey grid used was based on that of the November 2001 ADF&G-Industry survey (Figure 3). The November 2001 ADF&G-Industry survey was conducted as a commissioner's permit fishery (Bowers et al. 2002). Participants were allowed to fish 25 pot lifts anywhere within each of the 28 designated stations (see Figure 3, upper panel), with restrictions that included a pot spacing of no less than 1/8 nm apart, and they were allowed to retain any legal male red king crabs captured by those pots. During the 2006 ADF&G pot survey a survey station grid was established with station centers spaced by 2.50' latitude (2.50 nmi) north-to-south and 3.75' longitude (approximately 2.29 nmi) west-to-east. Four pots were fished at the centers of each station. Additionally, during the ADF&G survey several strings of pots were fished off the survey grid at locations based on the locations of strings of pots fished during the November 2001 ADF&G-Industry survey. A comparison of the effort and catch of red king crabs between the November 2001 ADF&G-Industry survey and the November 2006 ADF&G survey is provided in Table 2. A comparison of the catch of red king crabs captured in pots fished as off-survey-grid strings during the

November 2006 ADF&G pot survey with the catch at strings in the same location during the November 2001 ADF&G-Industry survey is provided in Table 3.

Another ADF&G-Industry survey was conducted as a commissioner's permit fishery in the Adak -Atka-Amlia Islands area in November 2002 (see Figure 4 and Granath 2003). Although the survey design called for a possible 2,900 pot lifts to be performed, survey participants only completed 1,085 pot lifts before withdrawing from participation. Four legal male red king crabs were captured: three legal males and one sublegal male red king crab were captured around Adak Island; no red king crabs were captured in areas on the north side of Atka Island, but an estimated 520 sublegal males and females were captured in one pot on the north side of Atka Island; one legal male and no sublegal or female red king crabs were captured on the north side of Amlia Island; and no red king crabs were captured on the south side of Atka and Amlia Islands. By comparison, ADF&G conducted a pot survey in the Atka-Amlia Islands area in 1977 and captured 4,035 male and 1,088 female red king crabs in 360 pot lifts (ADF&G 1978), although from those results it was reported that "King crab stocks at Adak still seem to be depressed" (ADF&G 1978, page 167).

Retained catch data

Harvest (retained catch) history for the red king crab fishery in the Adak Area (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) by fishery season from the 1984/85 season (the first season that the 171° W longitude line was used to divide the historic Adak and Dutch Harbor king crab Registration Areas) through the 2007/08 season is provided in Table 4a; data are from fish ticket database summaries produced by ADF&G Dutch Harbor during March 2008. A fishery data summary over the full history of the fishery (including years when the area was defined as west of 172° W longitude) is provided in Table 4b. Figure 5 provides a graphical presentation of the history of retained weights for the Adak Area red king crab fishery during 1984/85–2007/08, the period during which the Adak Area has been defined as is it presently is (i.e., the area west of 171° W longitude within the Aleutian Islands king crab Registration Area O).

The fishery was only managed strictly towards a preseason GHL in the 2002/03 and 2003/04 seasons. The GHL for both of those seasons was set at 500,000 pounds and the retained catch was within 1% of the GHL (at 505,642 pounds) in the 2002/03 season and was within 4% of the GHL (at 479,113 pounds) in the 2003/04 season.

Bycatch and discard data

Information on bycatch and discards during the Adak Area red king crab fishery is obtained by observers deployed on fishing vessels by the State of Alaska shellfish observer program (Schwenzfeier et al. 2008). Bycatch of red king crabs is also recorded by observers from randomly-sampled pot lifts during the Aleutian Islands golden king crab fishery. Additionally, during the 2001/02–2002/03 and 2004/05–2007/08 golden king crab fishery seasons, observers were instructed to document the catch and catch location of all red king crabs incidentally captured during the Aleutian Islands golden king crab fishery at all times that observers were present on the fishing vessels. During the 1988/89–1994/95 seasons observers were required only on vessels processing king crabs at sea, including catcher-processor vessels. Since 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, 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. A summary of the information obtained by observers on bycatch and discards during the Aleutian Islands crab fisheries is provided in annual reports (e.g., Barnard and Burt 2007). The Adak Area red king crab fishery and the Aleutian Islands golden king crab fishery are the only crab fisheries in which non-retained Adak Area red king crab are captured.

Observer data collected since the 1996/97 season on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of legal male, sublegal male, red king crabs during commercial fisheries for red king crabs in the Adak Area and for Aleutian Islands golden king crabs by season through the 2005/06 season according to the methods and parameters provided in Section 3.4 of NPFMC 2007. Estimates of the weight of non-retained catch of red king crabs during the king crab fisheries by sex-size class and season, 1996/97–2007/08, are provided and compared with weight of retained catch in Table 5. Weight of non-retained discards in crab fisheries was highest (35-thousand to 48-thousand pounds) during the 2001/02–2003/04 seasons, when the fishery in the Petrel Bank area was either open under permit conditions for performance of an ADF&G-Industry stock survey (2001/02) or opened for fishing under a GHL of 500-thousand pounds (2002/03–2003/04 seasons). Non-retained bycatch in crab fisheries during the 2002/03–2003/04 seasons was less than 10% of the retained catch.

Due to the frequent season closures of the directed red king crab fishery and to the restricted fishing area in the seasons when opened, the Aleutian Islands golden king crab fishery provides a longer and geographically broader data set on bycatch of Adak red king crabs than does the directed fishery. In addition to documenting the presence of red king crabs that occur in randomly-sampled pots during the Aleutian Islands golden king crab fishery, observers on fishing vessels during the 2001/02, 2002/03, and 2004/05–2007/08 Aleutian Islands golden king crab seasons have been instructed to document each red king crab that is captured while the observer is on the vessel. Data on the catch (numbers) of red king crabs during the 2001/02-2007/08 Aleutian Islands golden king crab seasons are summarized in Table 6. The trend in catch of red king crabs during the 2001/02-2006/07 Aleutian Islands golden king crab seasons (Table 6) is graphed as documented catch (number) per observed effort (numbers of pot lifts) in Figure 6. Except for the catch of legal males during the 2001/02-2003/04 seasons and of sublegal males and females during the 2003/04 season (which is based on only random pot samples), the documented catch of red king crabs per observed effort was low during the 2001/02-2006/07 Aleutian Islands golden king crab seasons. Catch per observed effort increased for sublegal males and, especially, females during 2007/08, but not appreciably for legal males. Nearly 60% of the red king crabs documented to have been captured as bycatch during the 2001/02–2007/08 Aleutian Islands golden king crab seasons were captured between 179° W longitude and 179° E longitude (Table 7), with most of those being captured on the margins of Petrel Bank and Petrel Spur. However, during the 2003/04 and 2007/08 seasons a large portion of the documented catch of red king crabs occurred between 178° W longitude and 179° W longitude (Table 7), in the vicinity of the Delarof Islands. A relatively large portion of the red king crab bycatch has also occurred in the area between 176° E longitude and 177° E longitude (i.e., between Kiska and Buldir Islands) in some seasons.

Estimated annual weight of red king crab captured as bycatch during groundfish fisheries, 1996-2007 and 2007/08, in reporting areas 541, 542, 543 (i.e., the Aleutian Islands west of 170° W longitude) is provided in Table 8. Highest bycatch tends to occur in reporting area 542 (defined as the Aleutian Islands between 177° W longitude and 177° E longitude), although the majority of bycatch since 2006 has been in reporting area 541 (defined as the Aleutian Islands between 170° W longitude and 177° W longitude).

Table 9 provides the estimated average annual bycatch weight of Adak red king crab during crab and groundfish fisheries, 1996/97–2007/08.

Total catch (retained catch and discard mortality) data for the crab fisheries

Table 10 provides the time series of GHLs/TACs, retained catch, estimated discard, and estimated total catch (estimated discard mortality and retained catch) for the period that estimates of bycatch during crab fisheries are available (i.e., the crab 1996/97–2007/08 seasons). The handling mortality rate for red king crabs during the red king crab fishery in the Adak Area and during the Aleutian Islands golden king crab fishery was not discussed by the Crab Plan Team during development of Amendment 24. However, as handling mortality rates of 10%, 20%, 30% were discussed for the Bristol Bay red king fishery (NPFMC 2007), we provide total catch estimates for assumptions of handling mortality rates of 10%, 20%, and 30%. Under the assumption that handling mortality of discards is 30%, the total catch during the 2002/03 and 2003/04 seasons, when the directed fishery was managed under a GHL of 500-thousand pounds within the Petrel bank area, is only 2–3% greater than the retained catch when considering only the handling mortality to bycatch during crab fisheries. Handling mortality of discards during the groundfish fishery was not included in the total catch estimation due to the mis-match in reporting periods (calendar years for the groundfish data during 1996–2007 and fishery seasons for the crab fishery data).

Catch at age or catch at length data
The size (carapace length, CL, mm) distribution of retained legal male red king crabs from the Adak Area red crab fishery sampled prior to processing at-sea and dockside by observers and ADF&G catch samplers by each opened season are provided in Table 11 and Table 12.

Fishing effort data
The 1984/95–2007/08 time series of fishing effort (pot lifts) is provided in Tables 4a and 4b.

Sample sizes for length sample data
Sample sizes for length samples from the Adak Area commercial fishery by season are provided in Table 11. Those from the three AD&G-Industry red king crab pot surveys in the Adak Area that were conducted as a commissioner's permit fishery are provided in Table 12.

Independently-Estimated Life-History Parameters

Length at age
There is no length-at-age relationship established for Adak Area red king crabs.

