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

2009 Crab SAFE

Compiled by

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of the Bering Sea and Aleutian Islands

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Introduction

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

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

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

The Crab Plan Team met from September 14-15, 2009 at the Alaska Fisheries Science Center in Seattle WA to review the draft stock assessments and survey and bycatch data issues, 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, Herman Savikko, Brian Garber-Yonts, Gretchen Harrington, Doug Pengilly, Bob Foy, Lou Rugolo, Wayne Donaldson, and Diana Stram. This report builds upon recommendations contained in the May 2009 report.

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The CPT participated in the Alaska Crab Stock Assessment Workshop on May 13 and 14. The goal of the workshop was to establish a set of standards for use in all modeling efforts and resolve issues related to the weighting of data sources, such as appropriate weights for different likelihood components and the most appropriate ways to estimate effective sample sizes for length and size composition data. A workshop report is appended to this SAFE report. This report is prescriptive, provides guidance to assessment authors, and ensures that the stock assessments approach these issues in a similar way. Guidance in the report is intended to inform the models for the 2010/11 assessment cycle.

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.

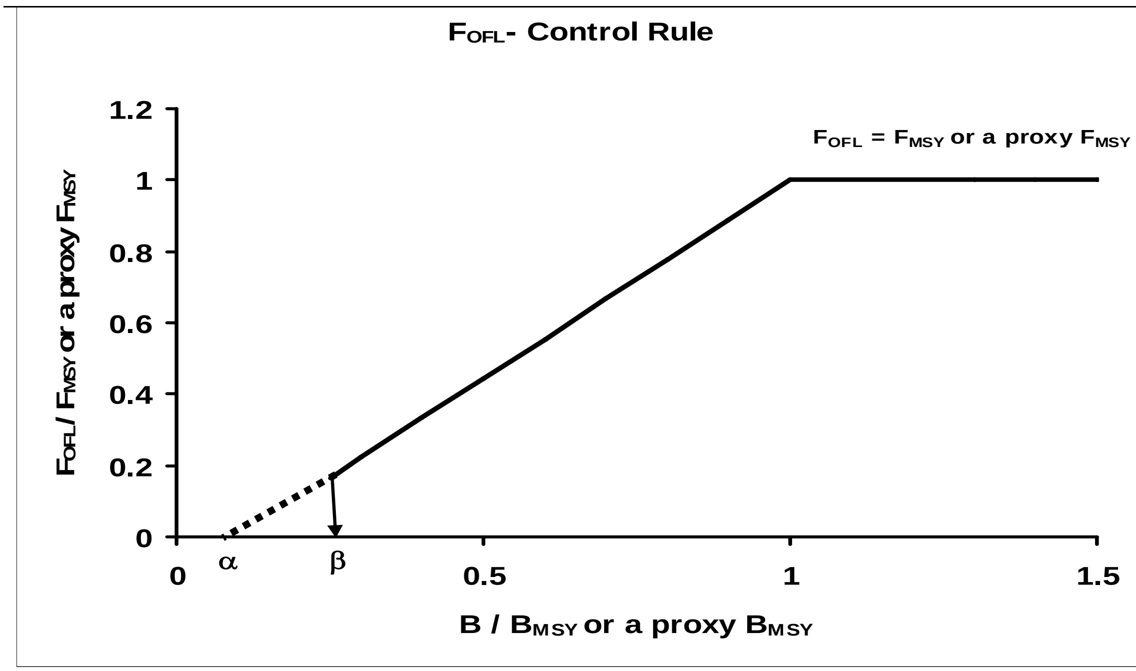

Table 1 Five-Tier System for setting overfishing limits for crab stocks. The tiers are listed in descending order of information availability. Table 6-2 contains a guide for understanding the five-tier system.

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

Overview of changes to the EBS bottom trawl survey timeseries

The EBS bottom trawl time series for crab has been revised from 1975 to 2008. Changes include error fixes and the inclusion of recalculated area swept estimates with net width estimated from net mensuration data instead of a fixed value. Thirty nine individual crab data points affecting abundance estimates in 19 different years were amended after transcription errors were found in the database. The error fixes resulted in minor survey catch count changes in 34 of the data records. Five fixes, however, resulted in increases or decreases in the survey catch count between 1000 and 2000 crabs/nm^2 affecting mostly snow crab and Tanner crab. Using net width estimated from net mensuration data resulted in changes to all haul records from 1981 to 2009. The range of average net widths estimated in the revised time series was 14.9 to 17.4 m effectively increasing the area swept from a fixed net width of 15.24 m which was used previously. This revised time series was used for the 2009/2010 assessments for Bristol Bay red king crab, Pribilof Islands red king crab, Pribilof Islands blue king crab, and Saint Matthews blue king crab. The revised time series was not used for assessment purposes in the assessments of Eastern Bering Sea snow crab and Eastern Bering Sea Tanner crab in the 2009/2010 assessment cycle. Regardless of whether the revised data set was used for OFL specification purposes, the individual stock assessments contain a comparison of the assessment results using both trawl survey datasets. A technical paper containing the information on the revisions to the data set in addition to changes to the survey strata and subsequent variance calculations will be available in May 2010. All stocks assessments employing the trawl survey time series data will use the revised dataset in the 2010/2011 assessment cycle.

Crab Plan Team Recommendations

Table 3 lists the team's final recommendations for 2009/2010 on Tier assignments, 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. The team recommends two stocks be placed in Tier 3 (EBS snow crab and Bristol Bay red king crab), five stocks in Tier 4 (EBS Tanner crab, St. Matthew blue king crab, Pribilof Island blue king crab, Pribilof Island red king crab and Norton Sound red king crab) and three stocks in Tier 5 (AI golden king crab, Pribilof Island golden king crab and Adak red king crab).

Stock status in relation to status determination criteria are evaluated in this report (Table 3, Table 4). No crab stocks were subject to overfishing in 2008/09. In 2008/09, three stocks (Bristol Bay red king crab, Pribilof Islands red king crab and St. Matthew Islands blue king crab) had estimated biomass above the B_{MSY} proxy level. Two stocks remain under rebuilding plans: EBS snow crab and Pribilof Islands blue king crab. Of these, the Pribilof Islands blue king crab estimated biomass remains below its MSST and is still considered overfished. For EBS snow crab, estimated biomass is above the MSST but below its B_{MSY} proxy level and thus this stock will not be rebuilt within its rebuilding period. Rebuilding plans for EBS snow crab and Pribilof Islands blue king crab are to be revised for implementation by the 2011/12 fishing year. St. Matthew blue king crab estimated biomass is above B_{MSY} for the second consecutive year and may now be considered rebuilt.

Projections for 2009/10 indicate that two stocks (Bristol Bay red king crab and St. Matthew islands blue king crab) will have estimated biomass above the B_{MSY} proxy level. EBS Tanner crab estimated biomass for 2009/10 is projected to be below its MSST and considered to be approaching an overfished condition. A new rebuilding plan to EBS Tanner crab will be developed for implementation by the 2011/12 fishing year. Pribilof Islands red king crab biomass is estimated to drop substantially in the 2009/10 assessment year and is close to its MSST.

The team has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2010 assessment cycle unless indicated otherwise. The general comments are listed below while the comments related to individual assessments are contained within the summary of plan team deliberations and recommendations contained in the stock specific summary section. Additional details regarding recommendations are contained in the Crab Plan Team Reports (May and September 2009 CPT Reports). Terms of reference and further guidelines for Crab Stock assessments following the April 2009 crab stock assessment workshop are appended to this report. This report contains information guidelines for the material to be included in all subsequent assessments.

General recommendations for all assessments

- All assessments should use the most recent data available, including revised survey data.
- All assessment should closely follow the guidelines in the Report of the Alaska Crab Stock Assessment Workshop (Appendix 1).
- The assessments should provide complete documentation on model formulation, assumptions, data sources and all calculations used when computing the OFL.
- Any tables depicting commercial fishery harvest or performance should be updated to include the most current information available.
- If the fishery year does not correspond to a calendar year then the fishery year notation should be used (e.g., 2007/08)

- The assessments must include consistent key management-related stock status information
- The assessments should include results based on the modeling approach used in the previous years to allow comparisons to be made with the proposed modeling approach for the current year.
- Estimates of precision for the survey data should be included in all assessments.
- Data (e.g. bycatch, survey) used in the assessment should be included in documentation.
- Table headings should clearly and accurately describe the data, including indicating when the values include a handling mortality assumption and the assumption used.
- Responses to all comments by the SSC and CPT on the September and May drafts of the stock assessment should be clearly addressed and responded to in the assessment.
- Research on handling mortality rates needs to be performed to better specify handling mortality rates used in the analyses.

Stock Status Summaries

1 Eastern Bering Sea Snow Crab

Fishery information relative to OFL setting.

The snow crab fishery has been opened, and harvest reported, every year since the 1960s. Prior to 2000, the GHL was 58% of abundance of male crab over 101 mm CW, estimated from the survey. The target harvest rate was reduced to 20% following the declaration of the stock as overfished in 1999, and the GHL/TAC since 2000 has been based on a harvest strategy that aims to allow recovery to the proxy for B_{MSY}.

Data and assessment methodology

The assessment is based on a size-structured population dynamics model in which crabs are categorized into mature, immature, new shell and old shell crabs by sex. The model is fitted to data on historical catches (landed and discard), survey estimates of biomass, and fishery, discard and survey size-composition data. It covers the 1978-2009 seasons and estimates abundance from 25-29mm to 130-135mm using 5mm size bins. The results of the annual Bering Sea bottom trawl survey are analyzed in three periods: before 1982, 1982-88, and 1989 onwards, with different selectivity and catchability parameters for each period. The model is based on the assumption of a terminal molt at maturity. The 2009 assessment is based on the same model and estimation framework as the 2008 assessment. Research is currently underway to evaluate the performance of the assessment method using the Management Strategy Evaluation approach, and to explore spatial structure and spatially-structured population dynamics models for snow crab. The impact of the BSFRF data regarding survey selectivity will be analyzed for the May 2010 CPT meeting.

Compared with the assessment presented to the CPT in May 2009, the final assessment uses catch and fishery length-frequency data for the 2008/09 season as well as survey abundance and length-frequency data for 2009. The 2009 assessment examines the sensitivity of the results to the use of survey data based on a variable net width.

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. However, the estimate of mature male biomass has not recovered as much as expected from the 2008 assessment. This reflects a continuing retrospective pattern in that biomass estimates are revised downwards with additional data. Recruitment has varied considerably over the period 1979-2009, with the recruitment (at 25mm) in 1986 the highest on record.

Tier determination/Plan Team discussion and resulting OFL determination

The CPT recommends that snow crab be in Tier 3 (stock status b), so the OFL is based on the $F_{35\%}$ control rule. The team recommends that the proxy for B_{MSY} ($B_{35\%}$) be the mature male biomass at mating, computed as the average recruitment from 1979 to the last year of the assessment multiplied by the mature male biomass-per-recruit corresponding to $F_{35\%}$ less the mature male catch under an $F_{35\%}$ harvest strategy. The estimate of B_{MSY} from the 2009 assessment is 326.7 million lbs. The MSST is defined as half of the proxy for B_{MSY} (163.4 million lbs).

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		N/A	36.9	37.0	42.9	
2006/07		N/A	36.2	36.4	44.9	
2007/08	158.9	218	63.0	63.0	77.1	
2008/09	163.4	241	58.6	58.5	69.5	77.3
2009/10		251*				73.0

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

The 2008/09 MMB (241 million lb) exceeds the proxy for MSST (163.4 million lbs) so the stock is not currently overfished. The total catch for 2008/09 (69.5 million lbs) was less than the 2008/09 OFL (77.3 million lbs) so overfishing did not occur during 2008/09.

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.

The OFL is uncertain (95% confidence interval of 20-113 million lbs). The uncertainty in the assessment is also reflected in terms of the relationship between the annual fishing mortality rate and that expected under the OFL control rule. For example, the TAC for 2008/09 was set less than the OFL, but the fishing mortality for 2008/09 equaled the value expected under the OFL control rule.

Rebuilding analysis

Under the current rebuilding plan, this stock had to recover to the B_{MSY} proxy in 2008/09 and 2009/10 to be defined as rebuilt. As the 2008/09 mature male biomass was smaller than B_{MSY}, the stock will fail to recover as planned. To assist the Council in amending the rebuilding plan for this stock, an approach to evaluate the trade-off between the rate of recovery to the B_{MSY} proxy and the catch during the period of recovery using projections based on the stock assessment has been developed. The assessment reports results for three candidate rebuilding harvest strategies which cover the range from closing the fishery to setting the fishing mortality to maximum permitted under the revised National Standard 1 Guidelines (75% of the F_{OFL}). It also reports some preliminary economic analyses of these rebuilding strategies. The assessment authors recommend an interim rebuilding strategy of 55% $F_{35\%}$ for the 2009/10 fishing season. The CPT did not evaluate the trade-offs among the various rebuilding strategies and hence does not have a recommendation for an interim harvest for 2009/10. The development of a revised rebuilding plan should also consider catches of snow crab in other fisheries, including groundfish fisheries.

Additional Plan Team recommendations

The next assessment should: (a) further justify the values chosen for the weighting factors (the lambdas) and explore sensitivity to alternative weights, as outlined in the report of the 13-14 May 2009 stock assessment workshop, (b) re-run the model setting the lambda on the survey data to unity and adjusting the remaining lambdas – this will not change the point estimates of the model outputs but should widen the confidence intervals, (c) include the predictions from the May version of the model in the September assessment to evaluate how well the model forecasts biomass, (d) use the revised trawl survey data and, (e) include a sensitivity test taking account of the 2009 data from the NMFS/BSFRF survey.

The next assessment should consider: (a) imposing a penalty to prevent the probability of maturity declining with increasing size if maturity is estimated within the model, (b) setting the effective sample sizes for the length-frequency data based on the effective sample sizes estimated from the fit of the model, (c) exploring whether it is possible to improve the residual patterns for the length-frequency data by modifying how maturity, growth and natural mortality are modeled and the implications of the change in distribution of the population over time, (d) reducing the number of size classes for females, and (e) fitting to the discard length-frequency data for males rather than to the total length-frequency data for males (to avoid fitting to the retained length-frequency data twice).

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

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

2 Bristol Bay red king crab

Fishery information relative to OFL setting.

The commercial harvest of Bristol Bay red king crab (BBRKC) dates to the 1930s, initially prosecuted mostly by foreign fleets but shifting to a largely domestic fishery in the early 1970s. Retained catch peaked in 1980 at 129.9 million lbs, but harvests dropped sharply in the early 1980s, and population abundance has remained at relatively low levels over the last two decades compared to that seen in the 1970s. The fishery is managed for a total allowable catch (TAC) coupled with restrictions for size (≥ 6.5-in carapace width), sex (male only), and season (no fishing during mating/molting periods). Prior to 1990, the harvest rate was based on estimated population size and prerecruit and postrecruit abundances, and varied from 20% to 60% of legal males. In 1990, the harvest strategy became 20% of the mature male (≥120-mm CL) abundance, with a maximum of 60% on legal males, and a threshold abundance of 8.4 million mature females. The current stepped harvest strategy allows a maximum harvest rate of 15% of mature males but also incorporates a maximum harvest rate of 50% of legal males, a threshold of 14.5 million lbs of effective spawning biomass (ESB), and a minimum GHL of 4.0 million lbs to prosecute a fishery. The TAC increased from 15.5 million lbs for the 2006/07 season 20.4 and 20.3 million lbs for the 2007/08 and 2008/09 seasons, respectively. Catch of legal males per pot lift was relatively high in the 1970s, low in the 1980s to mid-1990's, and increased to an average of 27.0 crab/pot lift over the last three years; CPUE increased markedly with the implementation of the crab rationalization program in 2005. Annual non-retained catch of female and sublegal male RKC during the fishery averaged less than 3.9 million lbs since data collection began in 1990. Estimates of fishing mortality ranged from 0.28 to 0.38yr^{-1} following implementation of crab rationalization. Total catch (retained and bycatch mortality) increased from 17.2 million lbs in 2006/07 to 23.2 million lbs in 2007/08 and 23.1

million lbs in 2008/09. Retained catch was 20.3 million lbs in the 2008/09 fishery.

Data and assessment methodology

The stock assessment model is based on a length-structured population dynamics model incorporating data from the eastern Bering Sea trawl survey, commercial catch, and at-sea observer data program. Stock abundance is estimated for male and female crabs ≥ 65-mm carapace length during 1968-2009, an extension from the previous assessment which considered the years 1985-2008. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date from the fishery which targets males ≥6.5" carapace width) were obtained from ADF&G fish tickets and reports, red king crab and Tanner crab fisheries bycatch data from the ADF&G observer database, and groundfish trawl bycatch data from the NMFS trawl observer database. Several other changes to the assessment, included re-analysis of the trawl survey data based on revised estimates of the area-swept from 1975 to 2009, and allowances for changes over time in the size at maturity for females, and mortality. The author evaluated three model scenarios: (1) a constant natural mortality ($0.18yr^{-1}$) with additional "unexplained" mortality for males and females, and incorporating Bering Sea Fisheries Research Foundation (BSFRF) survey data for 2007 and 2008; (2) constant $M = 0.18yr^{-1}$ with BSFRF 2008 survey data; and (3) similar to scenario 1, but without BSFRF data.

Stock biomass and recruitment trends

Estimates of total survey biomass increased from 177.2 million lbs in 1968 to 721.1 million lbs in 1978, decreased sharply to a low of 66.3 million lbs in 1985, then generally increased to 196.5 million lbs in 2009. Recent above-average year classes have largely recruited into the fished population with no evidence of new strong recruitment for the past three years. Mature male biomass at mating increased from 76.4 million lbs in 2007 to 95.2 million lbs in 2009.

Spatial aspects of red king crab distribution were identified as needing further exploration. For example, female survey abundance has increased in southwestern Bristol Bay, an area that also encounters extensive groundfish trawling. The distribution of this stock relative to the boundaries between the Bristol Bay management unit and the Northern District management unit warrants further examination.

Tier determination/Plan Team discussion and resulting OFL determination

All data used in the model need to be tabulated in the document and fits to all data components shown in figures. For example, model estimates of pot discard mortality and total catch from all sources should be included in the catch table for all years (1968 to present) and the BSFRF survey indices should be tabulated and the fit to them shown.

The team noted that the use of the NMFS survey data to set a prior for estimation of Q for the BSFRF survey is not appropriate as this uses the data twice.

Additional mortality for 1976-1993 is estimated in the model and referred to as natural mortality. The CPT recommends this additional mortality be referred to as unknown mortality, which could be fishing mortality or natural mortality. The CPT also requests better justification for the time periods used for unknown mortality estimation and exploration of alternative periods.

In May, the CPT considered four time periods for estimation of $B_{35\%}$ including: (1) adopt the author's recommendation using recruitment from 1995 to present; (2) 1985 to present, (3) all years, 1968 to present, and (4) pre-collapse years, 1968 to 1980. The team discussed whether changes in stock production have occurred over period 1968 to present. The team recommended, and the SSC concurred with, the author's suggested time period of 1995-current for estimation of $B_{35\%}$. For the May 2010 meeting, the team recommends additional analyses into whether stock production has changed over time, including a discussion on regime shifts in the Bering Sea and possible mechanisms for effects on red king crab recruitment.

In May, the CPT recommended model scenario 3, in particular because, the team did not have sufficient information regarding the BSFRF survey results, and in any case, not all of the BRFRF data were included in the assessment to recommend a model scenario which incorporates these data.

The Plan Team recommends Bristol Bay red king crab in Tier 3, stock status a. The team recommends that the proxy for B_{MSY} ($B_{35\%}$) be the mature male biomass at mating, computed as the average recruitment from 1995 to the last year of the assessment multiplied by the mature male biomass-per-recruit corresponding to $F_{35\%}$ less the mature male catch under an $F_{35\%}$ harvest strategy. Estimated $B_{35\%}$ is 68.5 million lbs. Total catch includes retained male catch and all other bycatch sources.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		NA	18.33	18.52	22.72	
2006/07		NA	15.53	15.75	17.22	
2007/08	44.8	85.9	20.38	20.51	23.23	
2008/09	37.6	87.8	20.37	20.32	23.10	24.20
2009/10		95.2*				22.56

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

The 2008/09 MMB exceeds the B_{MSY} proxy of $B_{35\%}$ so the stock is not currently overfished. The total catch for 2008/09 (23.1 million lbs) was less than the 2008/09 OFL (24.2 million lbs) so overfishing did not occur during 2008/09.

Additional Plan Team recommendations

For the May 2010 assessment, the CPT requests that model scenarios 1, 2 and 3 be reexamined. The Plan Team identified the need for all model input data to be tabulated.

The CPT appreciates the preliminary analysis of model sensitivity to different weightings (lambdas). The magnitudes of lambdas have a direct affect on projected biomass and likelihood profiles because increasing lambdas impact the widths of the profiles. In terms of evaluating uncertainty in some of the forcing parameters, the team recommends that the authors provide a plot of a likelihood profile for some of the parameters such as trawl survey catchability and M. It was also recommended that the author consider parameter estimation in a fully Bayesian context. Figures of standardized residuals were provided in the current assessment and the CPT encourages further analysis of some of the residual patterns for possible cohort or growth effects. The team also requested clarification of the effect of aging errors on molt probability.

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 red king crab females have likely shifted in response to changes in near bottom temperatures.

3 Eastern Bering Sea Tanner crab

Fishery information relative to OFL setting.

Two fisheries, one east and one west of 166˚ W. longitude, harvest eastern Bering Sea (EBS) Tanner crab. Under the Crab Rationalization Program, ADF&G sets separate TACs and NMFS issues separate individual fishing quota (IFQ) for these two fisheries. However, one OFL is set for the EBS Tanner crab because 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 to 2008/09 crab fishing years. In 2007, NMFS determined the stock was rebuilt because spawning biomass was above B_{MSY} for two consecutive years.

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

Data and assessment methodology

This stock is surveyed annually by the NMFS EBS trawl survey. Although a stock assessment model has been developed for the eastern portion of the stock, this model is not employed to assess the stock because it does not cover the entire EBS. Area-swept estimates of biomass from the EBS trawl survey are used to estimate biomass of stock components: mature male biomass (MMB), legal male biomass (LMB), and females. Fish ticket data are used for computing retained catch and observer data from the crab, and groundfish fisheries are used to estimate the non-retained catch; assumed handling mortality rates for fishery components are used to estimate the discard mortality.

Although the status determinations are based upon the original NMFS trawl survey data, the 2009 stock assessment contains an Appendix B that calculates stock status and overfishing levels using the revised NMFS bottom trawl survey data in response to an SSC request. The CPT notes that the May 2010 stock assessment will use the revised survey data.

Stock biomass and recruitment trends

MMB and LMB showed peaks in the mid-1970s and early 1990s. MMB at the survey revealed an all-time high of 623.9 million pounds in 1975, and a second peak of 255.7 million pounds in 1991. From late-1990s through 2007, MMB has risen at a moderate rate from a low of 25.1 million pounds in 1997. Post-1997, MMB at the time of survey increased to 185.2 million pounds in 2007 and subsequently decreased to 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. In the 2009 survey, the MMB at the time of survey decreased to 86.6 million pounds, a 36.8% decrease from 2008. Most other size classes of males and females also showed a decline in estimated abundance, except for small females (see Figure 9 in the stock assessment).

Tier determination/Plan Team discussion and resulting OFL determination

The team recommends the OFL for this stock be based on the Tier 4 control rule because no stock assessment model has been developed for the entire EBS stock. Based on the estimated biomass, the stock is at stock status level b. The team recommends that B_{MSY} is based on the average MMB for the years 1969-1980, discounted by fishery removals (retained and non-retained mortalities) and natural mortality between the time of survey and the time of mating. This time period is thought to represent the reproductive potential of the stock because it encompasses periods of both high and low stock status equivalently. This equates to a B_{MSY} of 189.76 MMB. The team recommends that gamma (γ) be set to γ=1.0.

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

Year	MSST	Biomass (MMB)	TAC (east + west)	Retained Catch	Total Catch	OFL
2005/06		86.24	1.6	0.95	4.19	
2006/07		126.58	2.97	2.12	11.95	
2007/08	94.8	150.74	5.62	2.11	8.80	
2008/09	94.8	118.23	4.3	1.94	4.96	15.52
2009/10		70.16*				5.57

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

The total catch for 2008/09 (4.96 million lbs) was less than the 2008/09 OFL (15.52 million lbs) so overfishing did not occur during 2008/09. Based on the stock assessment, the Tanner crab stock was not overfished in 2008/09. However, based on the survey for 2009, irrespective of the catch during 2010, MMB is projected to be below MSST on February 15, 2010, i.e. the stock is approaching an overfished condition.

Ecosystem Considerations summary

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

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

There is no harvest strategy for this fishery in State regulation. The fishery began as bycatch in 1973 during the blue king crab fishery. A red king crab fishery opened with a specified GHL for the first time in September 1993. The 1993/94 fishery yielded 2.6 million pounds under a 3.4 million pound GHL, with the highest catches occurred east of St. Paul Island, but harvests also south, southwest, west, and northeast of St. Paul Island. The 1994 fishery was also prosecuted with a specified red king crab GHL. Since 1995, a combined GHL for red and blue king crabs was set and ranged from 1.25 to 2.5 million pounds. The fishery has remained closed since 1999 because of uncertainty with estimated red king crab survey abundance and concerns for incidental catch and mortality of blue king crab, an overfished and very depressed stock. Prior to the closure, the CDQ harvest (3.5%) in 1998/99 was 35,958 pounds. The non-retained catches (without application of bycatch mortality rate) from pot and groundfish bycatch estimates of red king crab ranged from 0.11 to 0.19 million pounds during 1991/92 – 2008/09.

Data and assessment methodology

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

Stock biomass and recruitment trends

The stock exhibited widely varying mature male and female abundances during 1980-2009. The estimate of MMB from the 2009 survey was 4.46 million pounds. Recruitment indices are not well understood for Pribilof red king crab. Pre-recruitment have remained relatively consistent in the past 10 years, although may not be well assessed with the survey. Stock biomass in recent years has decreased since the 2007 survey with a substantial decrease in all size classes in 2009. Red king crabs have been historically harvested with blue king crabs and are currently the dominant of the two species in this area.

Tier determination/Plan Team discussion and resulting OFL determination

This stock is recommended to be in Tier 4, stock status b. For the 2009/2010 fishery, the CPT recommends using the period 1991-2009 to determine mean MMB at mating time as a proxy B_{MSY}. The estimated proxy B_{MSY} is 8.78 million pounds. The team recommends that γ be set to 1.0.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		2.59	Closed	0	0.064	
2006/07		13.87	Closed	0	0.024	
2007/08	4.33	14.70	Closed	0	0.008	
2008/09	4.39	11.06	Closed	0	0.021	3.32
2009/10		4.46*				0.50

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

The total catch for 2008/09 (0.021 million lbs) was less than the 2008/09 OFL (3.32 million lbs) so overfishing did not occur during 2008/09. The 2009 MMB estimate of 11.06 was above MSST in 2008/09 and therefore is not overfished.

Additional plan team recommendations

The CPT looks forward to an update on the catch survey model for May 2010.

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 observed 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. Seasonal ice cover has an effect on primary productivity and hence crab recruitment, but the effect of changes in ice cover on benthic communities of the Pribilof Islands are not well known. The trawl fishery ban around the Pribilof Islands protects red king crab critical habitat 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 2008/09 season. The stock was declared overfished in 2002.

Data and assessment methodology

The NMFS conducts an annual trawl survey that is used to produce area-swept abundance estimates. In 2009 NMFS updated the trawl survey time series resulting in a minor adjustment in current and historical survey biomass and a minor adjustment in the B_{MSY} calculation. This assessment uses the new survey data series with measured net widths. The CPT discussed the history of the fishery and the rapid decline in landings. It is clear that the stock has collapsed, although the annual area-swept abundance estimates are imprecise.

Stock biomass and recruitment trends

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

Tier determination/Plan Team discussion and resulting OFL determination

This stock is recommended for placement into Tier 4, stock status level c. The time period for B_{MSY} is 1980/81-1984/85 plus 1990/1991-1997/1998, excluding the period 1985/1986-1989/1990. This range was chosen because it eliminates periods of extremely low abundance that may not be representative of the production potential of the stock. B_{MSY} is estimated as 9.28 million pounds. The retained catch OFL is 0 because the 2009/10 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 due to inadequate progress towards rebuilding.

The OFL for 2008/09 was set at 0.004 million lbs, the average catch mortality between 1999/00 and 2005/06. The CPT recommends an OFL for 2009/10 at 0.004 million lbs, equal to the total catch OFL for 2008/09.

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

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		0.68	closed	0	0.002	
2006/07		0.33	closed	0	0.0004	
2007/08		0.66	closed	0	0.005	
2008/09	4.64	0.25	closed	0	0.001	0.004
2009/10	4.64	1.13*	closed	0		0.004

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

The total catch for 2008/09 (0.001 million lbs) was less than the 2008/09 OFL (0.004 million lbs) so overfishing did not occur during 2008/09. The 2009/10 projected MMB estimate of 1.13 million lbs is below the proxy for MSST so the stock continues to be in an overfished condition.

Additional Plan Team recommendations

The rebuilding plan needs to be revised given inadequate progress towards rebuilding. Management options for revising the rebuilding plan are contained in the Crab Plan Team minutes (May 2009).

6 St. Matthew blue king crab

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. The stock was declared overfished and closed in 1999, and was under a rebuilding plan until 2008/2009. The MMB has been over B_{MSY} for two years and is now rebuilt. The fishery has remained closed since 1999.

Data and assessment methodology

A four-stage catch survey analysis that incorporates annual trawl survey data from 1978 to present, triennial pot survey data from 1995 to 2007, and commercial catch data from 1978 to 2008, and uses a maximum likelihood approach to estimate male crab biomass and abundance forms the basis for the assessment. The model links crab abundance in four crab stages based on a growth matrix, estimated mortalities, and molting probabilities. The four stages are prerecruit-2s (90-104 mm CL), prerecruit-1s (105-119 mm CL), recruits (newshell 120-133 mm CL), and postrecruits (oldshell ≥ 120 mm CL and newshell ≥ 134 mm CL). The assessment considered five scenarios to related natural mortality (M) or survey catchability (Q). 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

MMB has fluctuated greatly in three periods. The first period 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 period had a steady increase from the low in 1985 to 13.3 million lbs. in 1997 followed by a rapid decrease to 2.8 million lbs. in 1999. The third period had a steady increase 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 blue king crab is recommended as a Tier 4 stock. The $B_{MSYproxy}$ varies as a function of years used to calculate average MMB. The time period selected by CPT for estimating $B_{MSYproxy}$ was 1989 to current. This because the stock was harvested at extremely high rates before 1986 and this time period incorporates stock rebuilding several years after the stock crash. $B_{MSYproxy}$ during this time period is 7.99 million lbs. and γ =1.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		5.3	closed	closed	0.47	
2006/07		7.1	closed	closed	0.67	
2007/08		9.7	closed	closed	0.35	
2008/09	4.0	10.74	closed	0.20	0.20	1.63 [retained]
2009/10	4.0	12.47*				1.72 total male catch

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

The retained catch for 2008/09 (0.20 million lbs) was less than the 2008/09 OFL (1.63 million lbs) so overfishing did not occur during 2008/09. The stock is considered rebuilt after two years of estimated MMB biomass above the $B_{MSYproxy.}$ The MMB has been over $B_{MSYproxy}$ for two years and is now rebuilt. The 2009/10 projected MMB estimate of 12.47 million lbs is also above the $B_{MSYproxy}$.

Additional Plan Team recommendations

1) The model should continue to be refined for review at the May 2010 CPT meeting to allow this stock to be considered for Tier 3.
2) Bycatch data in all fisheries must be compiled to generate a total catch OFL. Note this was only done for total (male) catch OFL in the 2009/10 fishery. The model should be modified in the future to allow for the total catch OFL to include both males and females.

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 blue king crab 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 observer program-based 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. The current 2009 stock assessment was updated with data from the 2008 fall trawl survey, 2008 winter pot survey, and the 2008 summer commercial fishery. The 2008/09 retained fishery catch data used in the analysis are incomplete. No directed fishery discard losses, or stock losses resulting from non-directed fishery bycatch were included in this 2009 assessment.

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 stock assessment model. The CPT had major concerns about the suitability of the model presented for OFL-setting, and offered several recommendations and requests of the authors:

1. The team requested that the assessment model from the previous year be included in the current assessment in order to evaluate the impact of changes made to the model, and to have those results as a fall-back option if the current model is unsuitable and rejected for OFL-determination.

2. In this assessment, stock losses due to natural morality and only retained catch are considered. Mortalities due to directed fishery discards and non-directed bycatch are not included; thus, handling mortality is explicitly set equal to zero. The team discussed the justification for a zero handling morality rate assumption and questioned the justification as described in the assessment.

   The author justified this rate based on the absence of observer data. The author also justified the lack of discard and bycatch mortality as the only source of such mortality is temperature (i.e. freezing) induced and this is not significant due to the timing of the fishery. This justification was considered inadequate by the team and the assumption of zero non-retained morality to be implausible. The team noted other sources of potential mortality such as that resulting from handling stress and physical damage of non-retained crab. The team recommended that in the absence of observer data on discards and bycatch, the assessment should include a sensitivity analysis as to a plausible range of non-retained mortalities. The team also suggested that the approach used in the Bristol Bay red king crab assessment for estimating discard catch in the directed fishery be used as a benchmark, and that these results be compared to those resulting from the zero non-retained mortality assumption.

3. The team did not approve the model scenario which included a naturally mortality rate = 0.3 and requested instead the use of 0.18. The team discussed the likelihood profiles of M presented in the assessment (Chapter 7, Figure 2) and did not consider the rate of 0.30 to be adequately supported by either profile. The team also did not support natural mortality arguments based on longevity as presented in the assessment.

4. The team had major concerns about the use of $\gamma = 0.6$ in the 2009 OFL analysis and requested that the model be revaluated with a $\gamma = 1$ as their preferred alternative. The assessment was modified to include this.

5. The team requests that the assessment be updated for September 2009 with the 2008/09 retained catch included in order to determine if overfishing was occurring in 2008/09.

6. The team requests further analysis of the retrospective pattern in the assessment given concerns regarding the consistent pattern indicating an overestimate of biomass compared to the trawl survey.

7. The team approved the authors' recommendation of the use of 1983-2009 to estimate the B_{MSY} proxy which excludes the 1976-1982 period due to uncertainty in biomass estimates, however the team requests that author provide a more complete rationale for choice of range of years in future assessments.

8. The team recommended inclusion of an assumed bycatch and discard mortality for the subsequent assessments.

9. The team requested that the subsequent assessment also include a Tier-5 calculation.

The team recommended Tier 4 stock status for a 2009/10 retained catch OFL of 0.7125 million pounds. The $B_{MSYproxy}$ is 3.07 million lbs, $F_{MSYproxy} = 0.18$, MMB in 2009 = 5.83 million lbs. This OFL is established in June 2009 in order to allow for the summer fishery.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		3.89	0.37	0.40		
2006/07		3.62	0.45	0.45	0.48	
2007/08		4.40	0.32	0.31*	0.35	
2008/09	1.55	5.24	0.41	0.39*	0.42	0.68 [retained]
2009/10	1.55	5.83	0.37			0.71 [retained]

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

The retained catch for 2008/09 (0.39 million lbs) was less than the 2008/09 OFL (0.68 million lbs) so overfishing did not occur during 2008/09. The 2009 MMB estimate of 5.83 was above MSST in 2009 and therefore is not overfished.

Additional Plan Team recommendations
The team also recommended that the summary fishery performance table include the most recent year's catch, the corresponding estimated catch used in the stock assessment model and the OFL. Finally, figures should be clearly configured for ease of interpretation (e.g., X-axes offset in the comparison of observed and estimated abundances, and the most recent observations clearly marked showing the relationship between harvest rates and mature male biomass).

The team reiterated the ongoing request that that the assessment show results of sensitivity analyses for key model parameters to assist in evaluating alternative model specifications.

8 Aleutian Islands golden king crab

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 the average harvest 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) remained at 5.7 million lbs through the 2007/08 season. In March 2008 the Alaska Board of Fisheries set the TAC for this stock in regulation at 5.985 million pounds. Average retained catch for the period 1996/97–2007/08 was 5.6 million lbs, including 5.5 million lbs in the 2007/08 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 ADF&G fish tickets (retained catch numbers, retained catch weight, and pot lifts by ADF&G statistical area and landing date), size-frequency data from samples of landed crabs, at-sea observer data from pot lifts sampled during the fishery (date, location, soak time, catch composition, size, sex, and reproductive condition of crabs, etc), data from a triennial pot survey in the Yunaska-Amukta Island area of the Aleutian Islands (approximately 171° W longitude), recovery data from tagged crabs released during the triennial pot surveys and bycatch data from the groundfish fisheries. These data are available through the 2007/08 season and the 2006 triennial pot survey. Most of the available data were obtained from the fishery which targets legal-size (≥6-inch CW) males, and trends in the data can be affected by changes in both fishery practices and the stock. The triennial survey is too limited in geographic scope and too infrequent to provide a reliable index of abundance for the Aleutian Islands area. A triennial survey was scheduled for 2009, but was cancelled.

Stock biomass and recruitment trends

Estimates of stock biomass are not available for this stock. Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. However, there is good evidence that the sharp increase in CPUE of retained legal males during recent fishery seasons was not due to a sharp increase in recruitment of legal-size males.

Tier determination/Plan Team discussion and resulting OFL determination

AIGKC is recommended for Tier 5 stock in 2009/2010. B_{MSY} and MSST are not estimated for this stock. Observer data on bycatch from the directed fishery is too incomplete to provide estimates of total catch for the time periods under consideration; there is no observer data from the directed fishery prior to the 1988/89 season and observer data are lacking or confidential for at least one management area in the Aleutian Islands for four seasons of seven seasons during 1988/89–1994/95. Hence, OFL was recommended for this year as a retained catch OFL. The time period for calculating average catch was selected as 1990/1991 to 1995/1996 because before 1990, during a period of unconstrained harvest, there were indications (declining CPUE and catch) that large catches prior to 1990 were not sustainable. Post 1996 harvests were constrained by a constant GHL/TAC and therefore may not be representative of true production potential. The CPT believes that the 1990/1991 to 1995/1996 time period best represents the sustainable, long-term production potential of the stock. This recommendation differs with the approach taken by the SSC in June 2008. However the reasons for recommending the year period 1990/1991 - 1995/1996 to calculate the OFL persist from the prior year's assessment.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL (retained)
2005/06	NA	NA	5.70	5.52	6.0	
2006/07	NA	NA	5.70	5.22	5.8	
2007/08	NA	NA	5.70	5.51	6.2	
2008/09	NA	NA	5.99	5.68	6.3	9.18 [retained]
2009/10	NA	NA	5.99			6.93 [retained]

No overfished determination is possible for this stock given the lack of biomass information. Retained catch in 2008/09 (5.68 million pounds) was less than the retained catch OFL for this stock in 2008/09 therefore overfishing did not occur.

Additional Plan Team recommendations

In May 2009, the plan team reviewed a new stock assessment model for Aleutian Islands golden king crab (Chapter 8b, Draft May Crab SAFE report). Use of an assessment model could allow for this stock to be moved to Tier 4 and would provide focus for establishing research and data collection priorities. The team believes that the model has been improved greatly from the 2008 iteration. The team recommends incorporation of plan team comments into the model for the September 2009 plan team meeting but did not recommend adopting the model for OFL determination in this year. Specific comments on model suggestions are contained in the May Crab Plan Team report.

Ecosystem Considerations summary

The assessment author should reference the Aleutian Islands Fishery Ecosystem Plan in future assessment reports. The author reviewed the June 2008 SSC comments on ecosystem considerations for this stock. However an ecosystem discussion was not included in the assessment. The specific SSC comments regarding sea bird predation on larval crabs may be difficult to address for this stock.

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 mm. 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 in the Bering Sea snow crab and grooved Tanner crab fisheries. This fishery was not included in the Crab Rationalization Program. This fishery is the only fishery considered here in which the fishery year corresponds with the calendar year; the fishery opens on January 1 and is open year round operating under an ADF&G commissioner's 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. Options for time periods and for considering a total catch OFL were presented. Due to either confidentiality of retained catch data or lack of observer data a total catch OFL can only be computed from the average of the 2001 and 2002 seasons, both of which were fished under the constraint of a 150,000 pound GHL. Hence it is recommended that the 2010 OFL for fishery be established as a retained catch OFL. The team recommended that the time period for the average catch calculation be 1993-1998 as this time frame contains average catch over a time period where catch is neither confidential nor constrained by a GHL.

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

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Catch (non retained all fisheries)*	OFL
2006	NA	NA	0.15	0		
2007	NA	NA	0.15	0		
2008	NA	NA	0.15	0		
2009	NA	NA	0.15	0	0.001	0.17 [retained]
2010	NA	NA				0.17 [retained]

*catch data for crab fisheries only

No overfished determination is possible for this stock given the lack of biomass information. Retained catch in 2009 did not exceed the retained catch OFL therefore overfishing did not occur in 2009.

Additional Plan Team recommendations

The team recommends the assessment author further evaluate all sources of mortality in order to present alternative total catch OFL options for the 2011 assessment (May 2010). The team encourages inclusion of further information on the slope survey to the extent possible to consider whether or not information may be sufficient to move this assessment up to tier 4 in future years.

10 Adak red king crab, Aleutian Islands

Fishery information relative to OFL setting

The domestic fishery has been prosecuted since 1960/61 and was opened every season through the 1995/96 season. Since 1995/96, the fishery was opened only occasionally, 1998/99, 2000/01-2003/04. Peak harvest occurred during the 1964/65 season with a retained catch of 21 million pounds. During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between 172° W longitude and 179° 15’ W longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of 179° 15’ W longitude began to account for a larger portion of the retained catch

Retained catch during the 10-year period, 1985/86 through 1994/95, averaged 0.943 million pounds, but the retained catch during the 1995/96 season was low, only 0.039 million pounds. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99; three Commissioner’s permit fisheries in limited areas during 2000/01 and 2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 0.5 million pounds during the 2002/03 and 2003/04 seasons. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude) and the last two commercial fishery seasons (2002/03 and 2003/04) were opened only in the Petrel Bank area. Retained catches in those two seasons were 0.506 million pounds (2002/03) and 0.479 million pounds (2003/04). The fishery has been closed through the 2008/09 season since the end of the 2003/04 season.

Non-retained catch of red king crabs occurs in both the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated bycatch mortality during the 1995/96-2008/09 seasons averaged 0.003 million pound in crab fisheries and 0.024 million pounds in groundfish fisheries. Estimated annual total fishing mortality (in terms of total crab removal) during 1995/96-2008/09 averaged 0.116 million pounds. The average retained catch during that period was 0.09 thousand pounds. This fishery is rationalized under the Crab Rationalization Program only for the area west of 179° W longitude.

Data and assessment methodology

The 1960/61-2008/09 time series of retained catch (number and pounds of crabs), effort (vessels, landings and pot lifts), average weight and average carapace length of landed crabs, and catch-per-unit effort (number of crabs per pot lift) are available. Bycatch from crab fisheries during 1995/96-2008/09 and from groundfish fisheries during 1992/93-2008/09 are available. There is no assessment model in use for this stock. The standardized surveys by ADF&G have been too limited in geographic scope and too infrequent for reliable estimation of abundance for the Aleutian Islands area. Prior to the 2006 survey, the last one conducted was in 2001, performed with industry participation under provisions of a commissioner’s permit. The department attempted to do another systematic pot survey in 2007, but did not receive any bids for a charter vessel. The department plans to conduct a survey in the Petrol Bank area in November 2009 using a chartered crab pot vessel. 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 collaboration for survey work in this area.

Stock biomass and recruitment trends

Estimates of stock biomass are not available for this stock. Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. The fishery has been closed since the end of 2003/04 season due to apparent poor recruitment. A pot survey conducted by ADF&G in the Petrol Bank area in 2006 provided no evidence of strong recruitment.

Tier determination/Plan Team discussion and resulting OFL determination

The CPT recommends this as a Tier 5 stock for the 2009/10 season. The team discussed at length whether to compute the OFL as total catch or only retained catch. The author suggested using the retained catch OFL because there would be errors in estimating bycatch during initial years of the fishery when it was developing. The CPT agrees with the author’s suggestion. The author provided three model alternatives (Alt.) with different time periods in addition to the “Base” that was used to determine the OFL for 2008/09 (Base:

1985/886-2007/08; Alt.1: 1984/85-2007/08; Alt.2: 1977/78-2007/08; and Alt.3: 1960/61-2007/08) to compute the average retained catch as OFL. Agreeing with SSC's recommendations the CPT recommends alternative 1 for the OFL calculation. The retained catch OFL for this period (1984/85-2007/08) is 0.50 million pounds. The CPT also recommends freezing the final fishing season for OFL calculation at 2007/08.

Status and catch specifications (millions of lbs) of Adak red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06	NA	NA	Closed	0	0.004	
2006/07	NA	NA	Closed	0	0.004	
2007/08	NA	NA	Closed	0	0.011	
2008/09	NA	NA	Closed	0	0.014	0.46[a] [retained]
2009/10	NA	NA	Closed	0		0.50[b] [retained]

a based on 1984/85-07/08 mean retained catch
b based on 1984/85-07/08 mean retained catch

No overfished determination is possible for this stock given the lack of biomass information. Retained catch in 2009 did not exceed the retained catch OFL therefore overfishing did not occur in 2009.

Additional Plan Team recommendations

For the May 2010 CPT meeting, the CPT requested the author to provide an analysis applying the available information on bycatch to time periods for which bycatch data are lacking to obtain an estimate of a total-catch OFL and to provide the CPT with total-catch OFLs options to consider for 2010/11.

Ecosystem Considerations summary

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

Table 3 Crab Plan Team recommendations September 2009
(Note diagonal fill indicates parameters not applicable for that tier level)

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2009/10[2 3] MMB	2009/10 MMB / MMB_{MSY}	γ	Mortality (M)	2009/10 OFL mill lbs [retained]
1	EBS snow crab	3	b	0.52	326.7	1979-current [recruitment]	251	0.77		0.23 (males, immat.) 0.29 (mature females)	73.0
2	BB red king crab	3	a	0.32	68.5	1995-current [recruitment] [5]	95.17	1.08		0.18 default , estimated otherwise[4]	22.56
3	EBS Tanner crab	4	b	0.07	189.76	1969-1980 [survey]	70.2	0.37	1.0	0.23	5.57
4	Pribilof Islands red king crab	4	b	0.08	8.78	1991-current [survey][5]	4.46	0.51	1.0	0.18	0.50
5	Pribilof Islands blue king crab	4	c	0	9.01	1980-1984; 1990-1997 [survey][5]	1.13	0.13	1.0	0.18	0.004
6	St. Matthew Island blue king crab	4	a	0.18	7.99	1989-current [model estimate] [5]	12.47	1.56	1.0	0.18 (1978-98, 2000-08); 1.8 (1999)	1.723 total male catch
7	Norton Sound red king crab	4	a	0.18	3.07	1983-current [model estimate]	5.83	1.9	1.0	0.18	0.7125 [retained]
8	AI golden king crab	5				1990/91-1995/96 [retained catch]					6.93 [retained]
9	Pribilof Island golden king crab	5				1993-1998 [retained catch]					0.176 [retained]
10	Adak red king crab	5				1984/85-2007/08 [retained catch]					0.50 [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 2/15/2010 at time of mating.
3 Model mature biomass
4 Additional mortality males: two periods-1980-1985; 1968-1979 and 1986-2008. Females three periods: 1980-1984; 1976-1979; 1985 to 1993 and 1968-1975; 1994-2008. See assessment for mortality rates associated with these time periods.
5 Revised EBS trawl survey timeseries data used
6 For calendar year 2010

Table 4 Stock status in relation to status determination criteria 2008/09
(Note diagonal fill indicates parameters not applicable for that tier level)

Chapter	Stock	Tier	MSST	B_{MSY} or $B_{MSYproxy}$	2008/2009[7] MMB	2008/2009 MMB / MMB_{MSY}	2008/09 OFL mill lbs [retained]	2008/09 Total catch
1	EBS snow crab	3	163.4	326.7	241	0.74	77.3	69.5
2	BB red king crab	3	34.3	68.5	87.8	1.28	24.2	23.1
3	EBS Tanner crab	4	94.9	189.76	118.0	0.62	15.52	4.96
4	Pribilof Islands red king crab	4	4.39	8.78	11.06	1.28	3.32	0.021
5	Pribilof Islands blue king crab	4	4.5	9.01	0.24	0.03	0.004	0.001
6	St. Matthew Island blue king crab	4	4.0	7.99	10.74	1.34	1.63 [retained]	0.20
7	Norton Sound red king crab	4	1.55	3.07	5.83	1.9	0.7125 [retained]	0.42
8	AI golden king crab	5					6.93 [retained]	6.3
9	Pribilof Island golden king crab	5					0.17 [retained]	0.001
10	Adak red king crab	5					0.46 [retained]	0.014

7 MMB as estimated during this assessment for 2008/09 as of 2/15/2009.

Stock Assessment of eastern Bering Sea snow crab

Benjamin J. Turnock and Louis J. Rugolo
National Marine Fisheries Service
September 16, 2009

EXECUTIVE SUMMARY

A size based model was developed for eastern Bering Sea snow crab (*Chionoecetes opilio*) to estimate population biomass and harvest levels. Model estimates of total mature biomass of snow crab increased from the early 1980's to a peak in 1990 of about 1,580 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 total mature biomass (330 million lbs) was below the minimum stock size threshold (MSST = 460 million lbs). A rebuilding plan was implemented in 2000. Under this rebuilding plan, NMFS required that the stock should be above B_{MSY} for two consecutive years (NPFMC 2000). The currency for estimating B_{MSY} changed during the 10 year rebuilding period. Using the current definitions for estimating B_{MSY}, the snow crab stock remained below B_{MSY} in the 2008/09 fishing year. Based on this finding, the current rebuilding strategy failed to make adequate progress towards rebuilding and has failed to rebuild the snow crab stock within the required 10 year time period.

Observed survey mature male biomass increased from 305.6 million lbs in 2008 to 359.1 million lbs in 2009, however, the 2009 biomass is below the 2007 estimate of 385.2 million lbs. Observed survey mature female biomass also increased from 203.5 million lbs in 2008 to 270.4 million lbs in 2009. The 2009 estimate of males greater than 101 mm was 150.1 million an increase from 119 million estimated in 2008.

Model estimates of mature male biomass at mating increased from 211 million lbs in 2007/8 to 241 million lbs in 2008/9 (74% of B35%). This is a lower value than estimated from the September 2008 assessment model projection of 2008/9 MMB of 260 million lbs (82% of B35%).

For comparison, runs of the model were made using the new analysis of the survey data with actual measured net widths in 2009. The 2009 observed survey mature male

biomass using the variable net width estimates was lower (311 million lbs) than the fixed width estimate (359.1 million lbs).

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 GHL since the 2000/01 fishery. Retained catch in the 2008/9 fishery was 58.5 million lbs compared to 63 million lbs in the 2007/08 fishery. The total catch in the 2008/09 fishery was estimated at 69.5 million lbs, below the OFL of 77.3 million lbs.

Estimated discard mortality (mostly undersized males and old shell males) in the directed pot fishery has averaged about 15.5% (with assumed mortality of 50%) of the retained catch biomass since 1992 when observers were first placed on crab vessels. Discards prior to 1992 were estimated based on fishery selectivities estimated for the period with observer data and the full selection fishing mortality estimated using the retained catch and retained fishery selectivities. Discard mortality was assumed to be 50%.