Growth per molt
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 (Table 13).

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 (Tables 14 and 15).

Weight at length or weight at age
Parameters for estimating weight (g) from carapace length (CL, mm) of BSAI red king crabs are provided in Table 16.

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.

Parameters governing maturity schedule:
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 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.

Background and Analysis for Tier-5 OFL and Recommended OFL

There is no regular survey of this stock and no assessment model for the Adak Area red king crab stock exists and none is in development; hence it is recommended 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 the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Additionally, NPFMC (2007) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." This section provides background for considering the appropriate time period for estimating OFL.

<u>Time periods for averaging the retained catch</u>.
NPFMC (2007) suggested using the average retained catch over the years 1985 to 1994 as the estimated OFL for Adak Area red 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 1995, NPFMC (2007) states, "The excluded years are from 1995 to 2005 for Adak red king crab when the fishery was closed, fishing effort was less than 10% of the average, or fishing was allowed only in a small part of the fishing ground." The annual retained catch during the post-1984 period is graphed in Figure 5.

<u>The 1985/86–1994/95 period</u>. There are several features about the fishery during the period 1985 to 1994 (which we take to be the 1985/86–1994/95 seasons) to note when considering the average harvest over this period as providing a measure of the "production potential of the stock" that provides "the required risk aversion for stock conservation and utilization goals." Although there were no area closures in effect for any of those seasons, 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 7). Before the 1990/92 season, however, significant portions of the harvest were attributable to areas east of the Petrel Bank area (the 1987/88-1989/90 seasons) or west of the Petrel Bank area (the 1985/86 season). Additionally, it is notable that both retained catch and the catch per pot lift (CPUE) of retained legal males declined during 1990/91–1994/95, the period when the majority of catch was harvested from the Petrel Bank area; the average annual retained catch was slightly over 1-million pounds and CPUE was 10–14 crabs per pot lift during the 1990/91–1992/93 seasons, whereas approximately 200-thousand pounds were harvested during the 1994/95 season at a CPUE of 2 crabs per pot lift (Table 4, Figure 8). Concurrent with the decline in catch and CPUE during the 1990/91–1994/95 seasons, the size frequency distribution in samples of the retained catch showed a clear progression of increasing size for 1990/91 through 1994/95, indicative of poor recruitment to legal size (Table 11, Figure 9). Finally, during the next season following the 1994/95 season (i.e., the 1995/96 season), less than 40,000 pounds were harvested (only half of that from the Petrel Bank area; Figure 7), although the entire area west of 171° W longitude remained open for red king crab fishing through the entire season (11/1/1995–02/15/1996; Failor-Rounds 2008).

<u>The post-1994/95 period</u>. Less than 40-thousand pounds were harvested during the 1995/96 season (see above) and the fishery in the Adak Area was closed for the next two seasons due to apparent low abundance and lack of recruitment.

The Adak Area east of 179° west longitude and west of 179° E longitude (i.e., outside of the Petrel Bank area was opened for limited exploratory fishing with a GHL of 15,000 pounds during the 1998/99 season. The GHL was not attained (Tables 4 and 10), but due to low participation in that season, the results of that exploratory fishing were inconclusive in providing information on the level of the stock outside of the Petrel Bank area at that time.

Results of two ADF&G-Industry surveys for red king crabs in the Petrel Bank area conducted as commissioner's permit fisheries in 2001 (Bowers et al. 2002) and the two fisheries opened for red king crabs in the Petrel Bank area in 2002/03 and 2003/04 (Bush et al. 2005) showed that legal males were present at least initially in high densities in the Petrel Bank area, although relatively few sublegal males or females were captured. However, CPUE declined from the 2001 surveys through the 2003/04 fishery season and fishery performance and observer data from those two seasons suggested that the harvests were supported largely by a single aging cohort of crabs and that prospects for new recruitment of legal males were poor (Bush et al. 2005). Based on those trends the fishery remained closed for the 2004/05–2006/07 seasons. The survey performed by ADF&G in the Petrel Bank area in November 2006 showed no indications of recovery of the stock there (Gish 2007; see also subsection "Survey data," in the section "DATA" of this chapter) and the fishery has remained closed through the 2007/08 season.

The ADF&G-Industry survey performed in the Adak, Atka, and Amlia Islands area in November 2002 provided no indication that red king crabs were at an abundance that could support a commercial fishery season in that area at that time (Granath 2002; see also subsection "Survey data," in the section "DATA" of this chapter).

The following changes in management measures by season after the 1995/96 season are also important if considering any seasons after the 1994/95 season to include in theestimat ion of the OFL from the average retained catch:

Season	Change in management measure
1996/97–1997/98	• Fishery closed
1998/99	• GHL of 15,000 pounds (for exploratory fishing) with fishery closed between 179° W longitude and 179° E longitude (i.e., the Petrel Bank area)
1999/00	• Fishery closed
2000/01	• Harvests during ADF&G-Industry survey of Petrel Bank area conducted as commissioner's permit fishery, Jan–Feb 2001
2001/02	• Harvests during 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
2004/05–2007/08	• Fishery closed

<u>Computations of average retained catch as estimate of OFL</u>

Average retained catch was computed for four periods during 1985/86–2007/08 and presented to the CPT at their May 2008 meeting (Table 17):

1) The full time period of the 1985/86–2007/08 seasons
2) The period of the 1985/86–1995/96, 2002/03, and 2003/04 seasons; i.e., the seasons during 1985/86–2007/08 that the fishery was opened, but not including the seasons that the fishery was opened only for limited exploratory fishing (1998/99) or opened under conditions of a commissioner's permit for conducting an ADF&G-Industry survey (2000/01 and 2001/02)
3) The period of the 1985/86–1994/95, 2002/03, and 2003/04 seasons; i.e., the same period as in (2), above, but excluding the 1995/96 season in which the harvest was low, fishery performance was poor, and which led managers to close the fishery for the next two seasons
4) The period during 1985/86–2007/08 in which the fishery was opened without intermittent closed seasons, but excluding the 1995/96 season in which the harvest was low, fishery performance was poor, and which led managers to close the fishery for the next two seasons.

The assessment author made no recommendation to the CPT at their May 2008 meeting on a specific time period for averaging retained catch to estimate the 2008/09 OFL; the apparent (to the author) current low level of the stock and the lack retained catch data from unconstrained fisheries in the last 12 seasons were cited as reasons for the difficulty in making such a recommendation. The CPT recommended that OFL be set as **26,287 pounds of bycatch only**, with the value 26,287 pounds computed as the estimated average annual bycatch for the period 1996-2007 (Note that Table 9 provides an estimate of the annual bycatch updated with data through mid-June 2008, resulting in an annual average bycatch of 25,040 pounds). The SSC at their June 2008 meeting recommended that the 2008/09 OFL be set at **464,762 pounds of retained catch**, computed as the average retained catch over the time period 1985/86–2007/08.

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Table 1. Relative frequency distribution (percentage) of depths (fathoms) of pot lifts sampled with catch per sampled pot by depth zone of red king crabs during the 2002/2003 Adak (Petrel Bank) red king crab fishery (top panel; Appendix C.31 from Barnard and Burt 2004) and the 2003/2004 Adak (Petrel Bank) red king crab fishery (bottom panel; Appendix C.31from Burt and Barnard 2005).

Appendix C.31. CPUE by depth for 592 pot lifts sampled during the 2002 Petrel Bank red king crab fishery.

Depth[a]	Percent of Sampled Pot lifts	Catch per sampled pot lift			
		Legal	Sublegal	Female	Total
41-45	0.5	0	0	0	0
46-50	1.0	0	0	0	0
51-55	2.9	0.2	0	0.1	0.3
56-60	3.7	11.7	0	5.0	16.8
61-65	24.8	17.4	0.7	5.1	23.1
66-70	40.4	15.0	0.9	0.6	16.5
71-75	19.8	11.7	0.1	0.1	11.8
76-80	4.7	13.4	1.1	0.4	14.9
81-85	2.0	12.4	0.2	0	12.6
86-90	--	--	--	--	--
91-95	0.2	1.0	0	0	1.0

[a] Mean depth = 67.6 fathoms.

Appendix C31.-CPUE by depth for 929 pot lifts sampled during the 2003 Petrel Bank red king crab fishery.

Depth[a] (fathoms)	Percent of Sampled Pots	Catch Per Sampled Pot			
		Legal	Sublegal	Female	Total
21-30	0.1	5.0	0	0	5.0
41-50	0.1	0	0	0	0
51-60	1.4	2.0	0.1	12.1	14.2
61-70	26.8	7.7	0.9	5.3	13.8
71-80	28.1	10.4	0.6	1.4	12.4
81-90	18.9	12.4	1.5	1.3	15.2
91-100	10.1	11.5	0.6	0.5	12.6
101-110	6.2	11.6	1.6	1.2	14.3
111-120	4.3	8.6	0.2	0.2	9.1
121-130	3.0	8.0	0	0	8.0
131-140	0.6	17.8	0	0	17.8
141-150	0.2	25.0	0	0	25.0

[a] Mean depth = 82.4 fathoms.

Table 2. Number of pots fished within station areas designated for the November 2001 ADF&G-Industry survey for red king crabs on Petrel Bank and number of legal male, sublegal male, and female red king crabs captured within station areas during the 2006 ADF&G Petrel Bank red king crab survey and the November 2001 ADF&G-Industry survey for red king crabs on Petrel Bank (from Gish 2007).

Station Area[a]	2006 Survey				November 2001 Industry Survey			
	Pots Fished	Legal Males	Sublegal Males	Females	Pots Fished	Legal Males	Sublegal Males	Females
1	16	0	0	0	25	0	0	0
2	8	0	0	0	25	271	0	0
3	12	0	0	0	25	75	1	2
4	24	0	0	1	25	320	0	1
5	16	0	0	0	25	1,765	5	1
6	20	0	0	0	25	1,424	25	0
7	16	0	0	0	24	0	0	0
8	24	0	0	0	25	0	0	0
9	16	0	0	0	25	419	2	2
10	16	0	0	0	25	1,723	135	9
11	16	0	0	0	25	0	0	0
12	16	0	0	0	25	0	0	1
13	24	7	6	3	25	49	0	0
14	8	62	76	31	25	1,312	30	6
15	15	0	0	0	25	2,648	106	207
16	16	0	0	0	25	275	10	149
17	16	0	0	0	25	0	0	0
18	16	0	0	0	25	0	0	0
19	12	0	0	0	25	38	0	0
20	12	67	4	9	25	3,227	189	197
21	16	154	35	33	26	2,674	216	353
22	16	5	0	49	25	2,541	451	1,040
23	16	0	0	0	25	22	0	0
24	8	0	0	0	25	54	0	0
25	24	80	2	4	25	1,147	13	3
26	20	187	20	7	25	1,198	206	403
27	8	0	0	0	25	1,340	19	17
28	24	0	0	0	25	39	1	1
Total	451	562	143	137	700	22,561	1,409	2,392

[a] Station areas are illustrated in Figure 3 and are described in Appendix B of Bowers et al. (2002).

Table 3. Number of pots fished within four off-survey-grid strings during the 2006 ADF&G Petrel Bank red king crab survey charter and catch of legal male, sublegal male, and female red king crabs compared with number of pots corresponding to those strings that were fished during the November 2001 industry survey for red king crabs on Petrel Bank and catch of legal male, sublegal male, and female red king crabs (from Gish 2007).

String	2006 Survey Charter				November 2001 Industry Survey			
	Pots Fished	Legal Males	Sublegal Males	Females	Pots Fished	Legal Males	Sublegal Males	Females
3	33	344	159	117	34	1,739	150	307
4	16	60	3	11	18	2,021	188	84
5	25	382	48	58	44	3,937	222	570
6	18	111	18	4	25	2,648	106	207
Total	92	897	228	190	121	10,345	666	1,168

Table 4a. Harvest history for the Adak Area red king crab fishery (number of crabs and pounds of crabs landed, pot lifts, fishery catch per unit effort, and average weight of landed crabs) by fishery season from the 1984/85 season through the 2007/08 season.

Season	Harvest Number[a]	Harvest Pounds[a]	Pot lifts	CPUE[b]	Average Weight[c]
1984/85	196,276	1,296,385	48,642	4.0	6.60
1985/86	156,097	868,828	29,095	5.4	5.58
1986/87	126,204	712,543	29,189	4.3	5.65
1987/88	211,692	1,213,892	43,433	4.9	5.73
1988/89	266,053	1,567,314	64,334	4.1	5.89
1989/90	193,177	1,105,971	54,213	3.6	5.73
1990/91	146,903	828,105	10,674	13.8	5.64
1991/92	165,356	951,278	16,636	9.9	5.75
1992/93	218,049	1,286,424	16,129	13.5	5.90
1993/94	119,330	698,077	13,575	8.8	5.85
1994/95	30,337	196,967	18,146	1.7	6.49
1995/96	6,880	38,941	1,986	3.5	5.66
1996/97			Fishery closed		
1997/98			Fishery closed		
1998/99[d]	749	5,900	102	7.3	7.88
1999/00			Fishery closed		
2000/01[e]	11,299	76,562	496	22.8	6.78
2001/02[f]	22,080	153,961	564	39.1	6.97
2002/03[g]	68,300	505,642	3,786	18.0	7.40
2003/04	59,828	479,113	5,774	10.4	8.01
2004/05			Fishery closed		
2005/06			Fishery closed		
2006/07			Fishery closed		
2007/08			Fishery closed		

a. Includes deadloss.
b. Catch (number of crabs) per pot lift.
c. Average weight (pounds) of landed crabs, including deadloss.
d. Fishery closed between 179° W longitude and 179° E longitude.
e. ADF&G-Industry pot survey of red kings in the Adak Area conducted as commissioner's permit fishery, January–February 2001 between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (Petrel Bank area).
f. ADF&G-Industry pot survey of red kings in the Adak Area conducted as commissioner's permit fishery, November 2001 between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (Petrel Bank area).
g. Does not include catch of legal males (4 in number) and effort (1,085 pot lifts) from ADF&G-Industry pot survey of red kings in the Adak Area conducted as commissioner's permit fishery during November 2002 in the vicinity of Adak, Atka, and Amlia Islands (Granath 2003).

Table 4b. Aleutian Islands, Area O, red king crab commercial fishery data, 1960/61 - 2006/07 (from Bowers et al. 2008); the fishery was closed for the 2007/08 season.

		Number of					Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1960/61	East of 172° W	NA	NA	NA	NA	NA	NA	NA	NA	NA
	West of 172° W	4	41	NA	NA	2,074,000	NA	NA	NA	NA
	TOTAL									
1961/62	East of 172° W	4	69	NA	NA	533,000	NA	NA	NA	NA
	West of 172° W	8	218	NA	NA	6,114,000	NA	NA	NA	NA
	TOTAL		**287**			**6,647,000**				
1962/63	East of 172° W	6	102	NA	NA	1,536,000	NA	NA	NA	NA
	West of 172° W	9	248	NA	NA	8,006,000	NA	NA	NA	NA
	TOTAL		**350**			**9,542,000**				
1963/64	East of 172° W	4	242	NA	NA	3,893,000	NA	NA	NA	NA
	West of 172° W	11	527	NA	NA	17,904,000	NA	NA	NA	NA
	TOTAL		**769**			**21,797,000**				
1964/65	East of 172° W	12	336	NA	NA	13,761,000	NA	NA	NA	NA
	West of 172° W	18	442	NA	NA	21,193,000	NA	NA	NA	NA
	TOTAL		**778**			**34,954,000**				
1965/66	East of 172° W	21	555	NA	NA	19,196,000	NA	NA	NA	NA
	West of 172° W	10	431	NA	NA	12,915,000	NA	NA	NA	NA
	TOTAL		**986**			**32,111,000**				
1966/67	East of 172° W	27	893	NA	NA	32,852,000	NA	NA	NA	NA
	West of 172° W	10	90	NA	NA	5,883,000	NA	NA	NA	NA
	TOTAL		**983**			**38,735,000**				
1967/68	East of 172° W	34	747	NA	NA	22,709,000	NA	NA	NA	NA
	West of 172° W	22	505	NA	NA	14,131,000	NA	NA	NA	NA
	TOTAL		**1,252**			**36,840,000**				
1968/69	East of 172° W	NA	NA	NA	NA	11,300,000	NA	NA	NA	NA
	West of 172° W	30	NA	NA	NA	16,100,000	NA	NA	NA	NA
	TOTAL					**27,400,000**				
1969/70	East of 172° W	41	375	NA	72,683	8,950,000	NA	NA	NA	NA
	West of 172° W	33	435	NA	115,929	18,016,000	6.5	NA	NA	NA
	TOTAL		**810**		**188,612**	**26,966,000**				
1970/71	East of 172° W	32	268	NA	56,198	9,652,000	NA	NA	NA	NA
	West of 172° W	35	378	NA	124,235	16,057,000	NA	NA	NA	NA
	TOTAL		**646**		**180,433**	**25,709,000**				
1971/72	East of 172° W	32	210	1,447,692	31,531	9,391,615	7	46	NA	NA
	West of 172° W	40	166	NA	46,011	15,475,940	NA	NA	NA	NA
	TOTAL		**376**		**77,542**	**24,867,555**				
1972/73	East of 172° W	51	291	1,500,904	34,037	10,450,380	7	44		
	West of 172° W	43	313	3,461,025	81,133	18,724,140	5.4	43	NA	NA
	TOTAL		**604**	**4,961,929**	**115,170**	**29,174,520**	**5.9**	**43**		
1973/74	East of 172° W	56	290	1,780,673	41,840	12,722,660	7.1	43	NA	NA
	West of 172° W	41	239	1,844,974	70,059	9,741,464	5.3	26	148.6	NA
	TOTAL		**529**	**3,625,647**	**111,899**	**22,464,124**	**6.2**	**32**		

(continued)

Table 4b. page 2 of 3.