Projected catch and biomass for 2009/10-2018/19 were estimated using mature male biomass at the time of mating (February) and fishing at five rebuilding strategies: 1)the OFL (F35%), 2) maximum permissible (75% F35%), 3) 55% F35%, 4) Current Rebuilding Strategy and 5) F=0 control rules. The OFL for the 2009/10 fishery was 73.0 million lbs of total catch (61.6 million lbs retained catch) compared to 77.3 million lbs OFL in 2008/9. The 2009 observed survey biomass estimate was higher than 2008, however, it was lower than expected from the September 2008 model projections. The 2008/9 mature male biomass at mating time was estimated to be at 74% of B35%. The projected MMB at mating in 2009/10 at F=0 is projected to be below B35% (316 million lbs, B35% = 326.7 million lbs), resulting in failure of the current rebuilding strategy.

The rebuilding strategy recommended by the authors for 2009/10 is 55% F35%, which is projected to have a 51% probability that MMB > B35% after four fishing seasons (2009/10 to 2012/13). This strategy provides a balance of time to rebuild the stock and consideration of the needs of the fishing community. The 55% F35% strategy also sets the exploitation rates on MMB for the first two years below the average observed values using the failed rebuilding strategy during 1999 to 2008, and the next two years near the average exploitation rates (during1999 to 2008). In their deliberations on conservation measures for Bering Sea pollock stocks, the SSC recently identified the spawning exploitation rate as a metric to consider. The 55% F35% recommended rebuilding strategy keeps the mature biomass exploitation rate at or below the level that failed to rebuild the snow crab stock.

The retained catch in 2009/10 for the 55% F35% strategy would be 40 million lbs, about 10.5 million lbs less than the maximum permissible strategy. The 55% F35% strategy is projected to rebuild the stock two years before the maximum permissible strategy and two years after an F=0 strategy.

2009/10	Total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Exp. Rate on MMB
Year						
OFL(F35%)	73.0	61.6	0.52	251.0	169.9	0.23
55% F35%	47.6	40.1	0.32	274.0	169.9	0.15

This assessment (Sept. 2009) uses fixed net width survey data, however, in comparison, the OFL using the complete time series of reanalyzed survey data (using actual measured net widths) was 61.9 million lbs total catch (52.6 million lbs retained catch) for 2009/10. The retained catch for 2009/10 using the 55% F35% strategy with measured net widths would be 34 million lbs.

The MMB projected for 2009/10 fishing at F35% is 251 million lbs with an OFL of 73.0 million lbs.

Year	Bmsy [a] proxy	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[b]	OFL
2005/06			N/A	36.9	37.0	42.9	
2006/07			N/A	36.2	36.4	44.9	
2007/08	317.7	158.9	218	63.0	63.0	77.1	
2008/09	326.7	163.4	241	58.6	58.5	69.5	77.3
2009/10			251				73.0

[a] Bmsy proxy for 2007/8 based Sept 2008 assessment. Bmsy proxy for 2008/09 and 2009/10 based on Sept 2009 assessment.
[b] 50% mortality applied to pot discard mortality, 80% mortality applied to groundfish bycatch.

Changes to the Model

No changes were made to the model for this assessment except the addition of data (Sept, 2009).

Changes to the Data

Catch from the 2008/09 crab fishery season and the 2009 NMFS summer survey data were added to the model. Updated groundfish bycatch estimates for 1991 to 2008 were added to the model. Directed snow crab fishery catch and length frequency data for 2008/09 season was added.

SSC Comments October 2008

In June, 2008, the SSC requested further work on refining estimates of selectivity and natural mortality, with the expectation of seeing the results in June, 2009. To clarify, we request that attention be given to the treatment of survey selectivity, noting that the model estimates of selectivity, which are close to 1 (Figure 24), are in conflict with the results of the underbag experiment shown in that Figure.

A study specific to snow crab was conducted in summer 2009 to estimate selectivity of the current National Marine Fisheries Service (NMFS) survey net. Results from this study will be analyzed and results considered in the May 2010 assessment model when available. Survey data using actual measured net widths will be used in the May 2010 assessment. This assessment (Sept. 2009) uses survey data with fixed 50 ft net widths which results in higher biomass estimates than when using actual measured net widths. The ratio of the 2009 mature male biomass with the 50 ft fixed net width to the actual measured net width was 0.87.

CPT Comments September 2008

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, (e) include past GHLs in the table of catches, and (f) 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.

The CPT comments (a) through (e) and (v) were addressed in this assessment. A retrospective analysis was added for ending years from 1995 to 2009. Documentation on population dynamics and likelihood equations was added to the assessment report and the reference list updated. A table of likelihood component weights has been included. A section documenting the projection model has been added to the report. A table of standard errors was added for mature male biomass at mating and recruitment deviations. The GHL and full selection fishing mortality have been added to tables. The data weighting workshop in May 2009 addressed (i) and (ii), which will be included in the next assessment in May 2010. Analysis of spatial differences in growth and maturity are being investigated using a spatial model to address (iii).

SSC Comments June 2009

The SSC reiterated its request for sensitivity analysis on survey selectivity.

A study specific to snow crab was conducted in summer 2009 to estimate selectivity of the current National Marine Fisheries Service (NMFS) survey net. Results from this study will be analyzed and results considered in the May 2010 assessment model when available. Survey data using actual measured net widths will be used in the May 2010 assessment. This assessment (Sept. 2009) uses survey data with fixed 50 ft net widths which results in higher biomass estimates than when using actual measured net widths. The ratio of the 2009 mature male biomass with the 50 ft fixed net width and the actual measured net widths was 0.87.

The SSC requested that the author include a run of the model using the revised area swept estimates for the NMFS bottom trawl survey.

A run using the updated variable net width, area swept estimates was added for comparison to the fixed width estimates. Projected catches and reference points were estimated. This assessment (Sept. 2009) uses survey data with fixed 50 ft net width.

CPT Comments May 2009

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

This assessment uses the survey biomass estimates with the fixed 50 ft net width. The May 2010 assessment will use the survey biomass estimates with the measured net width.

INTRODUCTION

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

FISHERY HISTORY

Snow crab were harvested in the Bering Sea by the Japanese from the 1960s until 1980 when the Magnuson Act prohibited foreign fishing. Retained catch in the domestic fishery increased in the late 1980’s to a high of about 328 million lbs in 1991, declined to 65 million lbs in 1996, increased to 243 million lbs in 1998 then declined to 33.5 million lbs in the 1999/2000 fishery (Table 1, Figure 1). Due to low abundance and a reduced harvest rate, retained catches remained low from about 24 to 37 million lbs from 2000/01 to 2006/07 fisheries. The retained catch for the 2007/08 fishery increased to 63 million lbs and was 58.5 million lbs in 2008/09 due to increasing biomass. The OFL (total catch) for the 2008/9 fishery was 77.3 million lbs using F35% control rule. The total catch for the 2008/09 fishery was estimated at 69.0 million lbs.

Discard from the directed pot fishery was estimated from observer data since 1992 and ranged from 11% to 64% (average 33%) of the retained catch of male crab biomass (Table 1). Female discard catch is very low and not a significant source of mortality. In 1992 trawl discard mortality was about 4 million lbs, increased to about 7.8 million lbs in 1995, then declined to about 2 to 3 million lbs until 1999. Trawl bycatch in 2007 and 2008 was 0.97 and 0.66 million lbs respectively. Discard in groundfish fisheries from highest to lowest snow crab bycatch is the yellowfin sole trawl fishery, flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery and the Pacific cod hook and line and pot fisheries.

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

The average size of retained crabs has remained fairly constant over time ranging between 105 mm and 118 mm, and most recently about 110 mm to 111 mm. The percent new shell animals in the catch has varied between 69% (2002 fishery) to 98% (1999), and was 87% for the 2005/6 fishery and 93% in the 2007/8 fishery. In the 2007/8 fishery 94% of the new shell males >101mm CW were retained, while 78% of the old shell males >101mm CW were retained. Only 3% of crab were retained between 78mm and 101 mm CW. The average weight of retained crab has varied between 1.1 lbs (1983-1984) and 1.6 lbs(1979), and 1.3 lbs in the recent fisheries.

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

Harvest rates

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

The realized retained catch typically exceeded the GHL historically, resulting in exploitation rates for the retained catch (using survey numbers) ranging from about 60% to 100% for most years (Figure 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, B_{MSY} (921.6 million lbs) was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (NPFMC 1998). MSST was defined as 50% of the B_{MSY} value (MSST=460 million lbs of total mature biomass). The rebuilding strategy since 2000/1 used a retained crab harvest rate on the mature male biomass of 0.10 on levels of total mature biomass greater than ½ MSST (230 million lbs), increasing linearly to 0.225 when biomass is equal to or greater than B_{MSY} (921.6 million lbs) (Zheng et al. 2002). The GHL was actually set as the number of retained crab allowed in the harvest, calculated by dividing the GHL in lbs by the average weight of a male crab > 101 mm. If the GHL in numbers was greater than 58% of the estimated number of new shell crabs greater than 101 mm plus 25% of the old shell crab greater than 101 mm, the GHL is capped at 58%. If natural mortality is 0.2, then this actually results in a realized exploitation rate cap for the retained catch of 66% at the time of the fishery, occurring approximately 7 months after the survey. The fishing mortality rate that results from this harvest strategy depends on the relationship between mature male size numbers and male numbers greater than 101 mm. The maximum full selection fishing mortality rate is close to 1.0 at the maximum harvest rate of 0.225 of mature male biomass.

DATA

Data Sources

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from 1978 to the 2008/09 season were used in this analysis. Observers were placed on directed crab fishery vessels starting in 1990. Size frequency data on the total catch (retained plus discarded) in the directed crab fishery were available from 1992 to 2008/09. Total discarded catch was estimated from observer data from 1992 to 2008/09 (Table 1). The discarded male catch was estimated for 1978 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period 1992 to

2008/09. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The mortality of discarded crab was assumed to be 50%. This estimate differs from the current rebuilding harvest strategy used since 2001, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discard mortality assumptions will be discussed in a later section. The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997.

The following table contains the various data components used in the model,

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1978/79-2008/09
Discarded male and female crab pot fishery size frequency	1992/3-2008/09
Trawl fishery bycatch size frequencies by sex	1991-2008
Survey size frequencies by sex and shell condition	1978-2009
Retained catch estimates	1978/79-2008/09
Discard catch estimates from snow crab pot fishery	1992/93-2008/09 from observer data
Trawl bycatch estimates	1973-2008/09
Total survey biomass estimates and coefficients of variation	1978-2009

Survey Biomass

Abundance is estimated from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS (see Rugolo et al. 2003 for design and methods). Since 1989, the survey has sampled stations farther north than previous years (61.2 ^{o} N previous to 1989). In 1982 the survey net was changed resulting in a change in catchability. Juvenile crabs tend to occupy more inshore northern regions (up to about 63 ^{o} N) and mature crabs deeper areas to the south of the juveniles (Zheng et al. 2001).

Prior to 2009, biomass estimates for all crab were based on an assumed 50 ft net width. In 2009, Chilton et al. (2009) provided new survey estimates based on measured net width. In 2009, the average measured net width was 17.08 meters which is about 89% of 50ft (15.24 meters) (Chilton et al. 2009). The 2009 mature male survey biomass was 359 million lbs using the fixed 50 ft net width and 311 million lbs using the measured net width for each tow. This ratio is 0.87 which would be equivalent to an assumed maximum survey selectivity for the current survey net. The difference between the survey male mature biomass estimates calculated with the fixed 50 ft width and the measured net width is small in the early part of the time series, and then is an average ratio of 0.86 (range 0.81 to 0.90) from 1998 to 2009 (Figure 64).

The revised estimates were not incorporated into the preliminary stock assessment in May 2009. Therefore, the CPT requested that the final assessment continue to utilize the fixed 50ft net width to calculate area swept. The SSC requested that the authors provide a run with the revised estimates for comparison. To accommodate these requests, the 2009 final stock assessment is based on abundance estimates derived from the fixed 50ft net width assumption, however, a run based on the measured net width is provided for comparison. The authors will fully review the implications of adopting measured net width data as part of an analysis of survey selectivity and catchability in the 2010 preliminary assessment. Unless otherwise noted, all subsequent references to survey abundance data reference estimates based on the 50ft fixed net width derivation.

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 to 607.8 million lbs in 2007, decreased in 2008 to 509.4 million lbs, then increased in 2009 to 629.5 million lbs.
Survey mature male biomass increased to 385.2 million lbs in 2007, decreased to 305.9 million lbs in 2008, then increased to 359.1 million lbs in 2009.

The observed survey estimate of males greater than 101 mm increased to151 million in 2007, then declined to 119 million in 2008, then increased to 150 million in 2009 (Table 2).

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

Survey Size Composition

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

Survey abundance by size for males and females indicate a moderate level of recruitment moving through the stock and resulting in the recent increase in abundance. (Figures 6 through 9). In 2009 small crab(<50mm) increased in abundance and may indicate a higher recruitment, however, more years of data are needed to verify this. High numbers of small crab in the late 1970's survey data did not follow through the population to the mid-1980's. The high numbers of small crab in the late 1980's resulted in the high biomass levels of the early 1990's and subsequent high catches. Moderate increase in numbers can also be seen in the mid 1990's.

Spatial distribution of catch and survey abundance

The majority of the fishery catch occurs south of 58.5 ° N., even in years when ice cover did not restrict the fishery moving farther north. In past years, most of the fishery catch occurred in the southern portion of the snow crab range possibly due to ice cover and proximity to port and practical constraints of meeting delivery schedules. In 2004 78% of the catch was south of 58.5 ° N. (Figure 10). In 2003 and 2004 the ice edge was farther north than past years, allowing some fishing to occur as far north as 60-61 ° N. Catch in the 2006/07 fishery was similar to recent years (Figure 11) with most catch south of 58 ° N. and west of the Pribilof Islands between about 171 ° W and 173 ° W. The pattern of catch was similar to previous years for the 2008/09 fishery however, about about 7.9 million lbs of retained catch was taken east and south of the Pribilof Islands at 168 to 167 ° longitude and 55.5 to 56.6 ° latitude which has not occurred in recent years (Figure 12). About 93% of the retained catch came from south of 58.5 ° N.

Summer survey data from 2003 to 2007 show approximately 75% of the mature male snow crab population resides in a region outside of the fishery zone (north of 58.5 ° N Latitude). The 2003 survey estimated about 24% of the male snow crab >101mm were south of 58.5 ° N. About 48% of those males were estimated to be new shell (which are preferred by the fishery). In 2004 and 2005, about 26 % of the survey abundance of male snow crab > 101 mm and the mature male biomass were south of 58.5 ° N. latitude (Figures 13 through 17). About 53% of those males south of 58.5 ° N. were estimated to be new shell. The 2004 fishery retained about 19 million crab of which about 14.8 million were caught south of 58.5 ° 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 ° 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 ° 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. Matthew Island, and to the north and west of St. Matthew Island. Males > 78 mm were distributed in similar areas to females, except the highest concentrations were between the Pribilof Islands and St. Matthew Island.

The spatial distribution of large male snow crab in the 2008 survey was farther south and east than in 2007 (Figures 18 and 18b). The distribution of males and females in 2009 are shown in Figures 18c to 18i. Males > 77 mm (approximately mature males) are mostly distributed between the Pribilof Islands and St. Matthew Island (Figure 18d). The distribution of large male crab (>101 mm) in 2009 was similar to 2008, however, the top three tows accounted for 36% of the total abundance (Figure 18e). Small males (<78 mm) and immature females were distributed mainly north of St. Matthew Island (Figures 18c and 18f). Mature old shell females with no eggs comprised 8% of old shell mature females, primarily from only one tow (Figure 18h). Mature females with less than or equal to a half clutch were 28% of old shell and 20% of new shell mature females, and were distributed between 58 ^{o} and 60 ^{o} N in the area south of St. Mathew Island(Figure 18g). Mature females with eggs (any clutch size) were distributed from 62 ^{o} N to about 57 ^{o} N, however, the higher CPUE was in the area 58 ^{o} N to 60 ^{o} N and between about 172 ^{o} and 174 ^{o} W (Figure 18i).

The difference between the summer survey distribution of large males and the fishery catch distribution indicates that survey catchability may be less than 1.0 and/or some movement occurs between the summer survey and the winter fishery. However, the exploitation rate on males south of 58.5 ^{o} N latitude may exceed the target rate, possibly resulting in a depletion of males from the southern part of their range. Snow crab larvae probably drift north and east after hatching in spring. Snow crab appear to move south and west as they age, however, no tagging studies have been conducted to fully characterize the ontogenetic or annual migration patterns of this stock. High exploitation rates in the southern area may have resulted in a northward shift in snow crab distribution. Lower egg production in the south from lower clutch fullness and higher percent barren females possibly due to insufficient males for mating may drive a change in distribution to the north. The northward shift in mature females is particularly problematic in terms of annual reproductive output due to lowered productivity from the shift to biennial spawning of animals in waters < 1.5 ^{o} C in the north. The lack of males in the southern areas at mating time (after the fishery occurs) may result in insufficient males for mating.

Ernst, et al. (2005) found the centroids of survey summer distributions have moved to the north over time (Figures 19 and 20). In the early 1980's the centroids of mature female distribution were near 58.5 ^{o} N, in the 1990's the centroids were about 59.5 ^{o} N. The centroids of old shell male distribution was south of 58 ^{o} N in the early 1980's, moved north in the late 1980's and early 1990's then shifted back to the south in the late 1990's (Figure 20). The distribution of males>101 mm was about at 58 ^{o}o N in the early 1980's, then was farther north (58.5 to 59 ^{o} N) in the late 1980's and early 1990's, went back south in 1996 and 1997 then has moved north with the centroid of the distribution in 2001 just north of 59 ^{o} N.(Figure 20). The centroids of the catch are generally south of 58 ^{o} 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 ^{o} N in 1997 and 1998, then moved north to above 58.5 ^{o} in 2002.

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 (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 90% at 120mm and 100% at 135 mm.

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 may be correlated with other parameters, and therefore are 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, Sainte-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 assume a terminal molt for both males and females.

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

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

Mating ratio and reproductive success

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

The fraction barren females and clutch fullness observed in the survey increased in the early 1990's then decreased in the mid- 1990's then increased again in the late 1990's (Figures 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 percentage of barren females was low in 2006, increased in 2007, then declined in 2008 and 2009 to below 1 percent for new and old shell females and about 17% for very old females. Clutch fullness for new shell females declined slightly in 2009 relative to 2008, however, on average is about 70% compared to about 80% before 1997. Clutch fullness for old and very old shell females was high in 2006, declined in 2007, then was higher in 2009 (about 78% old shell and 60% very old).

The fraction of barren females in the 2003 and 2004 survey south of 58.5 ^{o} N latitude was generally higher than north of 58.5 ^{o} N latitude (Figures 28 and 29). In 2004 the fraction barren females south of 58.5 ^{o} N latitude was greater for all shell conditions. In 2003, the fraction barren was greater for new shell and very very old shell south of 58.5 ^{o} N latitude.

Laboratory analysis of female snow crab collected in waters colder than 1.5 ^{o} C from the Bering Sea have been determined to be biennial spawners in the Bering Sea. Future recruitment may be affected by the fraction of biennial spawning females in the population as well as the estimated fecundity of females, which may depend on water temperature.

An index of reproductive potential for crab stocks needs to be defined that includes spawning biomass, fecundity, fertilization rates and frequency of spawning. In most animals, spawning biomass is a sufficient index of reproductive potential because it addresses size related impacts on fecundity, and because the fertilization rates and frequency of spawning are relatively constant over time. This is not the case for snow crab.

The centroids of the cold pool (<2.0 ^{o} C) were estimated from the summer survey data for 1982 to 2006 (Figure 30). The centroid is the average latitude and average longitude. In the 1980's the cold pool was farther south(about 58 to 59 ^{o} N latitude) except for 1987 when the centroid shifted to north of 60 ^{o} N latitude. The cold pool moved north from about 58 ^{o} N latitude in 1999 to about 60.5 ^{o} N latitude in 2003. The cold pool was farthest south in 1989, 1999 and 1982 and farthest north in 1987, 1998, 2002 and 2003. In 2005 the cold pool was north, then in 2006 back to the south. The last three years (2007, 2008 and 2009) have all been cold years.

The clutch fullness and fraction of unmated females however, does not account for the fraction of females that may have unfertilized eggs. The fraction of barren females observed in the survey may not be an accurate measure of fertilization success because females may retain unfertilized eggs for months after extrusion. To examine this hypothesis, RACE personnel sampled mature females from the Bering Sea in winter and held them in tanks until their eggs hatched in March of the same year. All females then extruded a new clutch of eggs in the absence of males. All eggs were retained until the crabs were sacrificed near the end of August. Approximately 20% of the females had full clutches of unfertilized eggs. The unfertilized eggs could not be distinguished from fertilized eggs by visual inspection at the time they were sacrificed. Indices of fertilized females based on the visual inspection method of assessing clutch fullness and percent unmated females may overestimate fertilized females and not an accurate index of reproductive success.

McMullen and Yoshihara (1969) examined female red king crab around Kodiak Island in 1968 and found high percentages of females without eggs in areas of most intense fishing (up to 72%). Females that did not extrude eggs and mate were found to resorb their eggs in the ovaries over a period of several months. One trawl haul captured 651 post-molt females and nine male red king crab during the period April to May 1968. Seventy-six percent of the 651 females were not carrying eggs. Ten females were collected that were carrying eggs and had firm post-molt shells. The eggs were sampled 8 and 10 days after capture and were examined microscopically. All eggs examined were found to be infertile. This indicates that all ten females had extruded and held egg clutches without mating. Eggs of females sampled in October of 1968 appear to have been all fertile from a table of results in McMullen and Yoshihara(1969), however the results are not discussed in the text, so this is unclear. This may mean that extruded eggs that are unfertilized are lost between May and October.

ANALYTIC APPROACH

Model Structure

The model structure was developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). The model was implemented using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. This software provides the derivative calculations needed for finding the objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

The model estimates the abundance by length bin and sex in the first year (1978) as parameters rather than estimating the recruitments previous to 1978. This results in 44 estimated parameters.

Recruitment is determined from the estimated mean recruitment, the yearly recruitment deviations and a gamma function that describes the proportion of recruits by length bin,

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

where,

R_0 Mean recruitment
pr_l proportion of recruits for each length bin
τ_t Recruitment deviations by year.

Recruitment is estimated equal for males and females in the model.

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

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

$G_{l',l}^{s}$ Growth transition matrix by sex, premolt and postmolt length bins.

Defines the fraction of crab of sex s and premolt length bin l', that move to length bin l after molting.

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

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

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

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

l' Premolt length bin

l Postmolt length bin

Growth

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

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

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

Where a = 8.436 , b = 1.128 , for males and a= 5.1 , b= 1.07 , for females.

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

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

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

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

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

The Gamma distribution is,

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

Where x is length, β for both males and females was set equal to 0.75, which was estimated from growth data on Bering Sea Tanner and King crab due to the small amount of growth data available for snow crab.

The probability of an immature crab becoming mature by size is applied to the post-molt size. Crab that mature and reach their terminal molt in year t then are mature new shell during their first year of maturity ($NMN^s_{t,l}$),

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

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

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

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

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

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

Where,

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

l Length bin,

Lbins number of length bins in the model,

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

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

W_l weight of a male crab for length bin l.

Catch of male snow crab was estimated as a pulse fishery 0.62 yr after the beginning of the assessment year (July 1),

$$catch = \sum_{l} (1 - e^{-(F * Sel_l + Ftrawl * TrawlSel_l)}) w_l N_l e^{-M * .62}$$

F	Full selection fishing mortality determined from the control rule using biomass including implementation error
$Sel_{,l}$	Fishery selectivity for length bin l for male crab
Ftrawl	Fishing mortality for trawl bycatch fixed at 0.01 (average F)
$TrawlSel_l$	Trawl bycatch fishery selectivity by length bin l
W_l	weight by length bin l
N_l	Numbers by length for length bin l
M	Natural Mortality

Selectivity

The selectivity curve total catch were estimated as two-parameter ascending logistic curves (Figure 23).

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

The probability of retaining crabs by size with combined shell condition was estimated as an ascending logistic function. The selectivities for the retained catch were estimated by multiplying a two parameter logistic retention curve by the selectivities for the total catch.

$$S_{ret,l} = \frac{1}{1 + e^{-a(l - b)}} \frac{1}{1 + e^{-c_{ret}(l - d_{ret})}}$$

The selectivities for the survey and trawl bycatch were estimated with two-parameter, ascending logistic functions (Survey selectivities in Figure 24).

$$S_{surv,l} = q \frac{1}{1 + e^{-a_{surv}(l - b_{surv})}}$$

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. The use of a 50ft fixed net width as described earlier to estimate survey biomass results in a larger biomass than if actual measured net widths were used. The 2009 mature male biomass ratio using measured net widths to fixed 50 ft net width was slightly less than the maximum selectivity from the underbag experiment at 0.87.

Likelihood Equations

Weighting values (λ) for each likelihood equation are shown in Table 9.

Catch biomass is assumed log-normal,

$$\lambda \sum_{t=1}^{T} \left[\log(C_{t,\,fishery,obs}) - \log(C_{t,\,fishery.pred}) \right]^2$$

There are separate likelihood components for the retained and total catch.

The robust multinomial likelihood is used for length frequencies from the survey and the catch (retained and total) for the fraction of animals by sex in each 5mm length interval. The number of samples measured in each year is used to weight the likelihood. However, since thousands of crab are measured each year, the sample size was set at 200.

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

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

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

An additional length likelihood weight (2) is added to the first year survey length composition fit to facilitate the estimation of the initial abundance parameters. A smoothness constraint is also added to the numbers at length by sex in the first year,

$$\sum_{S=1}^{2} \sum_{l=1}^{L} (first\ differences(N_{1978,s,l}))^2$$

The survey biomass assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

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

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

Recruitment deviations likelihood equation is,

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

Fishery cpue in average number of crab per pot lift.

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

Penalties on Fishing mortalities.

Penalty on average F for males,

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

Fishing mortality deviations for males,

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

Female bycatch fishing mortality penalty.

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

Trawl bycatch fishing mortality penalty

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

There were a total of 238 parameters estimated in the model (Table 7) for the 32 years of data (1978-2009). The 93 fishing mortality parameters (one set for the male catch, one set for the female discard catch, and one set for the trawl fishery bycatch) estimated in the model were constrained so that the estimated catch fit the observed catch closely. There were 32 recruitment parameters estimated in the model, one for the mean recruitment, 31 for each year from 1979 to 2009 (male and female recruitment were fixed to be equal). There were 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 7). 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.

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.

Projection Model Structure

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

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

$spr_{F=0}$	mature male biomass per recruit fishing at F=0. $B_0 = spr_{F=0}\ R_0$,
B_t	mature male biomass at time t,
h	steepness of the stock-recruitment curve defined as the fraction of R_0 at 20% of B_0,
R_0	recruitment when fishing at F=0, set at 1.0 billion,
σ_R^2	variance for recruitment deviations, estimated at 0.74 from the assessment model.

The temporal autocorrelation error (ε_t) was estimated as,

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

ρ_R	temporal autocorrelation coefficient for recruitment, set at 0.6.

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

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

$B_t^{'}$	mature male biomass in year t with implementation error input to the harvest control rule,
B_t	mature male biomass in year t,
ρ_I	temporal autocorrelation for implementation error, set at 0.6 (estimated from the recruitment time series),
σ_I	standard deviation of φ which determines the magnitude of the implementation error, set at 0.15.

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

RESULTS

The total mature biomass increased from about 964 million lbs in 1978 to the peak biomass of 1,586 million lbs in 1990. Biomass declined sharply after 1997 to about 352 million lbs in 2002, then increased to 554 million lbs in 2009 (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 crab in 1987, which followed through the population and resulted in the highest catches recorded in the early 1990’s.

Average discard catch mortality for 1978 to 2008 was estimated to be about 16.7% of the retained catch (with 50% mortality applied), similar to the average observed discards from 1992 to 2008 (15.5%) (Table 1 and Figure 31). Parameter estimates for the 50% discard mortality model are in Table 7. During the last three years (2006/7 to 2008/9 fishery seasons) under rationalization observed estimates of discard mortality averaged 15% of the retained catch compared to the average model estimates of discard mortality of 19%. Estimates of observed discard mortality ranged from 6% of the retained catch to 32% of the retained catch (assuming 50% discard mortality). In the 2008/9 observed fishery discard mortality was 13%, lower than the average values for either the last three years or the completer time series.

Mature male and female biomass show similar trends (Table 3, Figures 32 and 34). Mature male biomass increased from 261 million lbs in 2006 to 363 million lbs in 2009 (adjusted by survey selectivity). Observed survey mature male biomass declined from 385 million lbs in 2007 to 306 million lbs in 2008, then increased to 359 million lbs in 2009. Model estimates of mature female biomass increased from 170 million lbs in 2006 to 191 million lbs in 2009. Mature female biomass observed from the survey decreased from 223 million lbs in 2007 to 204 million lbs in 2008, then increased to 270 million lbs in 2009. Estimated model biomass was slightly lower in the last few years than in the 2008 assessment with the addition of the 2009 survey data, because, even though observed survey biomass was higher, the 2009 survey data was slightly lower than expected (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 50% at 29mm and 95% at 48.9 mm (Figure 24 and Table 7). Survey selectivities for the period 1982 to 1988 were estimated at 50% at about 43 mm and a maximum of 94% above about 85 mm. Survey selectivities for the period 1989 to the present were estimated at 50% at about

33.1 mm and 95% at about 44 mm. The maximum selectivity was estimated at 1.0 for the recent period (1989 to present), however, due to use of a 50 ft fixed net width this is equivalent to a maximum of about 0.87. 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 decreased from about 151 million in 2007 to 119 million in 2008, then increased to 150 million in 2009. The estimated 95% confidence interval for the observed survey large males in 2009 was +/-29% of the estimate. Model estimates of large males were about 130 million crab in 2007, 146 million crab in 2008 and 147 million crab in 2009.

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 and 2001 year classes appear to be about average recruitment that has resulted in an increase in biomass in recent years. The 2004 year class is also estimated to be average recruitment, however, the last few years recruitment have higher uncertainty. 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 0.21 to 1.59 (Figure 51 and Table 3). Fishing mortality rates were 0.62 to 1.59, for the 1986/87 to 1998/99 fishery seasons. For the period after the snow crab stock was declared overfished (1999/2000 to 2008/09), full selection fishing mortality ranged from 0.31 to 0.75, with an average of about 0.52.

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 Rebuilding Strategy

The harvest strategy described here is the current rebuilding strategy adopted in December 2000 in Amendment 14 and first applied in the 2000/01 fishing season (NPFMC 2000). Harvest strategy simulations are reported by Zheng et al. (2002) based on a model with structure and parameter values different than the model presented here. The harvest strategy by Zheng et al. (2002) was developed for use with survey biomass estimates and was applied to survey biomass estimates to calculate the 2008/09 fishery season retained catch of 58.6 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.

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

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

Where, α = -0.35 and averageTMB = 921.6 million lbs.

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

Retained Catch = E * MMB.

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

Overfishing Control Rule

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

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

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

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

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

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

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

Biomass and catch projections based on $F_{REF} = F_{35\%}$ and Bref = $B_{35\%}$ were used to estimate the catch OFL (Table 6). Projections at other rebuilding strategies were used to evaluate rebuilding probabilities and to provide catch projections with a buffer below the OFL to reduce the probability of overfishing, given uncertainty in current biomass and reference points. F35% was estimated at 0.703, similar to 2008 (0.707). B35% was estimated at 326.7 million lbs, slightly higher than 2008 (317.7 million lbs)

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

A measure of productivity can be estimated from the natural log of the ratio of recruitment to mature male biomass (Figures 59 and 60). 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 the 1979 fishing season to 2008/9 have been above the F35% control rule except for six years (1979, 1983-1985, 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 (2006/07-2008/09) F was estimated at 0.49 and 0.68, and 0.53, respectively. Of these years, the 2006/07 and 2007/08 seasons would have been above the F35% control rule, while the 2008/09 which was estimated at the Fofl. The F in 2008/09 was at the Fofl because the current model estimated lower mature male biomass in 2008/09 than the 2008 assessment and a slightly higher B35%. The buffer estimated in the May 2009 assessment between total catch in 2008/09 and the OFL was 10% (OFL =77.3 million lbs, projected catch = 70.1 million lbs) , before the 2009 survey data was added to the model, which was not adequate to prevent the F from exceeding the Fofl.

The total catch, including all bycatch of both sexes, using the control rule is estimated by the following equation,

$$catch = \sum_{s} \sum_{l} (1 - e^{-(F*Sel_{s,l} + F_{trawl}*Sel_{Trawl,l})}) w_{s,l} N_{s,l} \, e^{-M_s * .62}$$

Where $N_{S,l}$ is the 2009 numbers at length(l) and sex at the time of the survey estimated from the population dynamics model, M_s is natural mortality by sex, 0.62 is the time elapsed (in years) from when the survey occurs to the fishery, F is the value estimated from the rebuilding control rule using the 2009 mature male biomass projected forward to the time of mating time (Feb. 2010), and $w_{s,l}$ is weight at length by sex. $Sel_{s,l}$ are the fishery selectivities by length and sex for the total catch (retained plus discard) estimated from the population dynamics model (Figure 23).

Calculation of OFL

The OFL for 2009/10 estimated using the F35% control rule with F35% = 0.703 and B35% = 326.7 was 73.0 million lbs total catch (Table 6).

Rebuilding Analyses

The Eastern Bering Sea snow crab stock has failed to make adequate progress toward rebuilding in the required 10 year time period established in the rebuilding plan. The mature male biomass at mating (MMB) would have needed to be above the B35% level in 2008/09 and again in 2009/10 to be declared rebuilt within the 10 year limit (Figure 65). MMB in 2008/09 (241.1 million lbs) was below B35% (326.7 million lbs) and the projected MMB in 2009/10 fishing at F=0 would also be below B35% at 316.8 million lbs (Figure 56).

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

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

Considering the requirements of the MSA and NSG1, stock projections were run for four rebuilding strategies using methods described in Turnock and Rugolo (2008): 1) Maximum Permissible (75% F35%), 2) 55% F35% 3) Current rebuilding strategy, and 4) F=0 (Tables 6b to 6e). The current rebuilding strategy is presented for comparison only as it is above the maximum permissible strategy. For the 55% F35% and F=0 control rules, when MMB at mating was above B35%, fishing switched to the Maximum Permissible strategy (Table 6c and 6e). The F=0 projections show that MMB is less than B35% in 2009/10 and consequently the current rebuilding strategy (NPFMC 2000) has failed to rebuild the stock in the required 10 year time period. However, the F=0 strategy rebuilds the stock in the shortest time possible with a probability of 91% that MMB > B35% after two fishing seasons (2009/10 and 2010/11). The Maximum Permissible rebuilding strategy is the maximum that can be applied when adequate progress has not been made toward rebuilding the stock in the required time frame. The Maximum Permissible strategy is also used in the projections after rebuilding, as a proxy for the ACL rule, which may be put into place in the 2010/11 fishery season for crab stocks.

The authors do not recommend using the current rebuilding strategy because the fishing mortality rates associated with this strategy are consistently higher than $0.75*F_{MSY}$ and this strategy failed to make adequate progress towards rebuilding within the prescribed time frame. Under the current rebuilding strategy, nine additional fishing seasons (2009/10 to 2018/19) would be required to achieve rebuilding (Table 6)(8 seasons to have the probability >50% that MMB > B35%). This would result in a total of 18 years of stock status below B35% (19 total years to be rebuilt). This would be almost twice the expected time to rebuild (10 years) and increases the risk that the stock may go to lower levels if depensation occurs as we have seen in Gulf of Alaska Tanner and king crab stocks.

The Maximum Permissible strategy is slightly more conservative than the current rebuilding strategy. Under the Maximum Permissible strategy, it will take another 7 years to rebuild the stock (Table 6) (6 seasons to have the probability >50% that MMB > B35%). The harvest rates under the Maximum Permissible strategy are only slightly less than the current rebuilding strategy.

The authors do not recommend the F=0 strategy. The fishery would be closed the first year and have a high probability of closure in the second year (Table 6). This strategy has been applied to rebuild the EBS Tanner crab and St. Matthew blue king crab stocks. The EBS Tanner crab stock did rebuild and the St. Matthew blue king crab stocks have demonstrated encouraging signs toward rebuilding under an F=0 strategy. In other cases where GOA and EBS king and Tanner crab stocks declined to low levels, either the directed fisheries were closed and have remained closed (GOA red king crab and GOA Tanner crab), or the stock has not recovered to precollapse levels where fishing has continued (Bristol Bay red king crab).

The authors recommend the 55% F35% rebuilding strategy. This strategy rebuilds the snow crab stock in a shorter time period than the Maximum Permissible while providing an opportunity for the fishing community to continue fishing (Table 6 and Figure 55). Appendix A contains an economic analysis of the rebuilding strategies. The 55% F35% strategy achieves 51% probability of MMB > B35% after four fishing seasons (2012/13) compared to F=0 strategy which achieves 91% probability MMB>B35% after two fishing seasons. This allows the stock to be rebuilt in 5 fishing seasons, if MMB needs to be above B35% for two years to be declared rebuilt. Retained catches in the first year (2009/10) would be 40 million lbs, 10.5 million lbs less than the Maximum Permissible of 50.5 million lbs (Table 6). The 40 million lbs retained catch is higher than the retained catch in all other years of the rebuilding period (1999-2008) where MMB < B35% except the last two years (Figure 58).

In their deliberations on conservation measures for the Bering Sea walleye pollock stock, the SSC recently identified the spawning exploitation rate as a metric to consider. The recommended rebuilding strategy keeps the mature biomass exploitation rate at or below the level that failed to rebuild the snow crab stock (Figure 58). The exploitation rates on MMB ranged from 0.13 to 0.26 with an average of 0.18. Fishing mortality estimates during 1999 to 2008 ranged widely from 0.31 to 0.75 with an average of 0.52. Average exploitation rates under the 55% F35% strategy would be less than the 1999-2008 average in the first two years of rebuilding, then at about 0.19 the next two years (Figure

57). Average fishing mortality rates using the 55% F35% rebuilding strategy in the first four years of rebuilding range from 0.32 to 0.41, below the 1999-2008 average F of 0.52 (Figure 58).

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

The recommended rebuilding strategy strikes a balance between rebuilding the snow crab population as soon as possible and the socio-economic implications of reduced harvests (Appendix A for economic analyses). In addition to the 55% F35% rebuilding strategy, the authors recommend in the interim before a new rebuilding plan is developed that each year of the rebuilding period the recommended 55% F35% rebuilding strategy be evaluated and adjusted if necessary such that the stock will have greater than a 50% probability that MMB > B35% in 2012/13, taking into account needs of the fishing community and other requirements of the MSA.

Retrospective Analysis

The 2009 model (September 2009 assessment) was used with data ending in years from 1995 to 2009 to examine restropective patterns in mature male biomass at survey time and recruitment (Figures 61, 62 and 63). Observed survey mature male biomass was increasing rapidly from 1994 to 1996 then declined to 1999. The model run ending in 1995 and in 1996 fit the observed survey biomass well, however when observed biomass declined in 1997, then the model estimated of biomass in 1996 was lower. The model ending in 1998 estimated higher biomass in 1998 than in model runs including 1999 and later, due to the sharply decreasing biomass from 1997 to 1999. Model estimates were very close for the years ending in 1999 to 2005. Observed biomass increased from 2004 to 2007, declined in 2008, then increased in 2009. Model runs ending in 2005 and 2006 estimated biomass lower than the observed in 2005-2006. In 2007 the model estimated close to the observed 2007 biomass. Model estimates of biomass for 2006 and 2007 declined when the lower 2008 survey biomass was added. The model estimates for 2008 only were less when the 2009 survey data was added to the model. Recruitment estimates declined as years were added when the observed biomass reached a peak and then declined (Figure 62). Recruitment estimates increased in recent years (2003 to 2009) with the addition of the 2009 survey data. Model estimates of mature male biomass at survey time were very similar in the years before the last few terminal years indicating that survey selectivities estimates were stable over time (Figure 63).

Conservation concerns

- The Bering Sea snow crab stock has failed to rebuild in the required time period. MMB was estimated at 74% of B35% in 2008/2009. A 55% F35% rebuilding strategy is recommended to rebuild the stock.

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

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

- Exploitation rates in the southern portion of the range of snow crab may have been higher than target rates, possibly contributing to the shift in distribution to less productive waters in the north.

Data Gaps and Research Needs

Research is needed to improve our knowledge of snow crab life history and population dynamics to reduce uncertainty in the estimation of current stock size, stock status and optimum harvest rates.

Tagging programs need to be initiated to estimate longevity and migrations. Studies and analyses are needed to estimate natural mortality. Additional sampling of crabs that are close to molting is needed to estimate growth for immature males and females.

A method of verifying shell age is needed for all crab species. A study was conducted using lipofuscin to age crabs, however verification of the method is needed. Radiometric aging of shells of mature crabs is costly and time consuming. Aging methods will provide information to assess the accuracy of assumed ages from assigned shell conditions (i.e. new, old, very old, etc), which have not been verified, except with the 21 radiometric ages reported here from Orensanz (unpub data).

Techniques for determining which males are effective at mating and how many females they can successfully mate with in a mating season are needed to estimate population dynamics and optimum harvest rates. At the present time it is assumed that when males reach morphometric maturity they stop growing and they are effective at mating. Field studies are needed to determine how morphometric maturity corresponds to male effectiveness in mating. In addition the uncertainty associated with the determination of morphometric maturity (the measurement of chelae height and the discriminate analysis to separate crabs into mature and immature) needs to be analyzed and incorporated into the determination of the maturity by length for male snow crab.

The underbag 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).

Female opilio in waters less than 1.5 ^{o} C and colder have been determined to be biennial spawners in the Bering Sea. Future recruitment may be affected by the fraction of biennial spawning females in the population as well as the estimated fecundity of females, which may depend on water temperature.

A female reproductive index needs to be developed that incorporates males, mating ratios, fecundity, sperm reserves, biennial spawning and spatial aspects.

Analysis needs to be conducted to determine a method of accounting for the spatial distribution of the catch and abundance in computing quotas.

A full management strategy evaluation of the snow crab model has been funded by NPRB for the period 2008-2010.

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Table 1. Catch (1,000s 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 (no mort. applied)	Observed Retained + discard male catch(no mort. Applied)	Model estimate of male discard(50 % mort)	Discard female catch	Model estimate total directed catch	Year of trawl bycatch	trawl bycatch(no mort. Applied)	GHL(retained catch only)	OFL (2008/9 first year of total catch OFL)
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	39.5-91.0	
1982	29,355			11,392	46	40,793	1981	1,323	16.0-22.0	
1983	26,128			6,142	62	32,332	1982	538	15.8	
1984	26,813			3,289	44	30,146	1983	693	49.0	
1985	65,999			7,278	43	73,320	1984	737	98.0	
1986	97,984			14,930	44	112,958	1985	632	57.0	
1987	101,903			24,072	96	126,071	1986	2,716	56.4	
1988	135,355			34,065	139	169,559	1987	8	110.7	
1989	149,456			40,910	148	190,514	1988	974	132	
1990	161,821			46,669	192	208,682	1989	1,131	139.8	
1991	328,647			73,657	204	402,508	1990	865	315.0	
1992	315,302	96,214	411,516	53,970	234	369,506	1991	4,287	333.0	
1993	230,787	124,865	355,652	41,689	481	272,957	1992	4,047	207.2	
1994	149,776	38,922	188,698	28,458	321	178,555	1993	3,993	105.8	
1995	75,253	29,436	104,689	19,698	232	95,183	1994	7,833	55.7	
1996	65,713	42,104	107,817	18,216	63	83,992	1995	2,966	50.7	
1997	119,543	54,391	173,934	23,462	277	143,282	1996	2,055	117.0	
1998	243,342	41,982	285,324	36,701	22	280,065	1997	3,302	225.9	
1999	194,000	34,158	228,158	30,716	26	224,742	1998	2,248	186.2	
2000	33,500	3,790	37,290	5,416	2	38,918	1999	1,345	28.5	
2001	25,256	4,537	29,793	4,138	2	29,396	2000	1,174	27.3	
2002	32,722	13,824	46,546	7,280	17	40,019	2001	865	30.8	
2003	28,307	9,938	38,245	6,837	3	35,147	2002	511	25.6	
2004	23,942	4,196	28,138	4,011	6	27,959	2003	1,683	20.8	
2004/2005	24,892	3,716	28,608	3,012	3	27,907	2004	2,124	20.9	
2005/2006	36,974	9,965	46,939	5,311	12	42,297	2005	810	36.9	
2006/2007	36,356	12,995	49,351	7,040	5	43,401	2006	1,858	36.2	
2007/2008	63,034	18,560	81,594	13,408	66	76,364	2007	966	63.0	
2008/2009	58,548	15,115	73,663	10,526	52	68,987	2008	664	58.6	77.3

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	119
2009	270.4	359.1	629.5	150.1

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	Full selection fishing mortality
1978	1,366	7,958	481	483	964	101	*	341	2.9	0.64
1979	1,331	6,804	569	459	1,029	122	653	290	4.1	0.87
1980	1,208	5,768	598	351	949	80	574	210	5.4	1.44
1981	1,088	4,886	545	284	829	52	524	199	5.2	0.86
1982	1,049	4,575	452	348	800	103	867	259	4.0	0.35
1983	1,076	5,386	380	418	797	158	1,891	317	3.2	0.21
1984	1,120	5,731	356	430	786	167	1,568	276	3.2	0.55
1985	1,184	6,452	358	391	749	141	2,049	225	3.5	1.07
1986	1,511	11,342	376	375	751	123	6,398	211	3.6	1.36
1987	1,833	11,294	503	447	950	152	2,488	246	3.9	1.55
1988	2,096	10,370	607	544	1,152	182	1,671	293	3.7	1.54
1989	2,252	8,676	629	709	1,338	238	771	420	3.1	1.19
1990	2,275	7,051	571	1,015	1,586	414	524	485	2.6	1.59
1991	1,922	6,533	483	981	1,464	415	1,459	461	2.4	1.51
1992	1,586	7,506	421	736	1,157	282	2,775	371	2.6	1.49
1993	1,418	7,642	422	525	947	173	2,017	290	3.0	1.46
1994	1,378	6,715	444	421	865	114	899	279	3.1	0.97
1995	1,415	5,301	434	490	924	148	163	352	2.7	0.62
1996	1,419	4,217	379	663	1,042	255	191	441	2.2	0.68
1997	1,258	3,331	307	731	1,038	311	201	365	2.1	1.37
1998	883	2,827	243	517	760	201	491	237	2.3	1.81
1999	603	2,727	201	290	491	86	722	215	2.2	0.46
2000	544	2,382	181	241	423	69	296	173	2.3	0.45
2001	512	2,107	165	214	379	60	283	147	2.4	0.75
2002	503	2,227	147	206	352	61	628	146	2.3	0.61
2003	540	2,843	136	225	362	80	1,139	170	2.1	0.36
2004	592	3,130	147	239	387	92	928	180	2.2	0.31
2005	633	2,843	166	242	408	90	415	169	2.5	0.52
2006	719	3,675	170	261	431	96	1,492	186	2.3	0.49
2007	785	3,345	186	323	509	130	504	211	2.3	0.68
2008	805	3,305	192	351	542	146	756	241	2.2	0.53
2009	843	3,751	191	363	554	147	1,226			

*** 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

Tables 6a-f. Projections using various rebuilding strategies for 2009/10 to 2018/19 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). B35% is 326.7 million lbs and F35% = 0.70. 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). Exploitation rate is estimated using total catch and MMB at the time of the fishery.

Table 6a. OFL projections (F35% control rule).

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 MMB> B35%	Exp. Rate on MMB
Year										
2009/10	73.0	40.0	113.7	61.6	0.52	251.0	169.9	557.5	0.01	0.23
2010/11	83.2	43.6	129.5	70.0	0.56	265.6	184.3	591.9	0.03	0.24
2011/12	85.6	48.9	130.2	73.2	0.57	269.1	192.0	614.8	0.06	0.24
2012/13	79.3	44.0	123.9	66.4	0.56	268.2	176.6	619.7	0.07	0.23
2013/14	91.2	50.6	138.7	75.9	0.60	287.2	192.7	662.9	0.18	0.24
2014/15	103.6	52.3	181.1	87.1	0.61	307.3	215.4	707.7	0.34	0.25
2015/16	107.5	42.3	228.1	90.5	0.60	316.8	222.3	732.4	0.42	0.25
2016/17	109.3	32.1	253.2	91.9	0.60	323.4	224.4	753.0	0.49	0.25
2017/18	111.8	28.4	269.5	93.8	0.59	332.4	228.5	776.9	0.56	0.25
2018/19	116.8	26.1	282.1	97.9	0.60	344.0	236.3	803.7	0.62	0.25

Table 6b. Maximum permissible fishing mortality rate (75% F35%).

Max. Perm.	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 MMB> B35%	Exp. Rate on MMB
Year										
2009/10	59.9	32.3	94.4	50.5	0.41	262.8	169.9	557.5	0.03	0.19
2010/11	72.9	36.1	112.9	61.6	0.46	285.5	193.5	604.6	0.12	0.20
2011/12	77.4	40.4	118.3	66.6	0.47	294.0	206.5	635.5	0.20	0.21
2012/13	73.1	38.5	113.7	61.8	0.46	294.6	193.8	644.5	0.23	0.20
2013/14	83.3	45.2	126.4	69.9	0.48	316.3	210.6	689.2	0.41	0.21
2014/15	93.7	46.3	158.9	79.4	0.49	340.8	235.2	737.1	0.56	0.22
2015/16	97.3	37.3	195.0	82.7	0.48	354.5	245.1	767.0	0.63	0.22
2016/17	99.5	31.2	222.9	84.4	0.48	364.4	249.7	793.3	0.69	0.21
2017/18	101.6	26.5	243.3	86.1	0.47	377.3	255.9	823.3	0.74	0.21

Table 6c. Recommended control rule for rebuilding (55% F35%). When MMB is above B35%, the rebuilding strategy switches to fishing at the maximum permissible control rule.

55% 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 MMB> B35%	Exp. Rate on MMB
Year										
2009/10	47.6	25.3	72.7	40.1	0.32	274.0	169.9	557.5	0.07	0.15
2010/11	62.5	30.0	111.5	52.9	0.36	305.1	202.1	616.6	0.29	0.17
2011/12	72.7	35.3	122.6	62.8	0.40	315.4	220.9	655.5	0.44	0.19
2012/13	71.7	33.5	118.0	60.9	0.41	313.7	208.4	665.4	0.51	0.19
2013/14	80.9	40.1	128.6	68.2	0.43	334.0	223.2	707.5	0.70	0.19
2014/15	93.9	42.5	164.7	79.8	0.46	355.3	247.0	754.4	0.81	0.21
2015/16	98.7	35.6	198.7	84.0	0.47	365.1	254.3	781.5	0.84	0.21
2016/17	100.4	30.4	227.3	85.3	0.47	372.4	256.1	805.5	0.87	0.21
2017/18	102.2	26.4	245.5	86.6	0.46	384.1	260.6	835.5	0.89	0.21
2018/19	108.3	24.0	252.1	91.5	0.47	401.1	271.7	873.1	0.91	0.21

Table 6d. Current Rebuilding strategy.