Season	Locale	Number of Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Average Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1974/75	East of 172° W	87	372	1,812,647	71,821	13,991,190	7.7	25		
	West of 172° W	36	97	532,298	32,620	2,774,963	5.2	16	148.6	NA
	TOTAL		**469**	**2,344,945**	**104,441**	**16,766,153**	**7.1**	**22**		
1975/76	East of 172° W	79	369	2,147,350	86,874	15,906,660	7.4	25		
	West of 172° W	20	25	79,977	8,331	411,583	5.2	10	147.2	NA
	TOTAL		**394**	**2,227,327**	**95,205**	**16,318,243**	**7.3**	**23**		
1976/77	East of 172° W	72	226	1,273,298	65,796	9,367,965[f]	7.4	19		
	East of 172° W	38	61	86,619	17,298	830,458[g]	9.6	5	NA	NA
	West of 172° W	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 4b. 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	FISHERY CLOSED								
	West of 171° W	73	156	266,053	64,334	1,567,314	5.9	4	153.1	557
1989/90	East of 171° W	FISHERY CLOSED								
	West of 171° W	56	123	193,177	54,213	1,105,971	5.7	4	151.5	759
1990/91	East of 171° W	FISHERY CLOSED								
	West of 171° W	7	34	146,903	10,674	828,105	5.6	14	148.1	0
1991/92	East of 171° W	FISHERY CLOSED								
	West of 171° W	10	35	165,356	16,636	951,278	5.8	10	149.8	0
1992/93	East of 171° W	FISHERY CLOSED								
	West of 171° W	12	30	218,049	16,129	1,286,424	6.0	14	151.5	5,000
1993/94	East of 171° W	FISHERY CLOSED								
	West of 171° W	12	21	119,330	13,575	698,077	5.9	9	154.6	7,402
1994/95	East of 171° W	FISHERY CLOSED								
	West of 171° W	20	31	30,337	18,146	196,967	6.5	2	157.5	1,430
1995/96	East of 171° W	FISHERY CLOSED								
	West of 171° W	4	12	6,880	1,986	38,941	5.7	3	153.6	235
1996/97		FISHERY CLOSED								
1997/98		FISHERY CLOSED								
1998/99	West of 174° W	3	6	749	102	5,900	7.9	7	NA	0
1999/2000		FISHERY CLOSED								
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		FISHERY CLOSED								
2005/06		FISHERY CLOSED								
2006/07		FISHERY CLOSED								

Table 5. 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 1996/97–2007/08 seasons. (Bycatch weight estimates for 1996/97–2005/06 were provided by D. Barnard, ADF&G, 20 July 2007; bycatch weight estimates for 2006/07 were provided by D. Pengilly using data from the ADF&G crab observer database, Dutch Harbor, 7 April 2008; bycatch weight estimates for 2007/08 were provided by D. Pengilly using data from the ADF&G crab observer database, Kodiak, 18 August 2008 and are preliminary).

	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
1996/97	0	0	0	0	3,292	2,024	666	5,982
1997/98	0	0	0	0	178	579	179	936
1998/99[a]	5,900	-	-	-	747	138	186	1,071
1999/00	0	0	0	0	161	756	93	1,010
2000/01	76,562	0	771	374	365	274	35	1,819
2001/02	153,961	174	6,574	8,369	19,995	0	364	35,476
2002/03	505,642	1,658	6,027	17,432	21,738	355	512	47,722
2003/04	479,113	631	6,597	7,962	9,425	6,352	6,686	37,653
2004/05	0	0	0	0	2,143	210	0	2,353
2005/06	0	0	0	0	192	0	50	242
2006/07	0	0	0	0	315	114	49	478
2007/08	0	0	0	0	517	1,528	471	2,516
Average	101,765	224	1,815	3,103	4,922	1,028	744	11,438

a. Data on bycatch of red king crabs during the red king crab fishery not available (see Moore et al. 2000).

Table 6. Number of pot lifts (fishery effort), number of pot lifts performed with an observer on the vessel (observed effort), and number of red king crabs by sex-size class documented as captured during the Aleutian Islands golden king crab fishery, 2001/02-2007/08 seasons.

Season	Fishery effort[a]	Observed effort[b]	Number of red king crabs		
			Legal	Sublegal	Female
2001/02[c]	168,151	168,151	457	36	47
2002/03[c]	131,021	131,021	772	26	30
2003/04[d]	125,119	7,294	61	102	120
2004/05[c]	91,694	91,694	115	57	37
2005/06[e]	54,685	41,323	6	16	14
2006/07[e]	53,065	38,388	37	35	24
2007/08[e,f]	52,603	30,052	47	256	131

a. Number of pot lifts performed during the Aleutian Islands golden king crab season.
b. Number of pot lifts performed during the Aleutian Islands golden king crab season while an observer was present on the vessel. For the 2003/04 season "Observed effort" is the number of pot lifts randomly sampled by observers during the season.
c. Observers present on all vessels at all times when fishing during the Aleutian Islands golden king crab fishery season.
d. Program for documenting catch of all red king crabs during the Aleutian Islands golden king crab fishery not implemented in the 2003/04 season.
e. Partial-time observer presence on catcher-only vessels during the Aleutian Islands golden king crab fishery season (full-time observer presence on catcher-processor vessels).
f. Preliminary data summaries.

Table 7. Number of red king crabs documented as captured during the, 2001/02-2007/08 Aleutian Islands golden king crab fishery seasons by 1-degree zones of longitude.

Longitude zone	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08[b]	Total
169°–170° W[a]	4	0	1	0	0	0	0	5
170°–171° W[a]	0	1	0	0	0	0	0	1
171°–172° W	0	1	0	0	0	0	0	1
172°–173° W	0	0	0	0	0	0	0	0
173°–174° W	1	3	0	0	0	0	0	4
174°–175° W	0	0	0	0	0	0	0	0
175°–176° W	0	0	0	0	0	0	0	0
176°–177° W	0	1	0	0	0	0	0	1
177°–178° W	9	81	0	0	1	0	0	91
178°–179° W	36	18	216	5	17	0	182	474
179°–180° W	216	267	6	18	12	57	182	758
179°–180° E	163	398	54	59	1	4	6	685
178°–179° E	40	1	0	23	2	6	0	72
177°–178° E	5	0	0	0	0	1	2	8
176°–177° E	35	56	4	97	2	24	46	264
175°–176° E	19	0	1	7	1	4	10	342
174°–175° E	0	0	0	0	0	0	0	0
173°–174° E	0	0	0	0	0	0	0	0
172°–173° E	0	1	0	0	0	0	0	1
Unknown	12	0	1	0	0	0	6	19
Total	540	828	283	209	36	96	434	2,426

a. East of 171° W longitude and, hence, not inside the Adak Area.

b. Preliminary data summary.

Table 8. Estimated annual weight (pounds) of discarded bycatch of red king crabs (all sizes, males and females) during groundfish fisheries (all gear types and fisheries pooled) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1996–2007 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office, 31 March 2008) and 2007/08 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office through G. Harrington, NMFS-Alaska Region Office, 23 June 2008).

Year	541	542	543	Total
1996	1,379	359	25,374	27,113
1997	5	34	0	39
1998	16	2,854	570	3,440
1999	885	23	0	908
2000	3,013	5,373	1,449	9,835
2001	165	3,525	120	3,810
2002	0	39,068	0	39,068
2003	2,849	39,428	213	42,490
2004	15	4,541	16	4,572
2005	172	14,230	3,101	17,503
2006	3,386	121	2	3,510
2007	7,032	2,334	622	9,989
2007/08[a]	5,976	2,310	688	8,973
Average	1,915	8,785	2,473	13,173

a. Derived from groundfish observer data between 1-Jul-2007 and 18-Jun-2008.

Table 9. Estimated average annual weight (pounds) of discarded bycatch of red king crabs (all sizes, males and females) in Aleutian Islands crab fisheries during the 1996/97–2007/08 seasons and in groundfish fisheries (all gear types and fisheries pooled) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude) during 1996–2007 and the 2007/08 season); see Tables 5 and 8.

Fishery			
Red king crab	Golden king crab	Groundfish - all gears	Total
5,143	6,724	13,173	25,040

Table 10. Annual guideline harvest level (GHL, 1996/97–2004/05) or total allowable catch (TAC, 2005/06–2007/08) for retained catch (pounds), actual retained catch (pounds), estimated non-retained discards (pounds) during crab fisheries, and estimates of total catch (retained catch plus discard mortality; pounds) during crab fisheries for the red king crabs in the Adak Area, 1996/97–2007/08.

Season	Retained GHL/TAC	Retained Catch	Non-retained discards	Total Catch[a]		
				hm=10%	*hm*=20%	*hm*=30%
1996/97	0	0	5,982	598	1,196	1,795
1997/98	0	0	936	94	187	281
1998/99[b]	15,000	5,900	1,071	6,007	6,114	6,221
1999/00	0	0	1,010	101	202	303
2000/01[c]	-	76,562	1,819	76,744	76,926	77,108
2001/02[c]	-	153,961	35,476	157,509	161,056	164,604
2002/03	500,000	505,642	47,722	510,414	515,186	519,959
2003/04	500,000	479,113	37,653	482,878	486,644	490,409
2004/05	0	0	2,353	235	471	706
2005/06	0	0	242	24	48	73
2006/07	0	0	478	48	96	143
2007/08[d]	0	0	2,516	252	503	755

a. Total catch is the retained catch plus estimated discard mortality with assumed handling mortality rate, *hm*.
b. Estimated weight of non-retained discards is only from that attributable to the Aleutian Islands golden king crab fishery; estimated weight of non-retained discards from the directed red king crab fishery are not available.
c. Fishery was prosecuted as a commissioner's permit fishery with no GHL for purposes of conducting ADF&G-Industry survey for red king crab in the Petrel bank area.
d. Preliminary data summary.

Table 11. Carapace length (CL, mm) frequency distribution from biological measurements of retained red king crabs sampled by season during the 1984/85–1995/96 and 2002/03–2003/04 red king crab seasons in the Adak Area. The commercial fishery was not opened for the 1996/97–1997/98, 1999/2000, 2004/05–2007/08 seasons. No data is available from the 1998/99 season. For data from the ADF&G-Industry pot surveys in 2001 and 2002 that were conducted as a commissioner's permit fishery, see Table 12. Data from ADF&G shellfish observer database, Dutch Harbor, 16 April 2008.

CL (mm)	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94	94/95	95/96	02/03	03/04
<130	2	5	1	0	4	6	7	0	0	1	0	0	0	1
130	1	2	1	1	5	8	4	0	1	1	0	1	0	0
131	3	7	0	3	7	29	9	0	1	2	0	0	0	0
132	6	9	2	2	5	51	12	3	6	1	2	4	0	0
133	6	19	2	5	18	88	22	13	6	4	1	3	0	0
134	9	10	5	8	19	161	46	47	19	9	5	8	0	0
135	19	27	3	10	38	280	108	65	47	15	8	9	1	0
136	21	18	8	8	55	276	152	115	59	15	10	11	1	1
137	33	23	12	11	92	370	223	173	76	32	15	17	5	1
138	39	29	10	10	108	497	310	211	118	35	11	27	6	1
139	30	39	10	11	121	532	381	255	101	41	18	24	2	0
140	30	48	16	17	134	631	391	289	186	63	12	24	7	3
141	46	48	16	13	118	529	455	315	156	89	16	31	14	4
142	41	59	16	20	157	562	467	341	184	92	24	32	10	3
143	57	38	13	18	161	514	449	392	216	102	20	23	13	6
144	39	33	14	21	139	494	521	342	206	114	23	32	15	5
145	56	28	25	21	179	559	483	359	220	148	16	32	18	11
146	49	21	14	25	164	460	456	356	229	162	27	38	30	8
147	47	36	14	17	186	460	469	390	244	155	29	24	18	12
148	55	36	11	10	158	483	408	304	221	183	31	27	18	9
149	36	28	14	17	170	399	428	319	160	136	20	30	30	8
150	61	42	16	21	177	451	386	364	251	177	39	24	26	19
151	47	27	13	18	146	283	315	288	145	186	29	25	35	22
152	48	24	13	5	191	371	333	344	233	169	31	29	43	17
153	58	27	8	17	170	361	292	369	170	180	38	18	41	27
154	40	30	14	16	152	292	288	320	145	180	19	33	63	36
155	58	39	12	13	147	370	311	295	164	174	28	34	58	39
156	44	24	15	12	129	265	223	280	165	182	30	18	74	46
157	41	31	6	7	132	244	203	294	148	154	25	30	74	33
158	42	35	10	17	132	256	169	211	158	167	30	37	81	52
159	30	36	14	6	105	232	167	199	86	154	25	23	97	56

(continued)

Table 11. page 2 of 2.

CL (mm)	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94	94/95	95/96	02/03	03/04
160	62	31	7	5	128	233	136	149	142	154	43	23	81	78
161	30	17	6	9	105	190	106	121	88	149	28	21	69	64
162	53	34	6	7	98	178	103	115	92	114	33	27	84	72
163	52	23	6	4	97	185	77	118	96	115	34	16	78	57
164	26	34	7	9	108	134	78	80	76	117	30	23	100	98
165	50	24	5	8	92	153	78	66	79	95	21	22	75	115
166	38	18	5	5	72	92	48	51	52	85	33	17	91	95
167	41	17	3	2	71	92	59	56	74	77	24	29	82	105
168	45	19	2	3	70	76	34	47	69	68	24	33	80	99
169	32	18	5	2	57	85	33	43	29	70	16	13	53	99
170	39	12	5	2	65	85	25	33	52	39	22	15	71	126
171	22	3	3	1	45	65	29	33	33	47	13	10	58	87
172	30	12	1	1	50	51	24	20	37	30	14	16	60	119
173	24	7	2	1	32	48	14	19	23	19	17	10	41	99
174	30	10	3	0	48	32	17	15	20	27	13	6	44	86
175	24	5	1	0	48	35	18	12	19	23	8	11	49	92
176	17	7	3	0	28	23	11	11	19	12	13	4	35	62
177	17	2	0	0	19	26	4	5	12	19	13	2	27	68
178	18	7	1	0	21	18	6	3	12	7	4	5	20	50
179	12	1	6	0	14	19	7	7	11	9	3	1	20	53
180	8	4	2	0	13	16	1	8	9	5	6	1	20	45
>180	41	34	15	2	60	55	10	41	30	22	43	5	38	192
Total	1,805	1,217	422	441	4,860	12,405	9,406	8,306	5,195	4,426	1,037	978	2,056	2,381

Table 12. Carapace length (CL, mm) frequency distribution from biological measurements of retained red king crabs sampled during ADF&G-Industry pot surveys of red kings in the Adak Area conducted as commissioner's permit fisheries: January–February 2001, between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (Petrel Bank area); November 2001 in the Petrel Bank area; and November 2002 in the vicinity of Adak, Atka, and Amlia Islands (Adak–Amlia). Data from ADF&G shellfish observer database, Dutch Harbor, 16 April 2008.

CL (mm)	Petrel Bank Jan–Feb 2001	Petrel Bank Nov 2001	Adak–Amlia Nov 2002
<130	0	0	0
130	0	0	0
131	0	0	0
132	0	0	0
133	0	0	0
134	0	0	0
135	0	0	0
136	0	3	0
137	0	2	0
138	0	3	0
139	1	2	0
140	0	4	0
141	1	5	0
142	1	9	0
143	2	8	0
144	2	11	0
145	3	7	0
146	4	7	0
147	3	7	0
148	6	16	0
149	7	10	0
150	12	13	0
151	15	16	0
152	19	25	0
153	20	22	0
154	12	28	0
155	14	18	0
156	22	14	0
157	17	24	0
158	12	23	0
159	20	20	0

(continued)

Table 12. page 2 of 2.

CL (mm)	Petrel Bank Jan–Feb 2001	Petrel Bank Nov 2001	Adak–Amlia Nov 2002
160	26	19	0
161	16	15	0
162	22	25	0
163	15	30	0
164	26	25	0
165	20	13	0
166	22	17	0
167	21	24	0
168	13	18	0
169	20	13	0
170	9	13	0
171	16	6	0
172	12	13	0
173	4	18	0
174	7	5	0
175	6	9	0
176	3	4	0
177	5	4	0
178	0	2	0
179	1	6	0
180	2	2	0
>180	1	11	2[a]
Total	460	589	2[b]

a. One at 193-mm CL and one at 194-mm CL.
b. Only four legal males were captured (Granath 2003).

Table 13. Mixture model parameter estimates (Est.) and standard errors (SE) of proportion molting and mean and standard deviation of growth (mm carapace length, CL) for male red king crabs tagged during 1970, 1971, and 1973-1977 in the Adak Island to Amlia Island area of the Adak Area (from Vining et al. 2002).

Release Period	Feb Mar 1970		Apr, Dec 1971		Feb 1973		1974-1977		1971,1973-1974	
Shell Age at Release	New		New		New		New		Old	
Recovery Period	Oct 1970 – Mar 1971[1]		Nov-Dec 1971-1973[2]		Nov-Dec 1973, Jan-Mar 1975[3]		1975, 1978-1979		1972, 1973, 1975	
Sample Size	239		297		497		53		70	
	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
No Molts:										
Proportion	0.84	0.024	0.19	0.024	0.39	0.023	0.69	0.065	0.34	0.063
Mean[4]	-0.01	0.044	0.08	0.112	-0.07	0.033	0.13	0.151	0.03	0.134
Standard Deviation[5]	0.62	0.032	0.78	0.082	0.41	0.030	0.90	0.107	0.58	0.108
Single Molt:										
Proportion	0.16	0.024	0.77	0.026	0.55	0.025	0.31	0.065	0.66	0.063
Mean	10.56	0.514	15.70	0.202	10.83	0.382	8.29	0.807	8.81	0.781
Standard Deviation	3.13	0.386	2.85	0.147	5.35	0.337	2.99	0.628	4.69	0.542
Double Molt:										
Proportion	NA	NA	0.04	0.049	0.06	0.047	NA	NA	NA	NA
Mean	NA	NA	26.72	0.354	28.04	0.893	NA	NA	NA	NA
Standard Deviation	NA	NA	1.09	0.248	3.41	0.592	NA	NA	NA	NA

1. Also includes one recovery in February 1970 and one recovery in January 1973.
2. Also includes one recovery in February 1973, two recoveries in January 1975, and one recovery in March 1975.
3. Also includes one recovery in February 1974, one recovery in September 1974, one recovery in November 1977, and one recovery in March 1978.
4. Mean of measurement error.
5. Standard deviation of measurement error.

Table 14. Logit parameter estimates, slope ( ) and intercept ( ), and their standard errors (SE) for estimating probability of molting within 8–14 months from carapace length (CL) of new-shell male red king crabs tagged and released in the Adak Area during 1970, 1971, 1973, and 1974–1977, and old-shell male red king crabs tagged and released in the Adak Area during 1970, 1971, and 1973–1977 (from Vining et al. 2002).

Year	Shell Condition	Slope ( ) Estimate	Slope ( ) SE	Intercept ( ) Estimate	Intercept ( ) SE
1970	New	-0.205	0.0327	26.66	4.433
1971	New	-0.234	0.0373	33.54	5.202
1973	New	-0.202	0.0186	27.67	2.583
1974–1977	New	-0.124	0.0464	16.82	6.619
1970, 1971, 1973–1977	Old	-0.180	0.0555	25.59	7.908

Table 15. Logit estimates of carapace lengths (CL; mm) at which 10%, 50% and 90% of the crabs would molt within 8–14 months for new-shell male red king crabs tagged and released in the Adak Area during 1970, 1971, 1973, and 1974–1977, and old-shell male red king crabs tagged and released in the Adak Area during 1970, 1971, and 1973–1977 (from Vining et al. 2002).