	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 MMB> B35%	Exp. Rate on MMB
Year										
2009/10	69.7	41.0	104.8	58.8	0.50	253.9	169.9	557.5	0.02	0.22
2010/11	79.5	40.7	128.2	67.0	0.53	271.5	186.6	595.1	0.06	0.23
2011/12	81.5	43.4	128.8	69.8	0.52	278.0	196.4	621.1	0.10	0.23
2012/13	77.4	43.3	113.9	65.1	0.52	277.4	182.9	628.8	0.12	0.22
2013/14	90.9	47.4	144.4	75.9	0.57	295.3	198.9	672.2	0.22	0.24
2014/15	102.7	48.5	208.3	86.3	0.58	315.0	220.6	715.7	0.39	0.25
2015/16	106.4	41.7	236.6	89.7	0.57	324.1	227.1	739.9	0.49	0.25
2016/17	108.4	36.5	254.8	91.2	0.57	330.4	228.9	760.6	0.56	0.25
2017/18	110.2	31.9	273.6	92.5	0.57	339.9	232.7	785.1	0.61	0.24
2018/19	116.0	30.4	293.6	97.2	0.58	351.9	241.1	813.9	0.68	0.25

Table 6e. F=0 until MMB is above B35%, then fishing at maximum permissible control rule.

F=0	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 MMB> B35%	Exp. Rate on MMB
Year										
2009/10	0.9	0.7	1.2	0.0	0.00	316.8	169.9	557.5	0.40	0.00
2010/11	45.3	0.9	137.6	38.5	0.21	359.8	235.5	661.9	0.91	0.11
2011/12	95.2	1.0	139.2	83.2	0.46	340.3	260.1	709.2	0.99	0.22
2012/13	86.3	48.9	122.5	73.8	0.48	318.8	223.5	687.3	1.00	0.21
2013/14	90.0	54.3	130.1	76.0	0.49	328.6	224.8	710.9	1.00	0.22
2014/15	96.9	49.8	161.6	82.2	0.49	347.2	241.8	748.1	1.00	0.22
2015/16	98.9	38.7	199.4	84.0	0.49	358.2	248.2	775.5	1.00	0.22
2016/17	100.4	31.8	225.3	85.2	0.48	367.6	251.2	805.3	1.00	0.21
2017/18	103.0	27.1	244.3	87.0	0.47	382.7	257.7	842.5	1.00	0.21
2018/19	111.0	26.6	258.5	93.5	0.48	405.4	273.5	889.0	1.00	0.21

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%	103.97
Fishery selectivity retention curve males slope	0.2547
Fishery selectivity retention curve males length at 50%	97.91
Pot Fishery discard selectivity female slope	0.31
Pot Fishery discard selectivity female length at 50%	70.78
Trawl Fishery selectivity slope	0.067
Trawl Fishery selectivity length at 50%	120.0
Survey Q 1978-1981	1.0
Survey 1978-1981 length at 95% of Q	48.86
Survey 1978-1981 length at 50% of Q	28.55
Survey Q 1982-1988	0.938
Survey 1982-1988 length at 95% of Q	67.14
Survey 1982-1988 length at 50% of Q	42.81
Survey Q 1989-present	1.0
Survey 1989-present, length at 95% of Q	43.78
Survey 1989-present length at 50% of Q	33.13
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

Table 9. Weighting factors for likelihood equations.

Likelihood component	Weighting factor
Retained catch	1000
Retained catch length comp	1
Total catch	1000
Total catch length comp	1
Female pot catch	10
Female pot fishery length comp	0.2
Trawl catch	100
Trawl catch length comp	0.25
Survey biomass	0.25*survey cv by year
Survey length comp	1
Recruitment deviations	1
Fishing mortality average	1
Fishing mortality deviations early phases	50
Fishing mortality deviations late phases	0.1
Initial length comp smoothness	1
Fishery cpue	0.14 (cv = 5.0)

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

	Recruit (male,millions)	S.D.	MMB at survey (1000 tons)	S.D.
1978			219.0	5.0
1979	326.6	60.7	208.3	3.5
1980	286.9	57.5	159.4	2.6
1981	261.8	74.3	128.8	2.4
1982	433.3	106.7	157.8	3.9
1983	945.4	122.4	189.6	5.2
1984	784.1	123.5	195.2	5.1
1985	1024.3	146.7	177.6	4.3
1986	3198.9	201.6	170.3	3.4
1987	1244.0	188.3	202.9	3.5
1988	835.6	133.9	247.0	4.0
1989	385.6	92.1	321.5	4.7
1990	262.0	68.5	460.4	6.4
1991	729.6	86.3	445.1	6.5
1992	1387.7	108.6	333.9	4.7
1993	1008.6	94.1	238.2	3.3
1994	449.5	54.2	191.1	3.1
1995	81.7	24.3	222.1	3.5
1996	95.6	24.4	300.8	3.9
1997	100.5	28.5	331.8	3.6
1998	245.3	38.2	234.6	2.8
1999	361.2	39.5	131.5	2.0
2000	147.9	31.9	109.5	1.8
2001	141.5	33.4	96.9	1.8
2002	314.1	49.5	93.3	2.0
2003	569.7	60.9	102.3	2.3
2004	463.8	54.2	108.5	2.3
2005	207.6	51.1	109.9	2.2
2006	745.9	80.4	118.6	2.5
2007	252.0	70.8	146.6	2.6
2008	378.1	81.8	159.2	2.7
2009	613.1	127.8	164.9	3.3

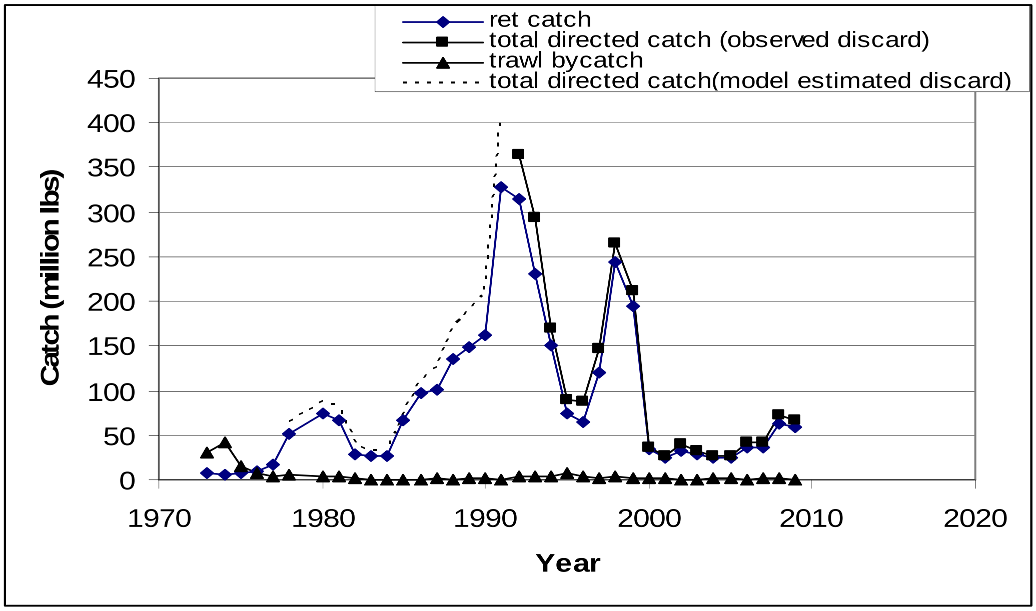

Figure 1. Catch (million lbs) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch is retained catch plus discarded catch after 50% discard mortality was applied. Discard catch was estimated from observer data 1992 to present. Discard for 1978 to 1991 was estimated from the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

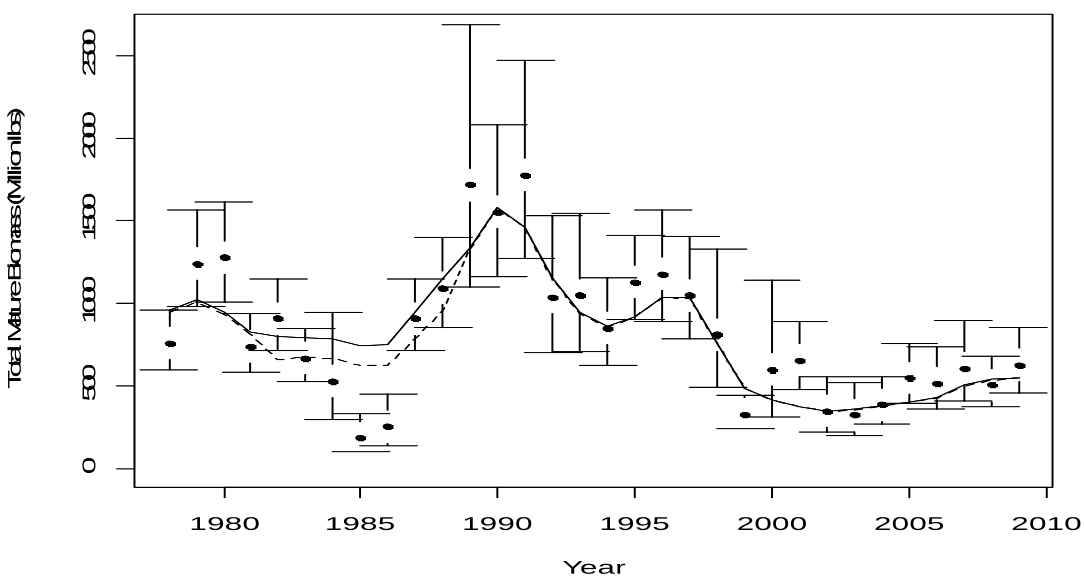

Figure 2. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

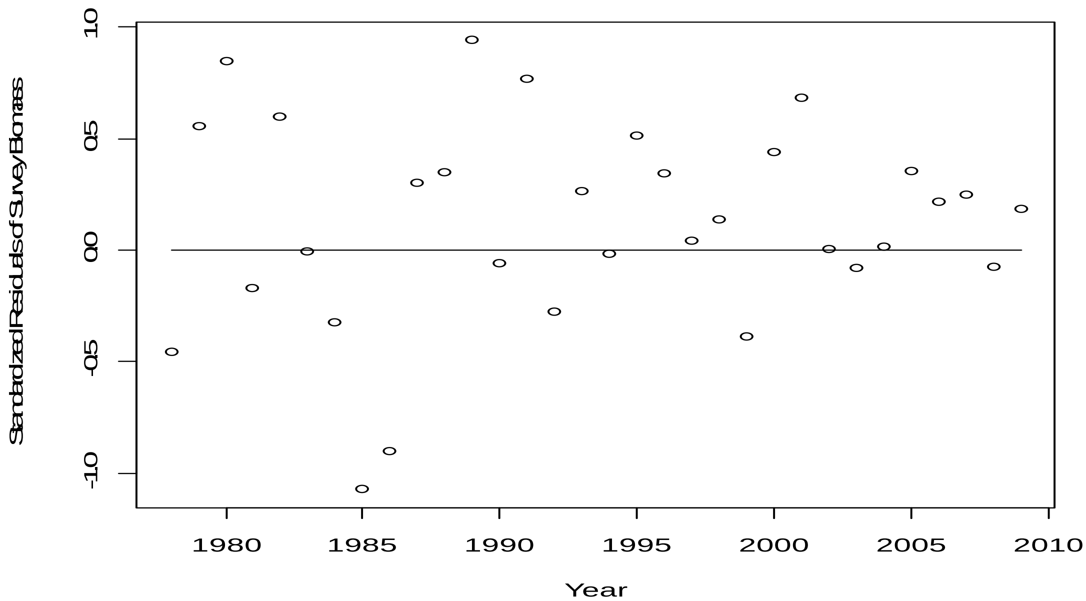

Figure 3. Standardized residuals for model fit to total mature biomass from Figure 2.

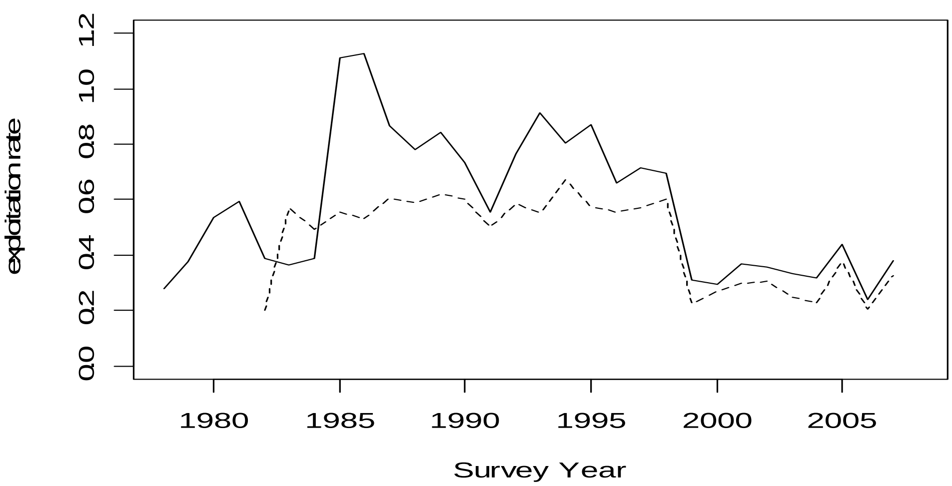

Figure 4. Exploitation rate estimated as the preseason GHL divided by the survey estimate of large male biomass (>101 mm) at the time the survey occurs (dotted line). The solid line is the retained catch divided by the survey estimate of large male biomass at the time the fishery occurs. Year is the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

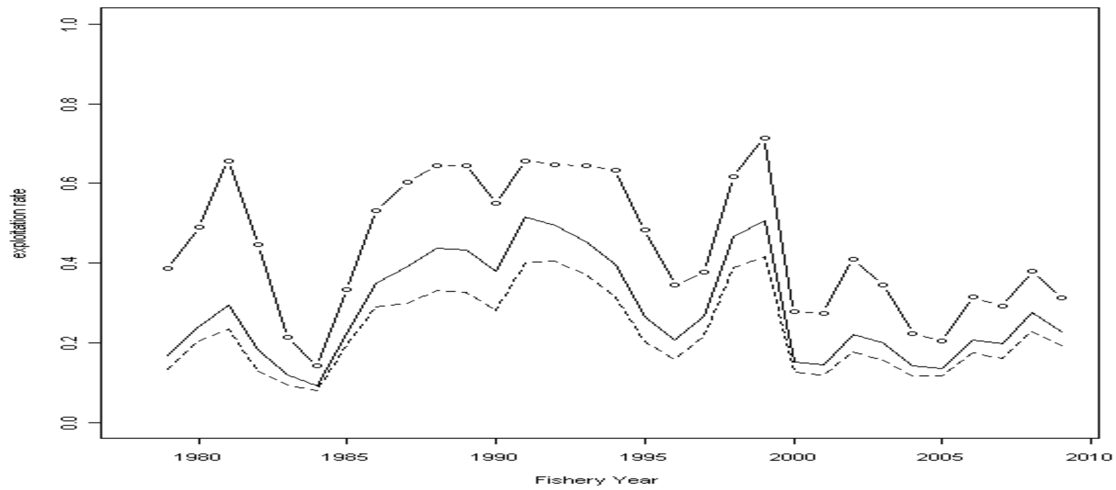

Figure 5. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line and dotted line). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the solid line with dots.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

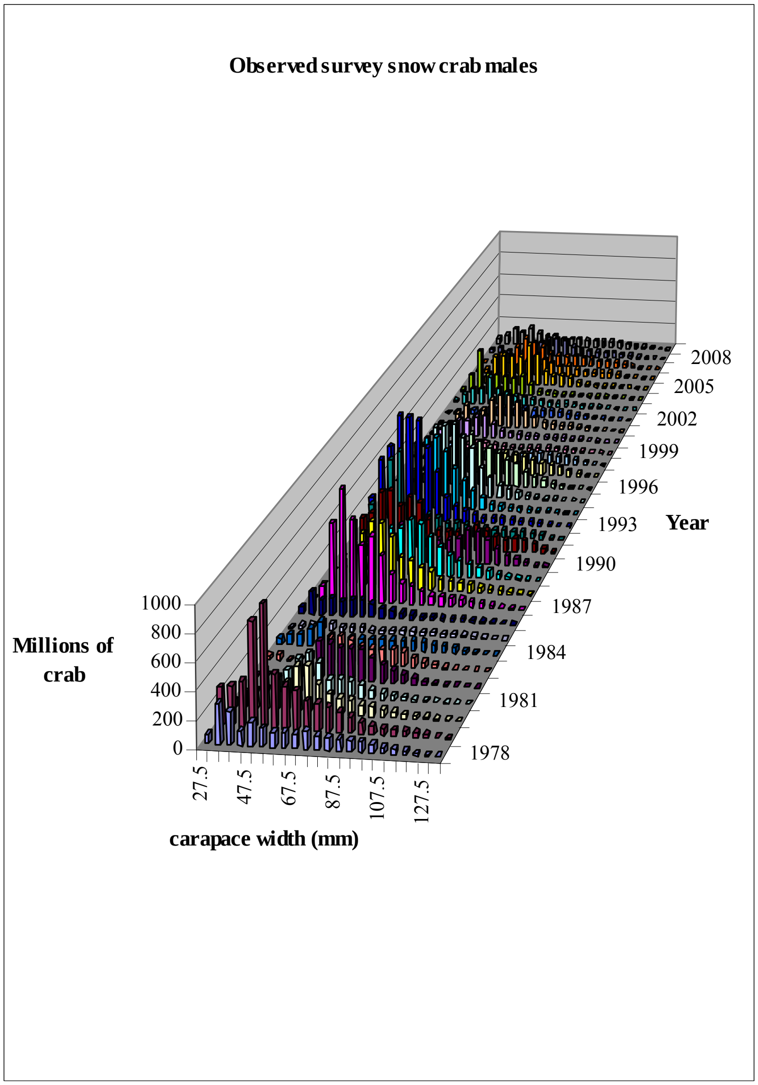

Figure 6. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

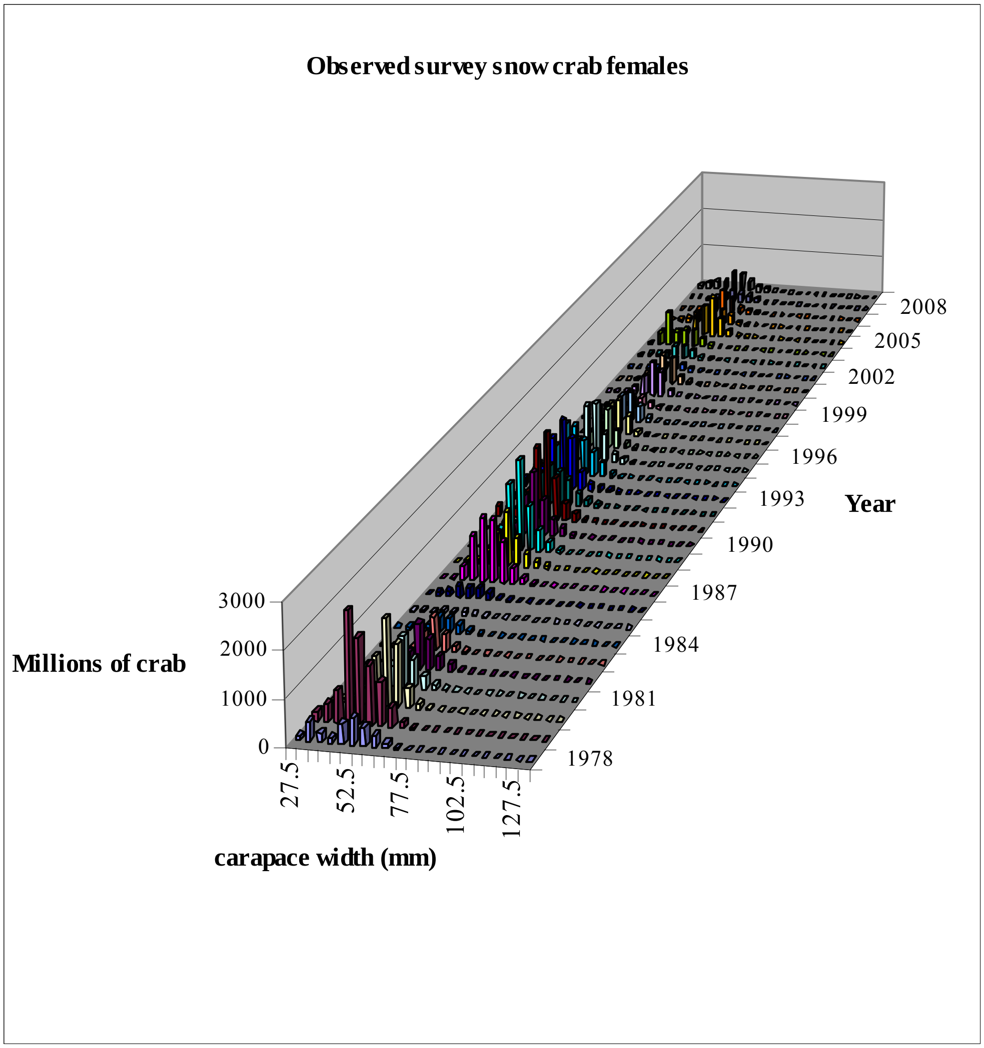

Figure 7. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

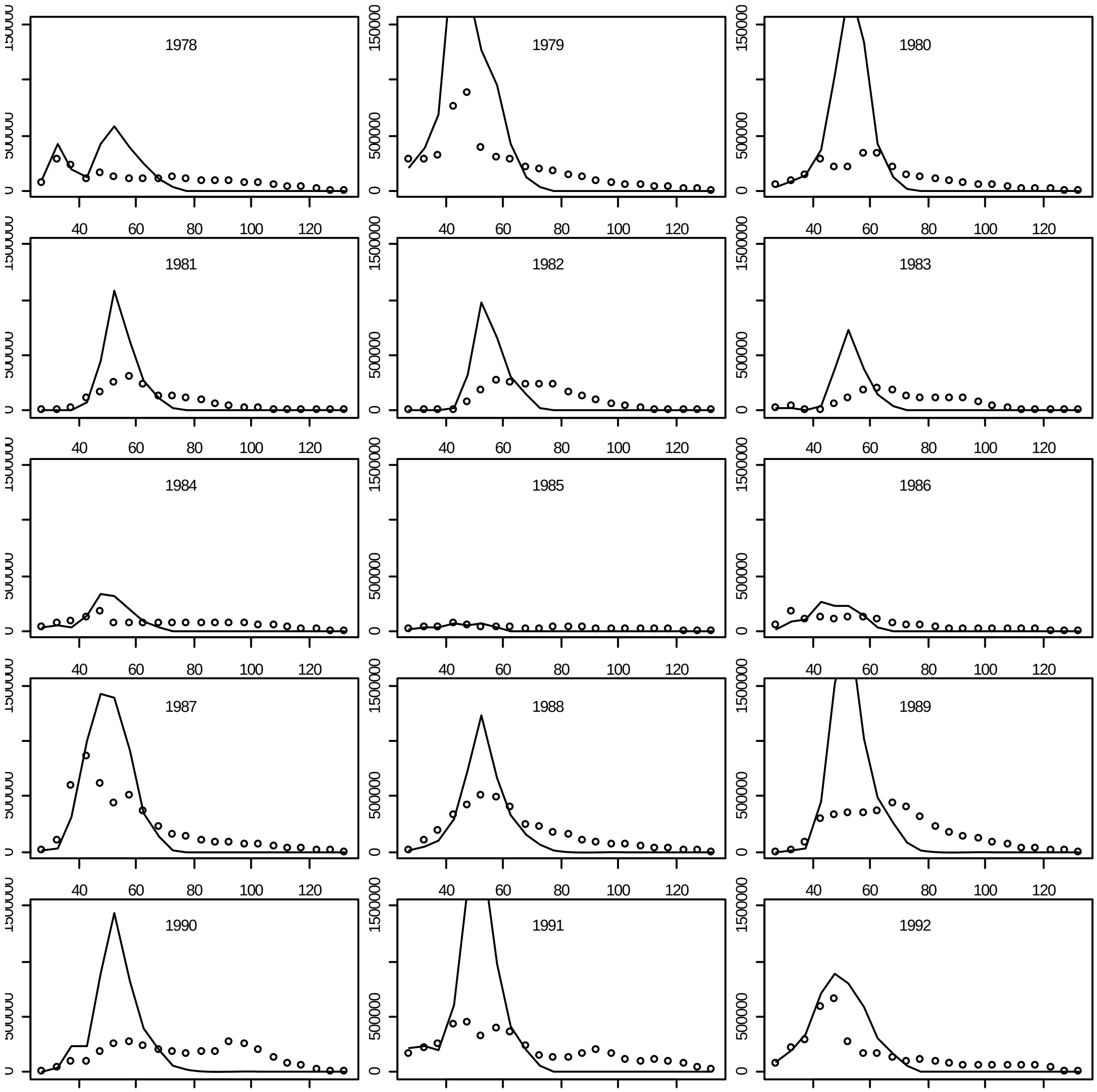

Figure 8. Observed survey numbers by length, males circles, females solid line.

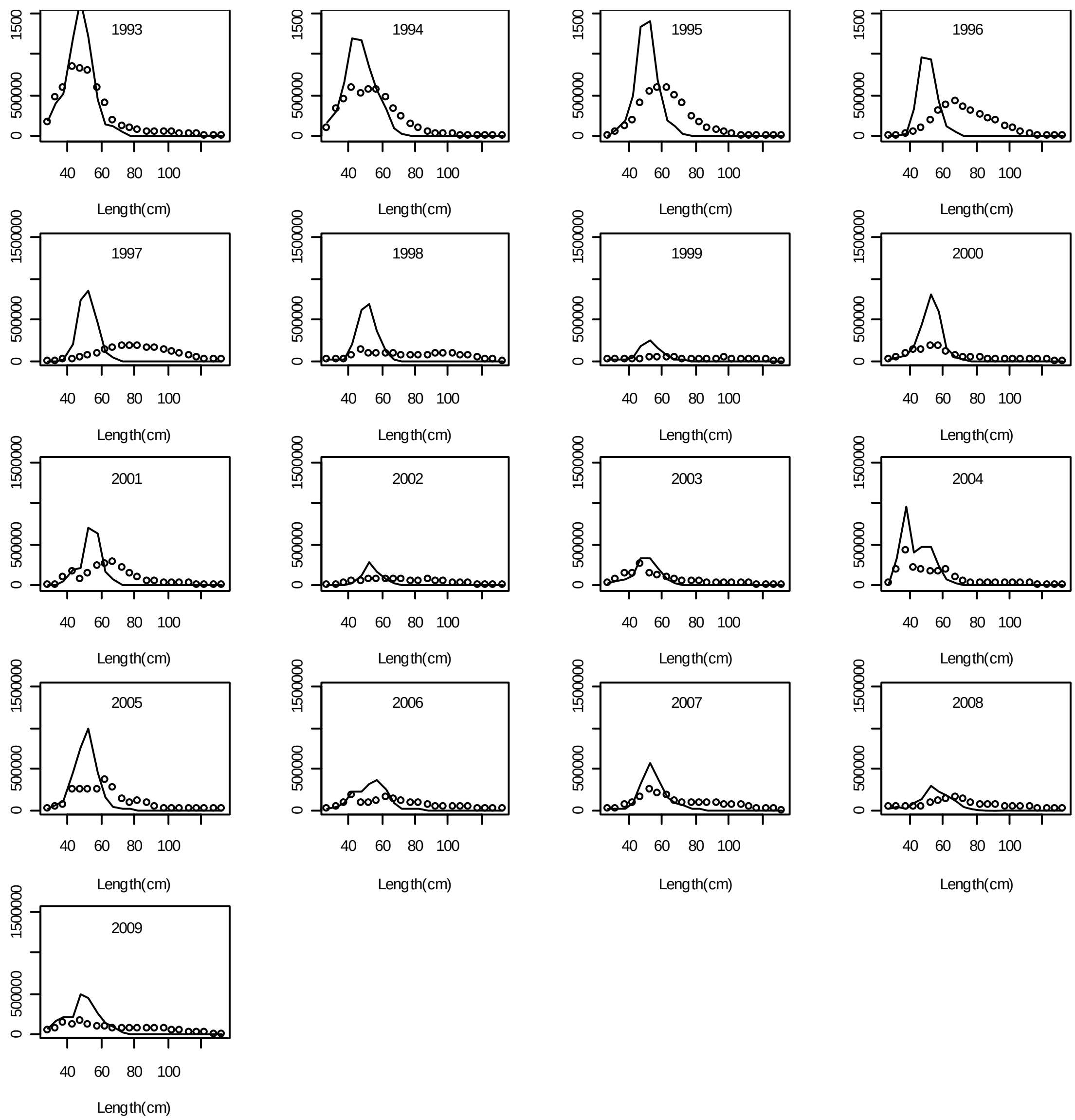

Figure 9. Observed survey numbers by length, males circles, females solid line.

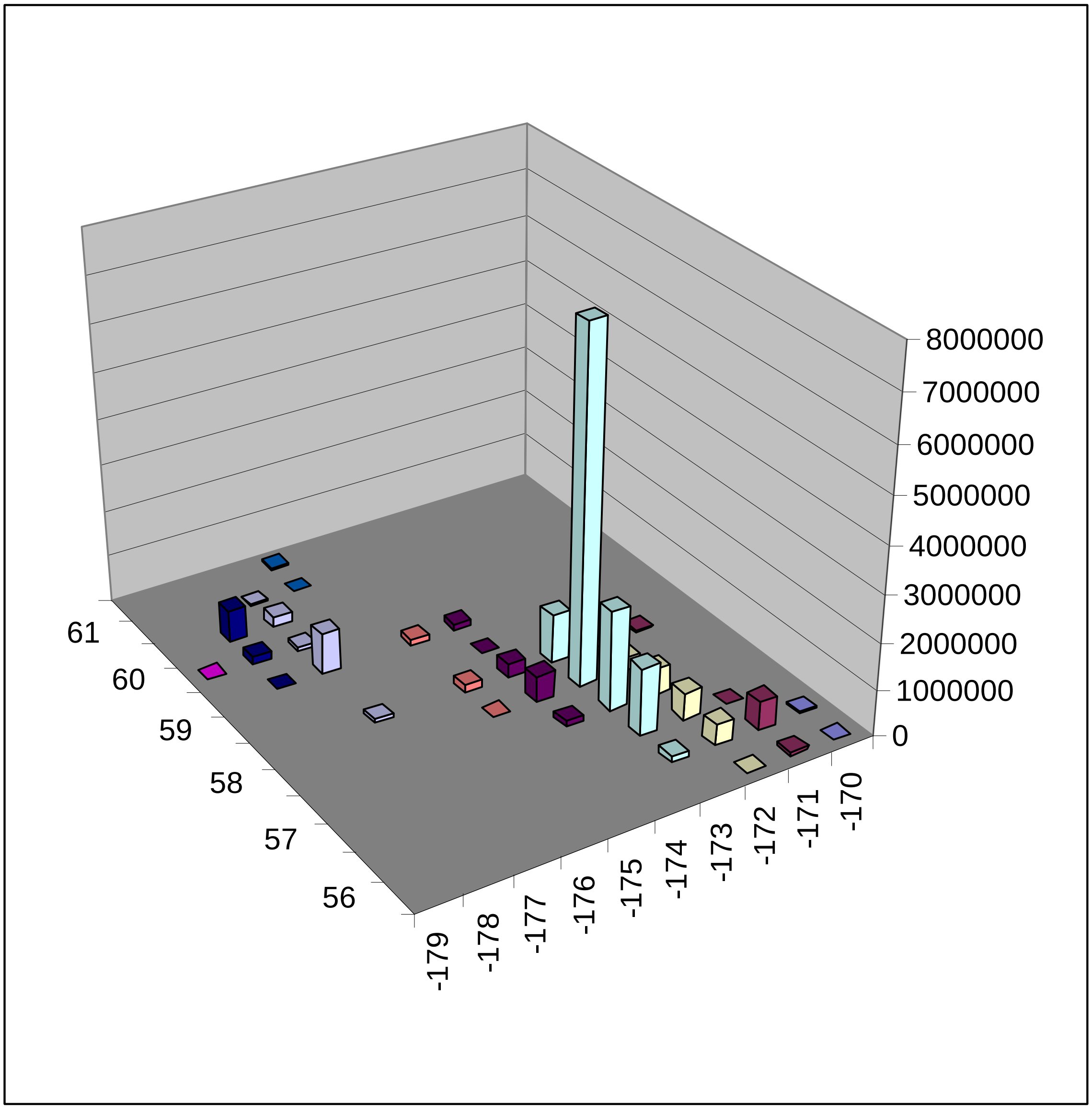

Figure 10. 2003/04 pot fishery retained catch in numbers by statistical area. Longitude in negative degrees. Areas are 1 degree longitude by 0.5 degree latitude.

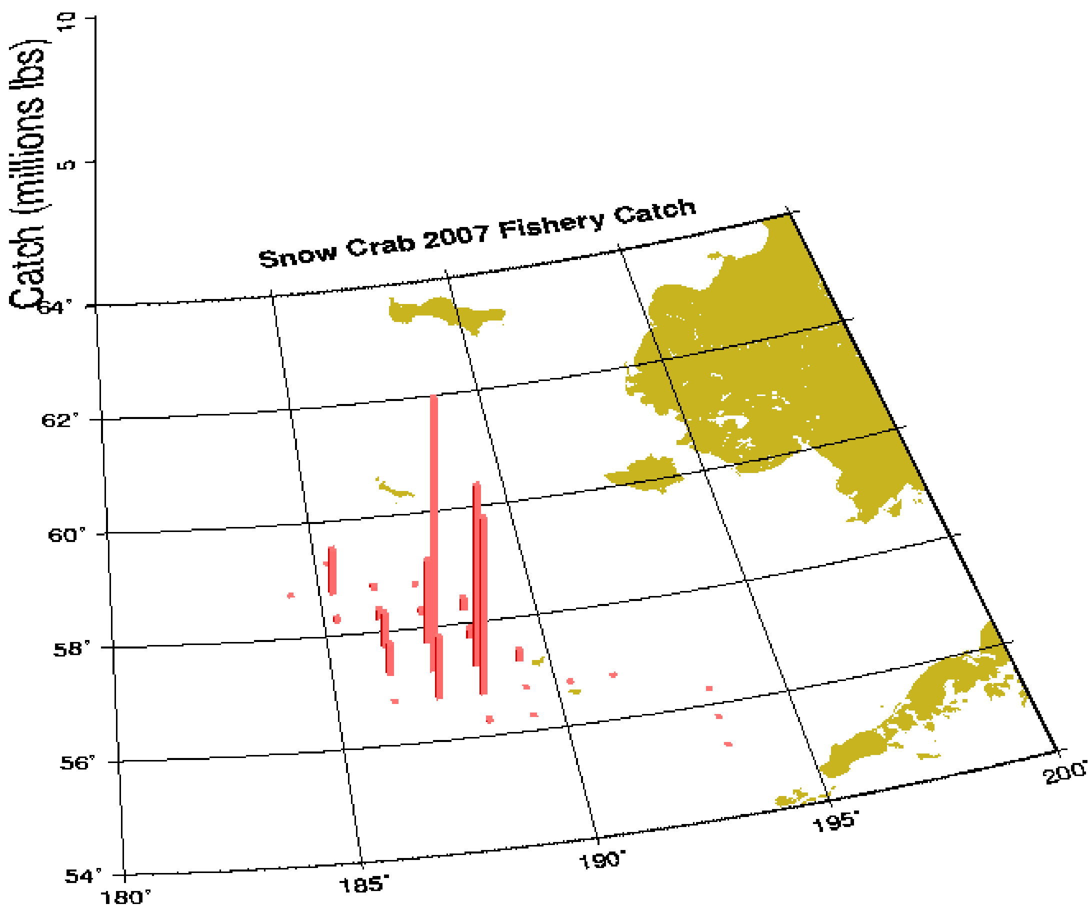

Figure 11. 2006/07 snow crab pot fishery retained catch(million lbs) by statistical area. Longitude increases from west to east (190 degrees = 170 degrees W longitude). Areas are 1 degree longitude by 0.5 degree latitude.

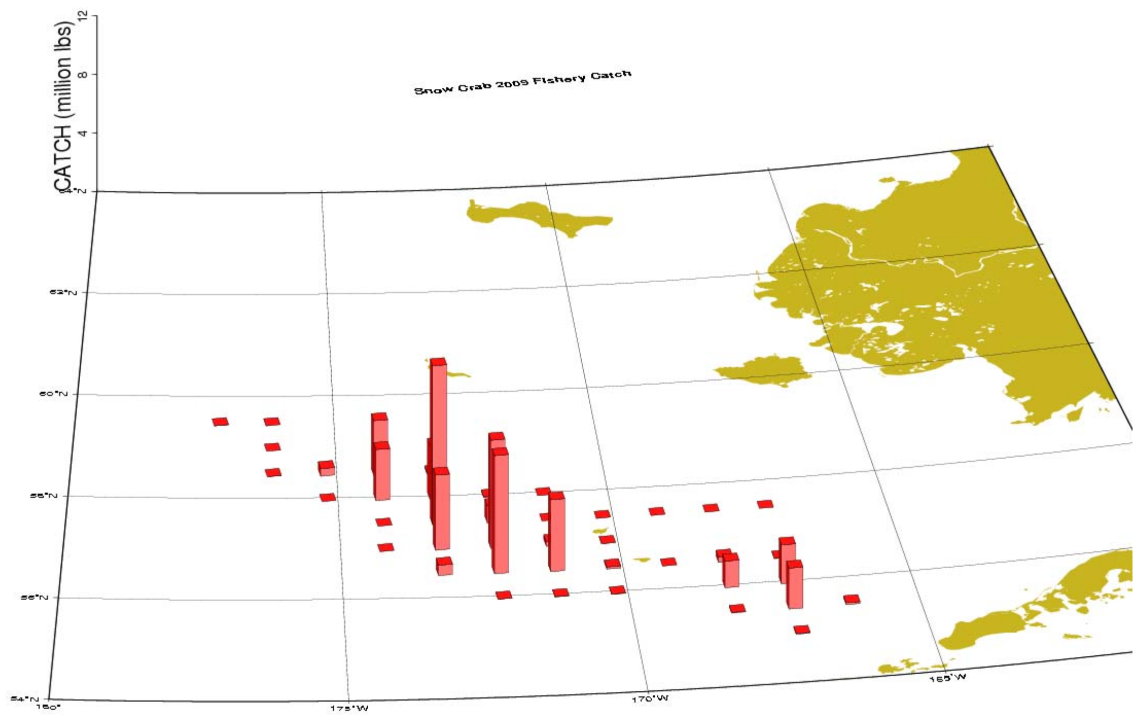

Figure 12. 2008/09 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

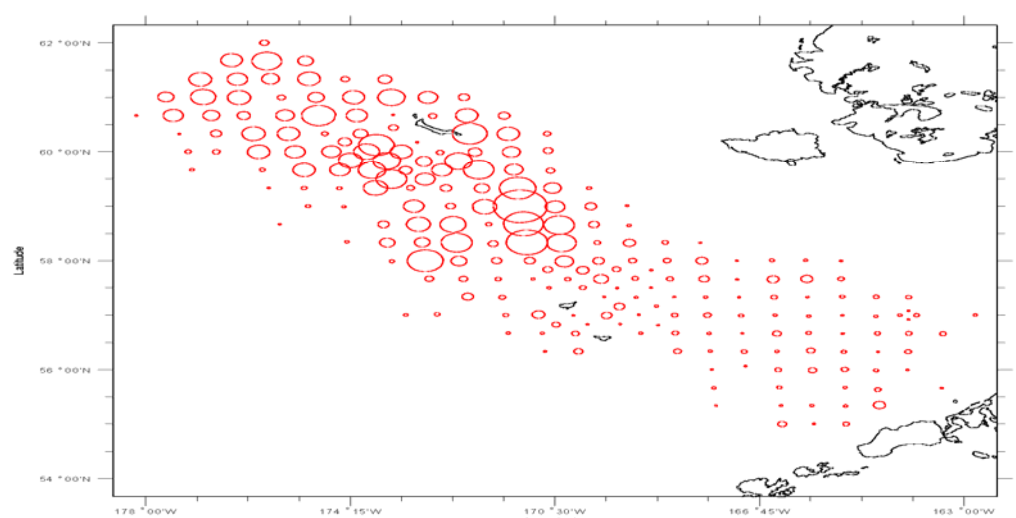

Figure 13. 2004 Survey abundance of males > 79 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle.

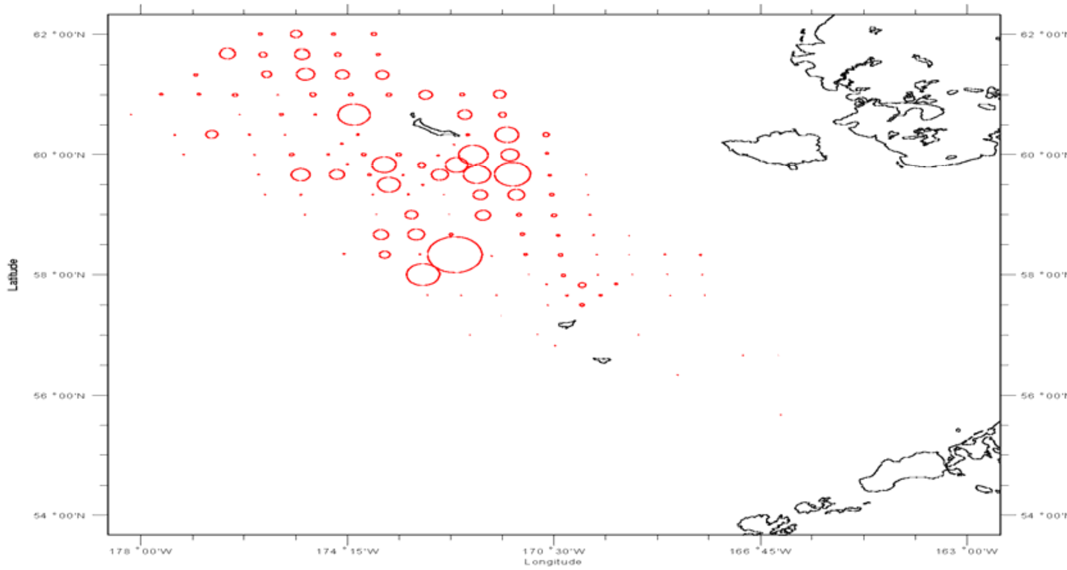

Figure 14. 2004 Survey abundance of females > 49 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle.

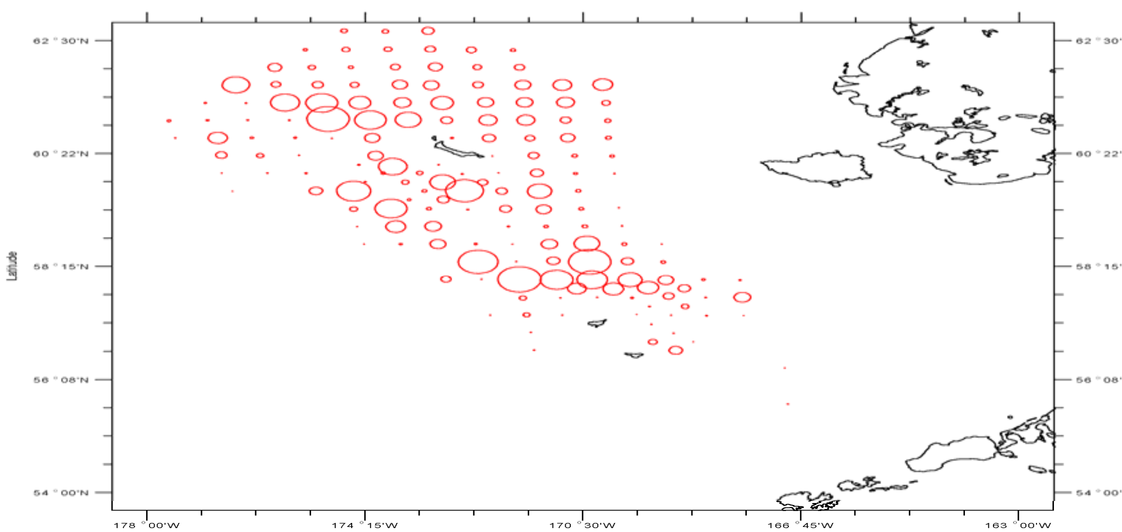

Figure 15. 2005 Survey abundance of females > 49 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle (not on the same scale as male abundance in Figure 54). Includes stations to the north of the standard survey area.

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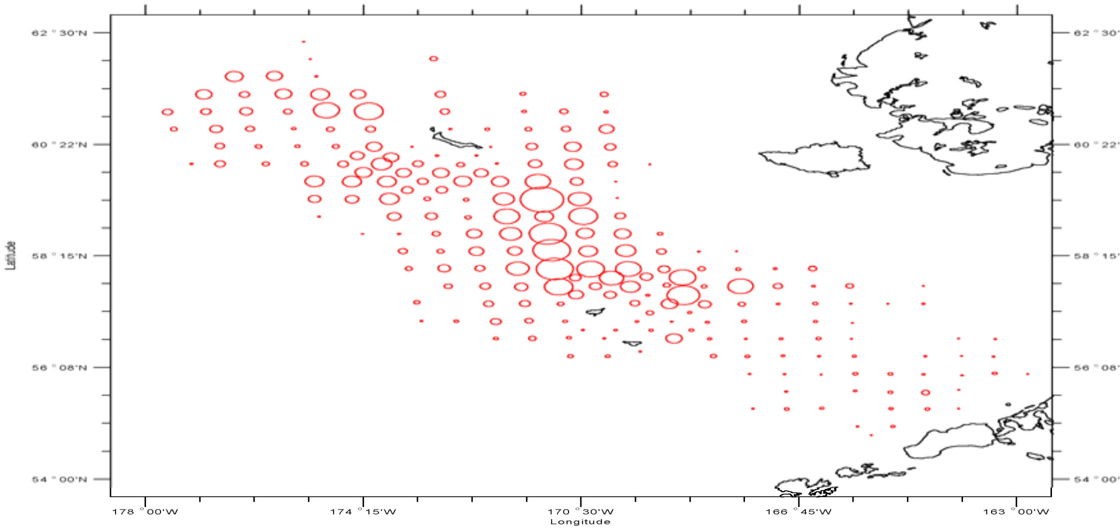

Figure 16. 2005 Survey abundance of males > 79 mm (approximately mature abundance) by tow. Abundance is proportional to the area of the circle (not on same scale as female abundance in Figure 53).

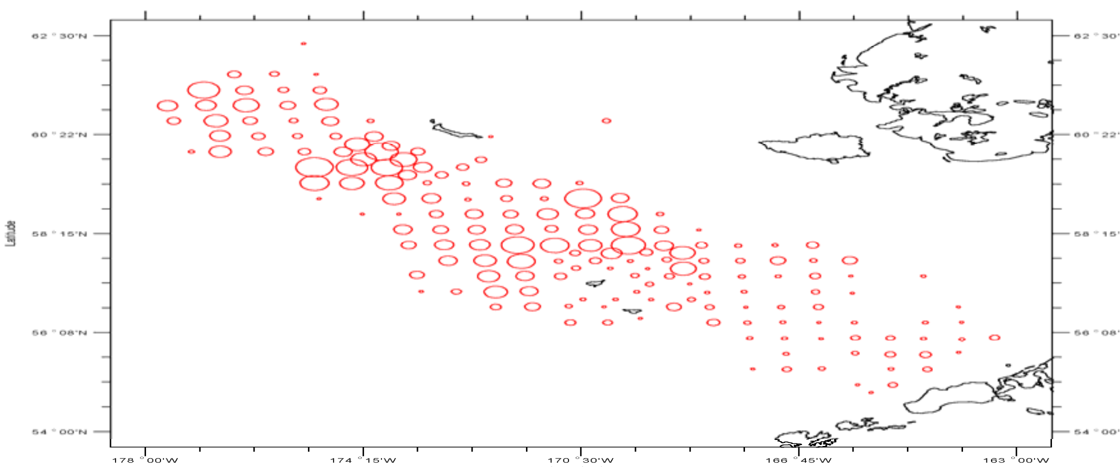

Figure 17. 2005 Survey abundance of males > 101 mm by tow. Abundance is proportional to the area of the circle.

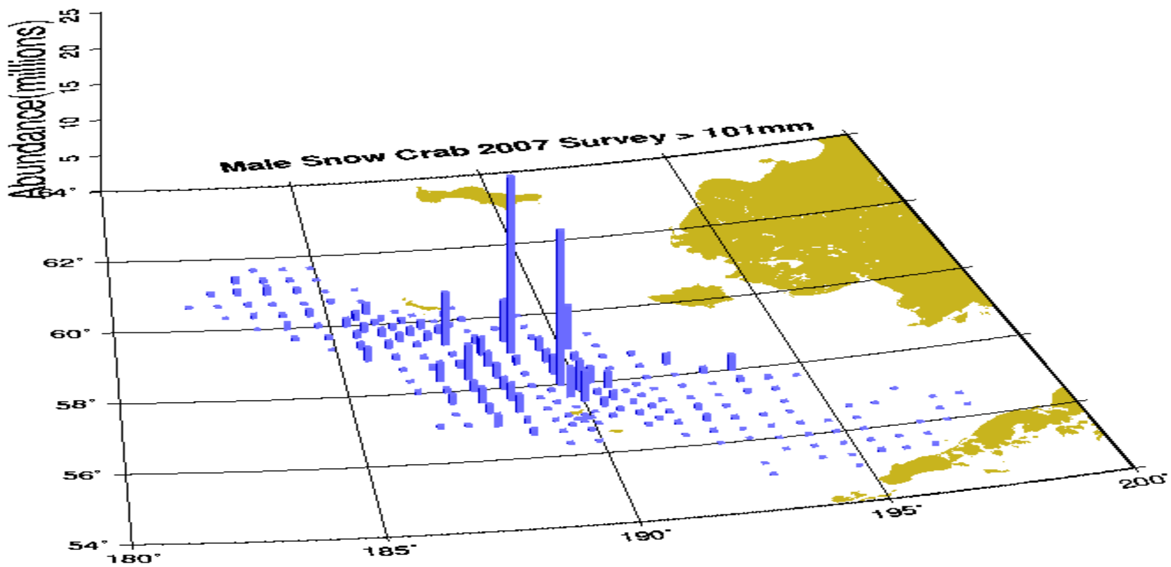

Figure 18. 2007 Survey abundance of males > 101 mm by tow. Abundance is in millions of crab.

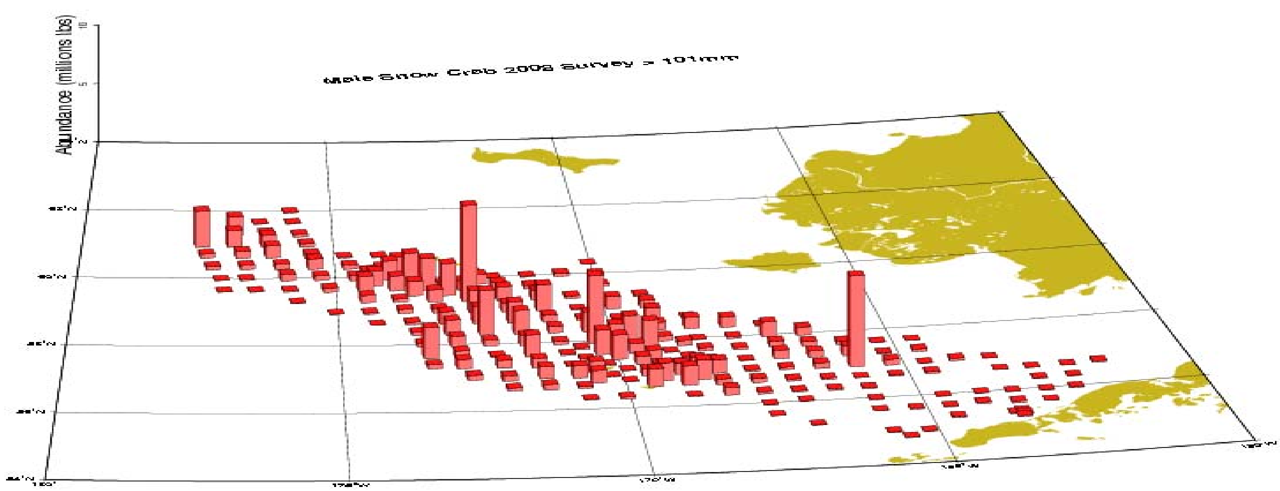

Figure 18b. 2008 Survey abundance of males > 101 mm by tow. Abundance is in millions of crab.