Year	Shell Condition	CL (mm) for 90% probability of molting	CL (mm) for 50% probability of molting	CL (mm) for 10% probability of molting
1970	New	119	130	140
1971	New	134	143	152
1973	New	126	137	148
1974–1977	New	118	136	154
1970, 1971, 1973–1977	Old	130	142	154

Table 16. Estimated parameters (A and B) for estimating weight (g) from carapace length (CL, mm) of male and ovigerous female red king crabs according to the equation, Weight = A*CL^B (from Table 3-5, NPFMC 2007).

Parameter	Males	Ovigerous females
A	0.000361	0.022863
B	3.16	2.23382

Table 17. Average retained catch (pounds) computed for four periods during 1985/86–2007/08 for consideration as the retained-catch OFL for the 2008/09 Adak red king crab fishery.

Time period	Number of seasons	OFL (= average retained catch, pounds)
1985/86–2007/08[a]	23	464,762
1985/86–1995/96, 2002/03, 2003/04[b]	13	804,084
1985/86–1994/95, 2002/03, 2003/04[c]	12	867,846
1985/86–1994/95[d]	10	942,940

a. The full time period of the 1985/86–2007/08 seasons.

b. The seasons during 1985/86–2007/08 that the fishery was opened, but not including the seasons that the fishery was opened only for limited exploratory fishing (1998/99) or opened under conditions of a commissioner's permit for conducting an ADF&G-Industry survey (2000/01 and 2001/02)

c. The same period as in (b), above, but excluding the 1995/96 season in which the harvest was low, fishery performance was poor, and which led managers to close the fishery for the next two seasons

d. The period during 1985/86–2007/08 in which the fishery was opened without intermittent closed seasons, but excluding the 1995/96 season in which the harvest was low, fishery performance was poor, and which led managers to close the fishery for the next two seasons.

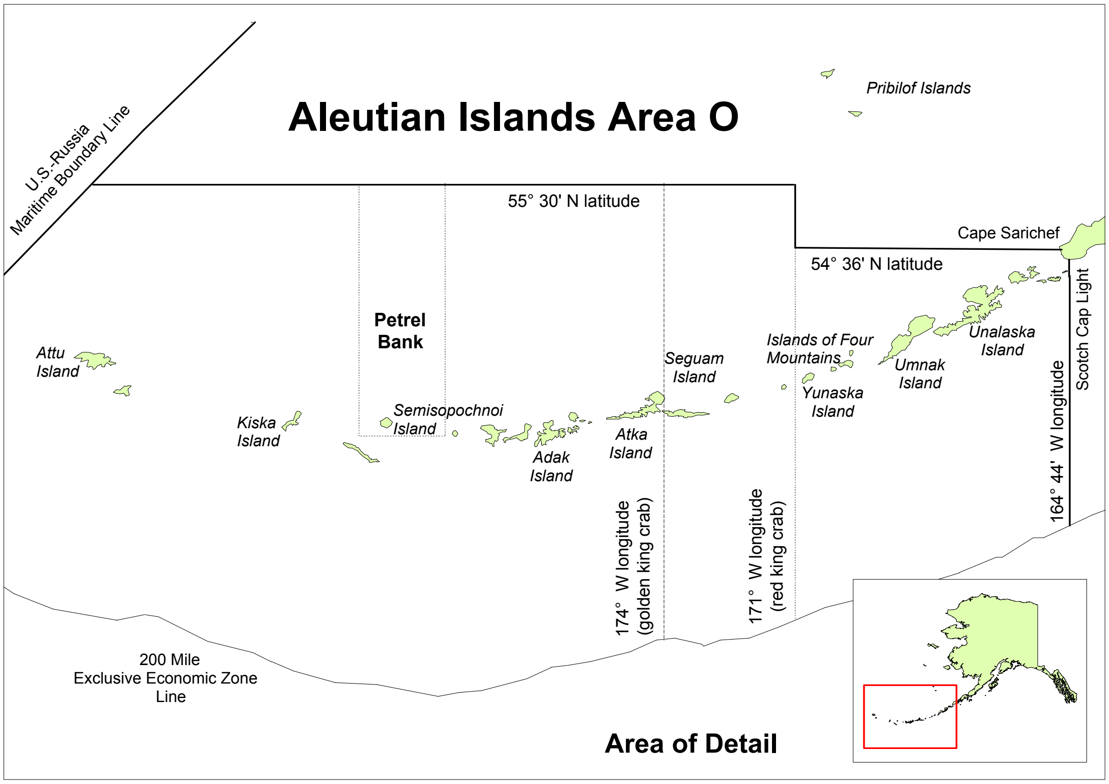

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Failor-Rounds 2008).

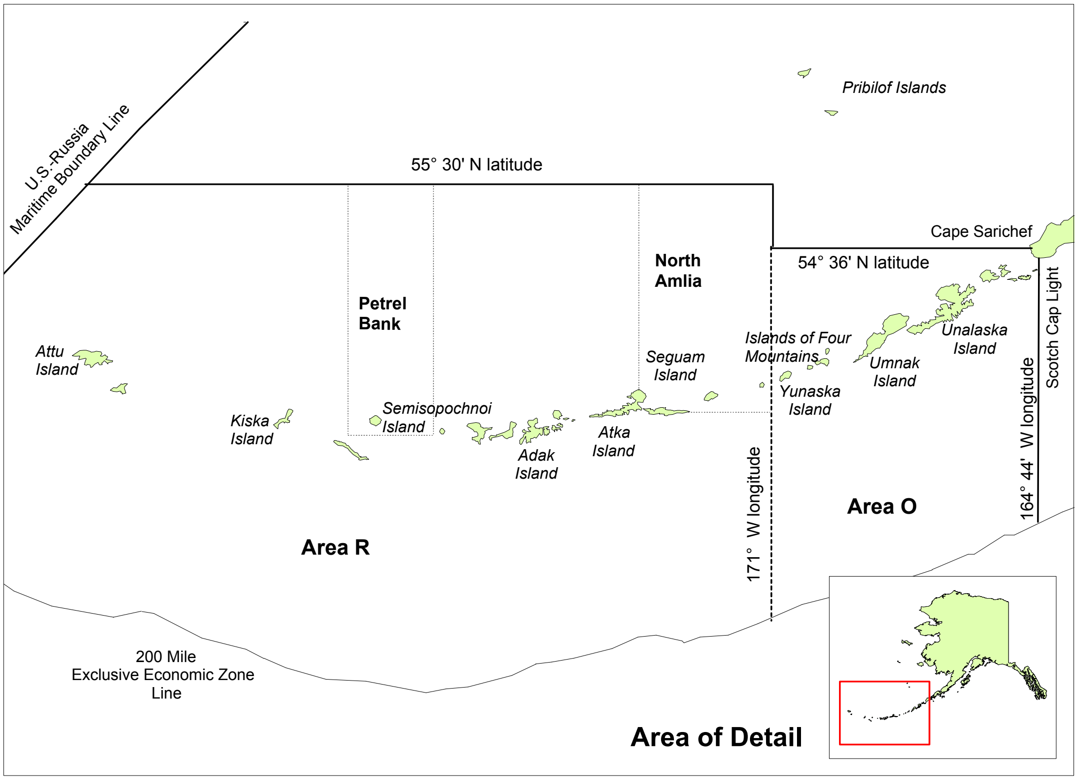

Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85 – 1995/1969 seasons (from Failor-Rounds 2008).