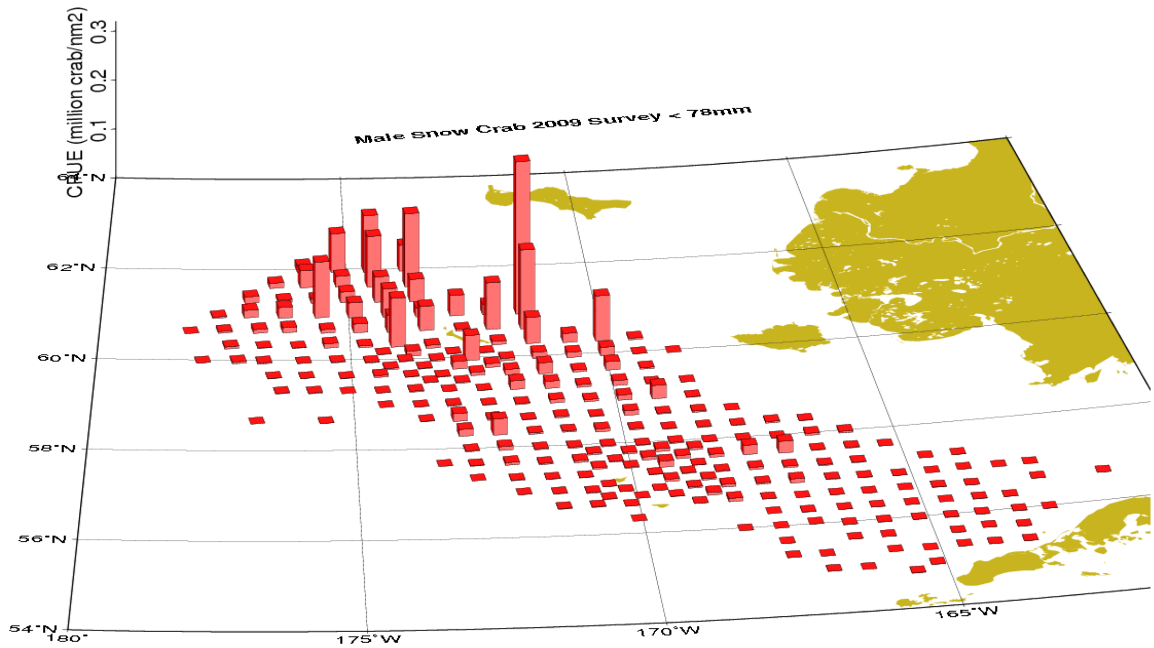

Figure 18c. 2009 Survey CPUE (million crab per nm2) of males < 78 mm by tow.

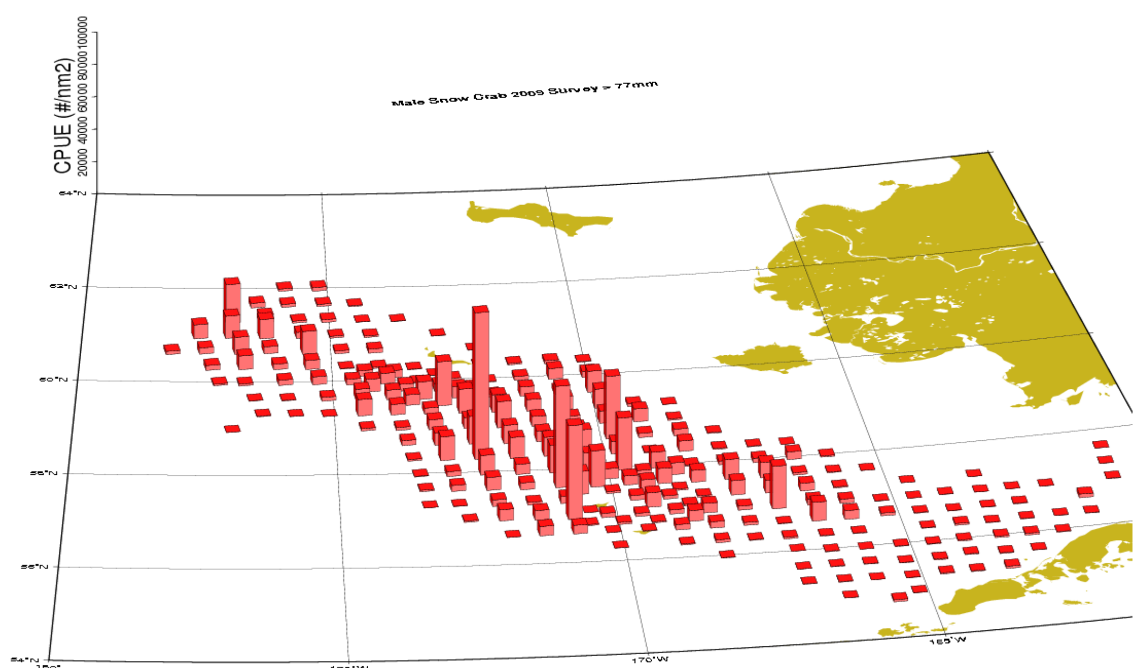

Figure 18d. 2009 Survey CPUE (number per nm2) of males > 77 mm by tow.

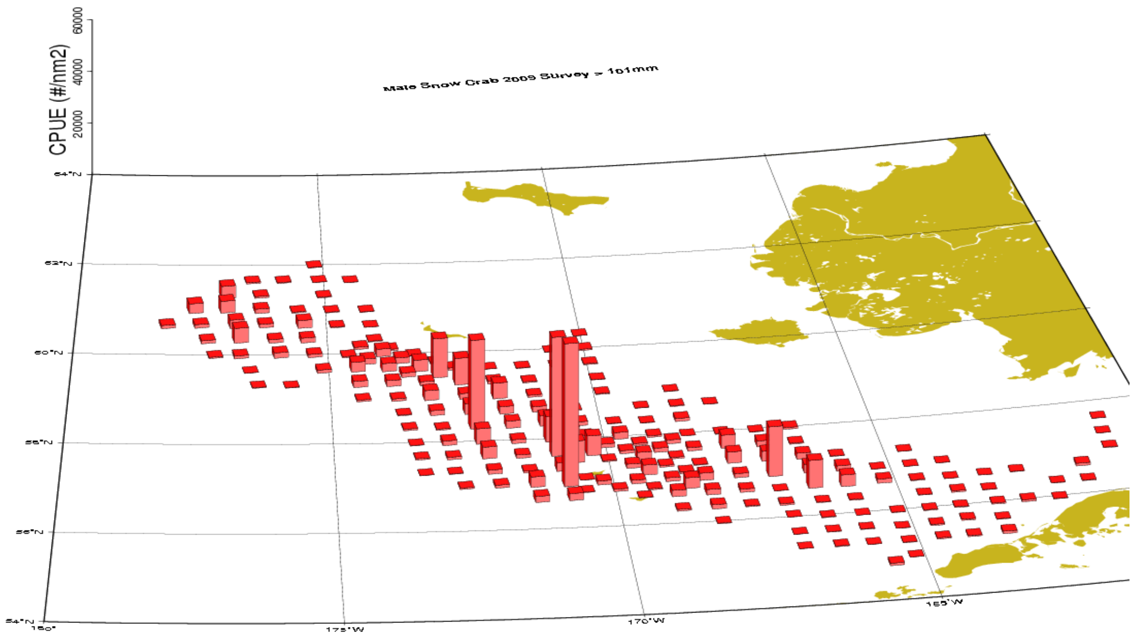

Figure 18e. 2009 Survey CPUE (number per nm2) of males > 101 mm by tow.

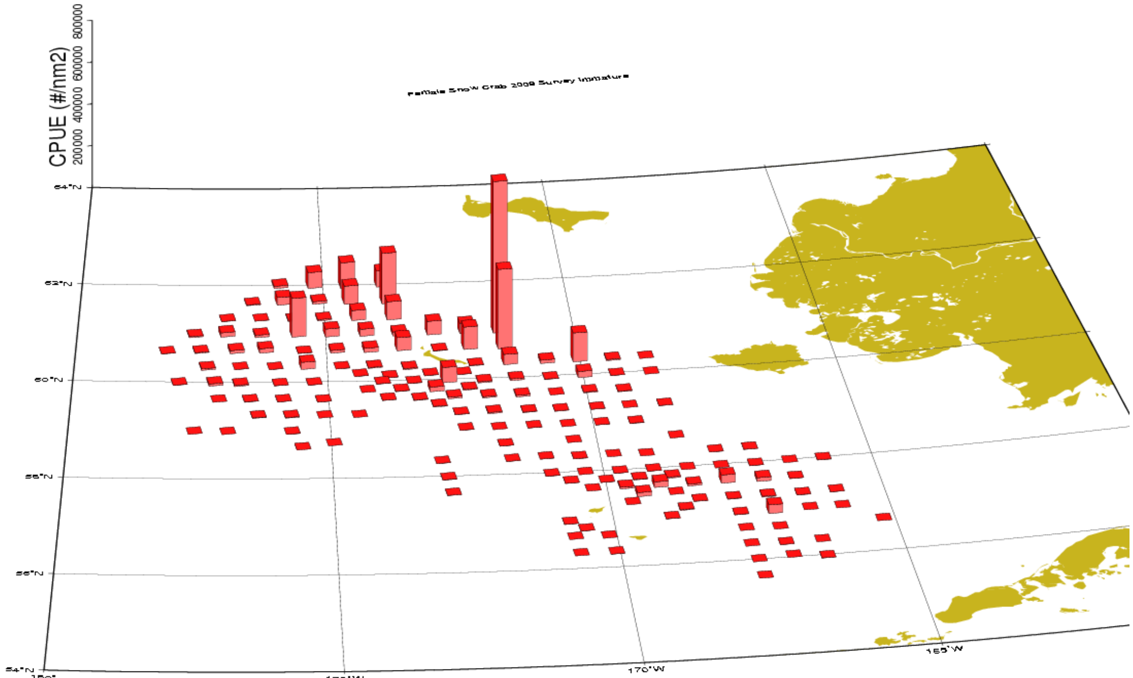

Figure 18f. Snow crab 2009 survey immature female cpue.

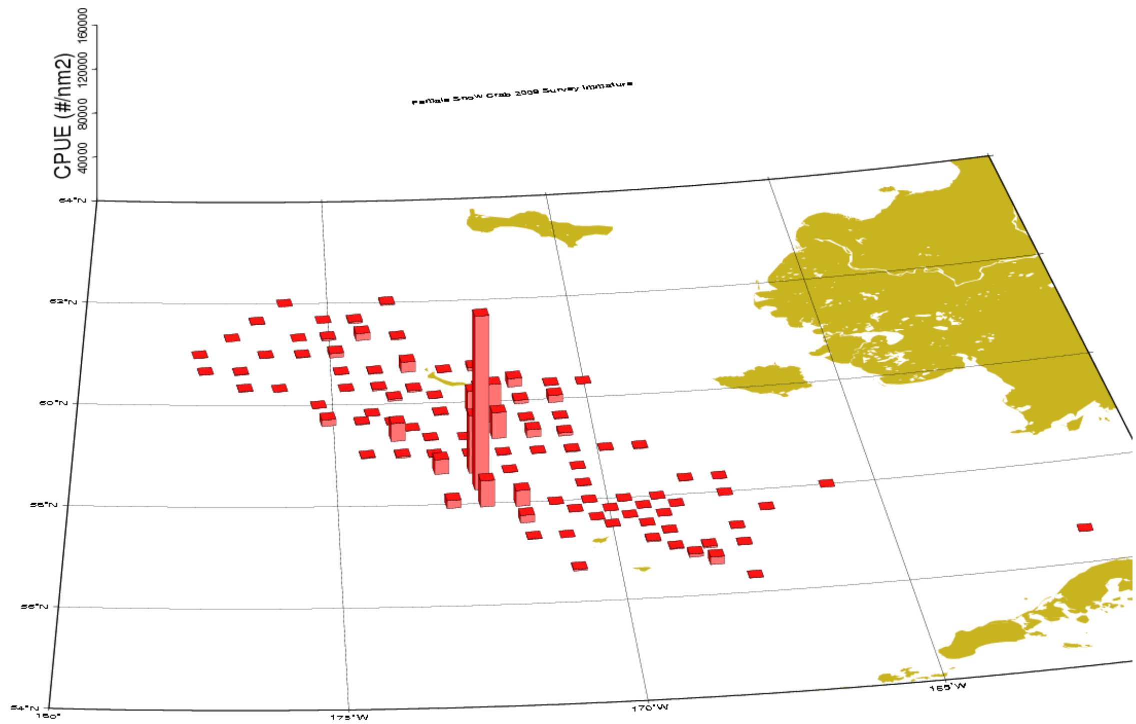

Figure 18g. Snow mature females cpue with less than or equal to half clutch of eggs.

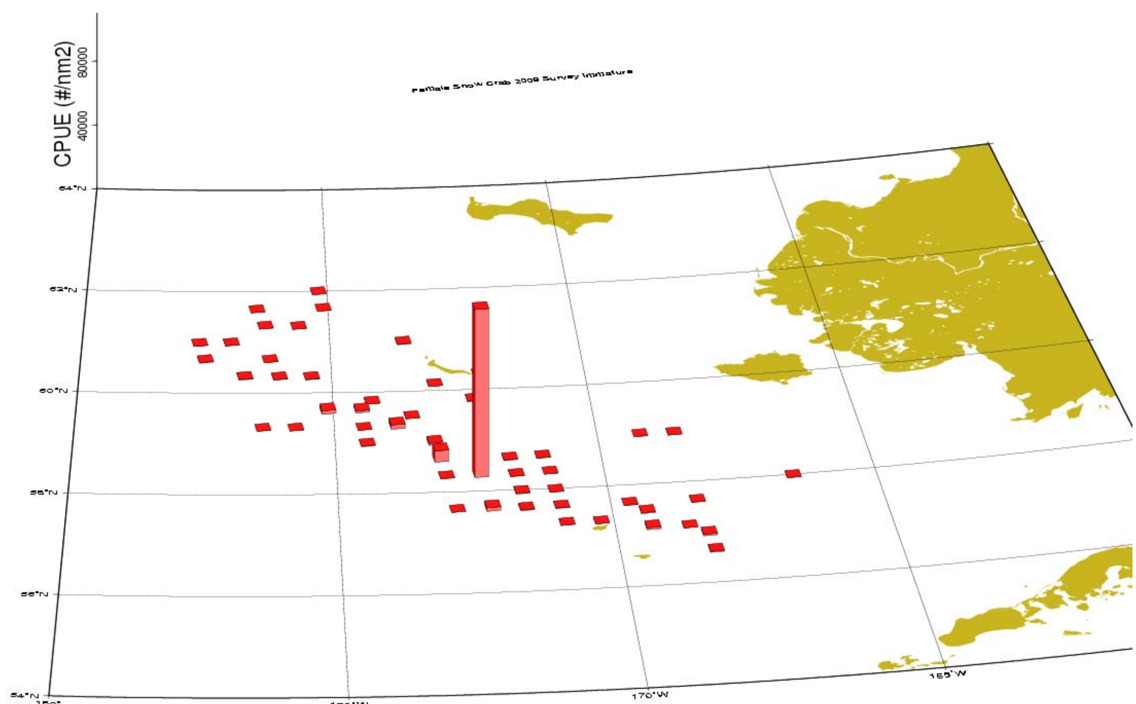

Figure 18h. Mature females with no eggs. Note scale not the same as other plots.

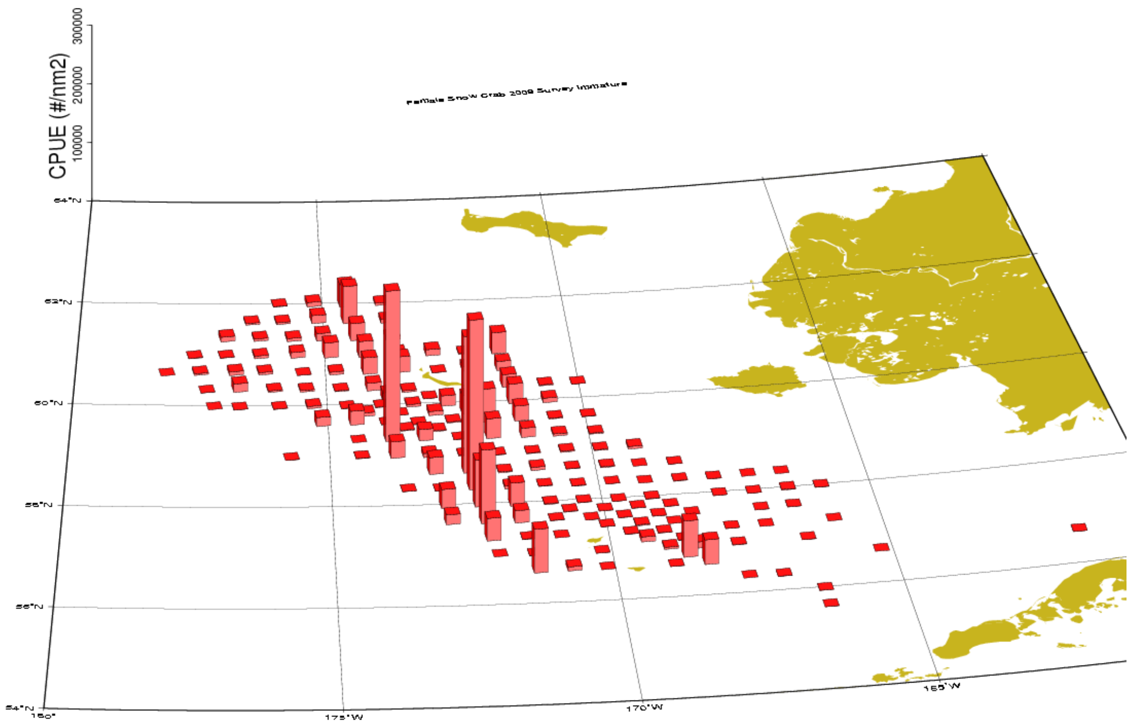

Figure 18i. Female survey cpue by haul for mature females with eggs. Scale not same as other plots.

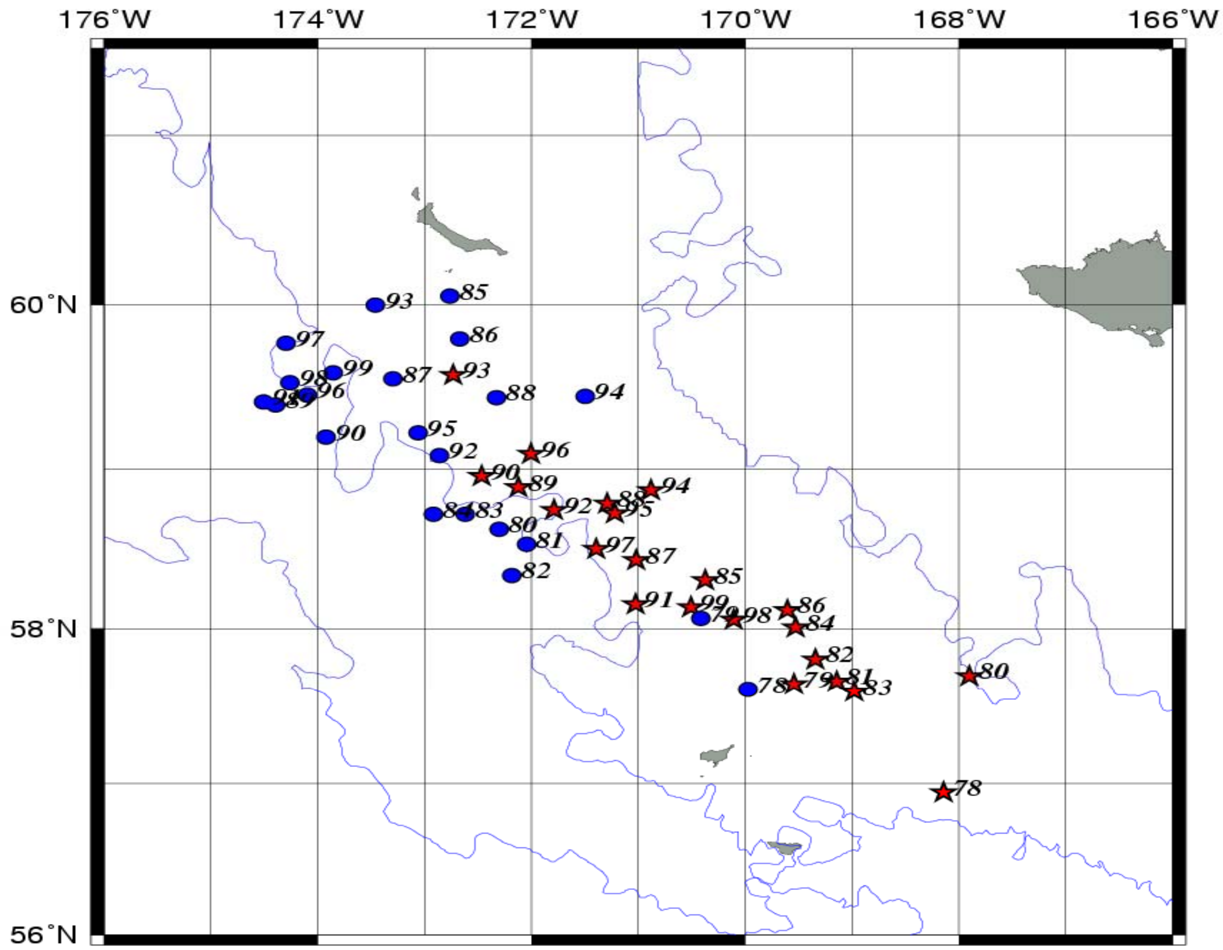

Figure 19. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars (Ernst, et al. 2005).

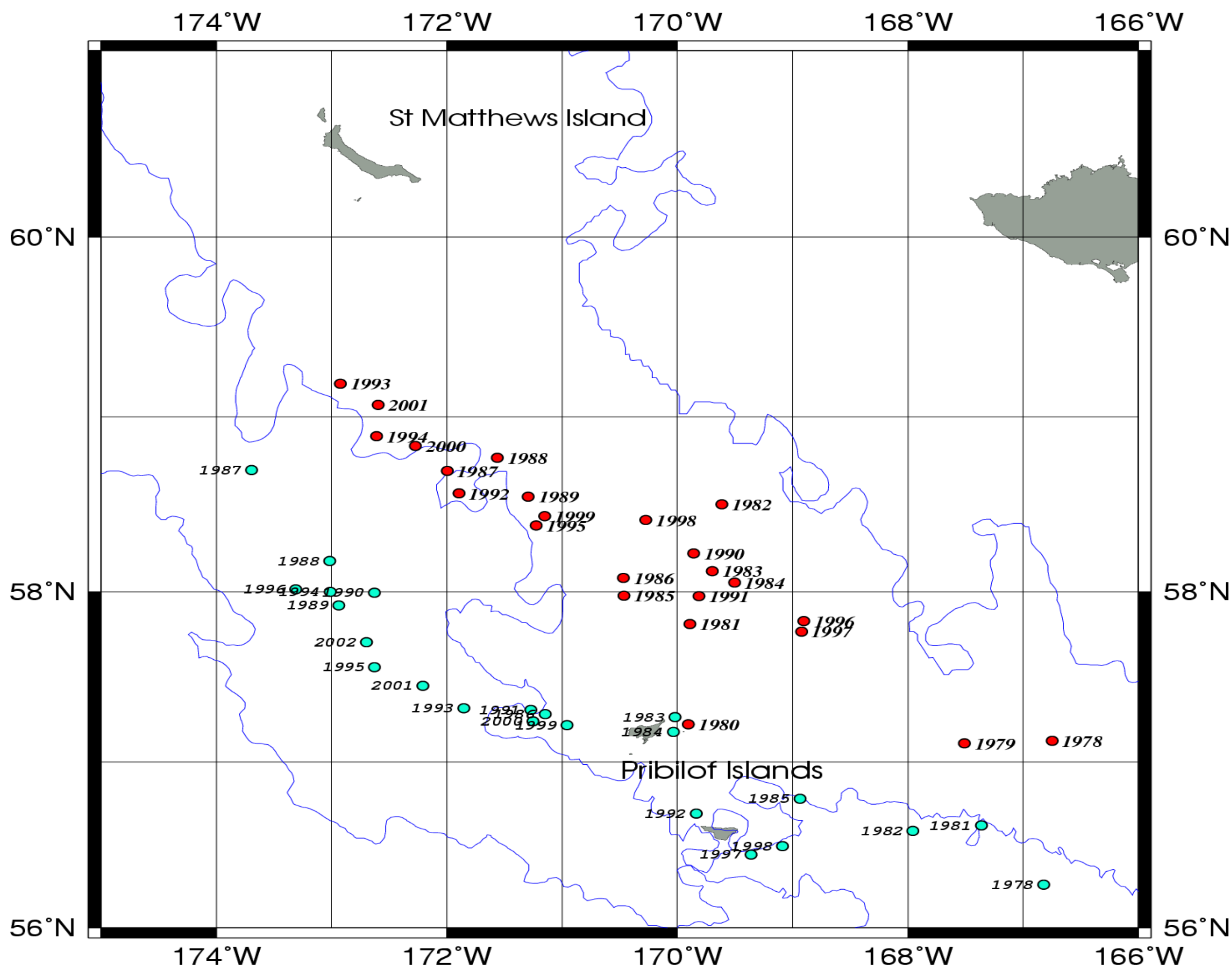

Figure 20. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green) (Ernst, et al. 2005).

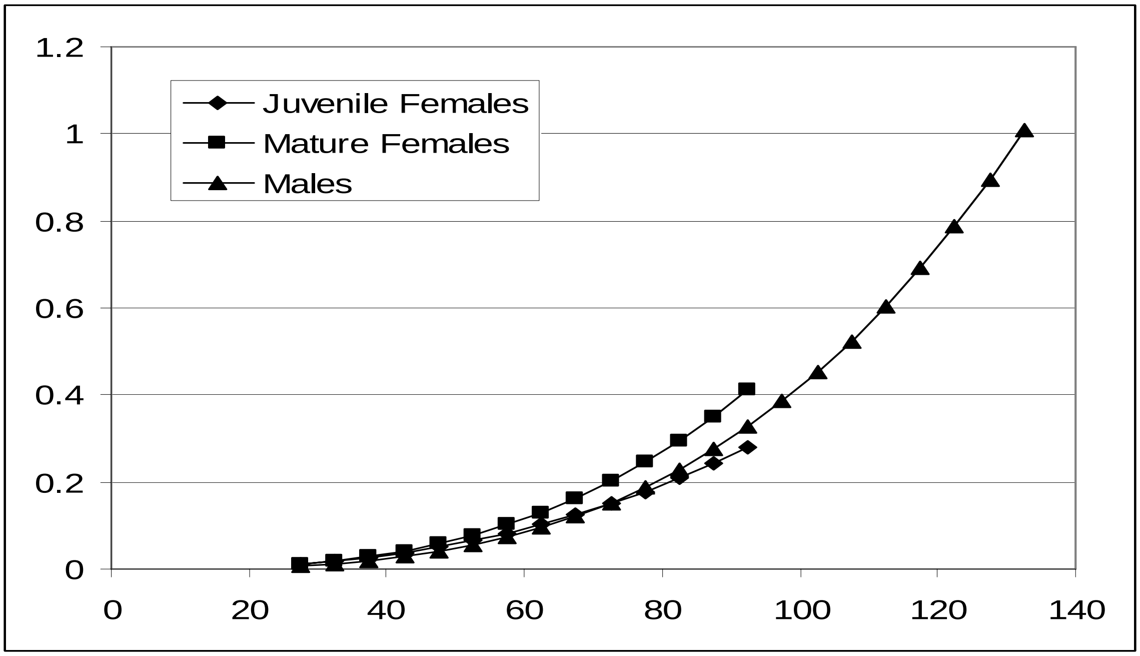

Figure 21. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

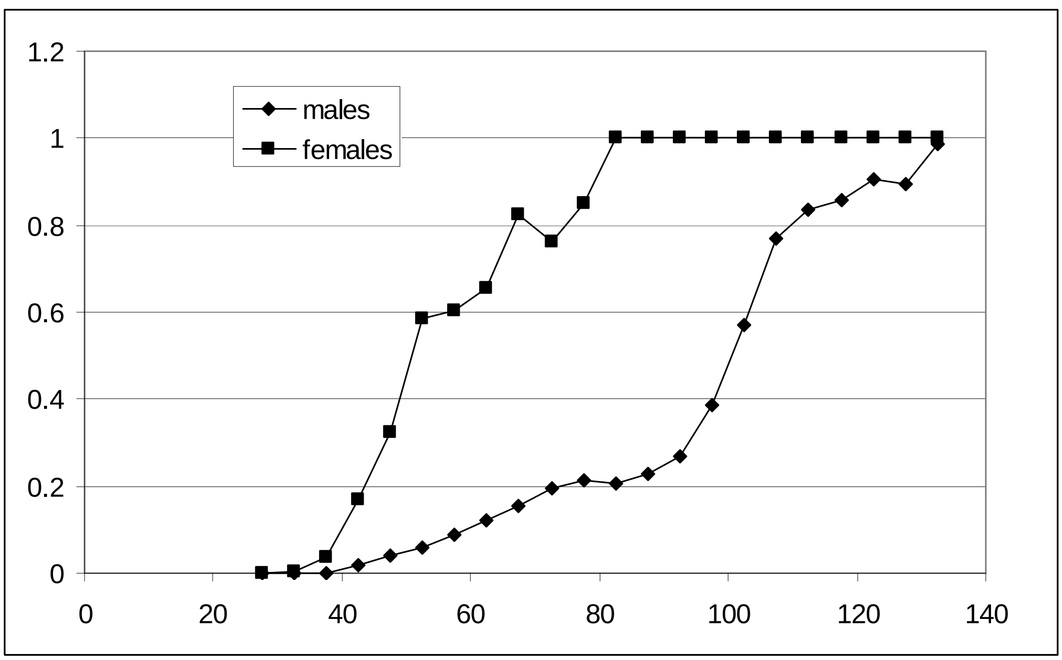

Figure 22. Probability of maturing by size for male and female snow crab (<u>not</u> the average fraction mature).

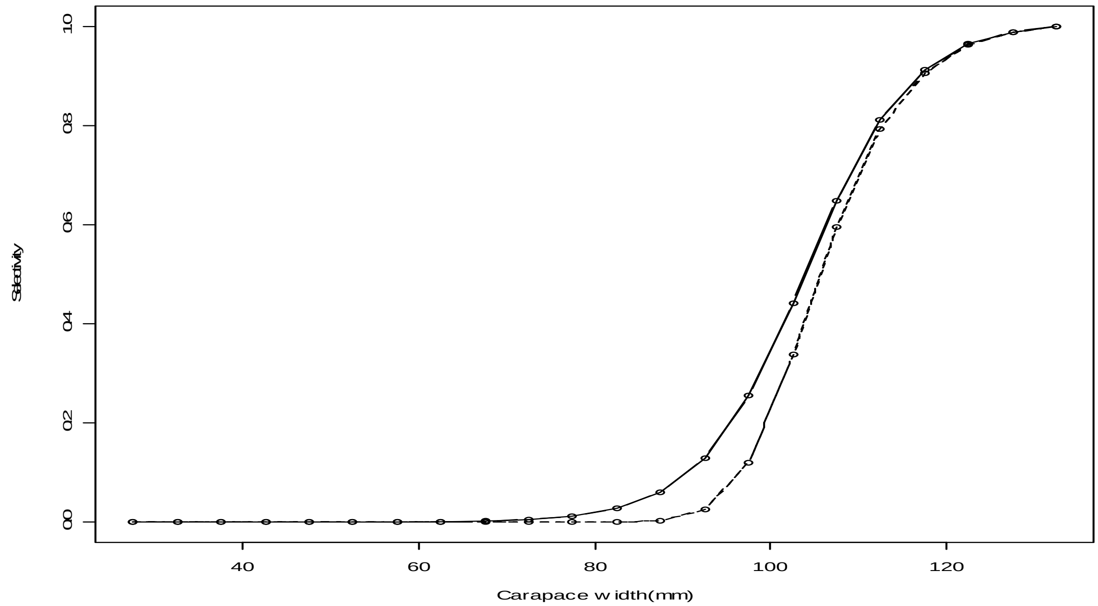

Figure 23. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

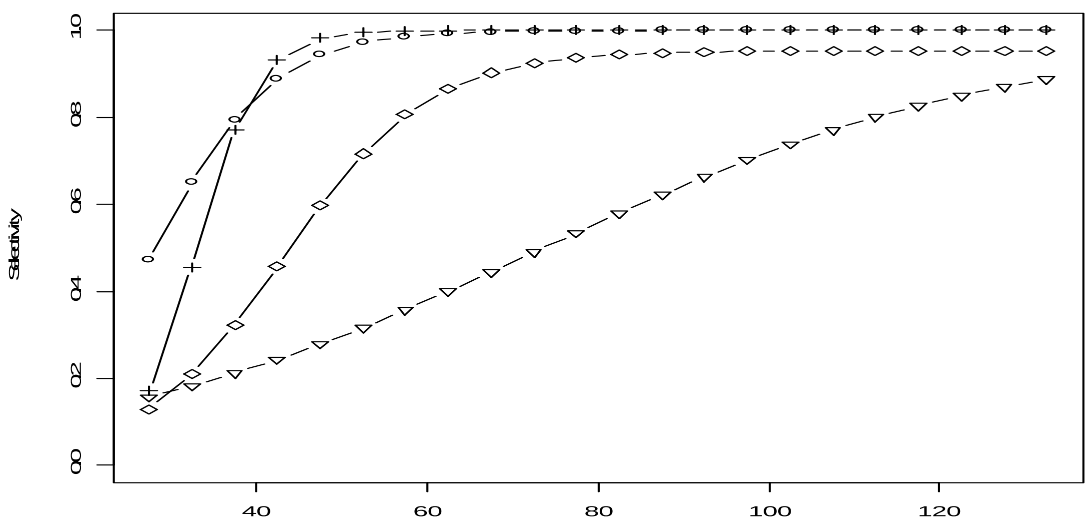

Figure 24. Survey selectivity curves for female and male snow crab estimated by the model for 1978-1981(solid line with circles), for 1982 to 1988 (solid line with diamonds), and 1989 to present (solid line with pluses). Survey selectivities estimated by Somerton and Otto (1998) are the solid line with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

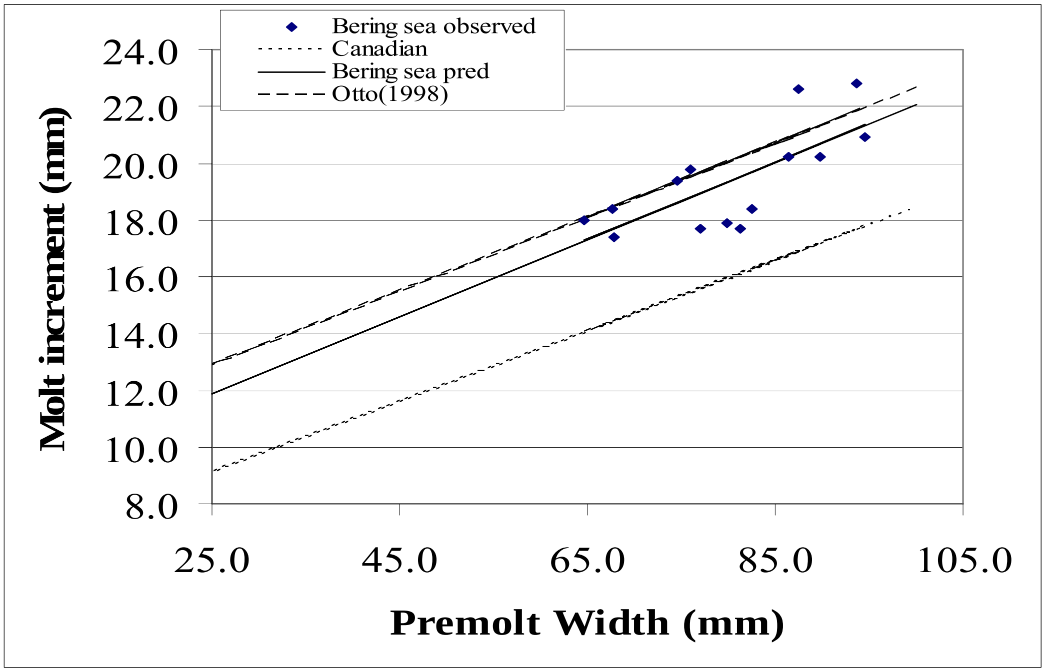

Figure 25. Growth increment as a function of premolt size for male snow crab. Points labeled Bering sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering sea pred is the predicted line from the Bering sea observed growth, which is used as a prior for the growth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

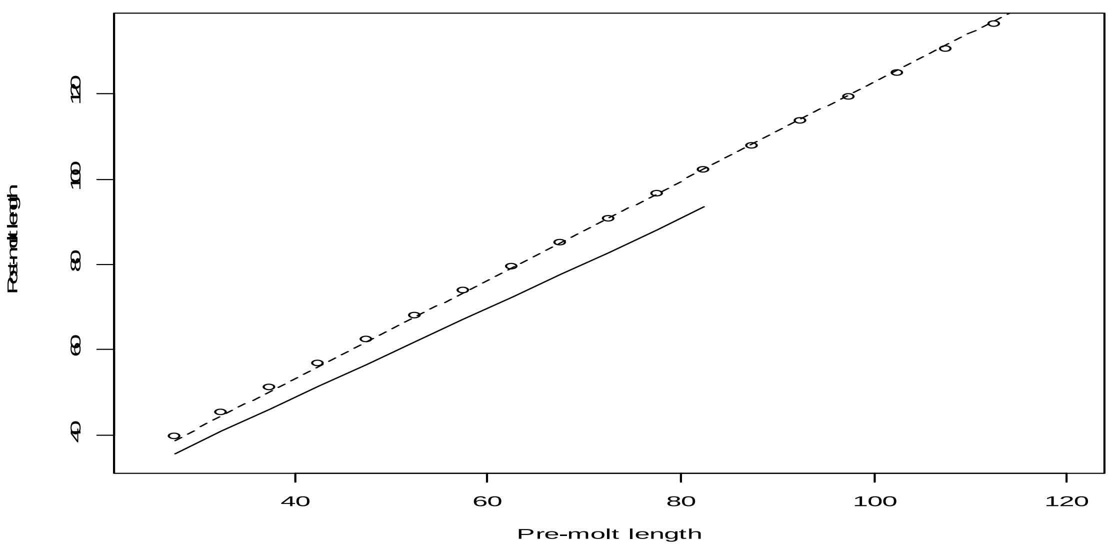

Figure 25. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the model. Circles are the observed growth curve.

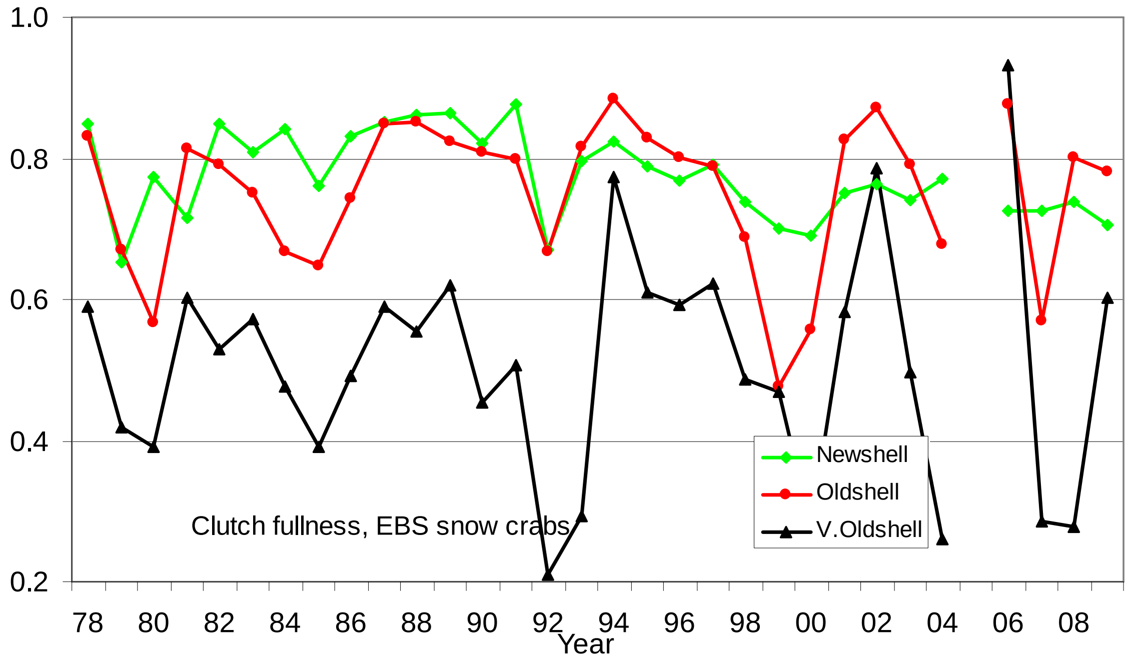

Figure 26. Clutch fullness for Bering sea snow crab survey data by shell condition for 1978 to 2009.

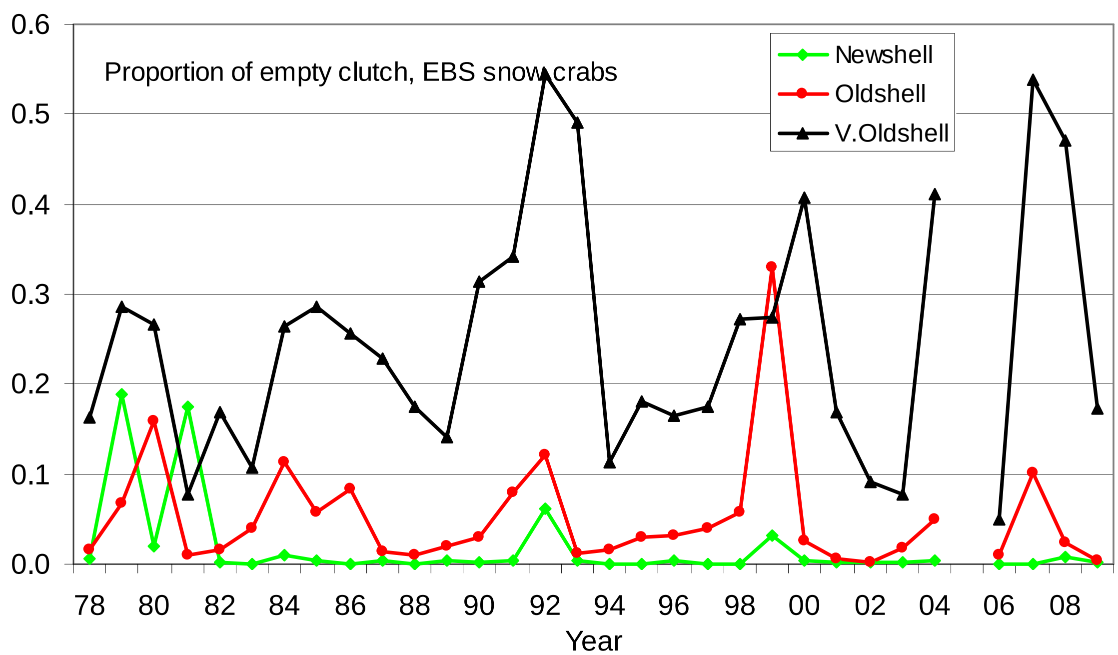

Figure 27. Proportion of barren females by shell condition from survey data 1978 to 2009.

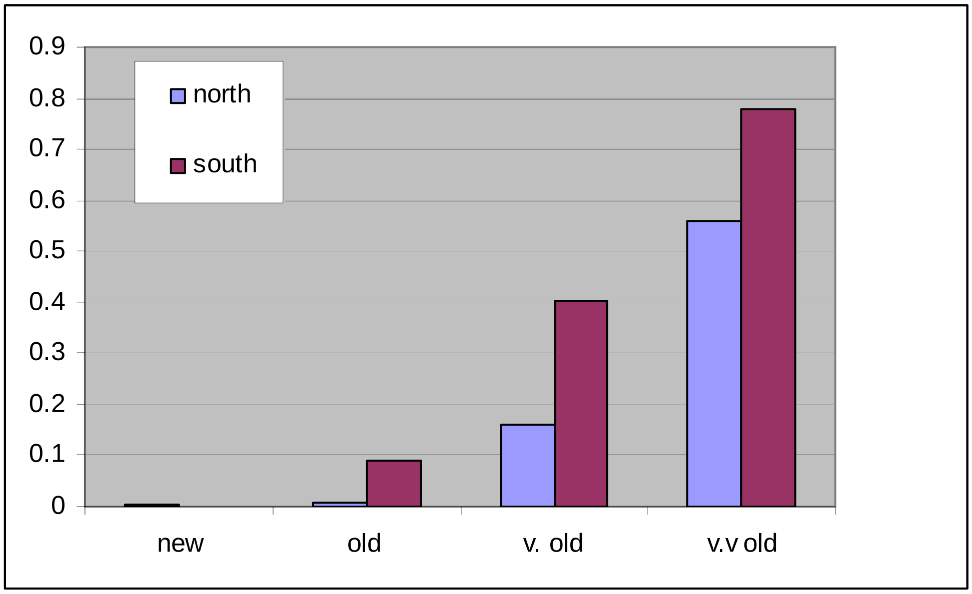

Figure 28. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

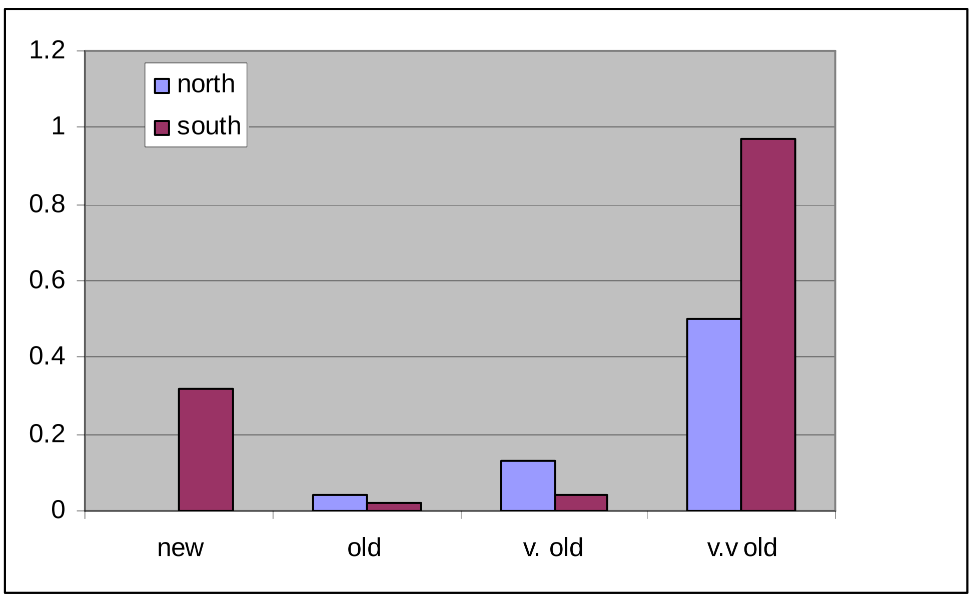

Figure 29. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

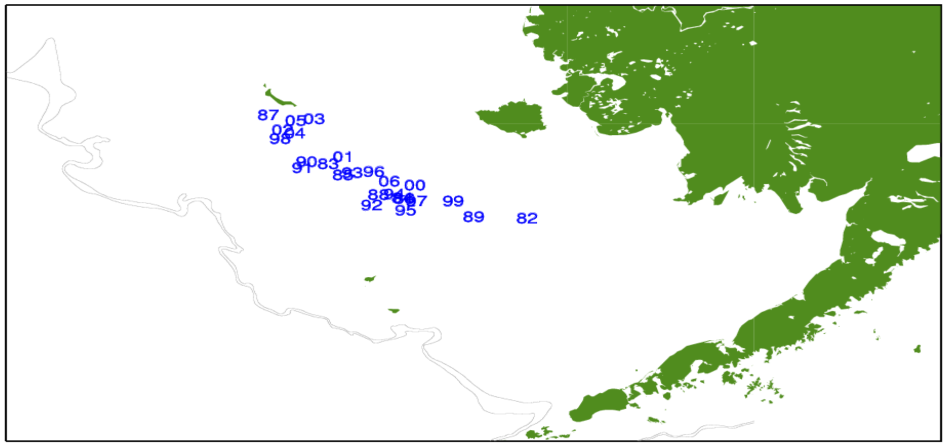

Figure 30. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

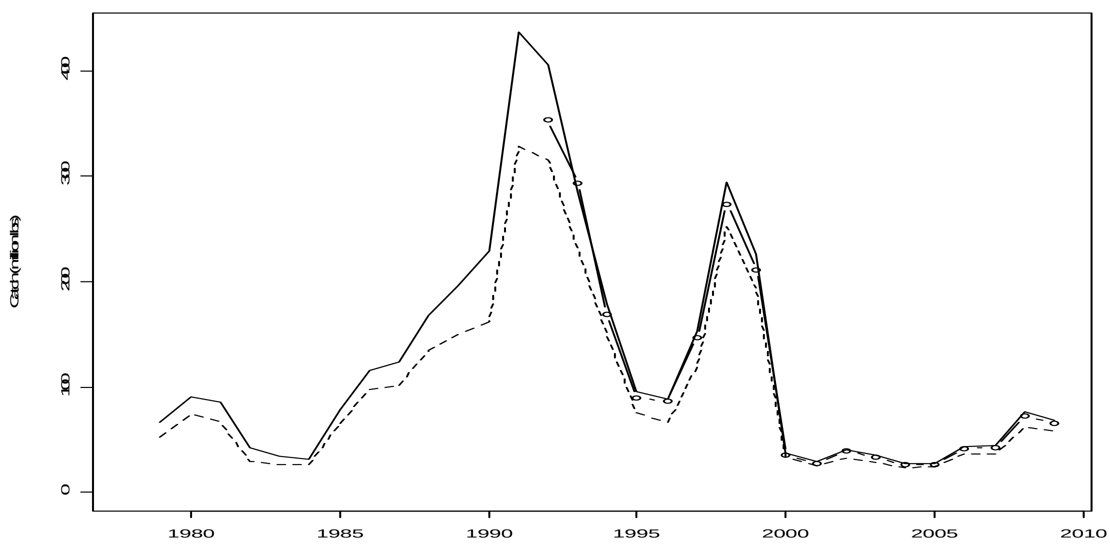

Figure 31. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 50% mortality of discarded crab) and observed retained catch (dotted line) for 1979 to 2008 fishery seasons.