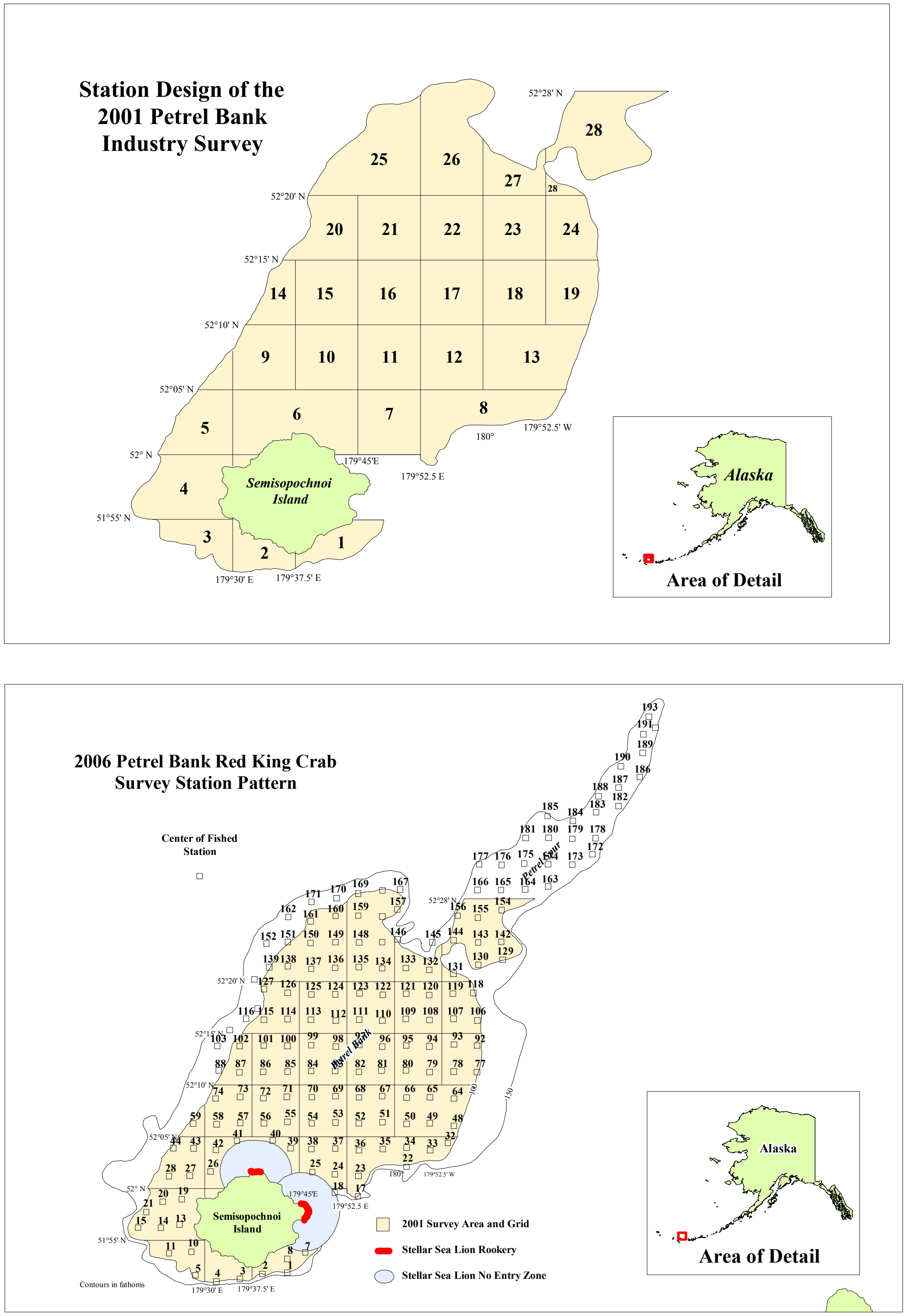

Figure 3. Survey area and grid design for the November 2001 ADFG-Industry industry survey (top panel) and station pattern and numbers of those fished during the November 2006 ADF&G Petrel Bank red king crab survey (bottom panel).

Figure 4. Locations (x) of pots fished in the Adak Island locale (top panel) and Atka-Amlia Islands locale (bottom panel) during the ADF&G-Industry red king crab pot survey conducted as a commissioner's permit fishery in November 2002; stars mark locations where legal male red king crabs were captured (from Granath 2002).

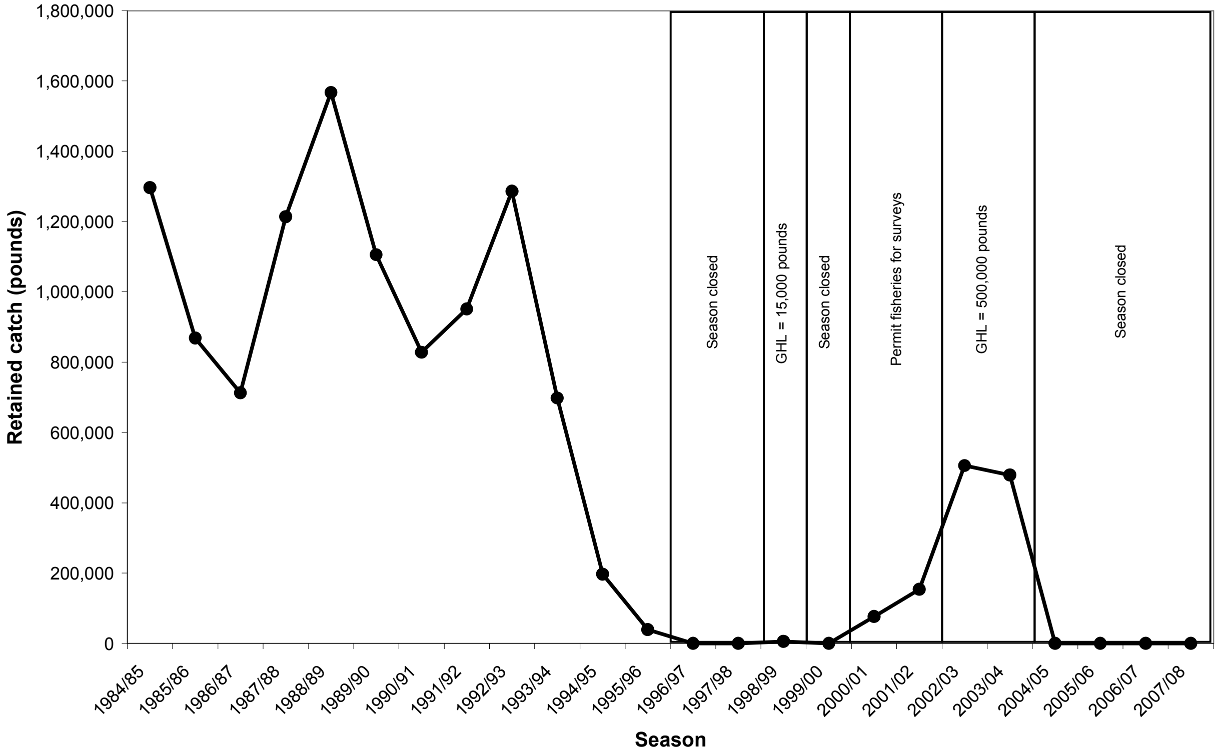

Figure 5. Retained catch (pounds) during the 1984/85–2007/08 seasons for the red king crab fishery in the Adak Area.

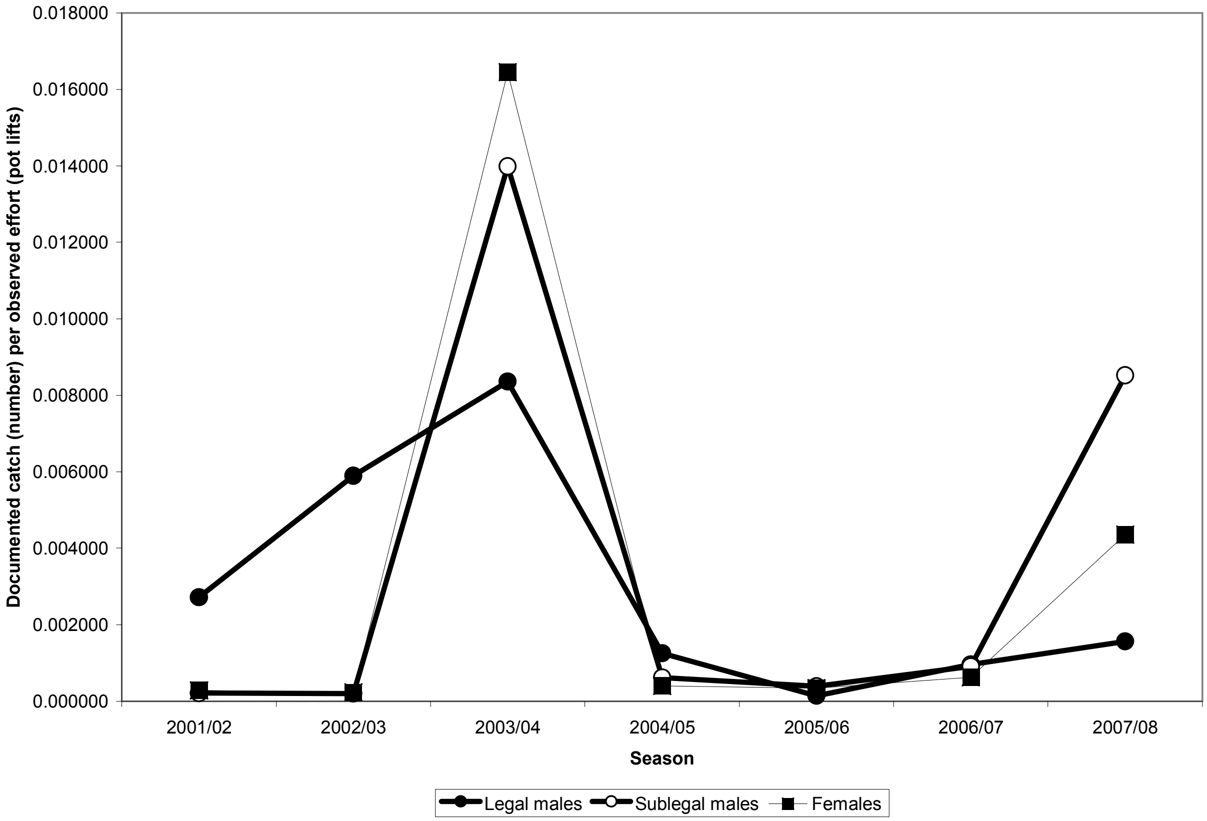

Figure 6. Catch of red king crabs by sex-size class documented by observers during the 2001/02-2007/08 Aleutian Islands golden king crab fishery per unit of observer effort; preliminary data summary for 2007/08 season.