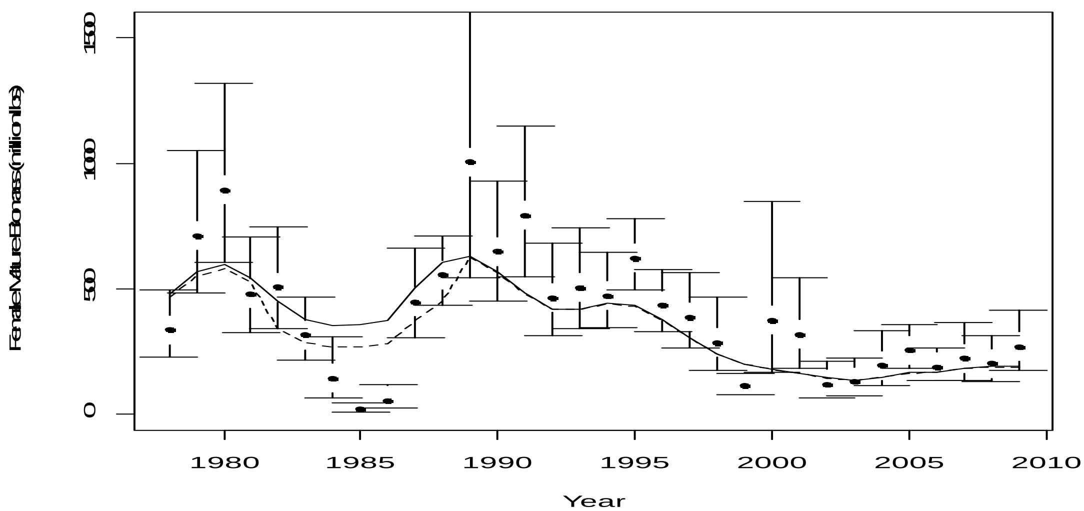

Figure 32. Population female mature biomass (millions of pounds, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

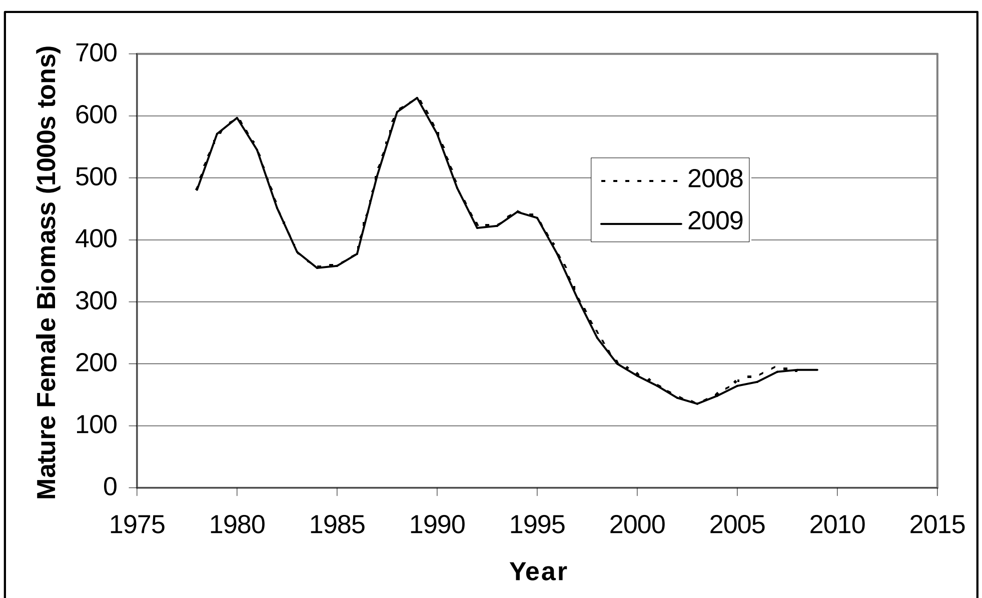

Figure 33. Population female mature biomass from the 2008 and 2009 assessment.

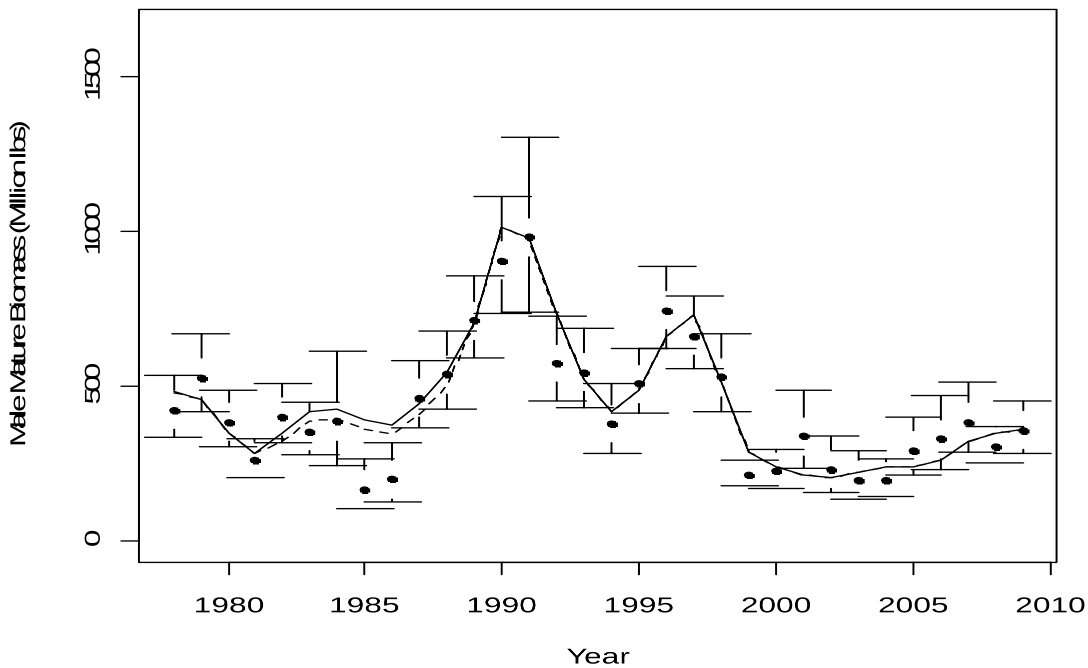

Figure 34. Population male mature biomass (millions of pounds, solid line), model estimate of survey male mature biomass (dotted line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

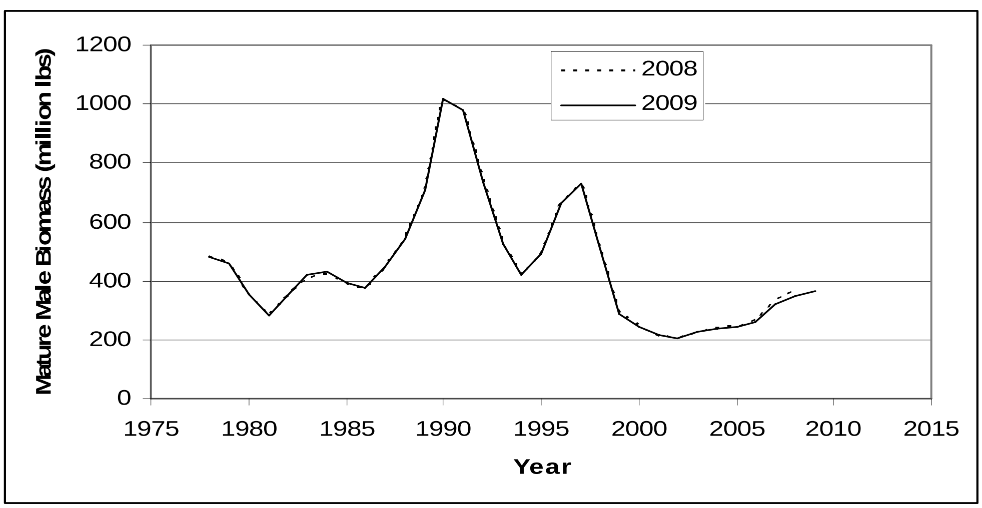

Figure 35. Population male mature biomass from the 2008 assessment and the 2009 assessment.

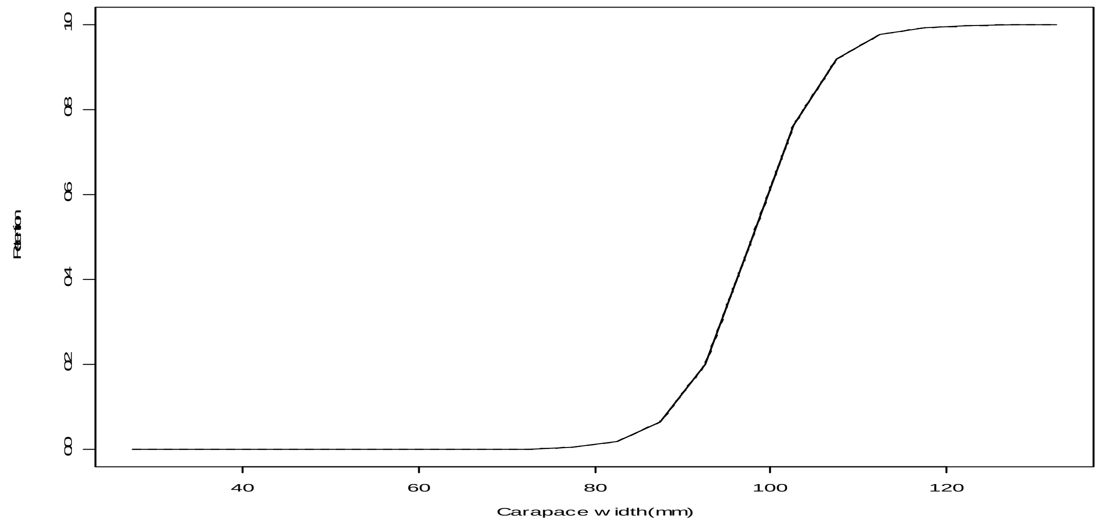

Figure 36. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

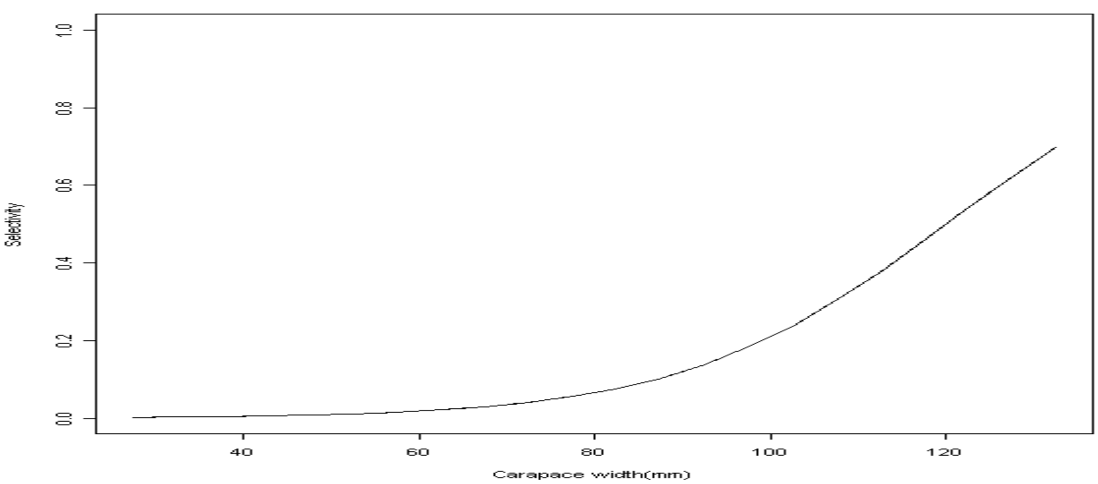

Figure 37. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

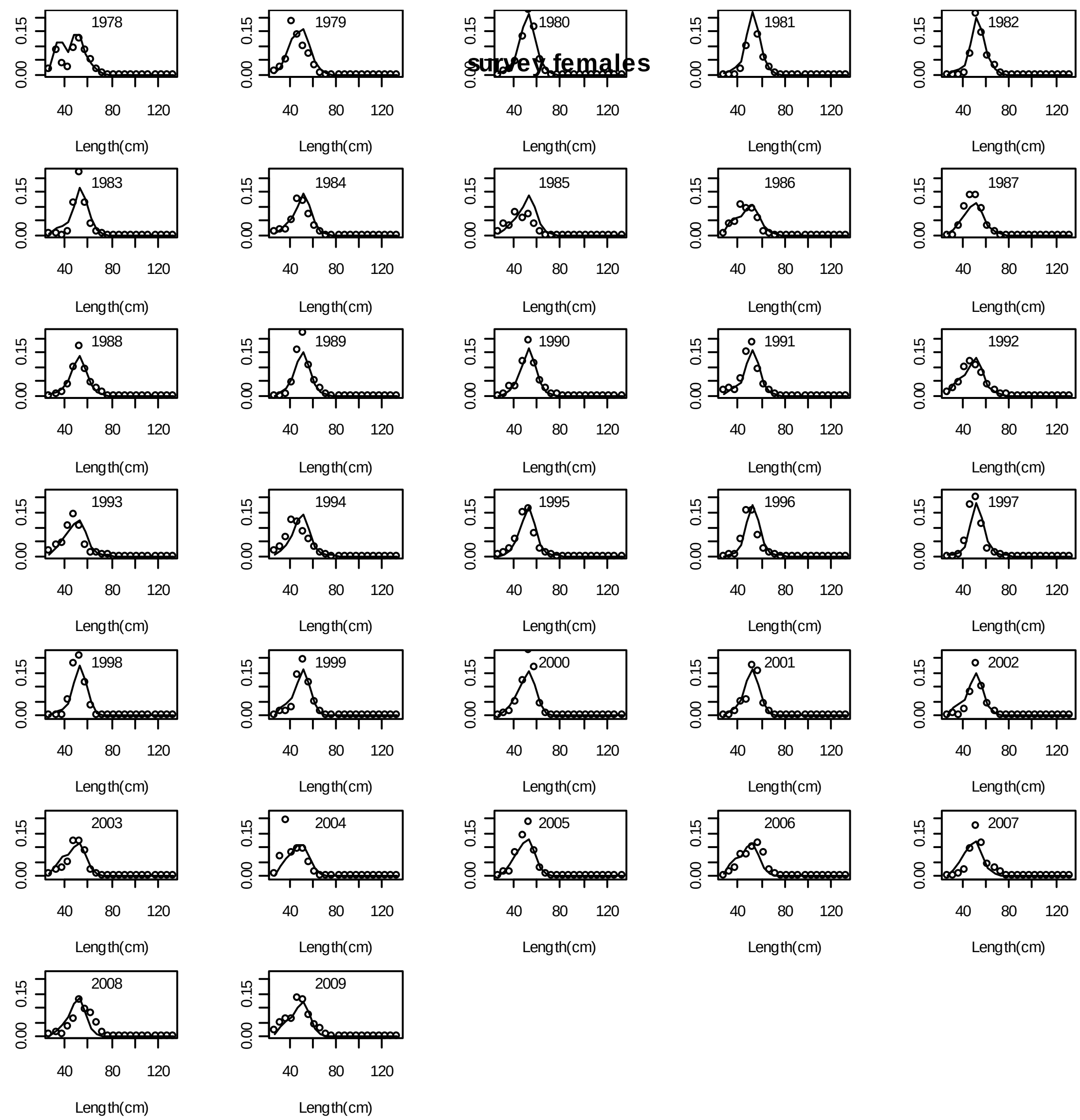

Figure 38. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

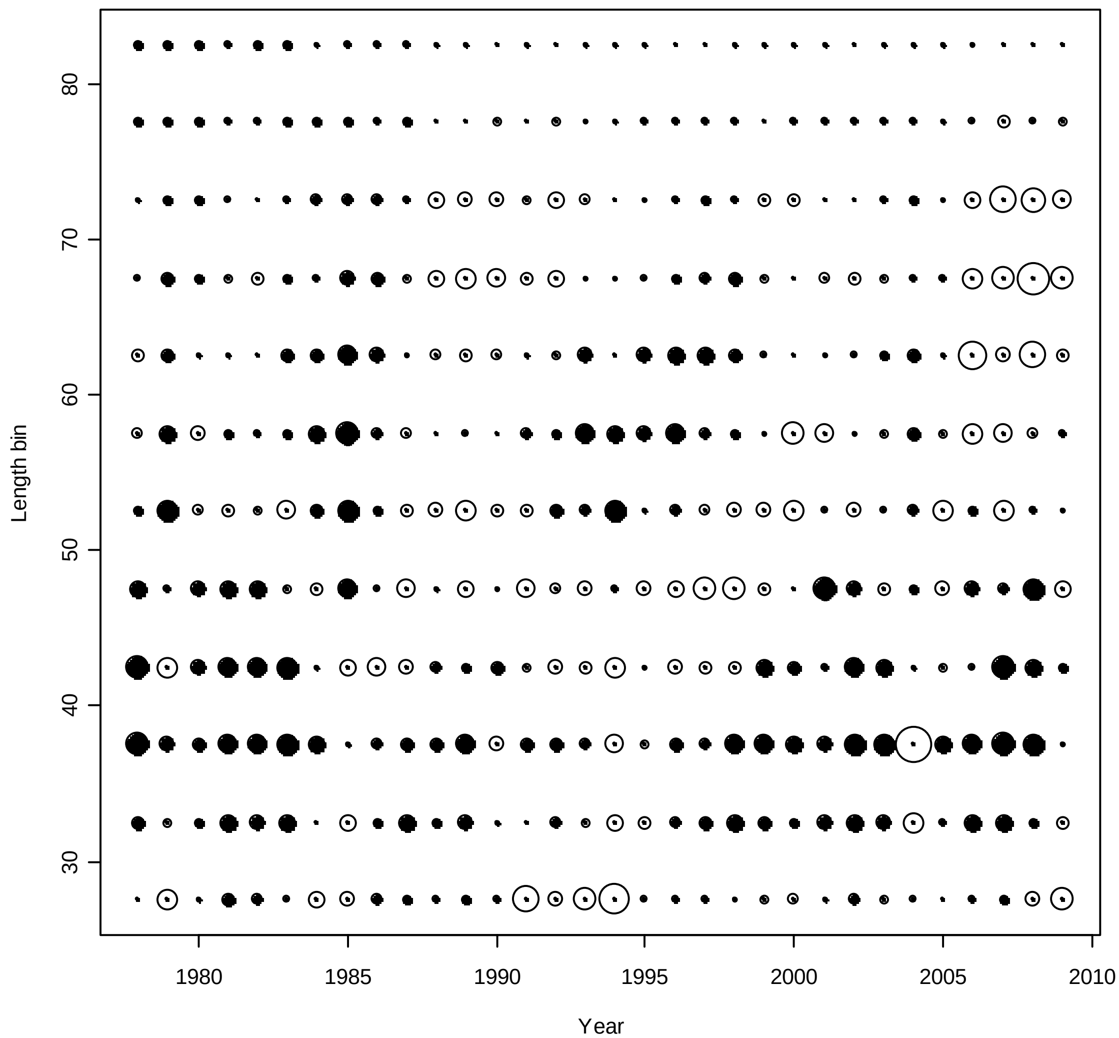

Figure 39. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

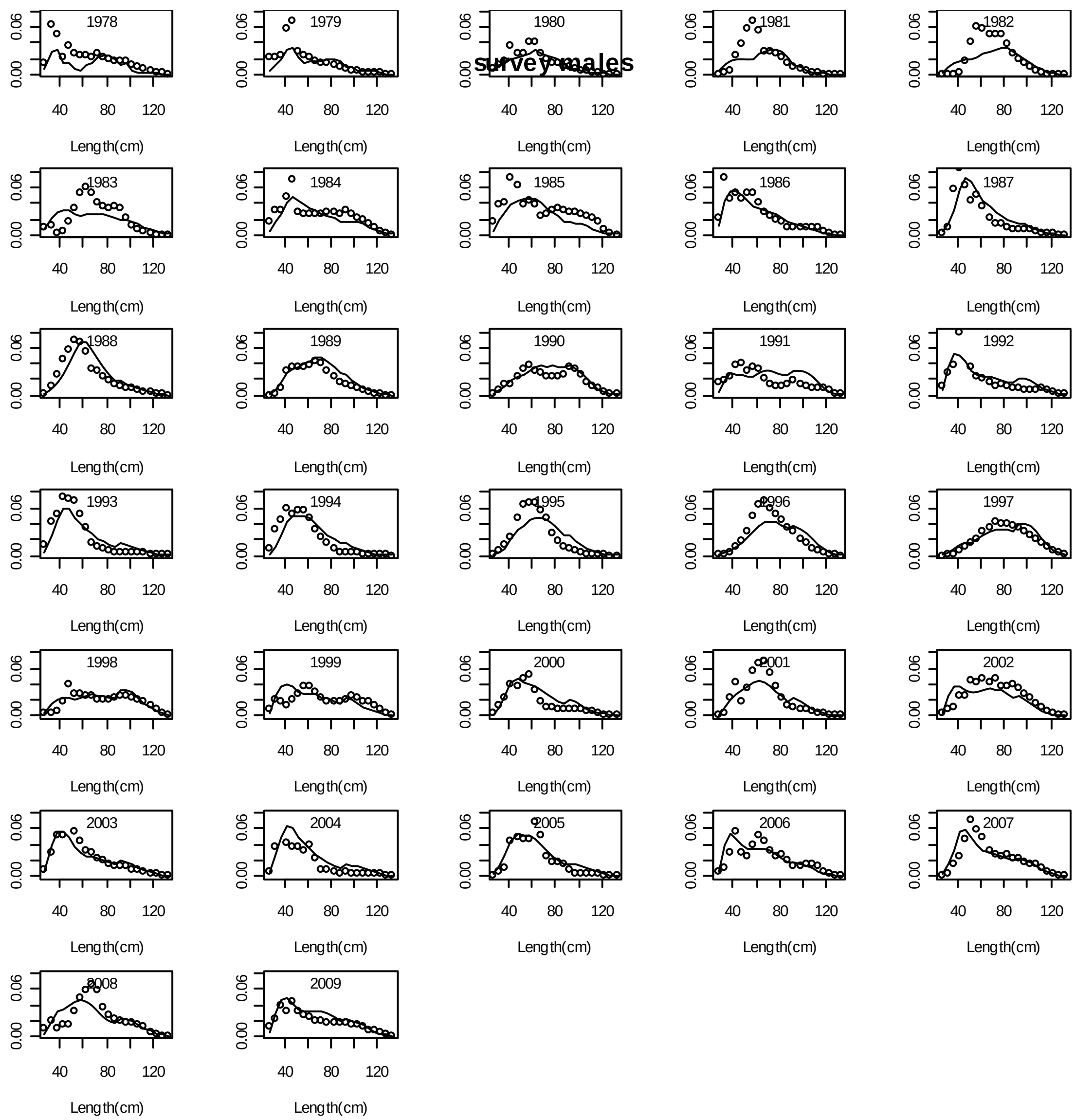

Figure 40. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

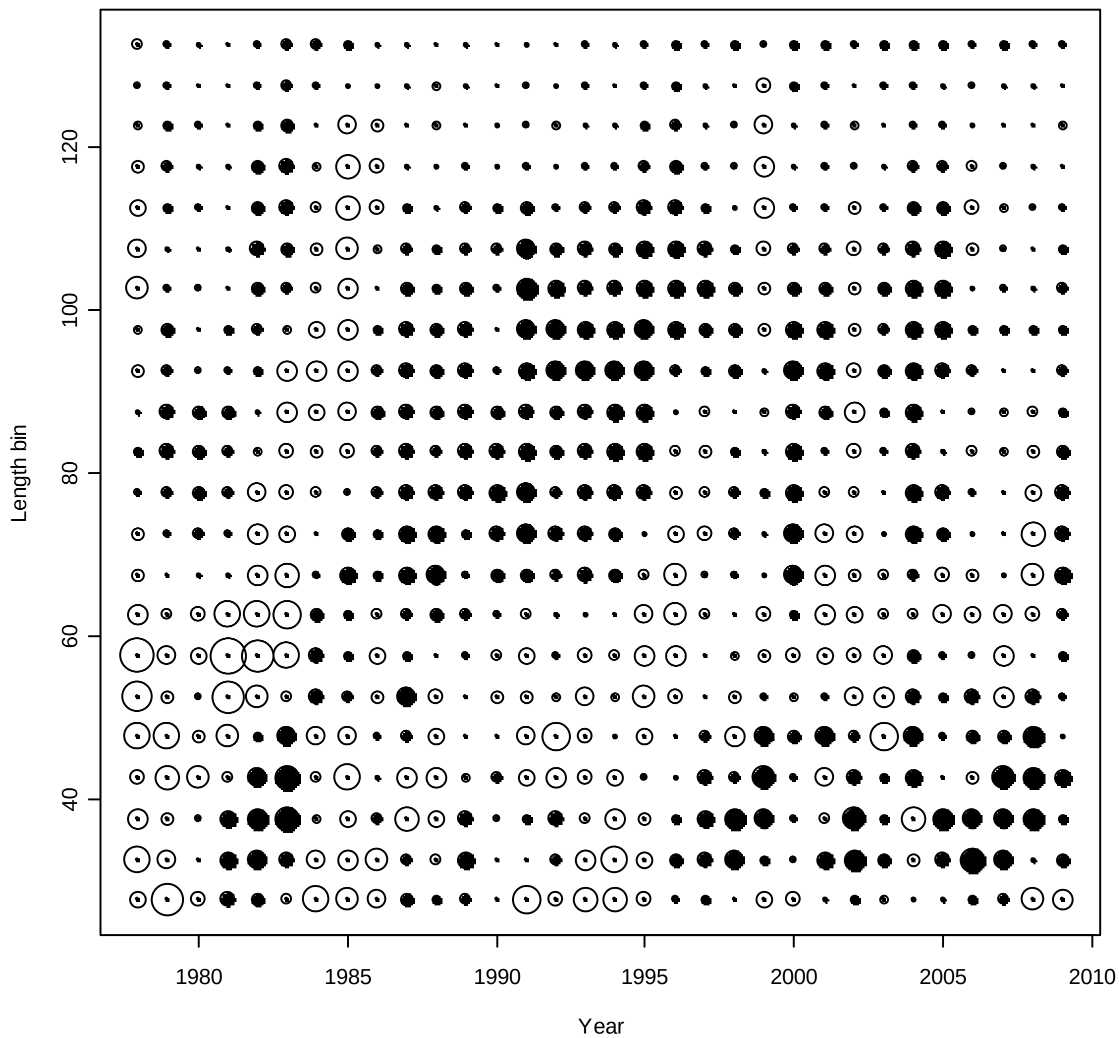

Figure 41. Residuals for fit to survey male size frequency. . Filled circles are negative residuals (predicted higher than observed).

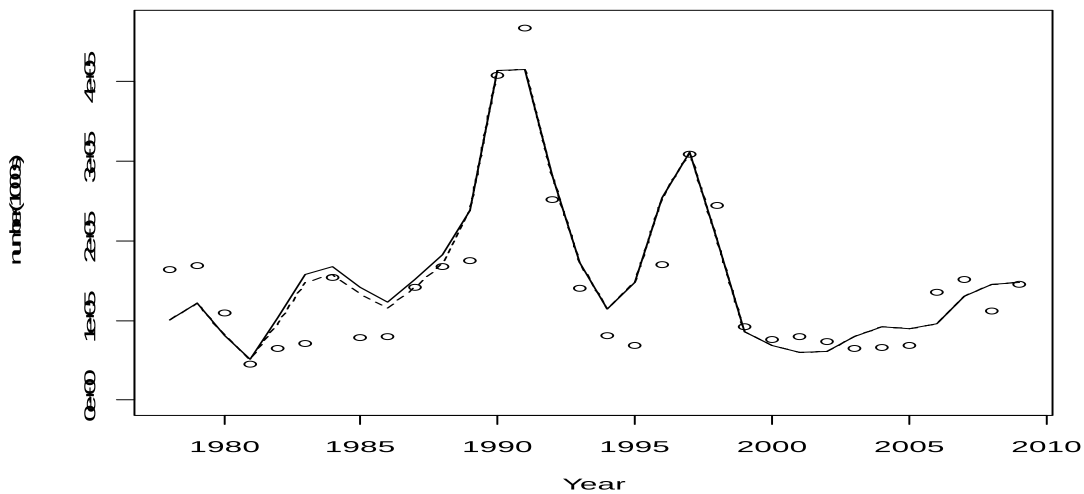

Figure 42. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

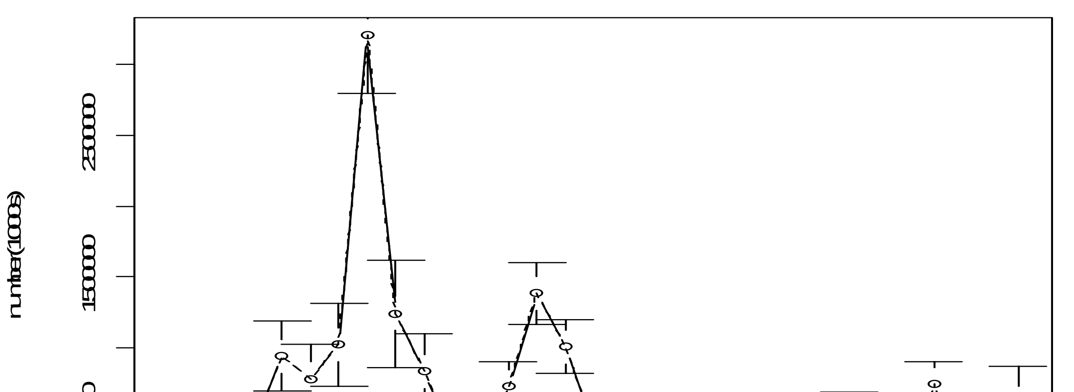

Figure 43. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

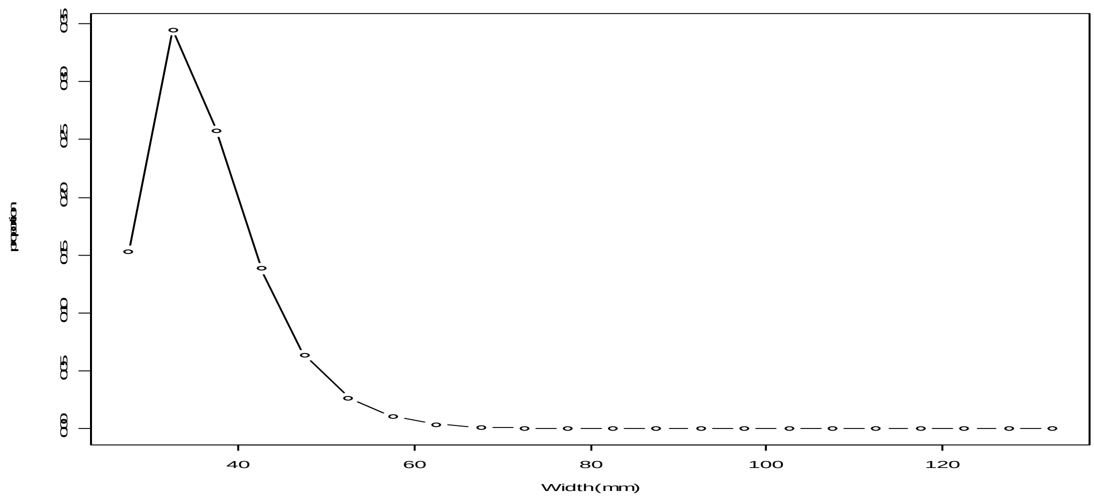

Figure 44. Distribution of recruits to length bins estimated by the model.

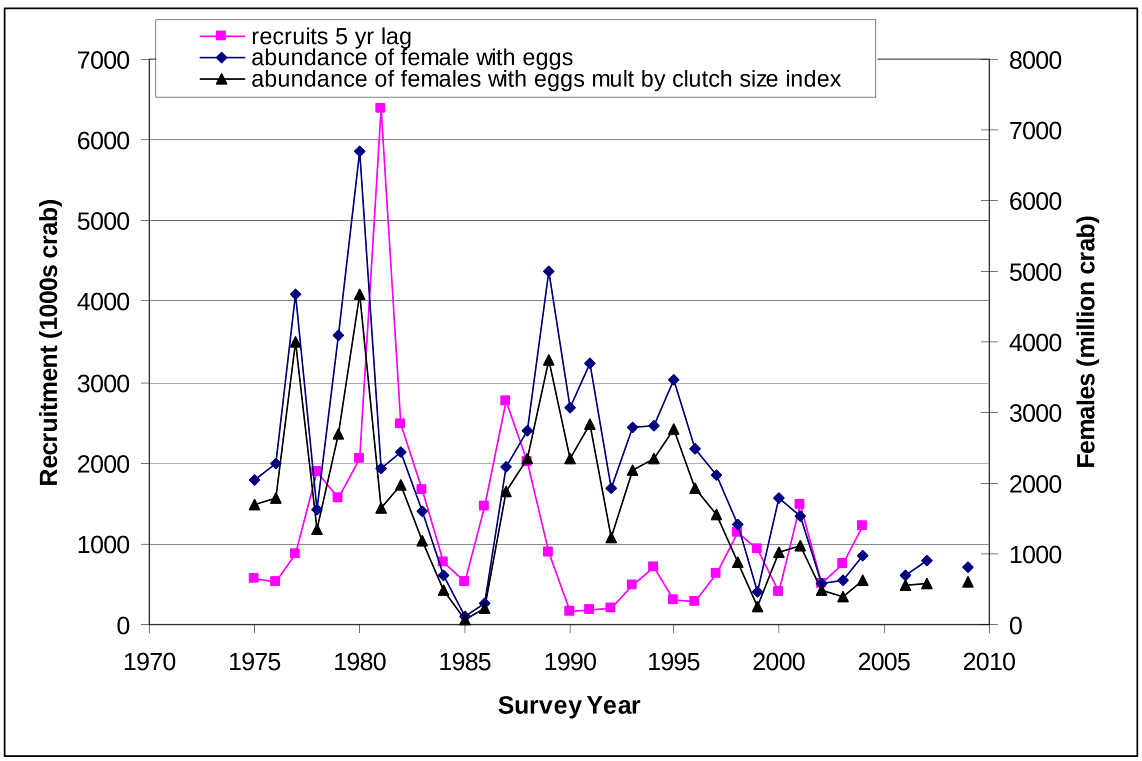

Figure 45. Model estimates of recruitment (5 yr lag fertilization year), survey abundance of females with eggs, and abundance of females with eggs multiplied by the fraction of full clutch from 1975 to 2009 .

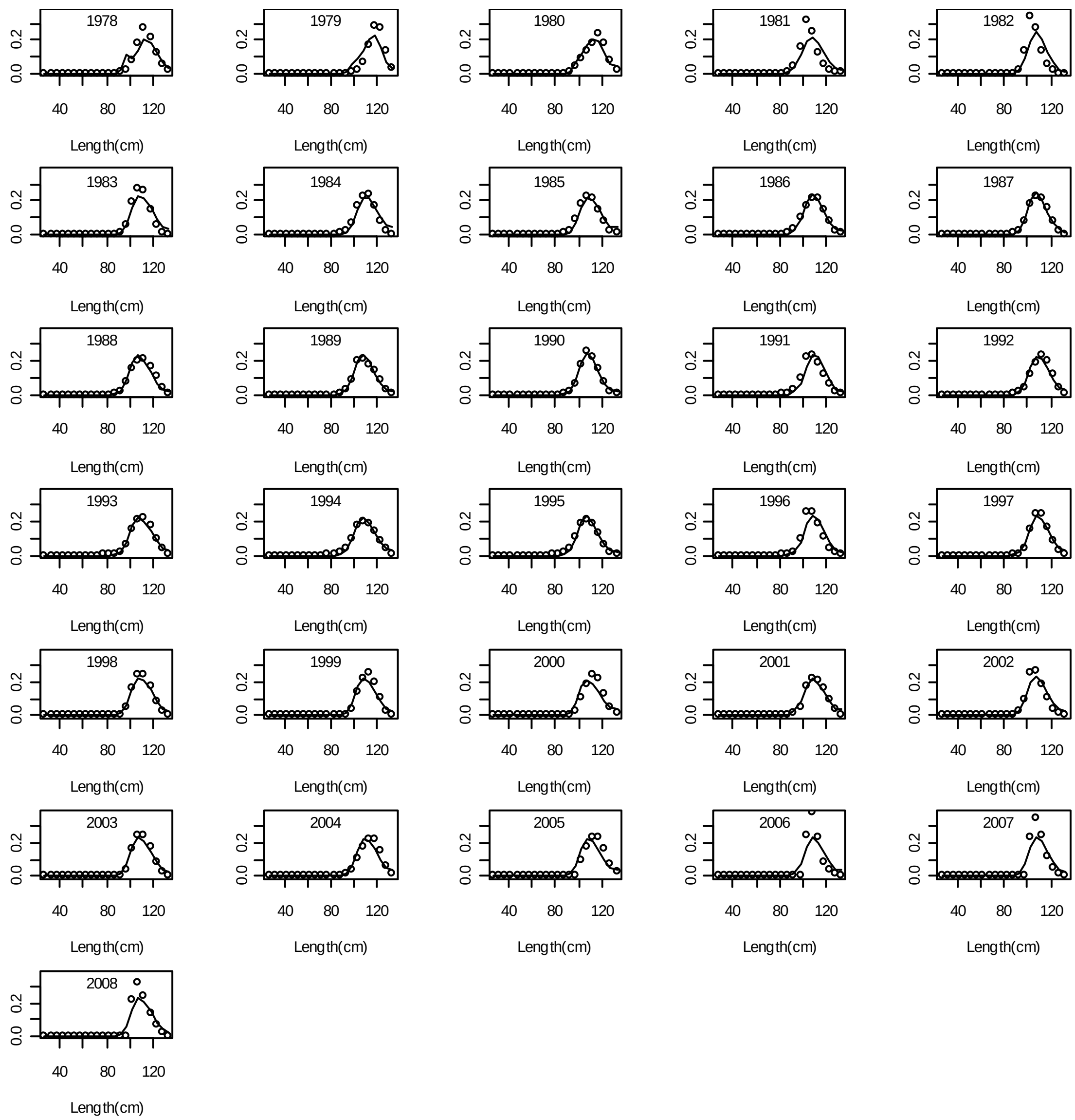

Figure 46. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

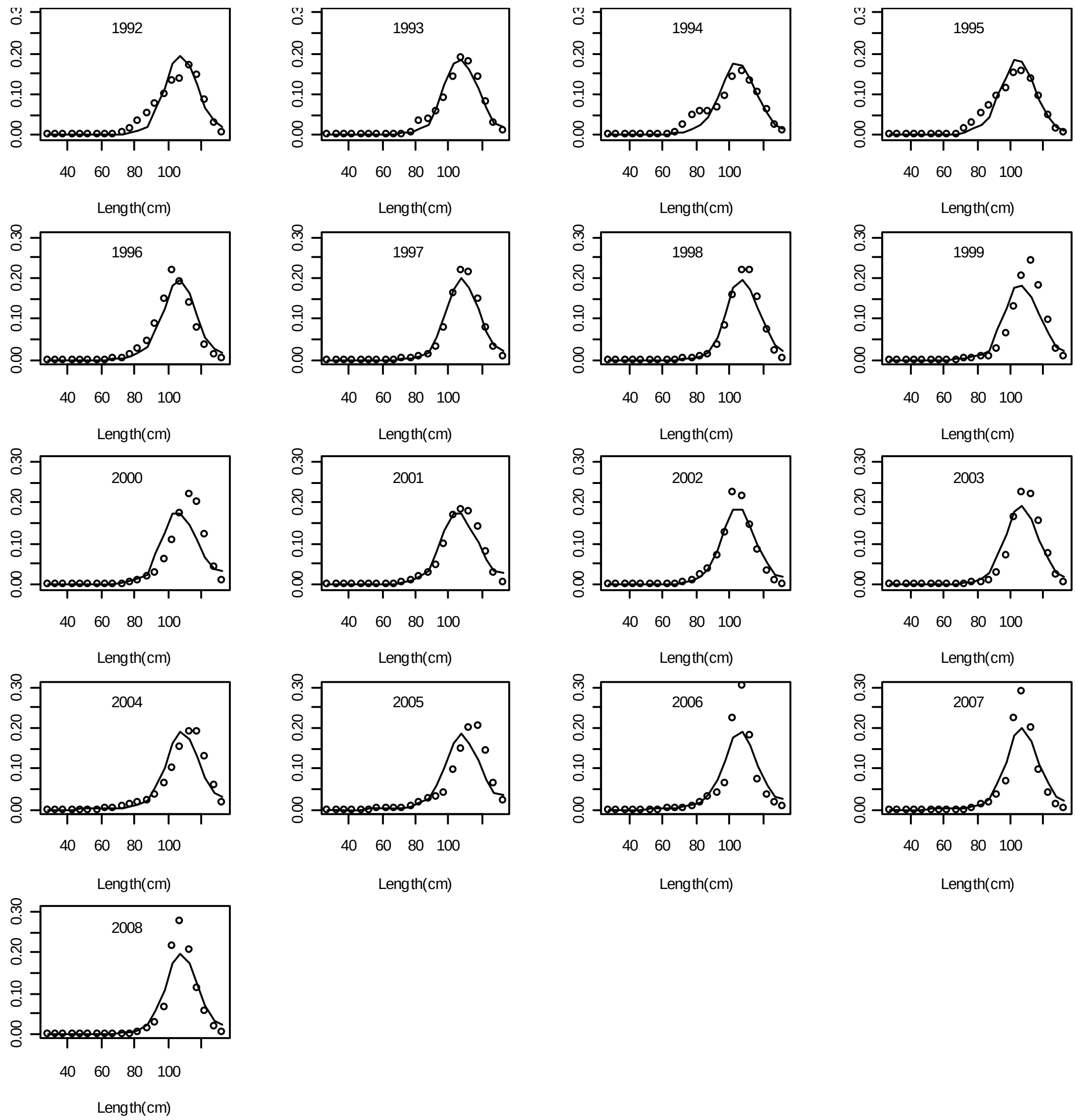

Figure 47. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

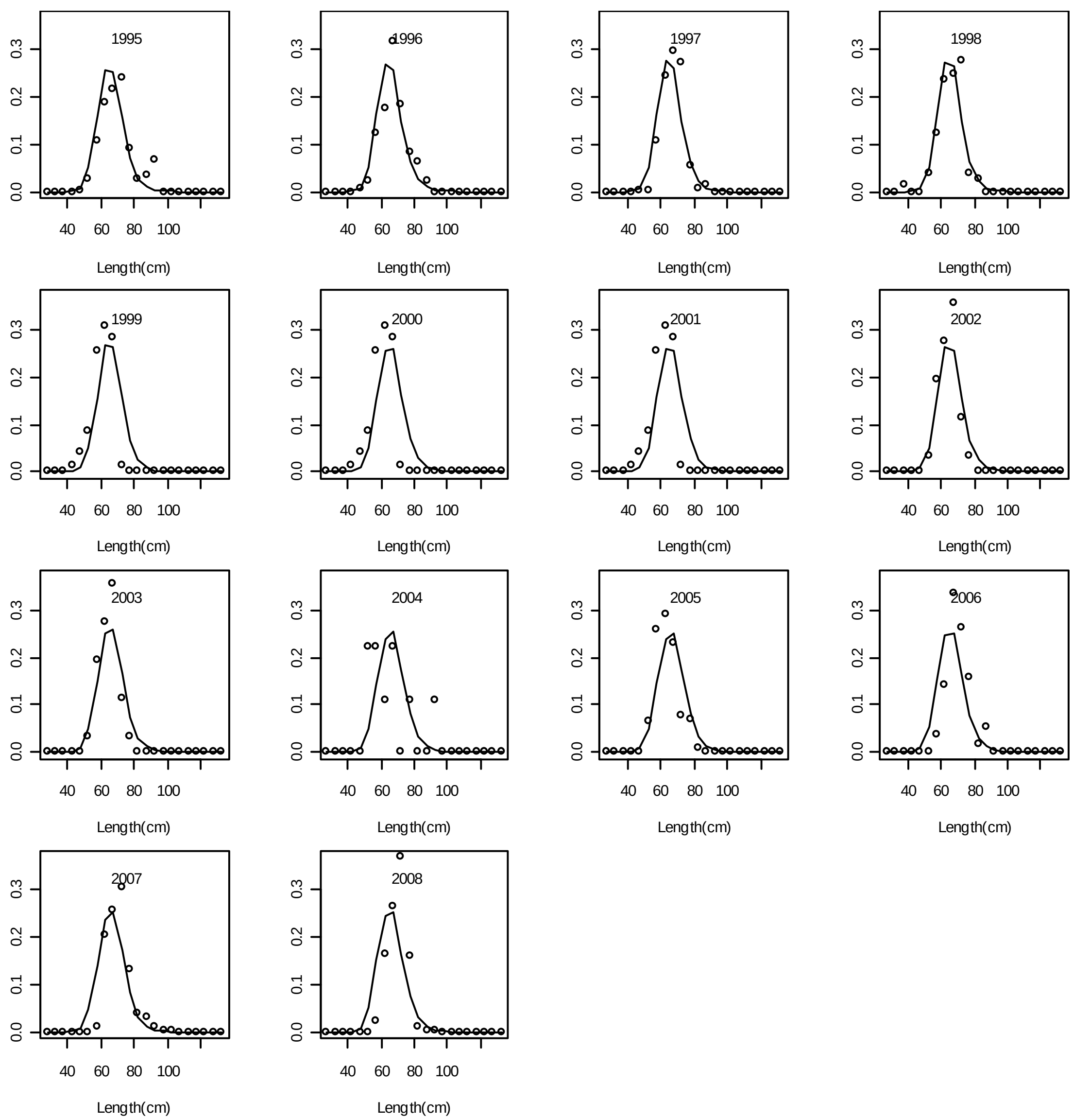

Figure 48. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

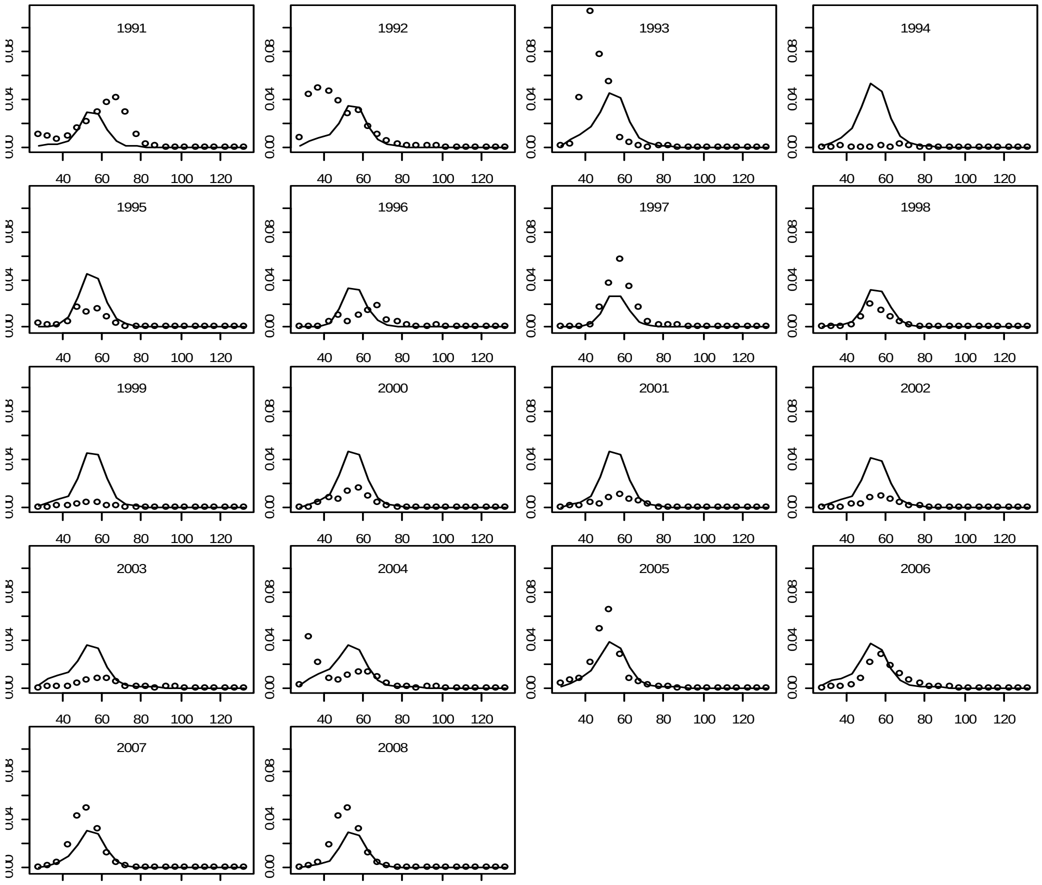

Figure 49. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

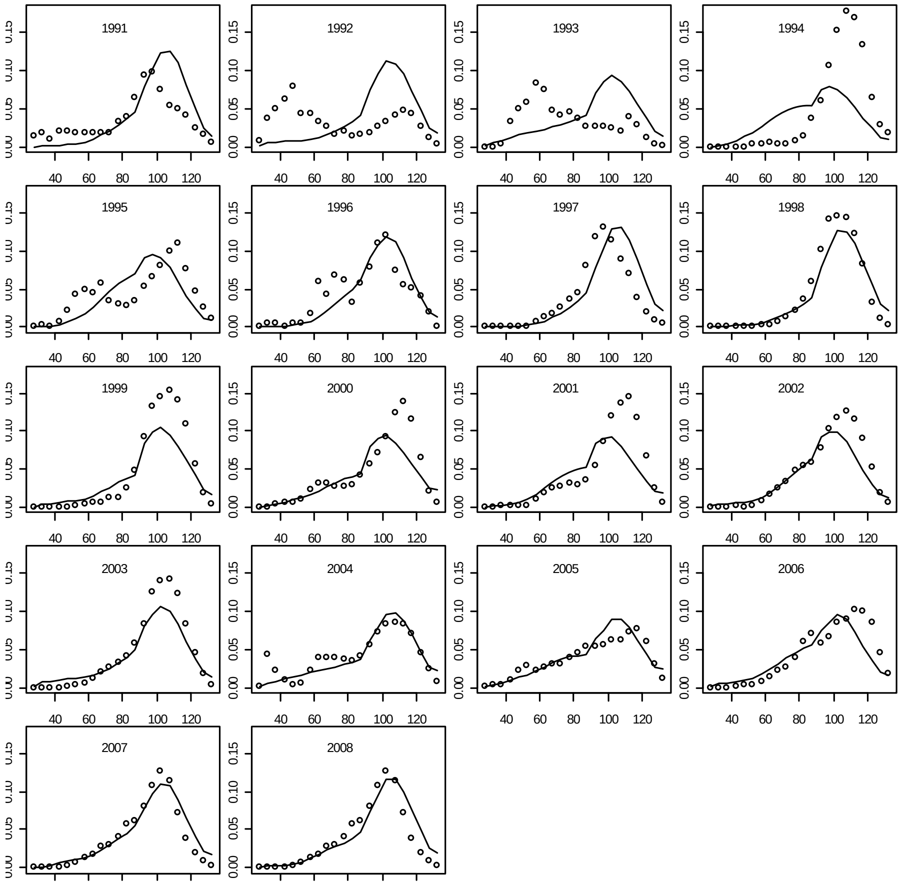

Figure 50. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

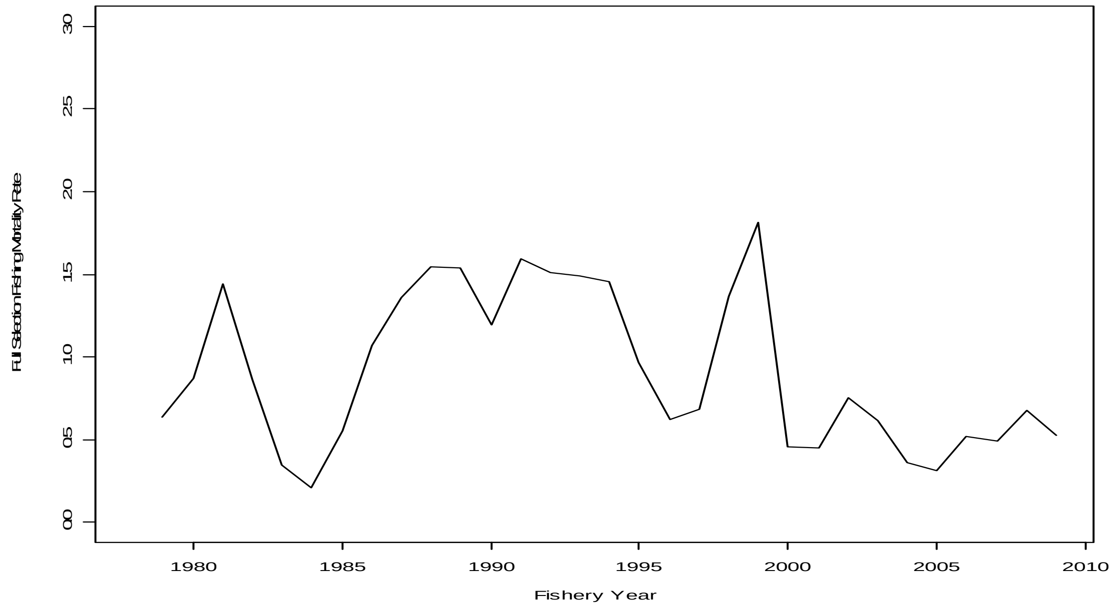

Figure 51. Full selection fishing mortality estimated in the model from 1979 to 2008 fishery seasons (1978 to 2007 survey years).

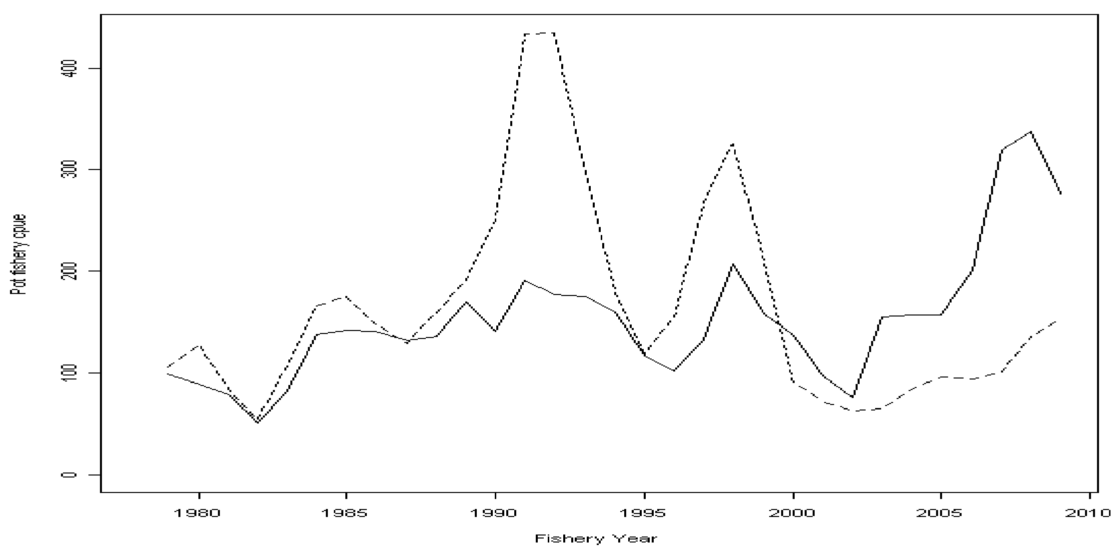

Figure 52. Fit to pot fishery cpue for retained males. Solid line is observed fishery cpue, dotted line model fit.

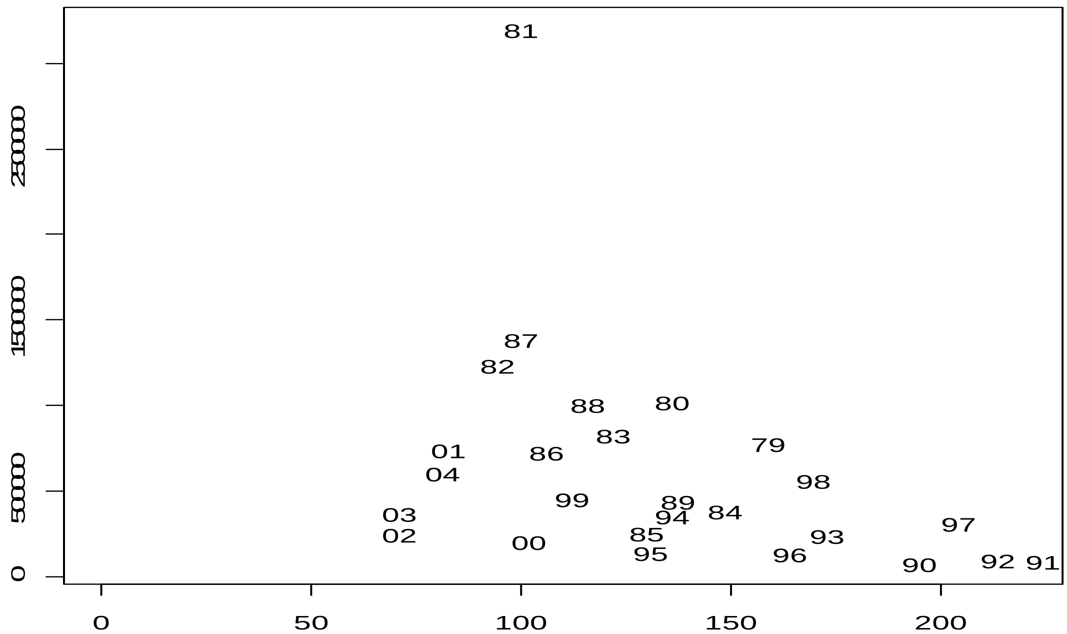

Figure 53. Spawner recruit estimates using male mature biomass at time of mating (1000s tons). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

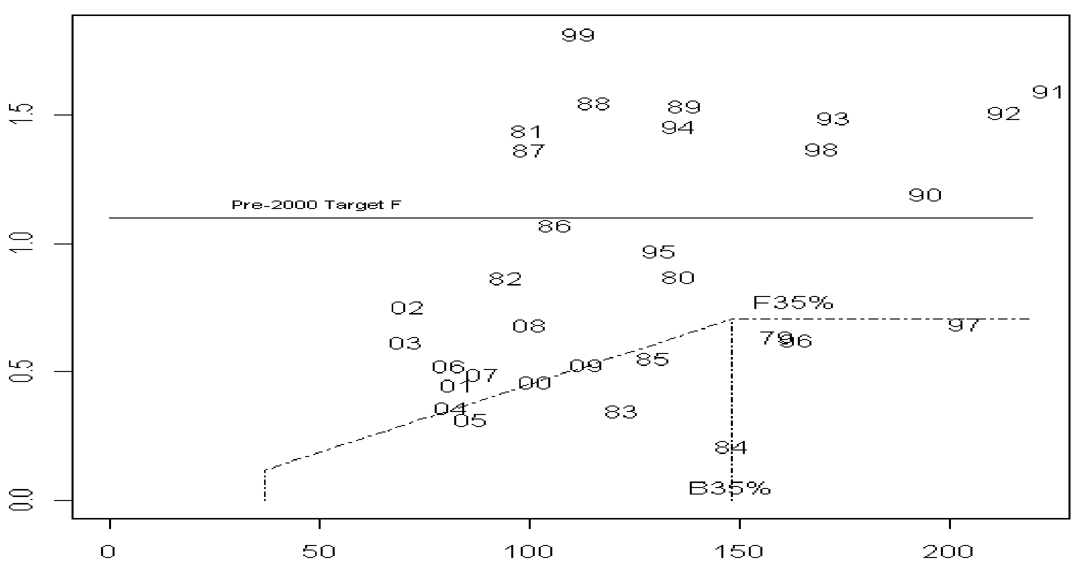

Figure 54. Fishing mortality estimated from fishing years 1979 to 2008/09 (labeled 09 in the plot). The OFL control rule (F35%) is shown for comparison. The pre-2000 target F was about 1.1. The vertical line is B35%, estimated from the product of spawning biomass per recruit fishing at F35% and mean recruitment from the stock assessment model.

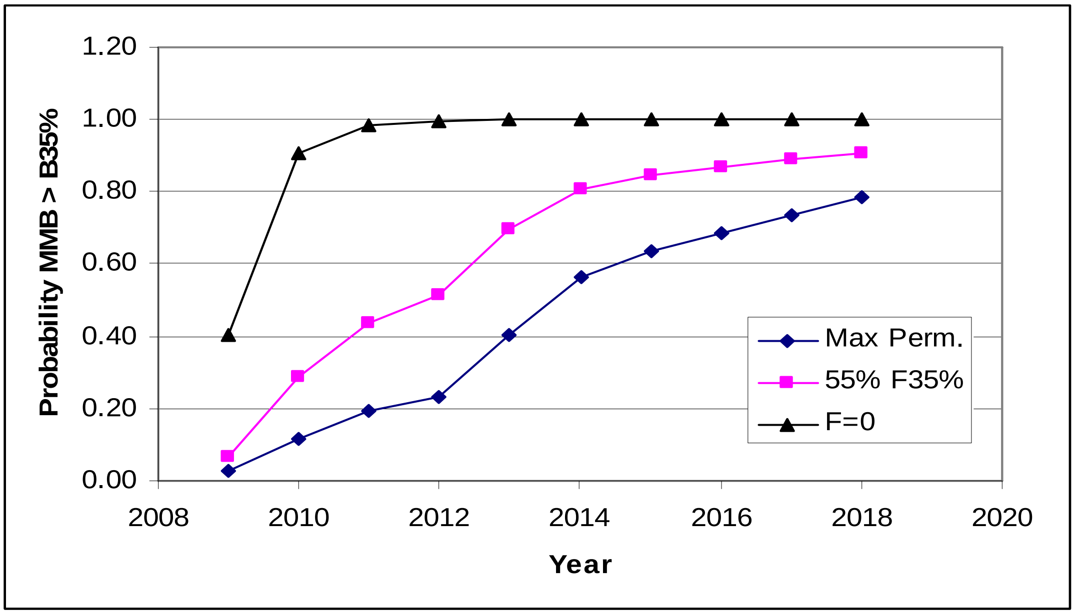

Figure 55. Probability of MMB at mating > B35% by survey year with three rebuilding strategies: 1) Maximum Permissible , 2) 55% F35% and 3) F=0. Under all strategies when MMB was above B35% the rebuilding strategy switched to the Maximum Permissible strategy.

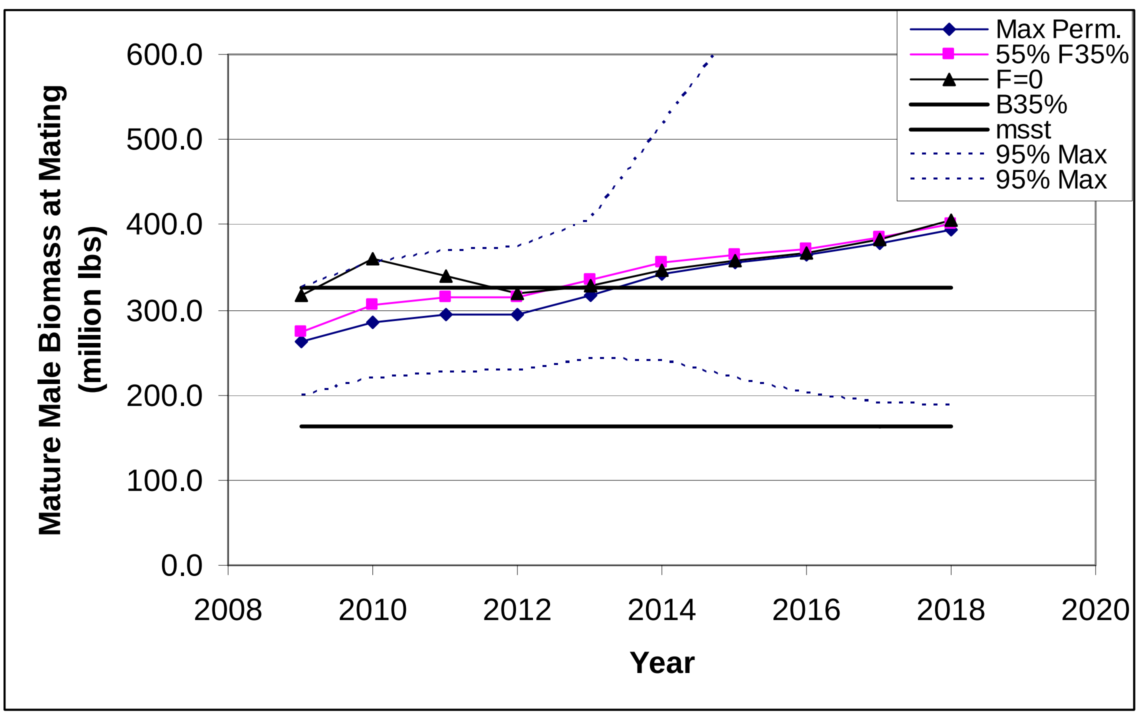

Figure 56. MMB at mating by survey year with three rebuilding strategies: 1) Maximum Permissible , 2) 55% of F35% and 3) F=0. Solid lines are B35% and MSST. Dotted lines are the 95% C.I. on the Maximum Permissible rebuilding strategy.

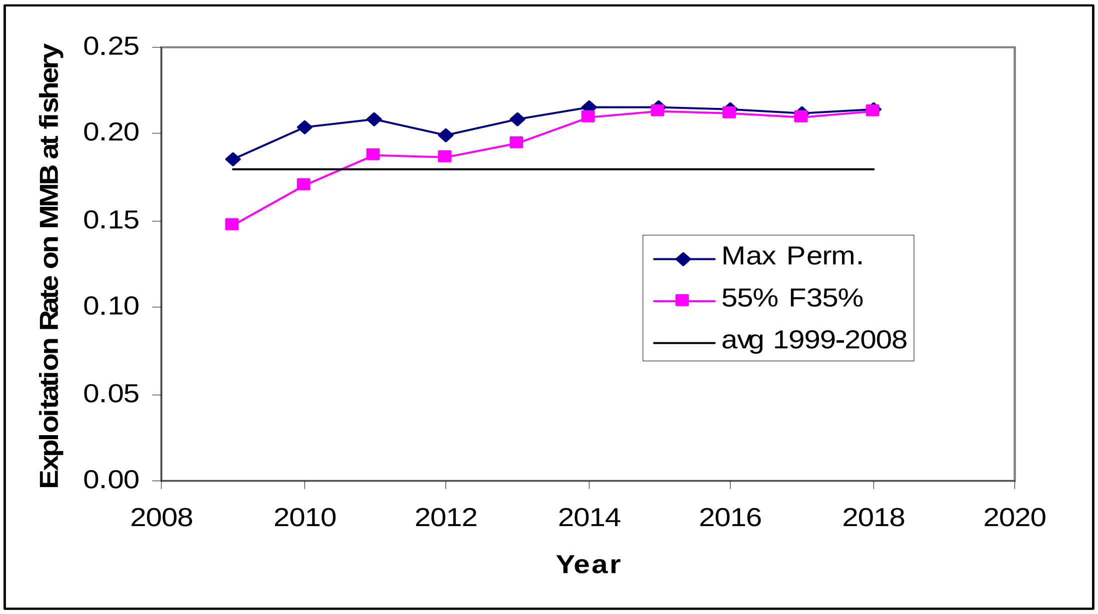

Figure 57. Exploitation rate on MMB with two rebuilding strategies: 1) Maximum Permissible , 2) 55% of F35%. Solid line is the average exploitation rate on MMB estimated from the stock assessment model.

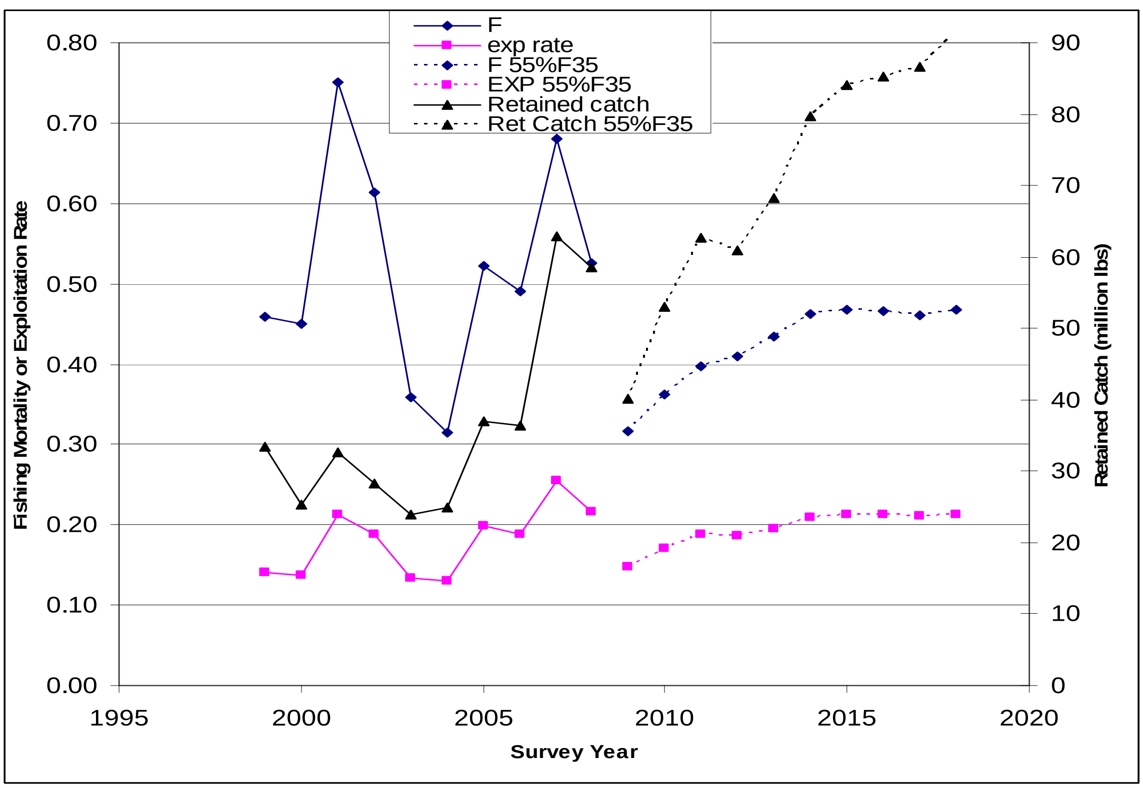

Figure 58. Fishing mortality, exploitation rate on MMB and retained catch from 1999 to 2008 with projections using the 55% F35 rebuilding strategy in 2009 to 2018.

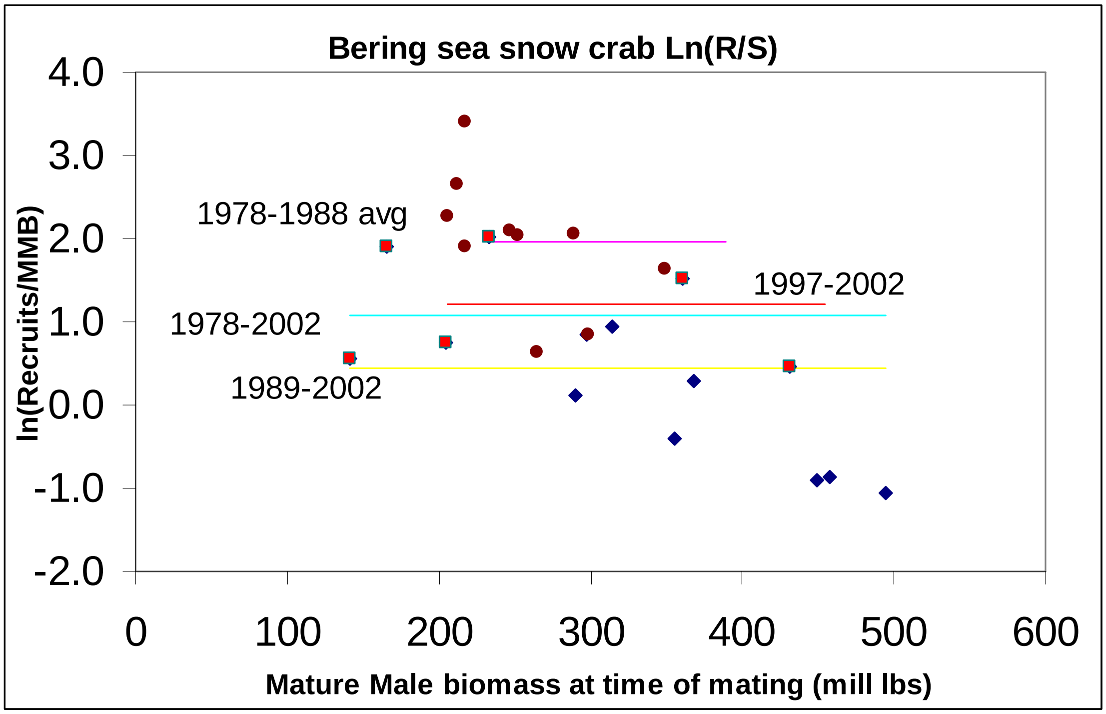

Figure 59. Productivity of snow crab (Ln(recruitment/mature male biomass at mating)) for different levels of mature male biomass at mating. Average values for various time periods are shown on the plot. Different symbols for MMB indicate which average they were included in.

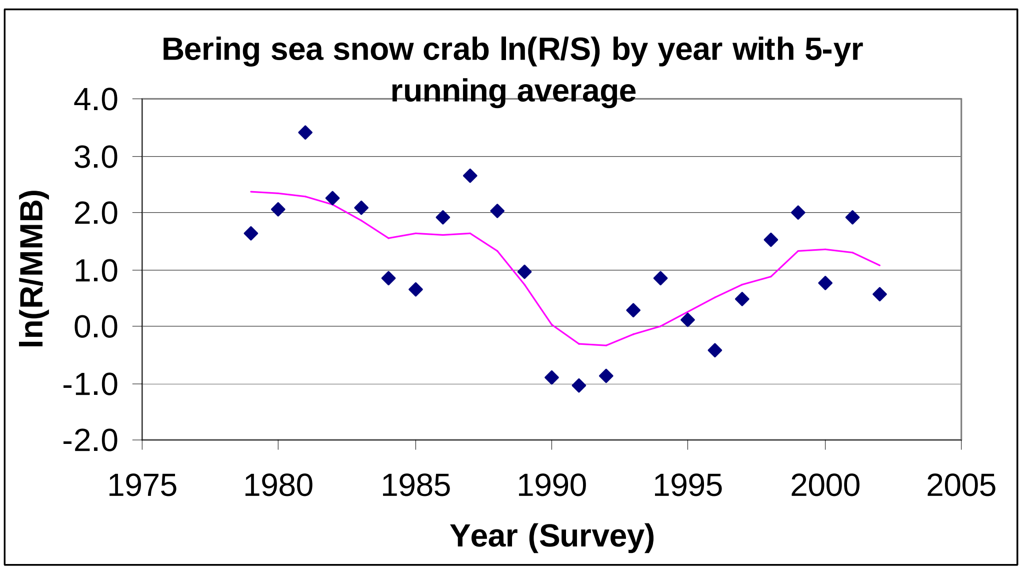

Figure 60. Productivity (ln(recruitment/Mature male biomass at mating)) from 1978 to 2002, with a 5-year running average.

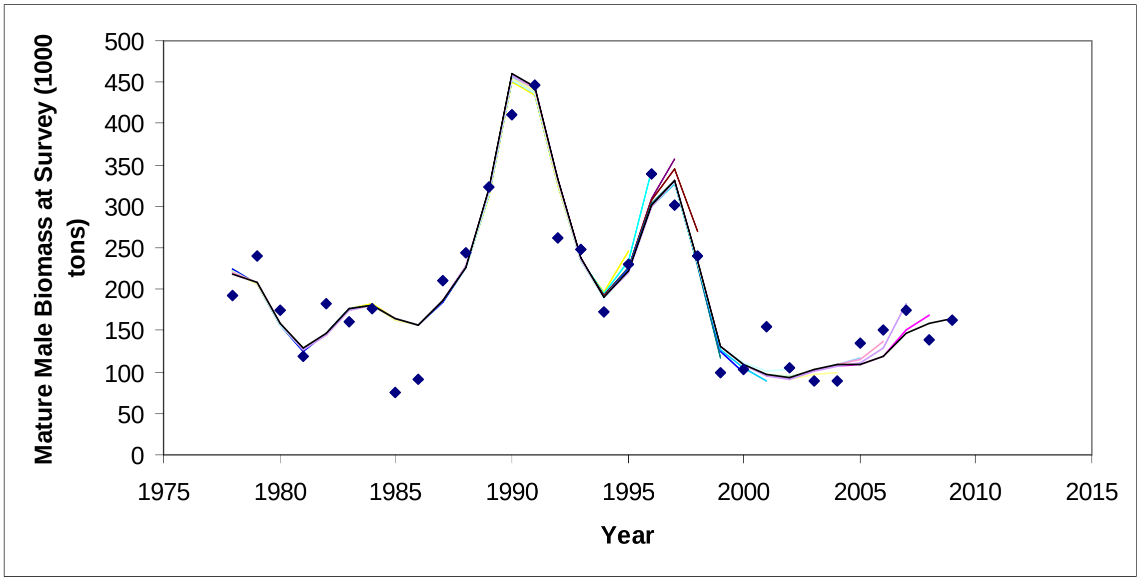

Figure 61. Retrospective model runs of model fit to survey mature male biomass with ending years 1995 to 2009 (lines). Observed survey mature male biomass shown as points.

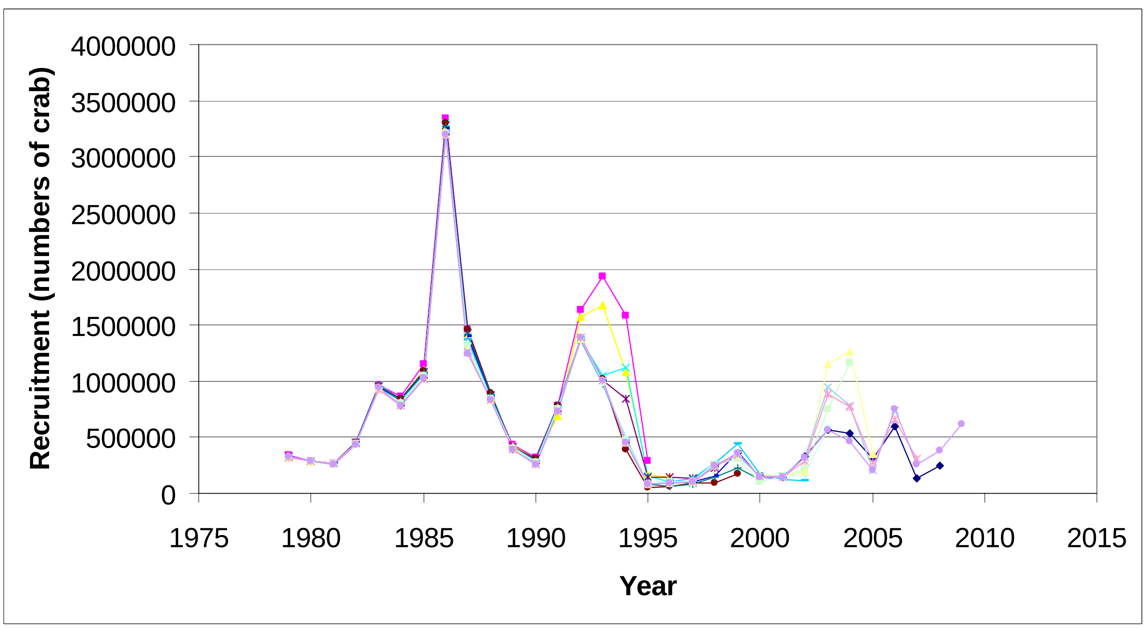

Figure 62. Retrospective model runs of estimated recruitment with ending years 1995 to 2009.

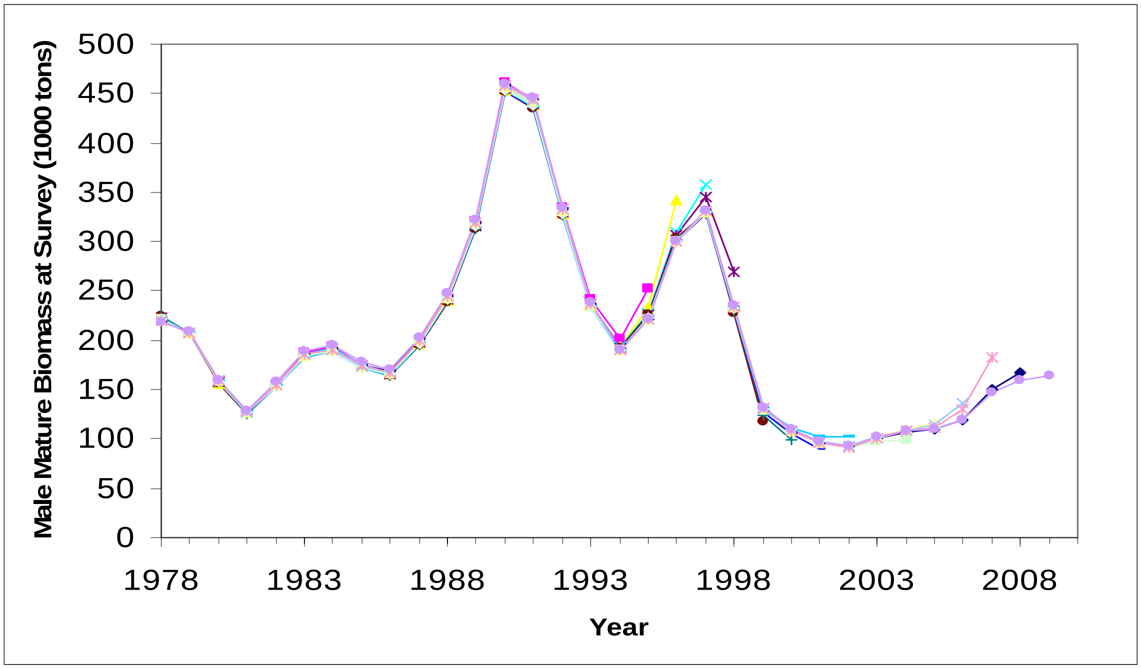

Figure 63. Retrospective model runs of model estimates of mature male biomass at survey time with ending years 1995 to 2008 (lines).

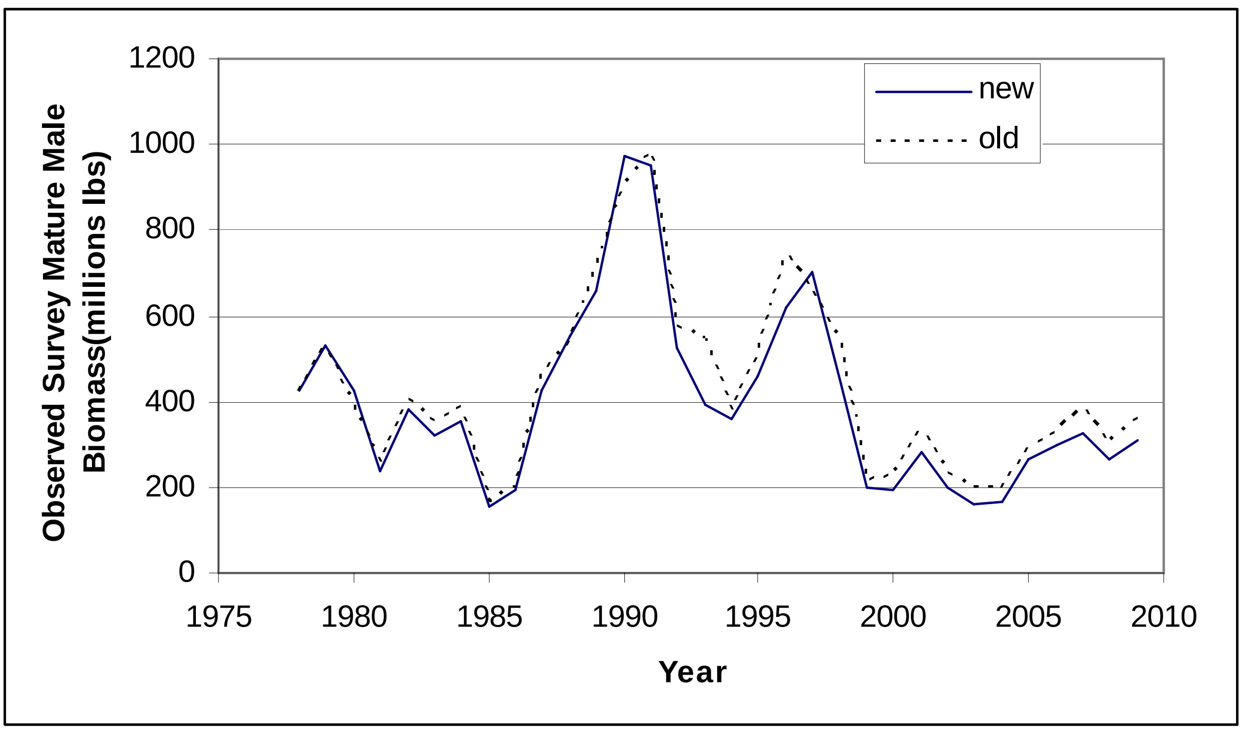

Figure 64. Observed survey mature male biomass from 1978 to 2009. New data uses actual measured net widths and well as some other corrections to the database. Old data uses fixed 50 ft net width.

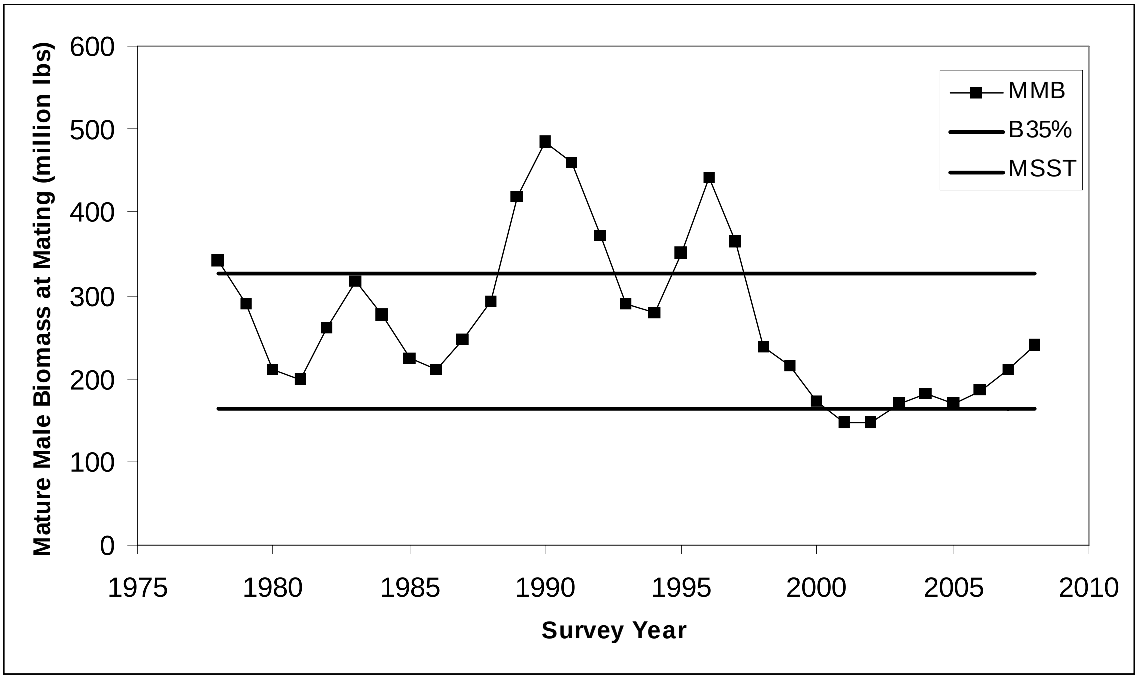

Figure 65. Mature male biomass at mating from 1978/79 to 2008/9. Solid lines are B35% and MSST (1/2 B35%).

Appendix A. Preliminary Economic Analysis of Alternative Snow Crab Rebuilding Strategies

Brian Garber-Yonts, Ph.D.
National Marine Fisheries Service
September 18, 2009

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This document summarizes a preliminary economic analysis of alternative rebuilding strategies for Eastern Bering Sea snow crab (Turnock and Rugolo, 2009). The analysis estimates the value of gross revenues in the harvest and processing sectors in the snow crab seasons for 2009/10 – 2018/19 using retained catch projections from the stock assessment model under alternative strategies. This analysis is intended to provide an estimate of the gross economic impact of alternative rebuilding strategies in the 2009/10 season for decision support in determination of total allowable catch. Strategies modeled in Turnock and Rugolo include the baseline CURRENT REBUILD rebuilding strategy, F=0, 55%F35%, and the maximum permissible 75%F35% (note that the rebuilding strategies all switch to 75%F35% once the projected stock size reaches the rebuilding target). Projected impacts of strategies in later years are provided as a preliminary view of expected impacts of rebuilding strategies, based on scenarios laid out in the rebuilding analysis referenced above. Further economic analysis will be performed in the development of a new or revised rebuilding plan.

In addition to data referenced in Turnock and Rugolo, data collected in the BSAI Crab Economic Data Report (EDR) program for pre-rationalization years 1998, 2001 and 2004, and 2005 to current was used in the analysis. These data (Garber-Yonts, 2008) include final ex-vessel[1] and first wholesale revenues in each of the rationalized crab fisheries, as well as total annual fisheries income reported by harvest vessels and processing plants that participate in these fisheries. Volume and revenue data were used to calculate the average ex-vessel price, first wholesale price, and average product recovery rate over the years included in the dataset (Tables 1-2; note: all dollar values are CPI-adjusted for inflation to 2008 equivalency). Average ex-vessel price was multiplied by the projected retained catch in each of the next ten years under the alternative rebuilding strategies to estimate expected gross harvest sector income in the snow crab fishery for each year. Expected gross processing sector income is estimated as the product of average product recovery rate, average first wholesale price, and projected retained catch for each year. This analysis does not reflect any possible price response due to changes in the supply of Alaskan snow crab in the world market. Evidence of the effect of Alaskan snow crab supply on prices is mixed, and a more detailed economic analysis of rebuilding would incorporate market effects, both in terms of snow crab prices as well as input (e.g. fuel, labor, landed fish and shellfish) market effects in other Alaskan fisheries.

Projected income over 2009/10 to 2018/19 under alternative strategies associated with mean and upper and lower 95% confidence bounds for projected retained catch are presented in Figures 1 and 2. Tables 3 and 4 present comparisons of foregone income under each alternative rebuilding strategy relative to a baseline. Because the baseline for analysis is indeterminate at the time of this analysis, Tables 3 and 4 present income impacts using each alternative strategy as a baseline for comparison to each of the other alternatives.

The F=0 strategy would result in zero earnings in 2009/10 and substantially lower gross earnings 2010/11 compared to alternative strategies, with the potential for zero harvest and production for the first three years

[1] CFEC fish ticket data include ex-vessel revenue and estimated prices, but are based on in-season monitoring; EDR ex-vessel values represent final settlement prices, including all post-season adjustments and bonuses, and are higher than in-season values.

(Figures 1-2). The benefits of more rapid rebuilding would be produced in the third to fifth years, but thereafter harvest, production, and earnings largely converge across all three alternatives. Under a range of assumptions regarding discount rates (1.5 to 5.0 percent) and applying the average ex-vessel price over the years for which we have data (1998, 2001, 2004, and 2005-2008) (Table 1), the mean projected catch under the F=0 strategy would result in \$53.3 million to \$59.6 million (present value) in income forgone over 10 years in the harvest sector relative to the maximum permissible 75%F35 strategy (Table 3; results for discount rate r=3.0% shown). Because the benefits of all three strategies under consideration converge in the out years, a higher discount rate places greater weight on forgone income in the first year. Despite the period of greater projected catch and earnings in the middle years, no positive discount rate changes the ordinal ranking of ten-year total present value of projected earnings under alternative strategies.

Of principal concern under the F=0 strategy is the dislocation associated with zero snow crab harvest or processing income in 2009/10, and potentially one to two years longer. Vessels in the snow crab fishery are dependent on the fishery for a large fraction of their fishing income (Table 1), averaging 47% over the 1998-2008 reference years. Gross income in the crab processing sector (Table 2), while less dependent on the snow crab fishery, is still substantial, averaging 25% of total gross annual earnings among plants that processed snow crab during the 1998-2008 reference years. To the degree that income in the processing sector has a greater effect on the BSAI-region communities in which the associated plants are located than income in the harvest sector, which is largely Seattle-based, the effects of suspending the snow crab fishery may be more heavily in the processing sector, despite the relatively lower dependence of the latter. Further analysis of the distribution of impacts could be addressed in more detail using income and residence information reported in the harvest and processing sector in the EDR and other data sources, for employees and crew, vessel and plant owners, and quota share owners.

The 55% F35% rebuilding strategy is expected to produce greater gross ex-vessel and first wholesale earnings in each of the next 10 years than were produced in five of the seven reference years (Figures 1-2). Revenues in 2009/10 would be \$66 million and \$158 million in the harvest and processing sectors, respectively. The mean projected catch under the 55%F35% strategy would result in \$17 million and \$41 million foregone in the harvest and processing sectors, respectively, relative to the 75%F35 strategy (Tables 3-4), and \$36 million and \$85 million (present value) total income foregone in the respective sectors over ten seasons. However, as shown in the rebuilding estimate tables, the probability of reaching the rebuilding targets are higher in each year for the 55%F35% strategy relative to the 75%F35 strategy. While the cost of the increased likelihood of rebuilding is clearly significant, this strategy would not result in the near-term dislocation associated with the F=0 strategy. Whether these costs to fishing communities are on the scale of economic effects required under MSA to delay rebuilding is to be determined by fishery managers and policy makers.

Table 1: Economic Data Report Catch and Ex-vessel Revenue and Price, and % of Fishing Income Derived from the Snow crab Fishery[1,] 1998-2008

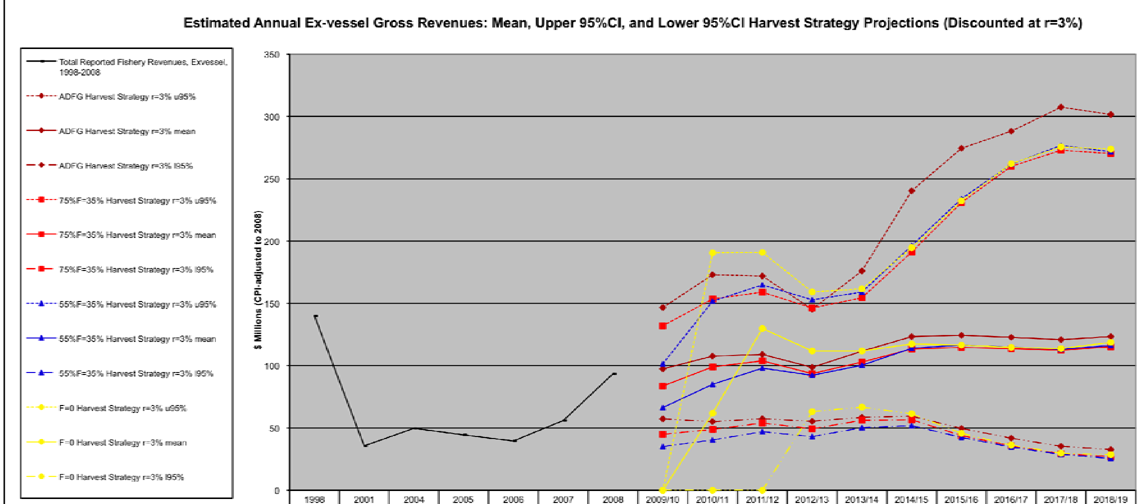
YEAR	Number of vessels	Ex-vessel revenue total	Landed pounds total	Mean Ex-vessel price	Snow crab earnings as proportion of total earnings in all fisheries
1998	172	139966254	187412079	0.75	0.80
2001	173	35666494	19044782	1.88	0.39
2004	174	49719980	21501729	2.32	0.51
2005	150	44424739	23669340	1.98	0.41
2006	74	39609485	33273189	1.19	0.34
2007	64	55996908	31474467	1.78	0.36
2008	72	93554849	54219308	1.70	0.44
Average		**65562673**	**52942128**	**1.66**	**0.47**

[1] Data are from the BSAI Crab Economic Data Reports; dollar values are CPI-adjusted to base year 2008

Table 2: Economic Data Report Production and Product Sales Income Derived from the Snow crab Fishery[1,] 1998-2008

YEAR	Number of processors	Total FOB revenues	Total finished pounds sold	1st Wholesale price mean[2]	Process sector fishery depend mean	Ratio of exvessel to 1st WS price*	Total raw pounds processed	Total finished pounds produced	Average product recovery rate
1998	24	394484339	150119442	2.71	0.33	0.28	223626220	151193665	0.64
2001	19	69048001	15547463	4.35	0.24	0.43	23678141	15671342	0.66
2004	19	78759250	14844977	5.67	0.21	0.41	23056686	15402135	0.67
2005	11	61016463	14494659	4.16	0.38	0.48	24219965	15617410	0.63
2006	8	55633578	18964872	2.71	0.17	0.44	38016198	24917240	0.65
2007	8	66538392	16081403	4.15	0.17	0.43	36830188	22656654	0.62
2008	11	122840945	31853469	3.78	0.22	0.45	64187544	40723870	0.64
Average	**14.29**	**121188710**	**37415184**	**3.93**	**0.25**	**0.42**	**61944991.71**	**40883188.00**	**0.64**

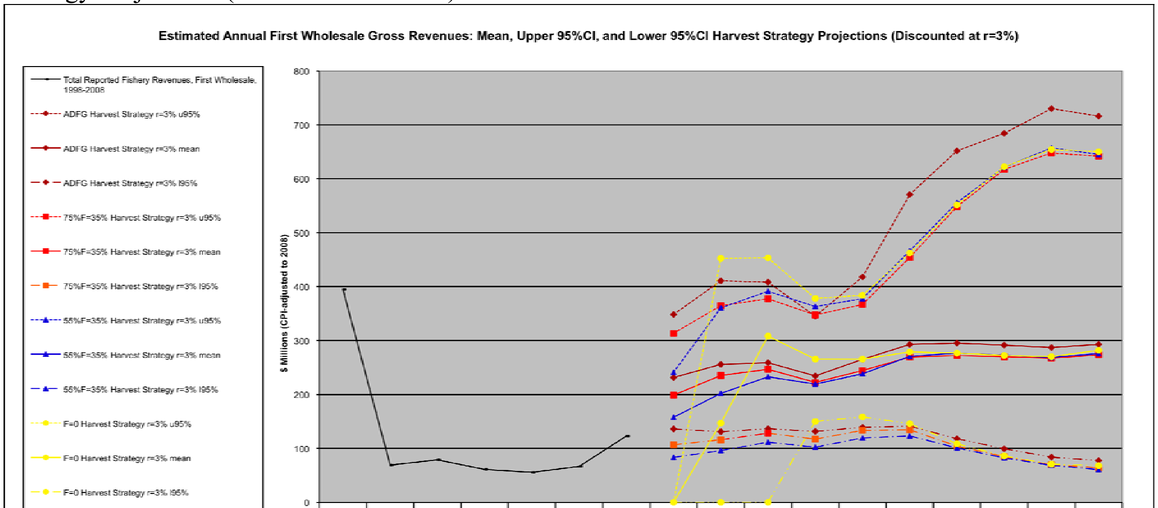
[1] Data are from the BSAI Crab Economic Data Reports; dollar values are CPI-adjusted to base year 2008
[2] Mean first wholesale price is calculated from reported unaffiliated, FOB Alaska sales only.