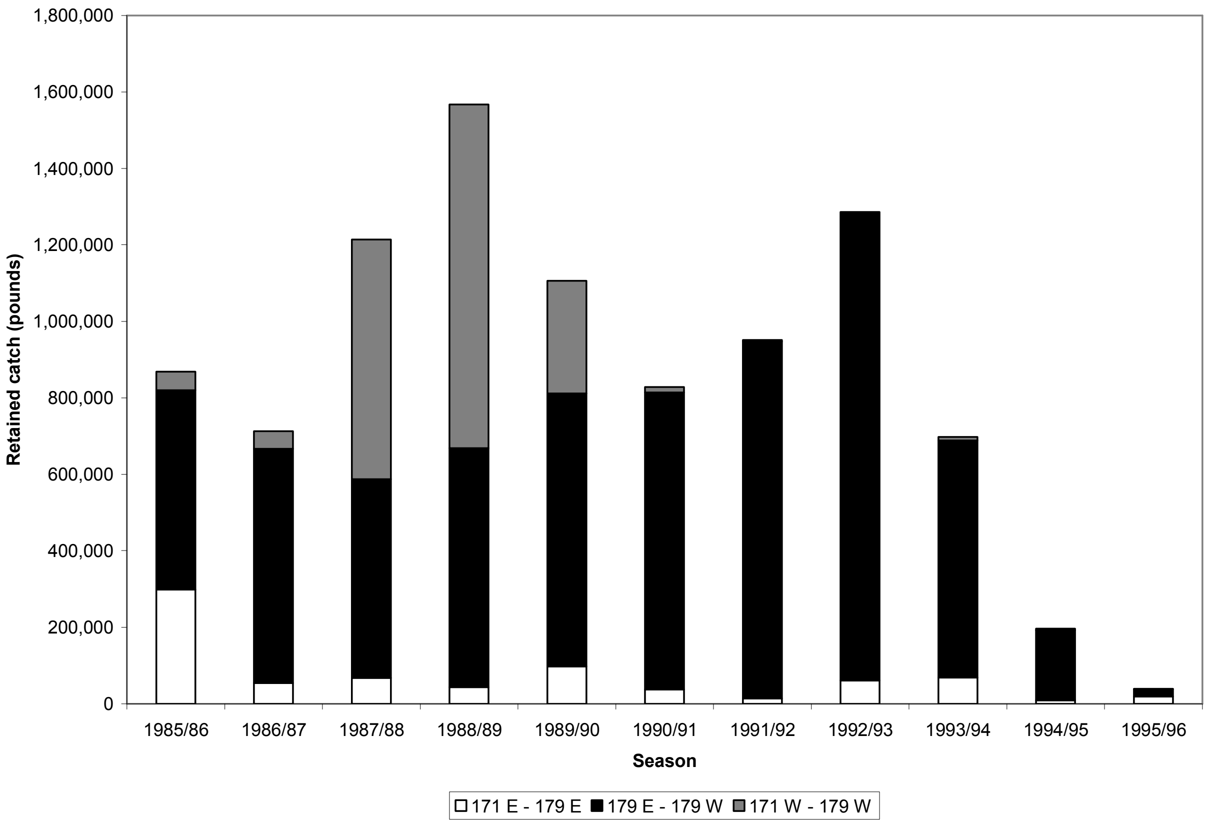

Figure 7. Retained catch (pounds) by longitudinal zones in the 1985/86–1995/96 red king crab fishery in the Adak Area (from fish ticket data summaries provided by ADF&G, Dutch Harbor, March 2008).

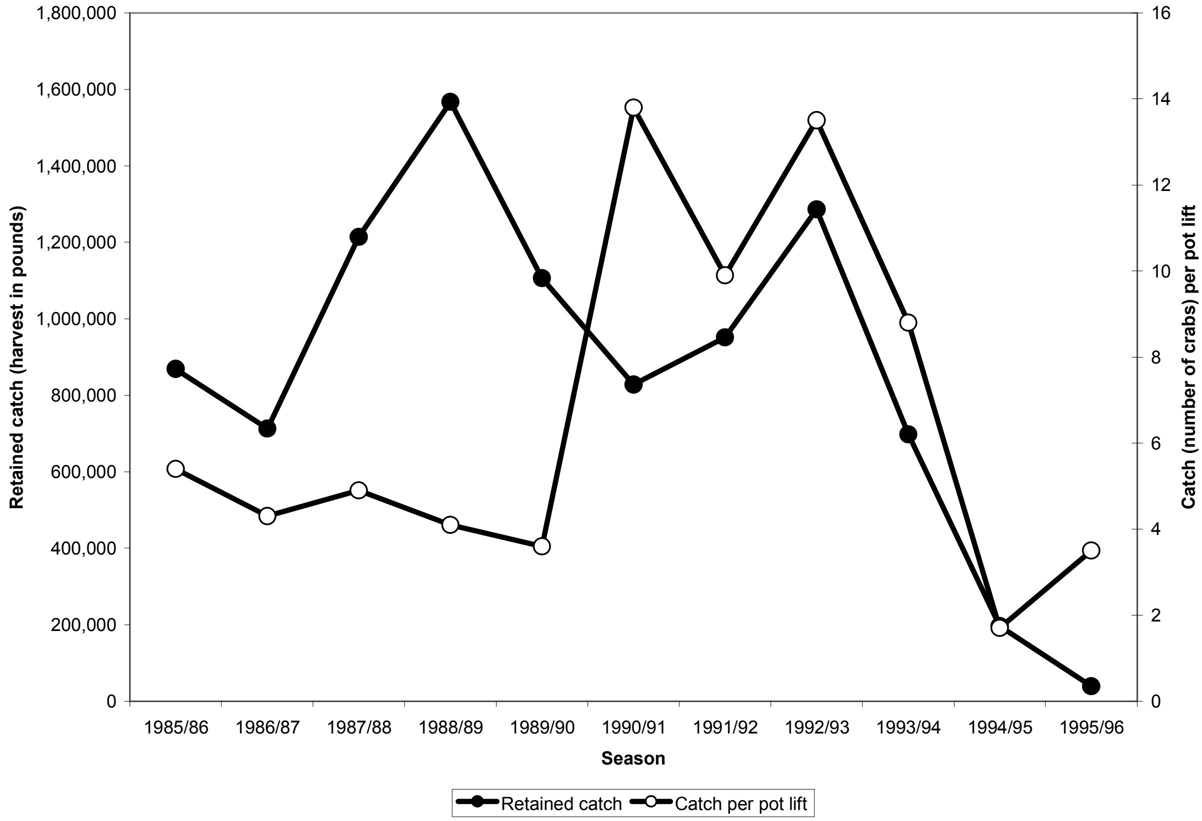

Figure 8. Retained catch (harvest in pounds) and catch (number of retained legal crabs) per pot lift (CPUE) in the Adak Area red king crab fishery, 1985/86–1995/96 seasons.

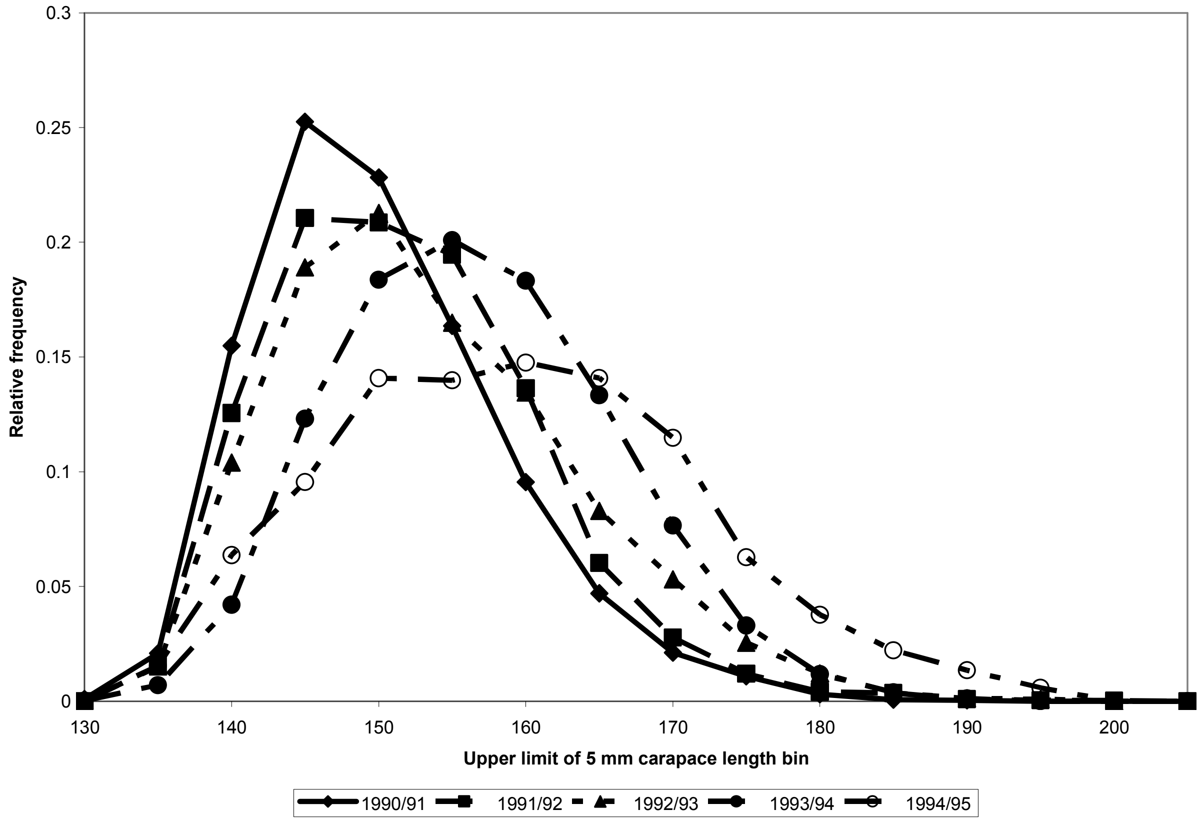

Figure 9. Size frequency distribution (carapace length, mm, in 5-mm bins) from samples of the retained catch during the 1990/91 through 1994/95 Adak red king crab fishery.