	1998	2001	2004	2005	2006	2007	2008	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Total Reported Fishery Revenues, Exvessel, 1998-2008	140	36	50	44	40	56	94										
ADFG Harvest Strategy r=3% u95%								146.65	172.95	171.91	145.27	176.00	240.30	274.46	288.13	307.41	301.56
ADFG Harvest Strategy r=3% mean								97.44	107.69	109.02	98.70	111.62	123.30	124.33	122.74	120.86	123.33
ADFG Harvest Strategy r=3% l95%								57.30	55.14	57.48	55.37	58.55	59.47	49.63	41.84	35.32	32.62
75%F=35% Harvest Strategy r=3% u95%								131.98	153.57	158.96	146.30	154.48	191.20	230.92	259.91	272.81	270.23
75%F=35% Harvest Strategy r=3% mean								83.67	99.05	103.87	93.66	102.90	113.40	114.65	113.66	112.51	115.13
75%F=35% Harvest Strategy r=3% l95%								44.97	48.80	54.00	49.35	56.21	56.61	43.91	35.66	29.32	26.93
55%F=35% Harvest Strategy r=3% u95%								101.48	151.82	164.79	152.88	159.01	196.33	233.93	261.67	276.74	271.66
55%F=35% Harvest Strategy r=3% mean								66.40	85.04	98.02	92.28	100.34	113.98	116.49	114.84	113.20	116.12
55%F=35% Harvest Strategy r=3% l95%								35.10	40.42	46.98	43.06	50.25	51.85	42.46	34.68	28.83	25.58
F=0 Harvest Strategy r=3% u95%								0.00	190.55	190.87	159.16	161.64	194.70	232.28	262.07	275.52	273.80
F=0 Harvest Strategy r=3% mean								0.00	61.83	129.87	111.81	111.80	117.41	116.51	114.65	113.73	118.70
F=0 Harvest Strategy r=3% l95%								0.00	0.00	0.00	63.16	66.72	61.44	45.69	36.27	29.77	28.65

Year

Figure 1: Estimated Annual Exvessel Gross Revenues: Mean, Upper 95%CI, and Lower 95%CI Rebuilding Strategy Projections (Discounted at r=3%)



	1998	2001	2004	2005	2006	2007	2008	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Total Reported Fishery Revenues, First Wholesale, 1998-2008	394	69	79	61	56	67	123										
ADFG Harvest Strategy r=3% u95%								348.28	410.72	408.27	344.99	417.97	570.68	651.81	684.26	730.05	716.16
ADFG Harvest Strategy r=3% mean								231.40	255.75	258.90	234.40	265.09	292.82	295.28	291.48	287.03	292.90
ADFG Harvest Strategy r=3% l95%								136.08	130.95	136.50	131.50	139.06	141.24	117.87	99.37	83.89	77.48
75%F=35% Harvest Strategy r=3% u95%								313.44	364.72	377.50	347.44	366.87	454.07	548.40	617.25	647.89	641.77
75%F=35% Harvest Strategy r=3% mean								198.71	235.24	246.68	222.44	244.37	269.30	272.29	269.93	267.19	273.42
75%F=35% Harvest Strategy r=3% l95%								106.80	115.90	128.25	117.20	133.50	134.44	104.28	84.70	69.63	63.96
55%F=35% Harvest Strategy r=3% u95%								241.00	360.55	391.34	363.07	377.62	466.25	555.56	621.43	657.21	645.16
55%F=35% Harvest Strategy r=3% mean								157.69	201.97	232.78	219.16	238.29	270.69	276.64	272.74	268.83	275.77
55%F=35% Harvest Strategy r=3% l95%								83.37	96.00	111.56	102.26	119.34	123.14	100.83	82.35	68.47	60.75
F=0 Harvest Strategy r=3% u95%								0.00	452.53	453.30	378.00	383.87	462.39	551.63	622.39	654.32	650.24
F=0 Harvest Strategy r=3% mean								0.00	146.84	308.41	265.53	265.51	278.83	276.69	272.29	270.11	281.89
F=0 Harvest Strategy r=3% l95%								0.00	0.00	0.00	149.99	158.46	145.90	108.51	86.13	70.71	68.03

Year

Figure 2: Estimated Annual First Wholesale Gross Revenues: Mean, Upper 95%CI, and Lower 95%CI Rebuilding Strategy Projections (Discounted at r=3%)

Table 3: Present Value of Foregone Gross Ex-vessel Earnings over 10 Years (2009-2019) , Comparisons Relative to Different Baseline Strategies

Baseline Rebuilding Strategy	Current Rebuilding Strategy			75%F35% Rebuilding Strategy			55%F35% Rebuilding Strategy			F=0 Rebuilding Strategy		
Alternative Rebuilding Strategy	75%F35%	55%F35%	F=0	Current Rebuild	55%F35%	F=0	Current Rebuild	75%F35%	F=0	Current Rebuild	75%F35%	55%F35%
Year												
2009/10	13.77	31.04	97.44	-13.77	17.27	83.67	-31.04	-17.27	66.40	-97.44	-83.67	-66.40
2010/11	8.90	23.33	47.24	-8.90	14.43	38.34	-23.33	-14.43	23.91	-47.24	-38.34	-23.91
2011/12	5.46	11.67	-22.12	-5.46	6.21	-27.58	-11.67	-6.21	-33.79	22.12	27.58	33.79
2012/13	5.50	7.01	-14.32	-5.50	1.51	-19.82	-7.01	-1.51	-21.33	14.32	19.82	21.33
2013/14	9.82	12.70	-0.20	-9.82	2.89	-10.02	-12.70	-2.89	-12.90	0.20	10.02	12.90
2014/15	11.48	10.80	6.83	-11.48	-0.68	-4.65	-10.80	0.68	-3.97	-6.83	4.65	3.97
2015/16	11.56	9.37	9.35	-11.56	-2.19	-2.21	-9.37	2.19	-0.02	-9.35	2.21	0.02
2016/17	11.16	9.71	9.94	-11.16	-1.45	-1.22	-9.71	1.45	0.23	-9.94	1.22	-0.23
2017/18	10.58	9.71	9.03	-10.58	-0.88	-1.56	-9.71	0.88	-0.68	-9.03	1.56	0.68
2018/19	10.70	9.41	6.05	-10.70	-1.29	-4.65	-9.41	1.29	-3.36	-6.05	4.65	3.36
PV, Total Exvessel Revenue, 2010-14	**43.44**	**85.74**	**108.03**	**-43.44**	**42.30**	**64.59**	**-85.74**	**-42.30**	**22.29**	**-108.03**	**-64.59**	**-22.29**
PV, Total Exvessel Revenue, 2010-14	**98.92**	**134.74**	**149.23**	**-98.92**	**35.81**	**50.30**	**-134.74**	**-35.81**	**14.49**	**-149.23**	**-50.30**	**-14.49**

Table 4: Present Value of Foregone Gross First Wholesale Earnings over 10 Years (2009-2019) , Comparisons Relative to Different Baseline Strategies

Baseline Rebuilding Strategy	Current Rebuilding Strategy			75%F35% Rebuilding Strategy			55%F35% Rebuilding Strategy			F=0 Rebuilding Strategy		
Alternative Rebuilding Strategy	75%F35%	55%F35%	F=0	Current Rebuild	55%F35%	F=0	Current Rebuild	75%F35%	F=0	Current Rebuild	75%F35%	55%F35%
Year												
2009/10	32.70	73.71	231.40	-32.70	41.02	198.71	-73.71	-41.02	157.69	-231.40	-198.71	-157.69
2010/11	21.13	55.40	112.18	-21.13	34.27	91.05	-55.40	-34.27	56.78	-112.18	-91.05	-56.78
2011/12	12.96	27.71	-52.53	-12.96	14.75	-65.49	-27.71	-14.75	-80.24	52.53	65.49	80.24
2012/13	13.07	16.65	-34.01	-13.07	3.58	-47.08	-16.65	-3.58	-50.66	34.01	47.08	50.66
2013/14	23.31	30.17	-0.47	-23.31	6.85	-23.79	-30.17	-6.85	-30.64	0.47	23.79	30.64
2014/15	27.27	25.65	16.22	-27.27	-1.62	-11.05	-25.65	1.62	-9.44	-16.22	11.05	9.44
2015/16	27.45	22.25	22.20	-27.45	-5.20	-5.25	-22.25	5.20	-0.05	-22.20	5.25	0.05
2016/17	26.50	23.05	23.61	-26.50	-3.45	-2.90	-23.05	3.45	0.56	-23.61	2.90	-0.56
2017/18	25.13	23.05	21.44	-25.13	-2.08	-3.70	-23.05	2.08	-1.61	-21.44	3.70	1.61
2018/19	25.41	22.35	14.37	-25.41	-3.06	-11.04	-22.35	3.06	-7.98	-14.37	11.04	7.98
PV, Total 1st Wholesale Revenue, 2010-14	**103.16**	**203.63**	**256.57**	**-103.16**	**100.47**	**153.40**	**-203.63**	**-100.47**	**52.93**	**-256.57**	**-153.40**	**-52.93**
PV, Total 1st Wholesale Revenue, 2010-19	**234.93**	**319.98**	**354.39**	**-234.93**	**85.05**	**119.47**	**-319.98**	**-85.05**	**34.41**	**-354.39**	**-119.47**	**-34.41**

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BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2009

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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 1968-2009. Three scenarios were compared for the model: (1) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and with the Bering Sea Fisheries Research Foundation (BSFRF) survey data; (2) constant natural mortality (0.18) with BSFRF survey data; and (3) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, but without the BSFRF survey data. The CPT chose scenarios (3) in May 2009 to compute the OFL for 2009. Scenario (3) resulted in higher mature and legal male abundance estimates for 2009 than scenario (1). In this report only results from scenario (3) were presented.

Average male recruitments during three periods were used to estimate $B_{35\%}$: 1968-present, 1985-present, and 1995-present. We recommend using the average recruitment during 1995-present, which was used in 2008 to set the overfishing limits. There are several reasons for supporting our recommendation. First, estimated recruitment was higher after 1994 than during 1985-1994 and there was a potential regime shift after 1989 (Overland et al. 1999), which corresponded to recruitment in 1995 and later. Second, recruitments estimated before 1985 came from a potentially higher natural mortality than we used to estimate $B_{35\%}$. Third, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in southern Bristol Bay

while the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in southern Bristol Bay (see the section on Ecosystem Considerations). Stock productivity (recruitment/mature male biomass) was much higher before the 1976/1977 regime shift: the mean value was 1.842 during 1968-1977 and 0.374 during 1978-2009. The Crab Plan Team selected the mean recruitment during 1995-present for setting the overfishing limits for the 2009 season.

Based on the $B_{35\%}$ estimated from the average male recruitment during 1995-2009, the biological reference points were estimated as follows:

Scenario 3

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

$F_{35\%}$ = 0.32

$F_{40\%}$ = 0.26

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

Retained catch: 19.914 million lbs, or 9033.012 t,

Total catch: 22.561 million lbs, or 10233.415 t,

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

Summary of Major Changes in 2009

1. Pot fisheries data in 2008/2009 were included.
2. Areas-swept for the NMFS surveys were re-estimated and trawl survey abundances were re-estimated, which were generally lower than previous assessments.
3. The trawl survey data from the Bering Sea Fisheries Research Foundation (BSFRF) were included in the model.
4. Red king crab bycatch from the eastern Bering Sea Tanner crab fishery was included to estimate bycatch mortality.
5. The model was extended to the data during 1968 to 2009.
6. Three scenarios were compared: (1) constant M=0.18 with additional mortality during 1976-1993 and with BSFRF data, (2) constant M=0.18 with BSFRF data,

and (3) constant *M*=0.18 with additional mortality during 1976-1993 but without BSFRF data.

7. Sizes at maturity for female red king crab were estimated annually, and different sizes at maturity during three periods (1968-1982, 1983-1993, and 1994-2009) were used to estimate growth increments per molt for females.
8. No weighting factors were used for survey biomass. All survey biomasses were weighted by CVs or variances.
9. Spatial and temporal distributions of females and tow numbers of groundfish fisheries were plotted.
10. High mortality during the early 1980s, pertaining to the "red bag" hypothesis, was discussed.
11. Alternative weights on biomasses and penalty terms were examined.
12. Effective sample sizes for length/sex composition data were estimated and compared to the assumed values.
13. Changes in stock productivity over time were examined.

Response to CPT Comments (from September 2008)

"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 authors 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 with attempt to address the female trawl survey residuals patterns. In addition, it is requested that when key parameters are fixed in the model, more justification, such 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 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 survey values. Survey abundances should be tabulated in the assessment."

These comments have been addressed as described under **Summary of Major Changes in 2009** above.

Response to CPT Comments (from May 2009)

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

All these recommendations have been addressed in this report except (1) likelihood profiles for natural mortality and survey catchability and (2) Bayesian approach. The likelihood profiles were estimated in the SAFE report last year and can be included in the report in May 2010. The Bayesian approach will be considered for the report in May 2010 as well.

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

> *"The SSC suggests that the authors address ecosystem considerations beyond predation of groundfish on crab (which was well covered). This section should also address apex predators, such as seabirds that rely on juvenile crab during winter, that might be affected by changes in the crab population. Although data on crab predation from apex predators may not be specific to this stock, there are data available for the region."*

This is a good suggestion and we will address it during the future reports. During this reporting period, the assessment authors were fully engaged with model extension and addressing the mortality issues during the early 1980s.

1. *"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.

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

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

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

All fishing mortalities were modeled in the model. Several more model scenarios were conducted to address different hypotheses in the updated SAFE report to the CIE review.

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

We will explore this issue in the future report.

3. *"The SSC continues to question the rationale for using the 1995 through the current time period of recruitment for estimating $B_{35\%}$. We recognize that the rationale is more developed for this stock than for some other stocks and that it is primarily based on a perceived shift in productivity in 1989 (first apparent in the 1995 recruitment of 6-year old crab). However, while recruitment was somewhat higher in the post-1988 period, the difference in mean*

recruitment is not significant (fertilization years 1977-88, i.e. post 76/77 shift, vs. 1989-2002: t = 0.125, p = 0.91; 1979-88, the period used in the assessment, vs. 1989-2002: t = 1.57, p = 0.13). Therefore, we request that model runs continue to be based on both periods, for comparison, and that the rationale for using only the post-1988 period be re-evaluated, perhaps as part of a broader evaluation of appropriate productivity periods across crab stocks in this region."

Agree.

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

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

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

We will examine this issue in the future report.

6. *"The SSC appreciates the inclusion of likelihood components that incorporate appropriate coefficients of variation, rather than arbitrary weights. We request that the weighting issue be explored further, following recommendations from the recent stock assessment/data weighting workshop. Possible approaches to pursue include conducting additional*

sensitivity analyses to examine the influence of different weights, estimating effective N for multinomial likelihood components within the model, as is done for many groundfish assessments, or employing a fully Bayesian implementation of the model with appropriate priors, as recommended by the CPT."

Some work has been done no this issue in this report (estimating effective sample sizes and examining the weights). We will further examine effective sample sizes and the Bayesian approach in the future report.

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

Since the BSFRF surveys were only for three years, the most important use of the data is to estimate capture probability. We will use the data to improve the capture probability estimates in the future report.

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^{o}36' N lat.), east of 168^{o} W long., and south of the latitude of Cape Newenham (58^{o}39' N lat.) (ADF&G 2005). Besides these five stocks, RKC stocks elsewhere in the Aleutian Islands and eastern Bering Sea are currently too small to support a commercial fishery. This report summarizes the stock assessment results for the Bristol Bay RKC stock.

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 relatively 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, usually about a week, in the fall, 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, 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 rates varied from less than 20% to 60% (Schmidt and Pengilly 1990). In 1990, the harvest strategy was modified, and a 20% mature male harvest rate was applied to the abundance of mature-sized (≥120-mm CL) males with a maximum 60% harvest rate cap of legal (≥135-mm CL) males (Pengilly and Schmidt 1995). In addition, a minimum threshold of 8.4 million mature-sized females (≥90-mm CL) was added to existing management measures to avoid recruitment overfishing (Pengilly and Schmidt 1995). Based on a new assessment model and research findings (Zheng et al. 1995a, 1995b, 1997a, 1997b), the Alaska Board of Fisheries adopted a new harvest strategy in 1996. That strategy had two mature male harvest rates: 10% when effective spawning biomass (ESB) is between 14.5 and 55.0 million lbs and 15% when ESB is at or above 55.0 million lbs (Zheng el al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. An additional threshold of 14.5 million lbs of ESB was also added. In 1997, 4.0 million lbs was established as the minimum GHL for opening the fishery and maintaining fishery manageability when the stock abundance is low. In 2003, the Board modified the current harvest strategy by adding a mature harvest rate of 12.5% when the ESB is between 34.75 and 55.0 million lbs. The current harvest strategy is illustrated in Figure 1.

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

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 2008 (Bowers et al. 2008). Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Bowers et al. 2008; Burt and Barnard 2006). Sample sizes for catch by length and shell condition are summarized in Table 3. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

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). Due to the difficulty in estimating commercial fishing catchability and the ready availability of NMFS annual trawl survey data, commercial CPUE data were not used in the model.

NMFS Survey Data

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

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach without post-stratification (Figures 4 and 5). If multiple tows were made for a single station in a given year, the average of the abundances from all tows was used as the estimate of abundance for that station. Until the late 1980s, NMFS used a post-stratification approach, but subsequently treated Bristol Bay as a single stratum. If more than one tow was conducted in a station because of high RKC abundance (i.e., the station is a “hot spot”), NMFS regards the station as a separate stratum. Due to poor documentation, it is difficult to duplicate past NMFS post-stratifications. A “hot spot” was not surveyed with multiple tows during the early years. Two such “hot spots” affected the survey abundance estimates greatly: station H13 in 1984 (mostly juvenile crabs 75-90 mm CL) and station F06 in 1991 (mostly newshell legal males). The tow at station F06 was discarded in the NMFS abundance estimates (Stevens et al. 1991). In this study, all tow data were used. NMFS re-estimated historic areas-swept in 2008 and re-estimated area-swept abundance as well. In this report we used area-swept abundances estimated by NMFS in July 2009.

In addition to standard surveys, NMFS also conducted some surveys after the standard surveys to assess mature female abundance. Two surveys were conducted for Bristol Bay RKC in 1999, 2000, 2006-2009: the standard survey was performed in late May and early June (about two weeks earlier than historic surveys) in 1999 and 2000 and in early June in 2006-2009 and resurveys of 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), and 32 stations (2007-2009) with high female density were performed in late July, about six weeks after the standard survey. The resurveys were necessary because a high proportion of mature females had not yet molted or mated prior to the standard surveys (Figure 6). Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000. As in 2006, area-swept estimates of males >89 mm CL, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different between the standard survey and resurvey (P=0.74, 0.74 and 0.95) based on t-tests of paired two sample for means. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 are significantly different between the standard survey and resurvey (*P*=0.03) based on the *t*-test. To maximize use of the survey data, we used data from both surveys to assess male abundance but only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundance during these six years.

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

Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay red king crab in 2007 and 2008 with a small mesh trawl net and 5-minute tows. The surveys occurred at similar times with the NMFS standard surveys and covered about 97% of the Bristol Bay area. Few Bristol Bay red king crab were outside of the BSFRF survey area. Because of small mesh size, the BSFRF surveys are expected to catch nearly all red king crabs within the swept area. Crab abundances of different size groups were estimated by the Kriging method.

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 estimated additional mortality beyond a basic constant natural mortality during 1976-1993. In this report, we present only the research model that was fit to the data from 1968 to 2009.

Model Scenarios

Three scenarios were examined in the MAY 2009 SAFE report: (1) constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, and with the Bering Sea Fisheries Research Foundation (BSFRF) survey data; (2) constant natural mortality (0.18) with BSFRF survey data; and (3) a basic constant natural mortality (0.18), estimation of additional mortality for males during 1980-1984 and for females during 1976-1993, but without the BSFRF survey data. Scenarios (1) and (3) were compared to examine the utility of the BSFRF surveys. As illustrated in our previous report, scenario (2) fits the data very poorly, and scenario (1) fits the data well. The CPT chose scenario (3) in May 2009 for estimating biological reference points and federal overfishing levels for 2009. The results of scenario (3) are similar to scenario (1) except that estimates of mature male and legal male abundances in 2009 are higher with scenario (3) than those with scenario (1).

Due to time constraint, only scenario (3) was updated and presented in this report. Within scenario (3), effective sample sizes of 50 (scenario 3) and 100 (scenario 3o) for trawl bycatch and pot female bycatch were compared. Effective sample size of 50 resulted in unbiased residuals of total survey biomass. Results with scenario (3o) were illustrated in Figure 12 only, and all other figures and tables are the results with scenario (3).

Main Assumptions for the Model

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

(1) The basic natural mortality is constant over shell condition and length and was estimated assuming a maximum age of 25 and applying the 1% rule (Zheng 2005).

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

(3) Growth is a function of length and did not change over time for males. For females, three growth increments per molt as a function of length were estimated based on sizes at maturity (1968-1982, 1983-1993, and 1994-2009). Once mature, female red king crabs grow with a much smaller growth increment per molt.

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

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

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

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

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

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

Population Model

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

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

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

where

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

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

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

$$G_l = a + b\,\iota, \tag{2}$$

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

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

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

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

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

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

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

where

β, L_{50} are parameters, and

ι is the mid-length of length class *l*.

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

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

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

Before 1990, no observed bycatch data were available in the directed pot fishery; the crabs that were discarded and died in those years were estimated as the product of handling mortality rate, legal harvest rates, and mean length-specific selectivities. It is difficult to estimate bycatches from the Tanner crab fishery before 1991. A reasonable index to estimate bycatch fishing mortalities is potlifts of the Tanner crab fishery within the distribution area of Bristol Bay red king crab. Thus, bycatch fishing mortalities from the Tanner crab fishery before 1991 were estimated to be proportional to the smoothing average of potlifts east of 163° W. The smoothing average is equal to (P_{t-2}+2P_{t-1}+3P_t)/6 for the potlift in year t. The smoothing process not only smoothes the annual number of potlifts, it also indexes the effects of lost pots during the previous years. For bycatch, all fishery catch and discard mortality bycatch are estimated as:

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

where

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

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

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

The female crab model is the same as the male crab model except that the retained catch equals zero and molting probability equals 1.0 to reflect annual molting (Powell 1967). The minimum carapace length for females is set at 65 mm, and the last length class includes all crabs ≥140-mm CL, resulting in length groups 1-16.

Fisheries Selectivities

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

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

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

Male pot bycatch selectivity is modeled by two linear functions:

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

Where

φ, κ, γ are parameters.

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

Trawl Survey Selectivities/Catchability

Trawl survey selectivities/catchability are estimated as

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

with different sets of parameters (β, L_{50}) estimated for males and females as well as four different periods (1968-69, 1970-72, 1973-81 and 1982-09). Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, L_{50} for females and L_{50} for males) were estimated in the model for each of the four periods. Parameter Q, the survey catchability, was estimated in a trawl experiment by Weinberg et al. (2004, Figure 7) and assumed to be constant over time, except during 1970-1972 when the survey catchability was small.

Assuming that the BSFRF survey caught all crabs within the area-swept, the ratio between NMFS abundance and BSFRF abundance is a capture probability for the NMFS survey net. The Delta method was used to estimate the variance for the capture probability. A maximum likelihood method was used to estimate parameters for a logistic function as an estimated capture probability curve (Figure 7). For a given size, the estimated capture probability is smaller based on the BSFRF survey than from the trawl experiment, but the Q value is similar between the trawl experiment and the BSFRF surveys (Figure 7). Because many small-sized crabs are in the shallow water areas that are not accessible for the trawl survey, NMFS survey catchability/selectivity consists of capture probability and crab availability.

Parameters Estimated Independently

Basic natural mortality, length-weight relationships, and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 72.5 for both males and females. Highgrading parameters hg_t were estimated to be 0.2785 in 2005, 0.0440 in 2006, 0.0197 in 2007, and 0.0198 in 2008 based on the proportions of discarded legal males to total caught legal males. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, and 0.8 for the trawl fisheries.

Natural Mortality

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

Length-weight Relationship

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

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

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 8). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1968-1993 and 1994-2008, respectively, and the data presented in Gray (1963) were used to estimate those for mature females (Figure 8). To make a smooth transition of growth increment per molt from immature to mature females, weighted growth increment averages of 70% and 30% at 92.5 mm CL pre-molt length and 90% and 10% at 97.5 mm CL were used, respectively, for mature and immature females during 1983-1993. These percentages are roughly close to the composition of maturity. During 1968-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2008, females matured at a slightly larger size, so the growth increment per molt was shifted to high increments for immature crabs (Figure 8). Once mature, the growth increment per molt for male crabs decreases slightly and annual molting probability decreases, whereas the growth increment for female crabs decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

Sizes at Maturity for Females

NMFS collected female reproductive condition data during the summer trawl surveys. Mature females are separated from immature females by a presence of egg clutches or egg cases. Proportions of mature females at 5-mm length intervals were summarized and a logistic curve was fitted to the data each year to estimate sizes at 50% maturity. Sizes at 50% maturity are illustrated in Figure 9 with mean values for three different periods (1975-82, 1983-93 and 1994-08).

Sizes at Maturity for Males

The size at functional maturity for Bristol Bay male RKC is assumed to be 120 mm CL (Schmidt and Pengilly 1990), based on mating pair data collected off Kodiak Island (Figure 10). The size at maturity for Bristol Bay female RKC is 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 = 1969 to 2009), total abundance in the first year (1968), growth parameter β and recruitment parameter β_r for males and females separately. Molting probability parameters β and L_{50} were also estimated for male crabs. Estimated parameters also include β and L_{50} for retained selectivity, β and L_{50} for pot-discarded female selectivity, β and L_{50} for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, β and L_{50} for groundfish trawl discarded selectivity, φ, κ and γ for pot-discarded male selectivity, and β for trawl survey selectivity and L_{50} for trawl survey male and females separately. NMFS survey catchabilities Q for 1968-69 and 1973-2009 and Q_m (for males) and Q_f (for females) for 1970-72 were also estimated. Annual fishing mortalities were also estimated for the directed pot fishery for males (1968-2008), pot-discarded females from the directed fishery (1990-2008), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93), and groundfish trawl discarded males and females (1976-2008). Three additional mortality parameters for Mm_t and Mf_t were also estimated. The total number of parameters to be estimated was 223. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

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

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

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

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

where

L is the number of length groups,

T is the number of years, and

n is the effective sample size, which was assumed to be 400 for retained males, 200 for trawl survey, 100 for pot male and Tanner crab fisheries bycatch, and 50 for trawl and pot female bycatch length composition data.

The weighted negative log-likelihood functions are:

$$Length\ compositions: \quad -\sum \ln(Rf_i)\ ,$$

$$Biomasses\ other\ than\ survey: \quad \lambda_j \sum \left[\ln(B_t / \hat{B}_t)^2\right],$$

$$NMFS\ survey\ biomass: \quad \sum \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))\right],$$

$$BSFRF\ mature\ males: \quad \sum [\ln(N_t / \hat{N}_t)^2 / (2\ln(CV_t^2 + 1))], \qquad (13)$$

$$R\ variation: \quad \lambda_R \sum [\ln(R_t / \overline{R})^2]\ ,$$

$$R\ sex\ ratio: \quad \lambda_s [\ln(\overline{R}_M / \overline{R}_F)^2]\ ,$$

Where

R_t is the recruitment in year t,

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

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

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

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

RESULTS

Population Abundance

The model (scenario 1) fit the fishery biomass data well and the survey biomass reasonably well (Figures 11 and 12). Because the model estimates annual fishing mortality for pot male catch, pot female bycatch, and trawl bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences. The model did not fit the mature crab abundance directly, but depicted the trends of the mature abundance well (Figure 12). Estimated mature crab abundance increased dramatically in the mid 1970s and decreased precipitously in the early 1980s. Estimated mature crab abundance has increased during the last 20 years with mature females being 4.5 times more abundant in 2009 than in 1985 and mature males being 3.1 times more abundant in 2009 than in 1985 (Figure 12).

The model also fit the length and shell composition data well (Figures 13-20). Model fit of length compositions in the trawl survey was better for newshell males and females than for oldshell males. The model predicted lower proportions of oldshell males in 1993, 1994, 2002, 2007 and 2008, and higher proportions of oldshell males in 1997, 2001, 2003, 2004, 2006 and 2009 than the area-swept estimates (Figure 14). In addition to size, molting probability may also be affected by age and environmental conditions. Tagging data show that molting probability changed over time (Basilger 1974). Therefore, the relatively poor fit to oldshell males may be due to use of a constant molting probability function as well as shell aging errors. It is surprising that the model fit the length proportions of the pot male bycatch well with two simple linear selectivity functions (Figure 17). We explored a logistic selectivity function, but due to the long left tail of the pot male bycatch selectivity, the logistic selectivity function did not fit the data well.

Modal progressions are tracked well in the trawl survey data, particularly beginning in the mid-1990s (Figures 13 and 15). Cohorts first seen in the trawl survey data in 1975, 1986, 1990, 1995, 1999, 2002 and 2005 can be tracked over time. Some cohorts can be tracked over time in the pot bycatch as well (Figure 17), but the bycatch data did not track the cohorts as well as the survey data. Groundfish trawl bycatch data provide little information to track modal progression (Figures 19 and 20).

Parameter Estimates

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

One of the most important results is estimated trawl survey selectivity/catchability (Figure 21). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. Estimated survey selectivities in Figure 21 are generally smaller than the capture probabilities in Figure 7 because survey selectivities include capture probabilities and crab availability. NMFS survey catchability was estimated to be 0.896 from the trawl experiment and higher than that estimated from the BSFRF surveys (0.854). The reliability of estimated survey selectivities will greatly affect the application of the model to fisheries management. Under- or overestimates of survey selectivities will cause a systematic upward or downward bias of abundance estimates. Information about crab availability to the survey area at survey times will help estimate the survey selectivities.

Estimated molting probabilities during 1968-2009 (Figure 22) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crabs, possibly due to changes in molting probabilities over time or shell aging errors. Overestimates or underestimates of oldshell crabs will result in lower or higher estimates of male molting probabilities.

Residual Patterns

Residuals of total survey biomass and proportions of length and shell condition, calculated as observed minus predicted, were plotted to examine their patterns. Residuals of total survey biomass were standardized by the estimated standard deviation. The residuals of total survey biomass did not show any consistent patterns (Figure 23). Standardized residuals of proportions of survey newshell males appear to be random over length and year (Figure 24). Residuals of proportions of survey oldshell males were mostly positive or negative for some years (Figure 25). This is expected since a constant molting probability function over time was used. Changes in molting probability over time or shell aging errors would create such residual patterns. There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females during 1969-1987 (Figure 26). Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors. Further study for female growth and availability for survey gears due to different molting times may be needed.

Comparison of Scenarios

Since only scenario (3) was updated in this report, no detailed comparison for different scenarios was presented. The detailed comparison of three different scenarios was presented in the SAFE report in May 2009. In this report, we compared two different effective sample sizes for trawl bycatch and pot female bycatch in Figure 12. Effective sample size for length composition data affects the model results greatly, and further work is needed to better estimate effective sample sizes.

Retrospective Analyses

Two kinds of retrospective analyses were conducted for this report: (1) historical results and (2) the 2009 model results. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Treating the 2009 estimates as the baseline values, we can also evaluate how well the model had done in the past. The 2009 model results are based on sequentially excluding one-year of data to evaluate the current model performance with less data.

Historical Results

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

In 2005, to improve the fit for retained catch data, the weight for retained catch biomass was increased to 3000 and the weight for retained catch proportions was increased to 6. All other weights were not changed. In 2006, all weights were re-configured. No weights were used for proportion data, and instead, effective sample sizes were set to 500 for retained catch, 200 for survey data, and 100 for bycatch data. Weights for biomasses were changed to 800 for retained catch, 300 for survey and 50 for bycatches. The weights in 2007 were the same as 2006. Generally, estimates of time series of abundance in 2005 were slightly lower than in 2006 and 2007, and there were few differences between estimates in 2006 and 2007 (Figure 27).

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

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

2009 Model Results

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

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

Effects of Handling Mortality Rate on Abundance Estimates

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

Potential Reasons for High Mortality during the Early 1980s

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

Red king crab bycatch in the eastern Bering Sea Tanner crab fishery is another potential factor. The main overlap between Tanner crab and Bristol Bay red king crab is east of 163^{o} W. No absolute red king crab bycatch estimates are available until 1991, so there are insufficient data to fully evaluate the impact. Retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure 31. The observed red king crab bycatches in the Tanner crab fishery during 1991-1993 and total potlifts east of 163° W during 1968 to 2005 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

Dew and Mcconnaughey (2005) speculated that bottom trawling in southern Bristol Bay wiped out the mature red king crab stock. The main data to support this speculation are illustrated in Figure 32. The observed red king crab bycatch was very small relative to red king crab abundance, so the focus here is the unobserved bycatch, such as incomplete bycatch reporting. However, there are major flaws in the data analysis by Dew and Mcconnaughey (2005). The relationship established for trawling and mature female crab density was from log-transformed data. When plotting the data in a normal scale, the crab density declined more than 80% before any meaningful trawling occurred in the main crab habitat (Figure 32). From the spatial distributions of female red king crab and numbers of bottom trawling tows over time (See Appendix), we also see that there is a space and time mismatch of crab distribution and bottom trawling. The crab distribution started to shift in 1977, and a large majority of mature females were far away from the Unimak and Amak area since 1978, before the trawling was allowed into the area outside of the crab seasons in 1982 (Witherell and Pautzke 1997). In 1980 and 1981, very limited domestic trawling was allowed in the pot sanctuary during the crab seasons, a traditional practice of crab vessels catching baits using the trawl gear (D. Witherell, NPFMC, pers. comm.). The pot sanctuary was opened year-round to domestic trawling after January 1, 1984 (D. Witherell, NPFMC, pers. comm.), and the heavy trawling inside the pot sanctuary occurred after that day. Therefore, the bottom trawling was unlikely to have had a great impact on the stock decline in southern Bristol Bay in the early 1980s. However, heavy trawling in the southern Bristol Bay may have damaged habitat, possibly affecting the crab stock rebuilding. Furthermore, trawling and the red king crab broodstock overlapped in the mid 1980s in the central Bristol Bay area, which may have impacted crab stock rebuilding as well.

Several factors may have caused increases in natural mortality. Crab diseases in the early 1980s were documented by Sparks and Morado (1985), but inadequate data were collected to examine their effects on the stock. Stevens (1990) speculated that senescence may be a factor because many crabs in the early 1980s were very old due to low temperatures in the 1960s and early 1970s. The biomass of the main crab predator, Pacific cod, increased about 10 times during the late 1970s and early 1980s. Yellowfin sole biomass also increased substantially during this period. Predation is primarily on juvenile and molting/softshell crabs. But we lack stomach samples in shallow waters (juvenile habitat) and during the period when red king crabs molt. Also cannibalism occurs during molting periods for red king crabs. High crab abundance in the late 1970s and early 1980s may have increased the occurrence of cannibalism.

Overall, the likely causes for the sharp decline in the early 1980s are combinations of the above factors, such as pot fisheries on legal males, bycatch and predation on females and juvenile and sublegal males, senescence on older crabs, and disease on all crabs. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of 0.18, all directed fishing mortality, and non-directed fishing mortality. These three mortality parameters could be attributed to natural mortality as well as undocumented non-directed fishing mortality. The model fit the data much better with these three parameters (scenarios 1 and 3) than without them (scenario 2).

Sensitivity of Weights

Weights to biomasses (trawl survey biomass, retained catch biomass, and bycatch biomasses) were reduced to 50% or increased to 200% to examine their sensitivity to abundance estimates. Weights to the penalty terms for recruitment variation and sex ratio were also reduced or increased. Estimated mature male biomasses and survey biomasses were compared in Figure 33. Overall, estimated biomasses were very close under different weights except during the mid-1970s (Figure 33). The variation of estimated biomasses in the mid-1970s was mainly caused by the changes in estimates of additional mortalities in the early 1980s.

Estimated Effective Sample Sizes for Length Composition Data

We assumed a constant effective sample size for the length/sex composition data. These assumed sample sizes are compared with estimated effective sample sizes in Figure 34. Estimated effective sample sizes were computed as:

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

Where $\hat{P}_{y,l}$ and $P_{y,l}$ is estimated and observed size compositions in year *y* and length group *l*, respectively. Estimated effective sample sizes vary greatly over time. Further study on effective sample sizes are needed for this stock.

Exploitation

The average of estimated male recruits from 1995 to 2009 (Figure 35) and mature male biomass per recruit was used to estimate $B_{35\%}$. Alternative periods of 1968-present and 1985-present were compared in our previous report. The choice of this recruitment is 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 36). Before the current harvest strategy was adopted in 1996, many fishing mortalities were above $F_{35\%}$ (Figure 36). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, 2007 and 2008 but below the $F_{35\%}$ limits in other years.

Estimated full pot fishing mortalities ranged from 0.0 to 1.05 during 1968-2008 with estimated values over 0.4 during 1968-1981, 1986-1987, 1990-1991, 1993, and 1998 (Table 6, Figure 36). Estimated fishing mortalities for pot female bycatch and trawl bycatch were generally less than 0.06.

Stock-Recruitment Relationships

Estimated mature male biomass and recruitment were plotted to illustrate their relationships (Figure 37a). Annual stock productivity is illustrated in Figure 37b.

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 38). 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 38). The average clutch fullness was almost identical for these two periods (Figure 38).

BIOLOGICAL REFERENCE POINTS AND OVERFISHING LIMITS FOR 2009

Bristol Bay RKC is currently placed in Tier 3 (NPFMC 2007). For Tier 3 stocks, estimated biological reference points include $B_{35\%}$, $F_{35\%}$, and $F_{40\%}$. Estimated model parameters were used to conduct mature male biomass per recruit analysis. Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 1999 to 2008 was used for the per recruit analysis as well as for projections in the next section. Pot female bycatch fishing mortality was set equal to pot male fishing mortality times 0.02, an intermediate level during 1990-2008. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2006-2008 than in 2005 after the fishing industry minimized discards of legal males. Thus, the average of retained selectivities and discard male selectivities during 2006-2008 were used to represent current trends for per recruit analysis and projections.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1968-2009, 1985-2009, and 1995-2009 (Figure 35). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 37. We recommend using the average recruitment during 1995-present, which was used in 2008 to set the overfishing limits. There are several reasons for supporting our recommendation. First, estimated recruitment was higher after 1994 than during 1985-1994 and there was a potential regime shift after 1989 (Overland et al. 1999), which corresponded to recruitment in 1995 and later. Second, recruitments estimated before 1985 came from a potentially higher natural mortality than we used to estimate $B_{35\%}$. Third, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay while the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in the southern Bristol Bay (see the section on Ecosystem Considerations). Stock productivity (recruitment/mature male biomass) was much higher before the 1976/1977 regime shift: the mean value was 1.842 during 1968-1977 and 0.374 during 1978-2003 (Figure 37).

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

Scenario 3

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

$F_{35\%}$ = 0.32

$F_{40\%}$ = 0.26

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

Retained catch: 19.914 million lbs, or 9033.012 t,

Total catch: 22.561 million lbs, or 10233.415 t,

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

Total catch includes retained catch and all other bycatches. Likelihood profiles of mature male biomass on February 15, exploitable abundance and biomass at fishing time for 2009 are illustrated in Figure 39. 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 1995-2009. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2009. The 2009 abundance was randomly selected from the estimated normal distribution of the assessment model output for each replicate. Four scenarios of fishing mortality for the directed pot fishery were used in the projections:

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

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

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

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

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

As expected, projected mature male biomasses were much higher without the directed fishing mortality than under the other scenarios. Among three scenarios with directed fishing, the ADF&G harvest strategy produced the most stable mature male biomass and catch over time (Table 8, Figures 40 and 41). 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 40).

Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a starting declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 42). Most individuals from the 1997 year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population this year and will continue to recruit to the legal population next year (Figure 42). However, no strong cohorts have been observed in the survey data after this cohort (Figure 42). Due to lack of recruitment, mature and legal crabs should decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

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 found 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 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 observed 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 44). 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 was at a relatively low density in Bristol Bay.

Other striking examples of changes in spatial distributions are provided by rock sole and skates (Figure 45). 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 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 46). 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 years 1975, 1987 and 2004, but very different among different hatching locations (Figure 47). 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 47).

Settling locations appear to have an important impact on resultant year-class strength for Bristol Bay RKC (Figure 48). 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 48).

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.

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Table 1. Bristol Bay red king crab annual catch and bycatch mortality biomass (million lbs) from June 1 to May 31. A handling mortality rate of 20% for pot and 80% for trawl was assumed to estimate bycatch mortality biomass.

	Retained Catch				Pot Bycatch		Trawl	Total
Year	U.S.	Cost-recovery	Foreign	Total	Males	Females	Bycatch	Catch
1960	0.600		26.898	27.498				27.498
1961	0.427		44.592	45.019				45.019
1962	0.068		54.275	54.343				54.343
1963	0.653		54.963	55.616				55.616
1964	0.823		58.170	58.993				58.993
1965	1.429		41.294	42.723				43.410
1966	0.997		42.356	43.353				44.732
1967	3.102		33.636	36.738				38.430
1968	8.686		27.469	36.155				34.523
1969	10.403		14.383	24.786				24.463
1970	8.559		12.984	21.543				20.516
1971	12.946		6.134	19.080				20.459
1972	21.745		4.720	26.465				27.296
1973	26.914		0.228	27.142				24.167
1974	42.266		0.476	42.742				42.742
1975	51.326		0.000	51.326				51.326
1976	63.920		0.000	63.920			1.426	65.346
1977	69.968		0.000	69.968			2.685	72.653
1978	87.618		0.000	87.618			2.757	90.375
1979	107.828		0.000	107.828			2.783	110.611
1980	129.948		0.000	129.948			2.135	132.083
1981	33.591		0.000	33.591			0.448	34.039
1982	3.001		0.000	3.001			1.201	4.202
1983	0.000		0.000	0.000			0.885	0.885
1984	4.182		0.000	4.182			2.316	6.498
1985	4.175		0.000	4.175			0.829	5.004
1986	11.394		0.000	11.394			0.432	11.825
1987	12.289		0.000	12.289			0.311	12.600
1988	7.388		0.000	7.388			1.174	8.561
1989	10.265		0.000	10.265			0.374	10.638
1990	20.362	0.081	0.000	20.443	1.139	1.154	0.501	23.237
1991	17.178	0.206	0.000	17.384	0.881	0.142	0.576	18.982
1992	8.043	0.074	0.000	8.117	1.191	0.780	0.571	10.659
1993	14.629	0.053	0.000	14.682	1.649	1.133	0.836	18.300
1994	0.000	0.093	0.000	0.093	0.000	0.000	0.180	0.274
1995	0.000	0.080	0.000	0.080	0.000	0.000	0.213	0.293
1996	8.406	0.108	0.000	8.514	0.356	0.002	0.238	9.109
1997	8.756	0.155	0.000	8.911	0.528	0.034	0.168	9.641
1998	14.757	0.188	0.000	14.946	2.074	1.547	0.355	18.922
1999	11.670	0.186	0.000	11.856	0.679	0.015	0.408	12.958
2000	8.154	0.086	0.000	8.241	0.779	0.078	0.230	9.328
2001	8.403	0.120	0.000	8.523	0.902	0.309	0.330	10.065
2002	9.570	0.096	0.000	9.666	0.956	0.013	0.245	10.881
2003	15.697	0.034	0.000	15.731	1.945	0.709	0.298	18.682
2004	15.245	0.202	0.000	15.447	0.746	0.338	0.277	16.807
2005	18.309	0.209	0.000	18.518	2.923	0.879	0.403	22.723
2006	15.444	0.304	0.000	15.748	1.199	0.067	0.205	17.220
2007	20.366	0.146	0.000	20.512	2.150	0.330	0.233	23.225
2008	20.318	0.000	0.000	20.318	2.518	0.264	0.334	23.100

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

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

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

	Trawl Survey		Retained	Pot Bycatch		Trawl Bycatch	
Year	Males	Females	Catch	Males	Females	Males	Females
1968	3,684	2,165	18,044				
1969	6,144	4,992	22,812				
1970	1,546	1,216	3,394				
1971			10,340				
1972	1,106	767	15,046				
1973	1,783	1,888	11,848				
1974	2,505	1,800	27,067				
1975	2,943	2,139	29,570				
1976	4,724	2,956	26,450			2,327	676
1977	3,636	4,178	32,596			14,014	689
1978	4,132	3,948	27,529			8,983	1,456
1979	5,807	4,663	27,900			7,228	2,821
1980	2,412	1,387	34,747			47,463	39,689
1981	3,478	4,097	18,029			42,172	49,634
1982	2,063	2,051	11,466			84,240	47,229
1983	1,524	944	0			204,464	104,910
1984	2,679	1,942	4,404			357,981	147,134
1985	792	415	4,582			169,767	30,693
1986	1,962	367	5,773			62,023	20,800
1987	1,168	1,018	4,230			60,606	32,734
1988	1,834	546	9,833			102,037	57,564
1989	1,257	550	32,858			47,905	17,355
1990	858	603	7,218	873	699	5,876	2,665
1991	1,378	491	36,820	1,801	375	2,964	962
1992	513	360	23,552	3,248	2,389	1,157	2,678
1993	1,009	534	32,777	5,803	5,942		
1994	443	266	0	0	0	4,953	3,341
1995	2,154	1,718	0	0	0	1,729	6,006
1996	835	816	8,896	230	11	24,583	9,373
1997	1,282	707	15,747	4,102	906	9,035	5,759
1998	1,097	1,150	16,131	11,079	9,130	25,051	9,594
1999	820	540	17,666	1,048	36	16,653	5,187
2000	1,278	1,225	14,091	8,970	1,486	36,972	10,673
2001	611	743	12,854	9,102	4,567	56,070	32,745
2002	1,032	896	15,932	9,943	302	27,705	25,425
2003	1,669	1,311	16,212	17,998	10,327	281	307
2004	2,871	1,599	20,038	8,258	4,112	137	120
2005	1,283	1,682	21,938	55,019	26,775	186	124
2006	2,321	2,672	18,027	29,383	3,594	217	168
2007	2,252	2,499	22,387	58,097	12,411	1,981	2,880
2008	2,362	3,352	14,567	49,315	8,488	1,013	673
2009	1,385	1,857					

Table 4. Annual catch (million crabs) and catch per unit effort of the Bristol Bay red king crab fishery.

	Japanese Tanglenet		Russian Tanglenet		U.S. Pot/trawl		Standardized
Year	Catch	Crabs/tan	Catch	Crabs/tan	Catch	Crabs/potlift	Crabs/tan
1960	1.949	15.2	1.995	10.4	0.088		15.8
1961	3.031	11.8	3.441	8.9	0.062		12.9
1962	4.951	11.3	3.019	7.2	0.010		11.3
1963	5.476	8.5	3.019	5.6	0.101		8.6
1964	5.895	9.2	2.800	4.6	0.123		8.5
1965	4.216	9.3	2.226	3.6	0.223		7.7
1966	4.206	9.4	2.560	4.1	0.140	52	8.1
1967	3.764	8.3	1.592	2.4	0.397	37	6.3
1968	3.853	7.5	0.549	2.3	1.278	27	7.8
1969	2.073	7.2	0.369	1.5	1.749	18	5.6
1970	2.080	7.3	0.320	1.4	1.683	17	5.6
1971	0.886	6.7	0.265	1.3	2.405	20	5.8
1972	0.874	6.7			3.994	19	
1973	0.228				4.826	25	
1974	0.476				7.710	36	
1975					8.745	43	
1976					10.603	33	
1977					11.733	26	
1978					14.746	36	
1979					16.809	53	
1980					20.845	37	
1981					5.308	10	
1982					0.541	4	
1983					0.000		
1984					0.794	7	
1985					0.796	9	
1986					2.100	12	
1987					2.122	10	
1988					1.236	8	
1989					1.685	8	
1990					3.130	12	
1991					2.661	12	
1992					1.208	6	
1993					2.270	9	
1994					0.015		
1995					0.014		
1996					1.264	16	
1997					1.338	15	
1998					2.238	15	
1999					1.923	12	
2000					1.272	12	
2001					1.287	19	
2002					1.484	20	
2003					2.510	18	
2004					2.272	23	
2005					2.763	30	
2006					2.477	31	
2007					3.131	28	
2008					3.064	22	

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

Parameter counts

Fixed growth parameters	9
Fixed recruitment parameters	2
Fixed length-weight relationship parameters	6
Fixed mortality parameters	4
Fixed survey catchability parameter	1
Fixed highgrading parameters	4
Fixed initial (1968) length composition parameters	56
Total number of fixed parameters	82
Free growth parameters	4
Initial abundance (1968)	1
Recruitment-distribution parameters	2
Mean recruitment parameters	1
Male recruitment deviations	41
Female recruitment deviations	41
Natural and fishing mortality parameters	6
Survey catchability parameters	2
Pot male fishing mortality deviations	44
Pot female bycatch fishing mortality deviations	22
Trawl bycatch fishing mortality deviations	33
Free selectivity parameters	28
Total number of free parameters	225
Total number of fixed and free parameters	307

Negative log likelihood components

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

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

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

2009	-0.122	0.414	-2.148	0.259

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

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

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

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

2009	26.878	15.626	95.169	4.379	51.699	196.504	178.893

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

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

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

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

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

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

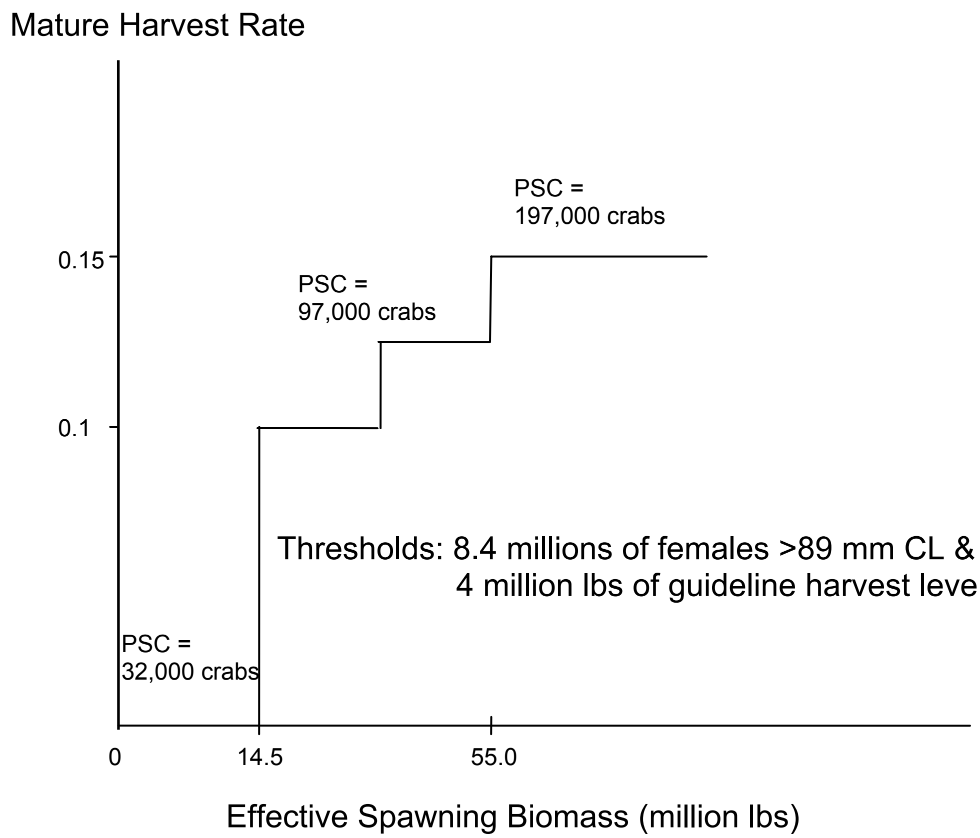

Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crabs) of Bristol Bay red king crabs in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates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

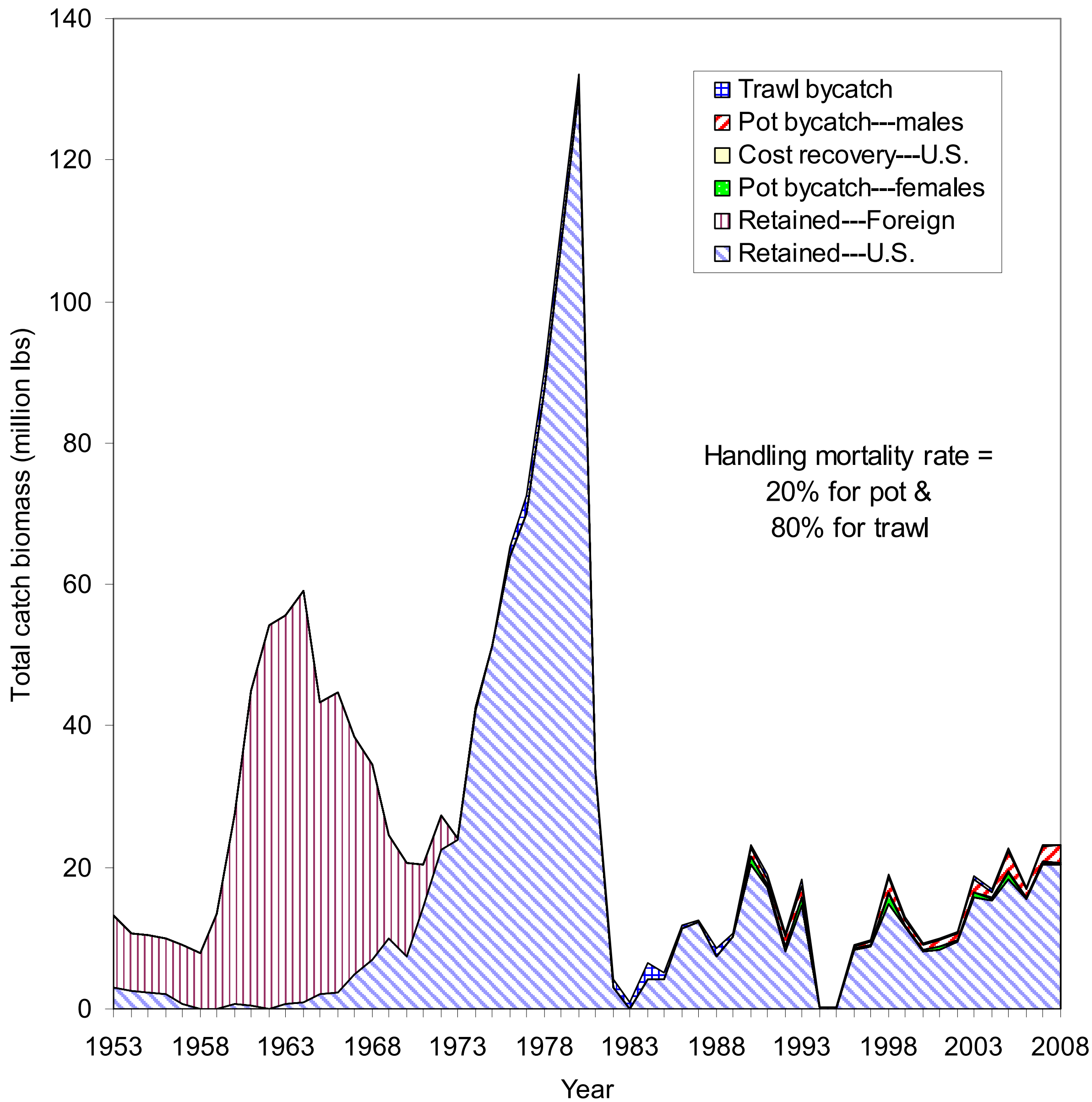

Figure 2. Retained catch biomass and bycatch mortality biomass (million lbs) for Bristol Bay red king crab from 1960 to 2008. Handling mortality rates were assumed to be 0.2 for the directed pot fishery and 0.8 for the trawl fisheries.

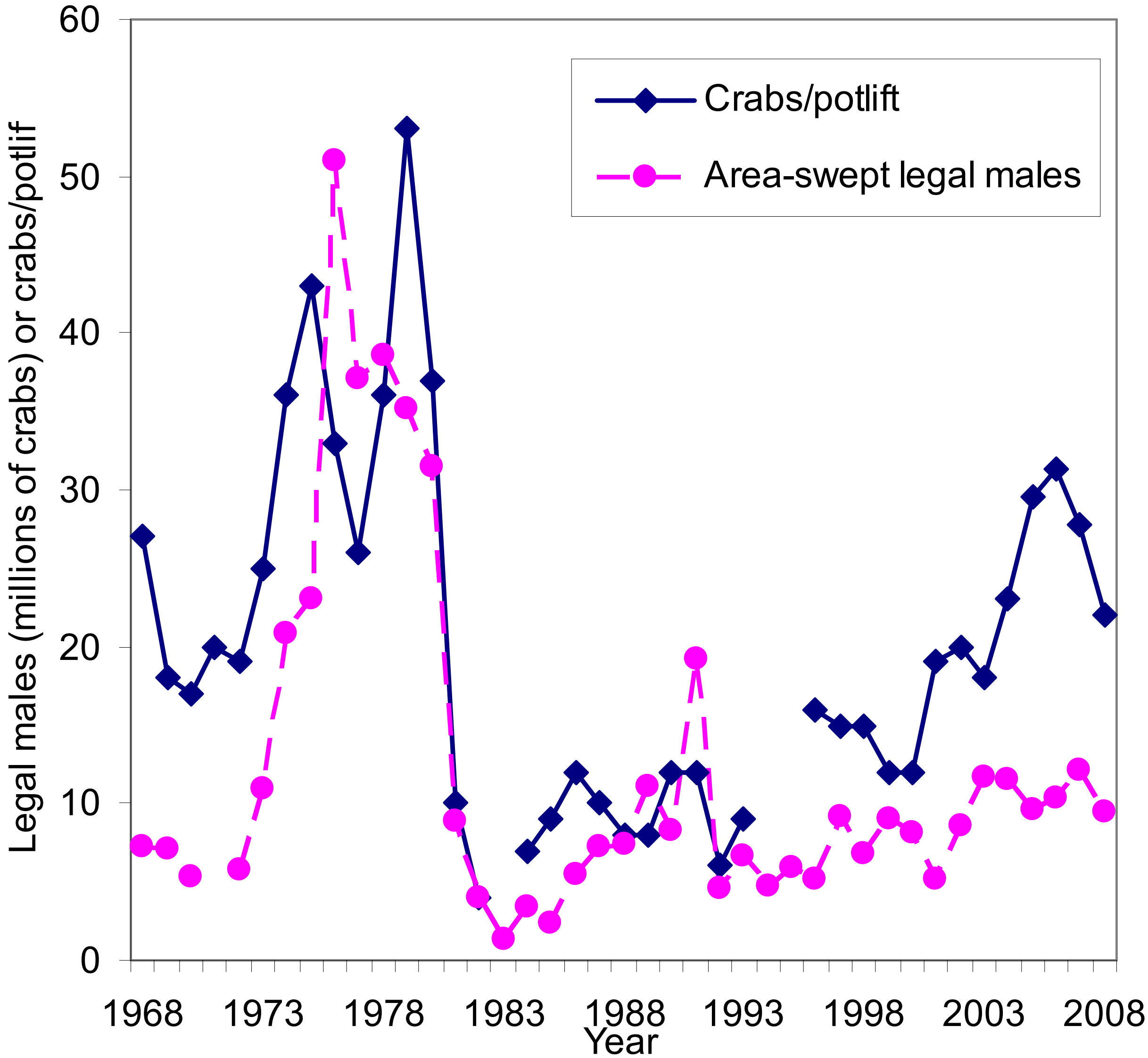

Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2008.

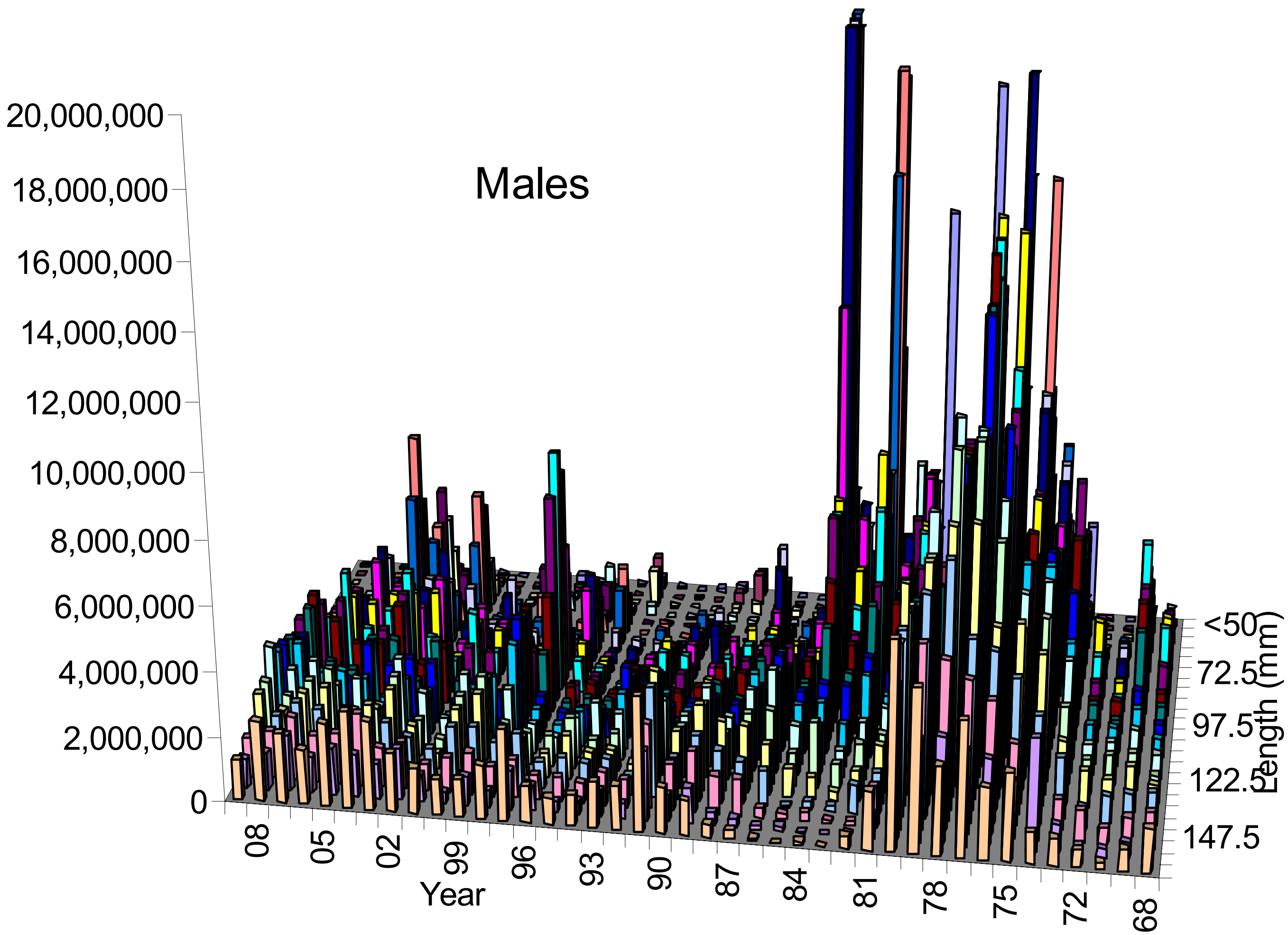

Figure 4. Survey abundances by length for male Bristol Bay red king crabs from 1968 to 2009.

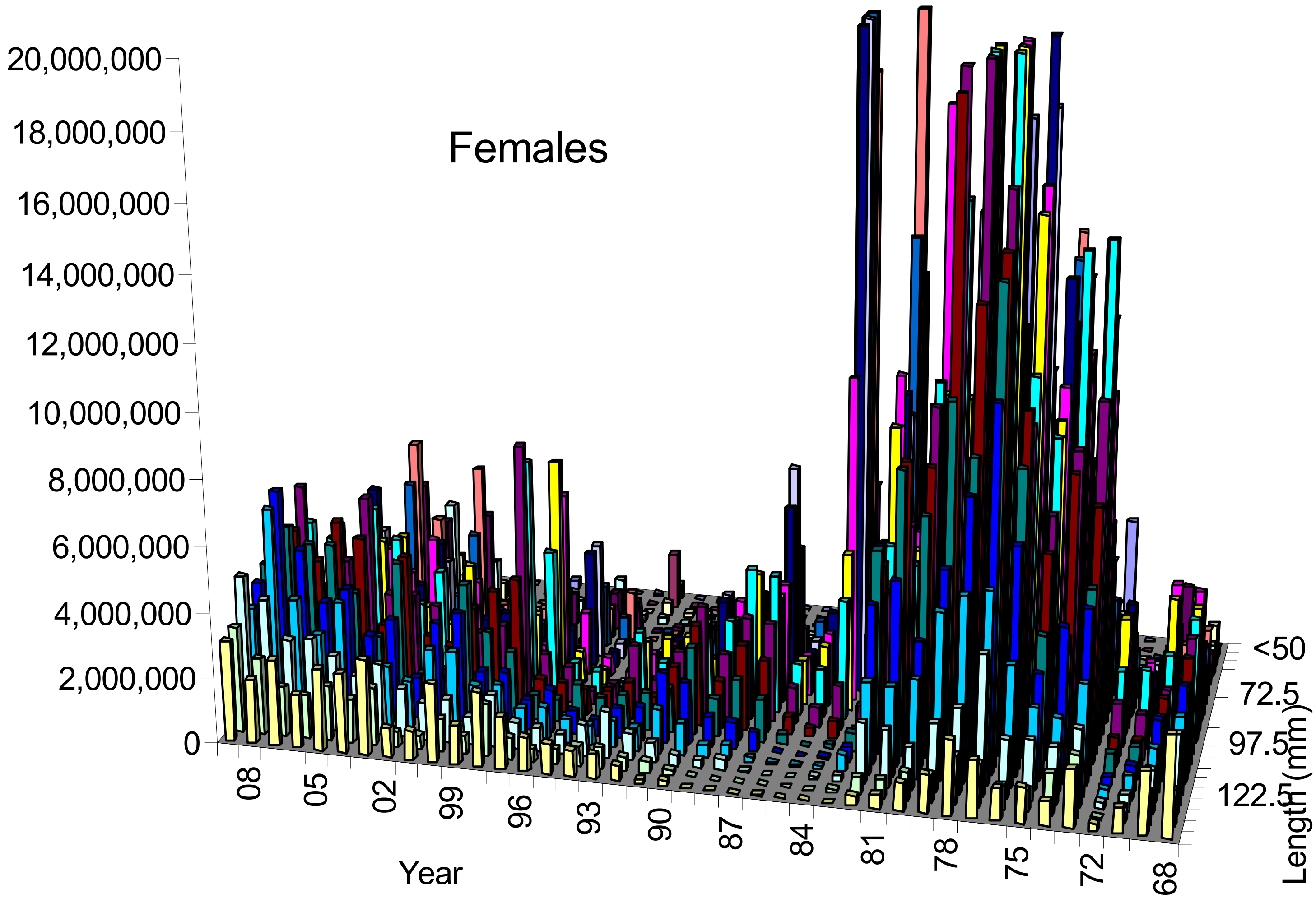

Figure 5. Survey abundances by length for female Bristol Bay red king crabs from 1968 to 2008.

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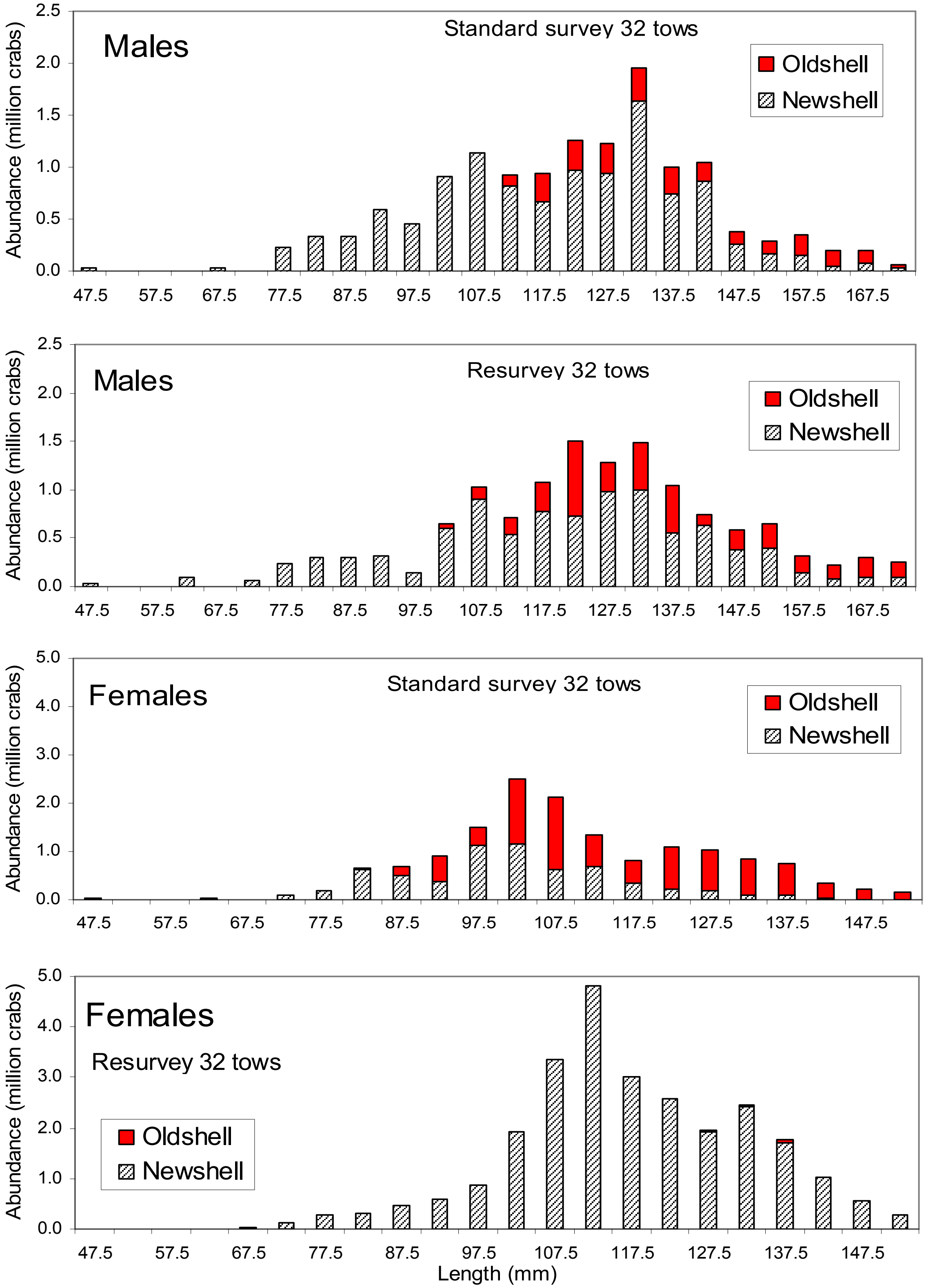

Figure 6. Comparison of area-swept estimates of abundance in 32 stations from the standard trawl survey and resurvey in 2009.

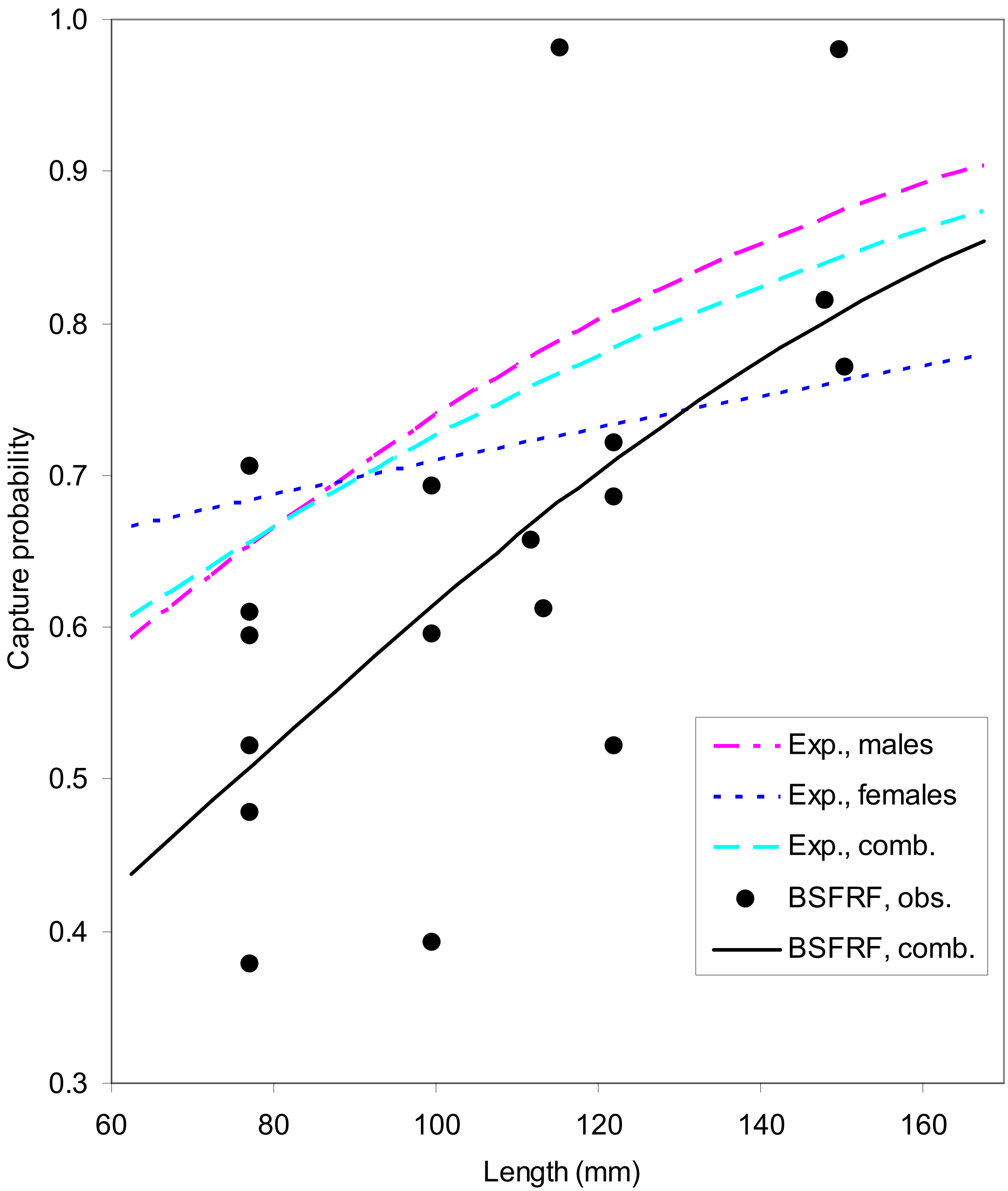

Figure 7. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.

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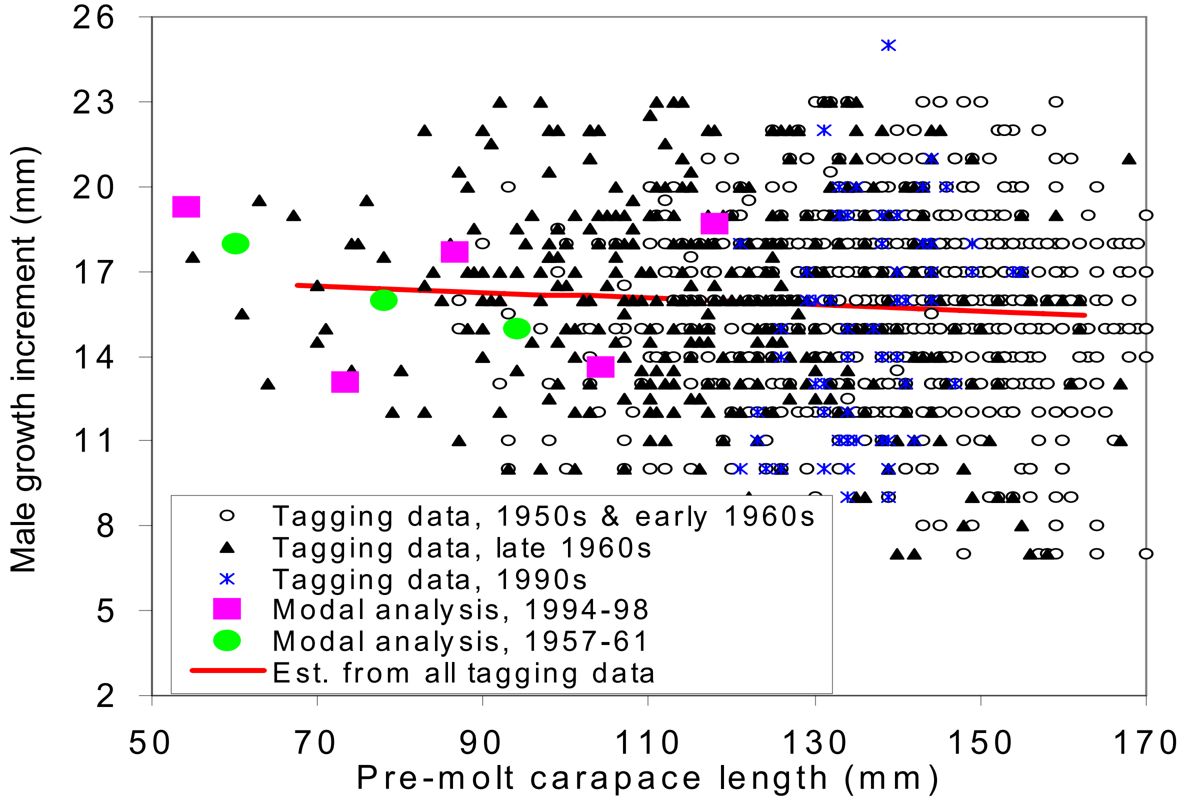

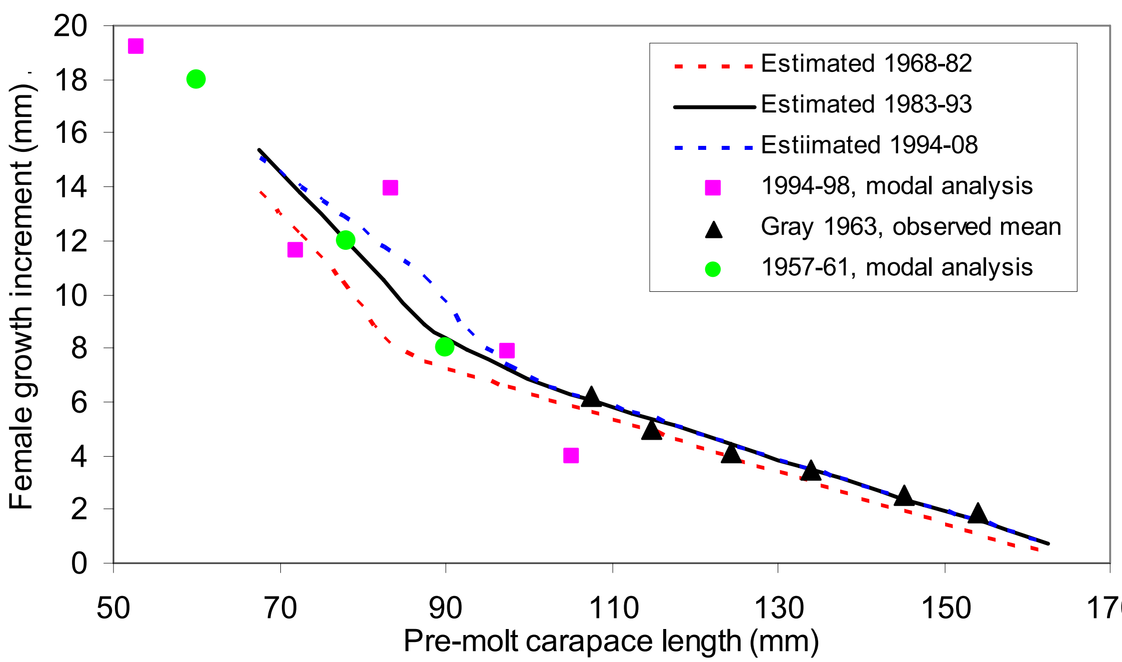

Figure 8. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis.

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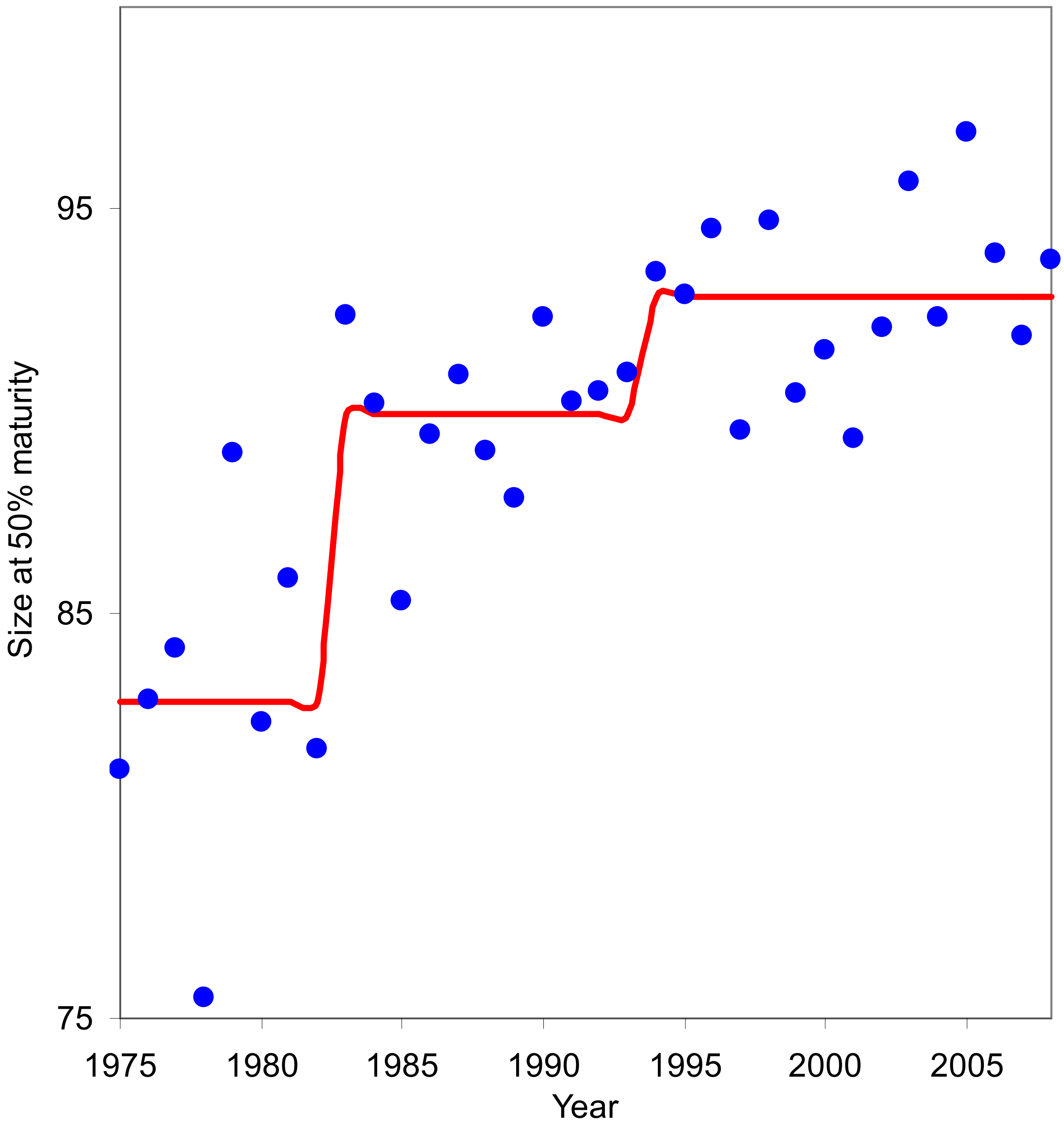

Figure 9. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

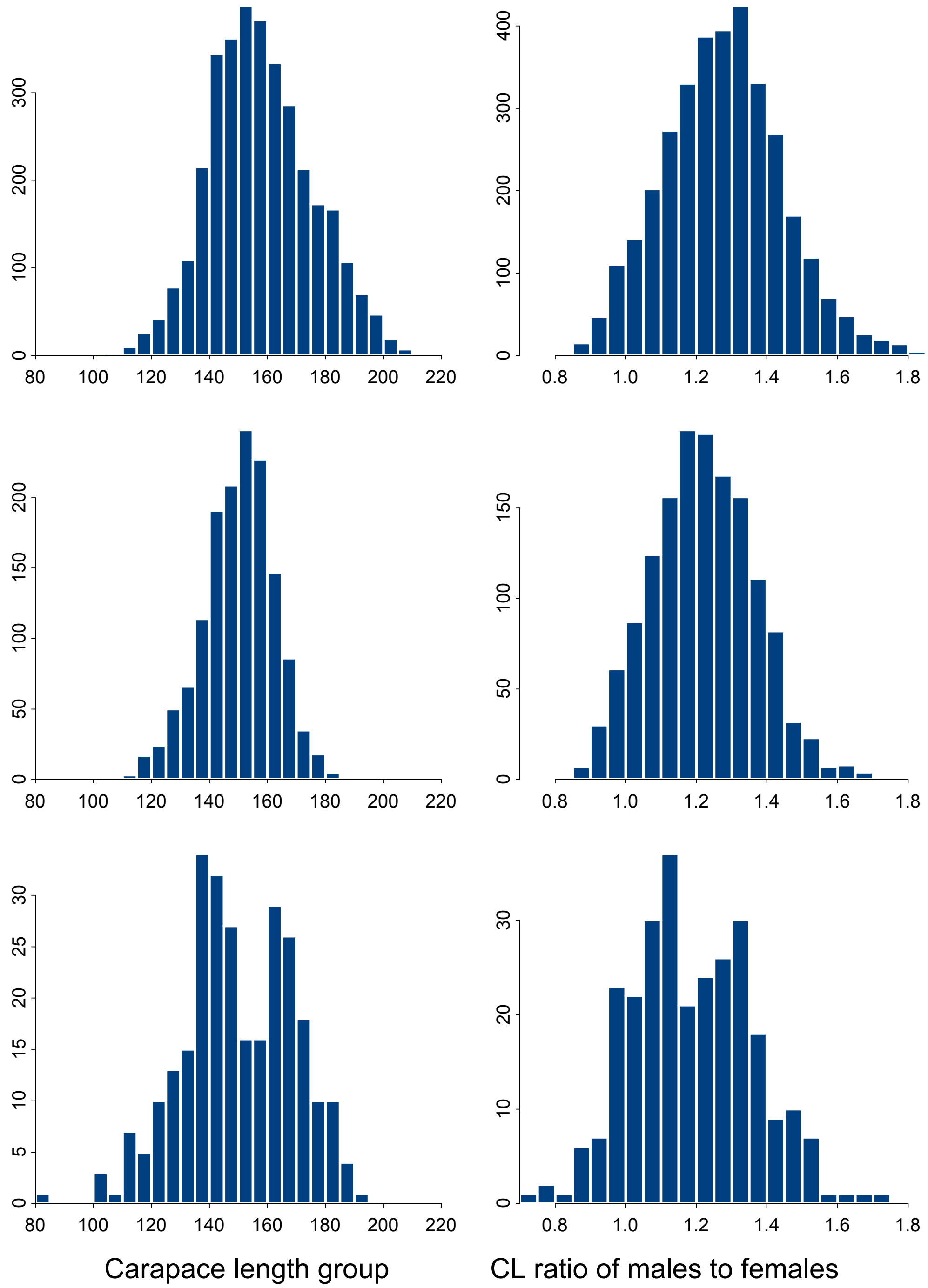

Figure 10. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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

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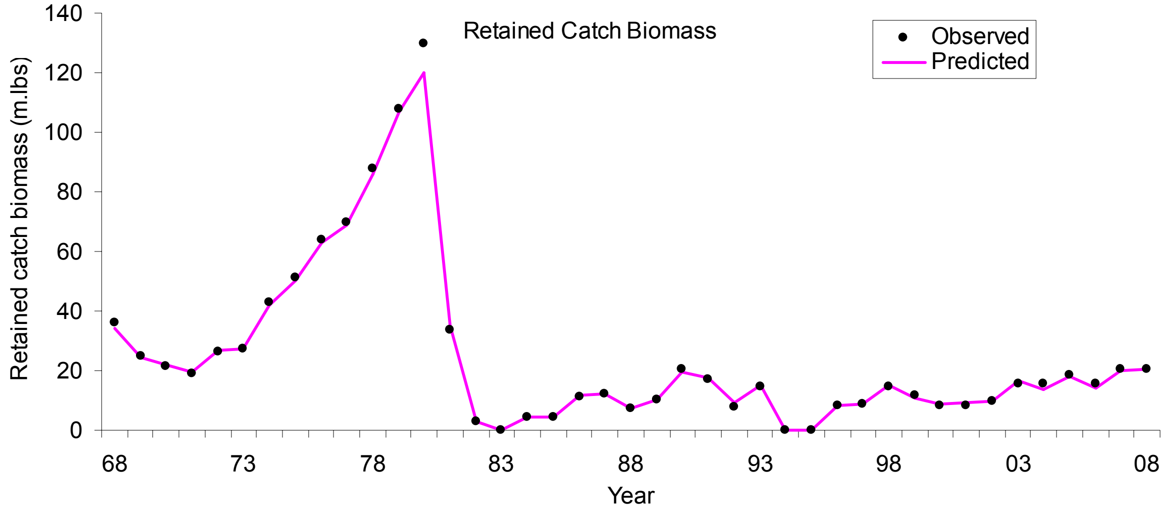

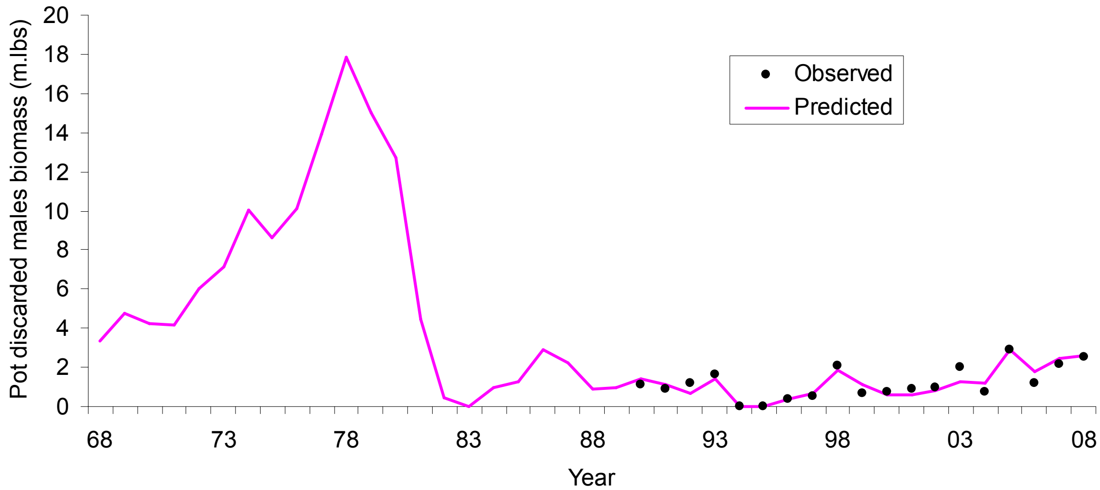

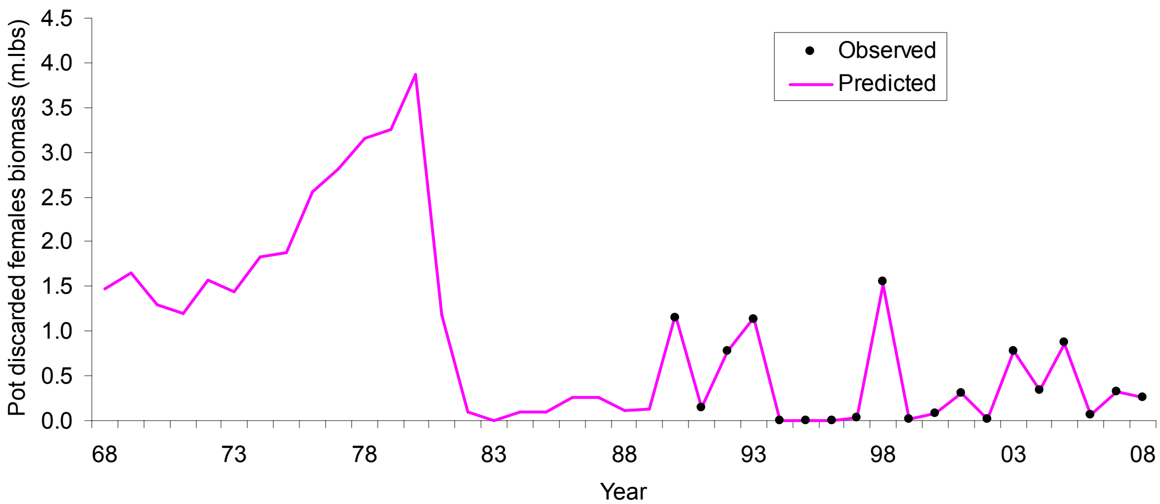

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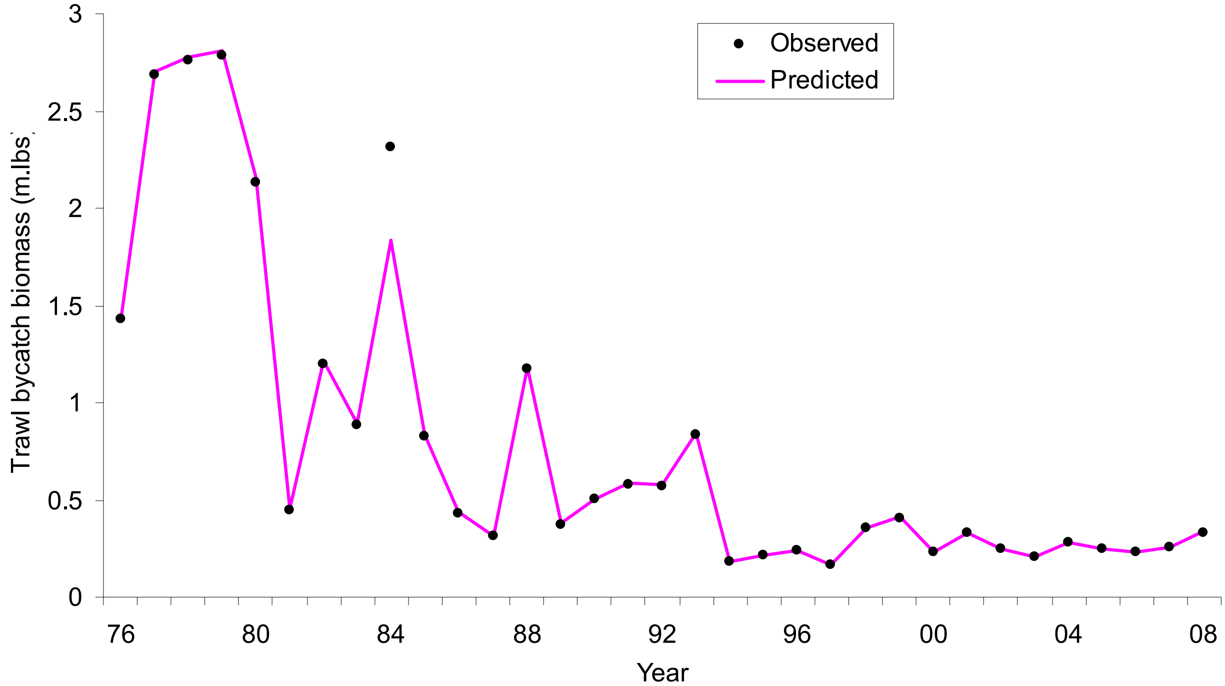
Figure 11a. Observed and predicted catch mortality biomass. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

70



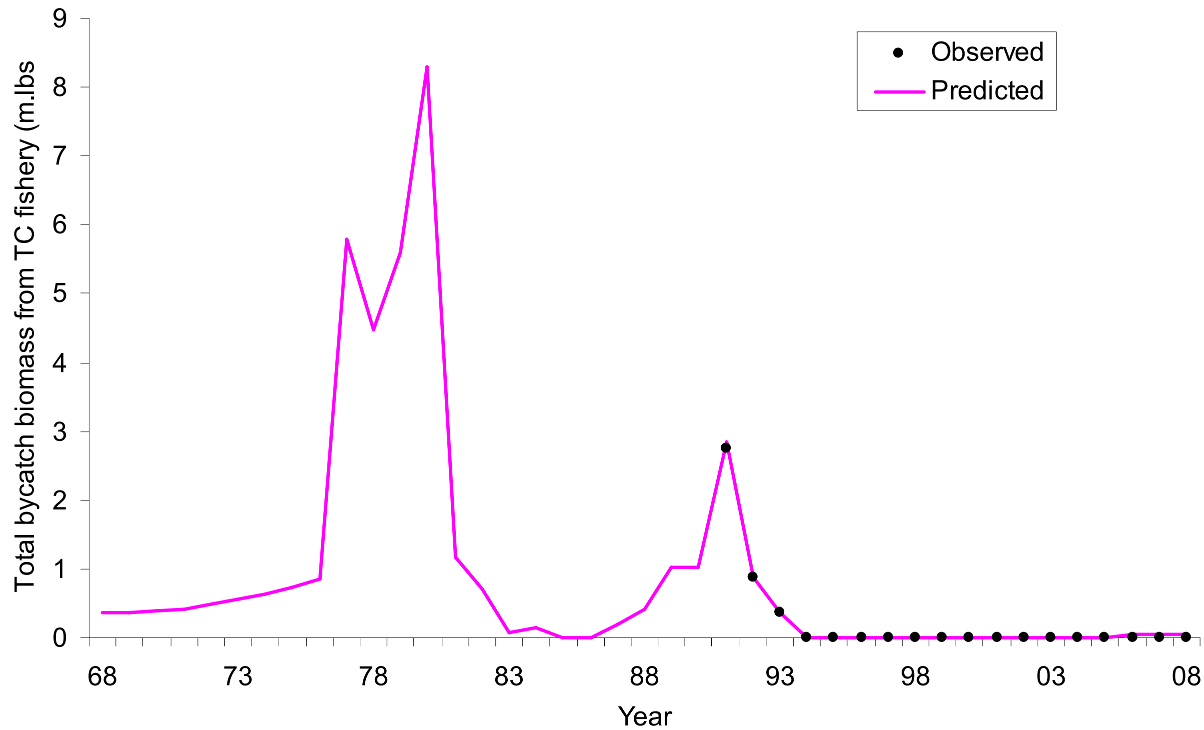


Figure 11(b). Observed and predicted catch mortality biomass from trawl and Tanner crab fisheries. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25.

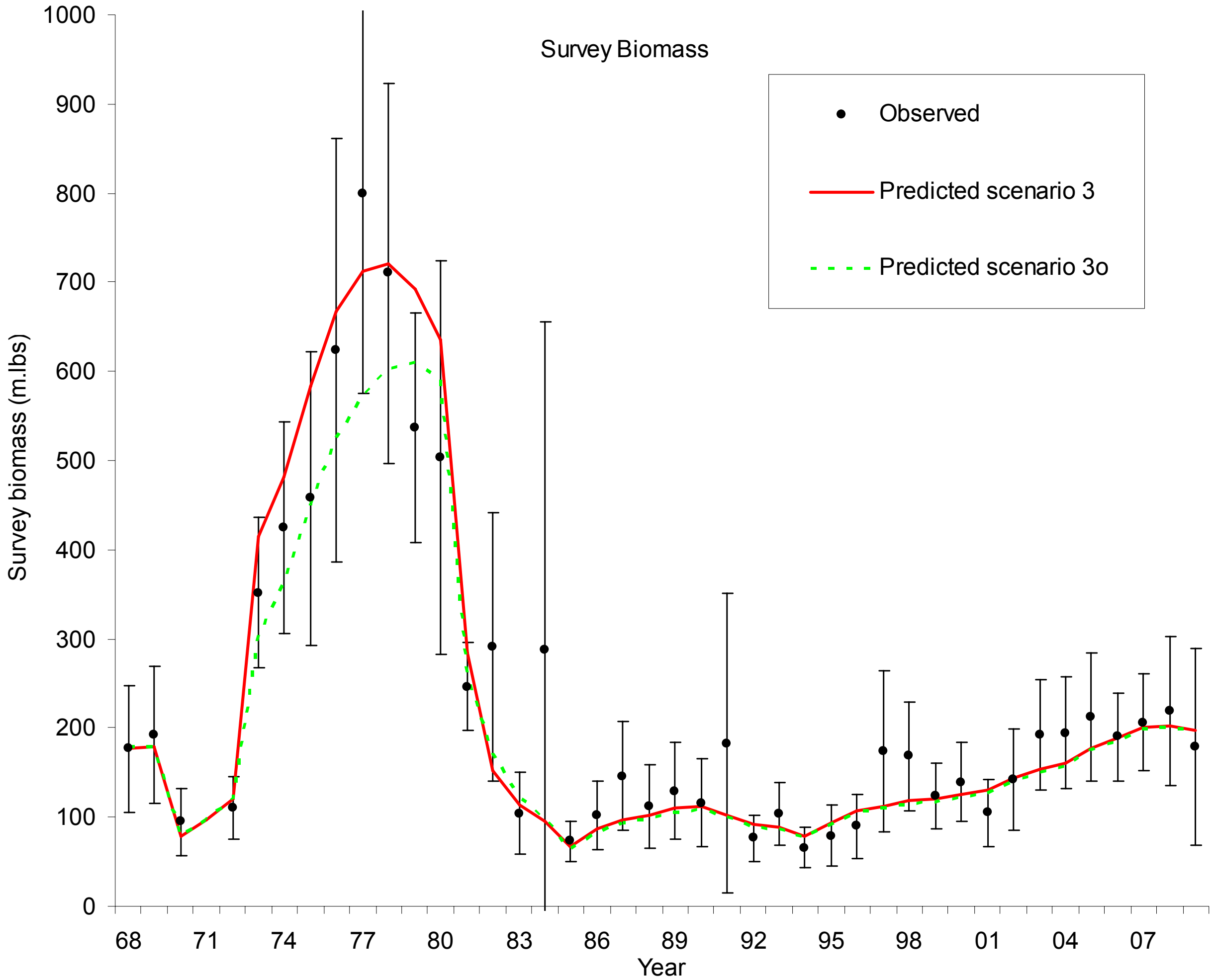


Figure 12a. Comparisons of area-swept estimates of total survey biomass and model prediction for scenario (3). Difference between scenario (3) and scenario (3o) is annual effective sampling size of 50 for trawl bycatch and pot female bycatch for scenario (3) and the effective sample size of 100 for scenario (3o). Pot handling mortality rate is 0.2.

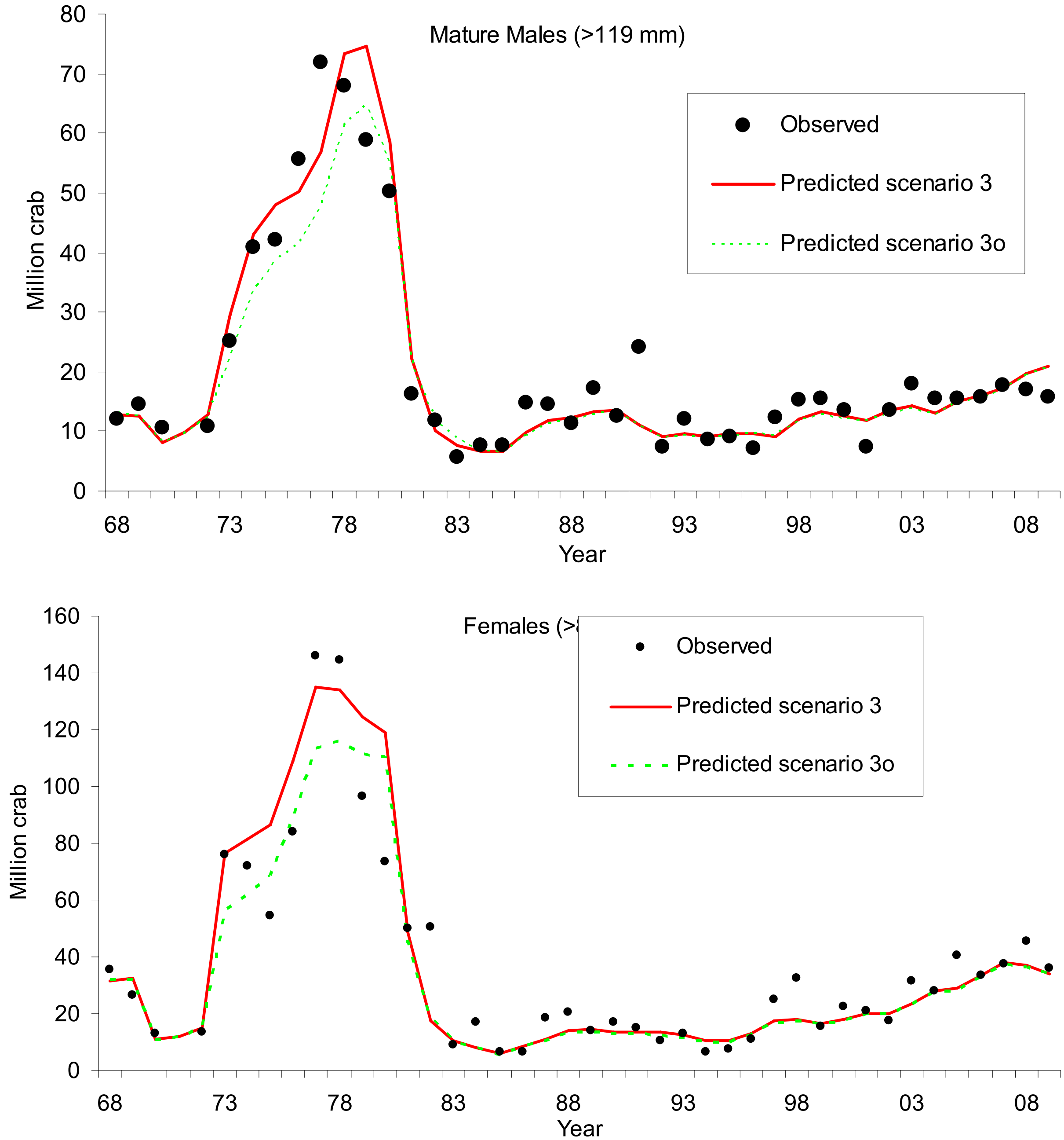


Figure 12b. Comparisons of area-swept estimates of mature male (>119 mm) and female (>89 mm) abundance and model prediction for scenario (3). Difference between scenario (3) and scenario (3o) is annual effective sampling size of 50 for trawl bycatch and pot female bycatch for scenario (3) and the effective sample size of 100 for scenario (3o). Pot handling mortality rate is 0.2.

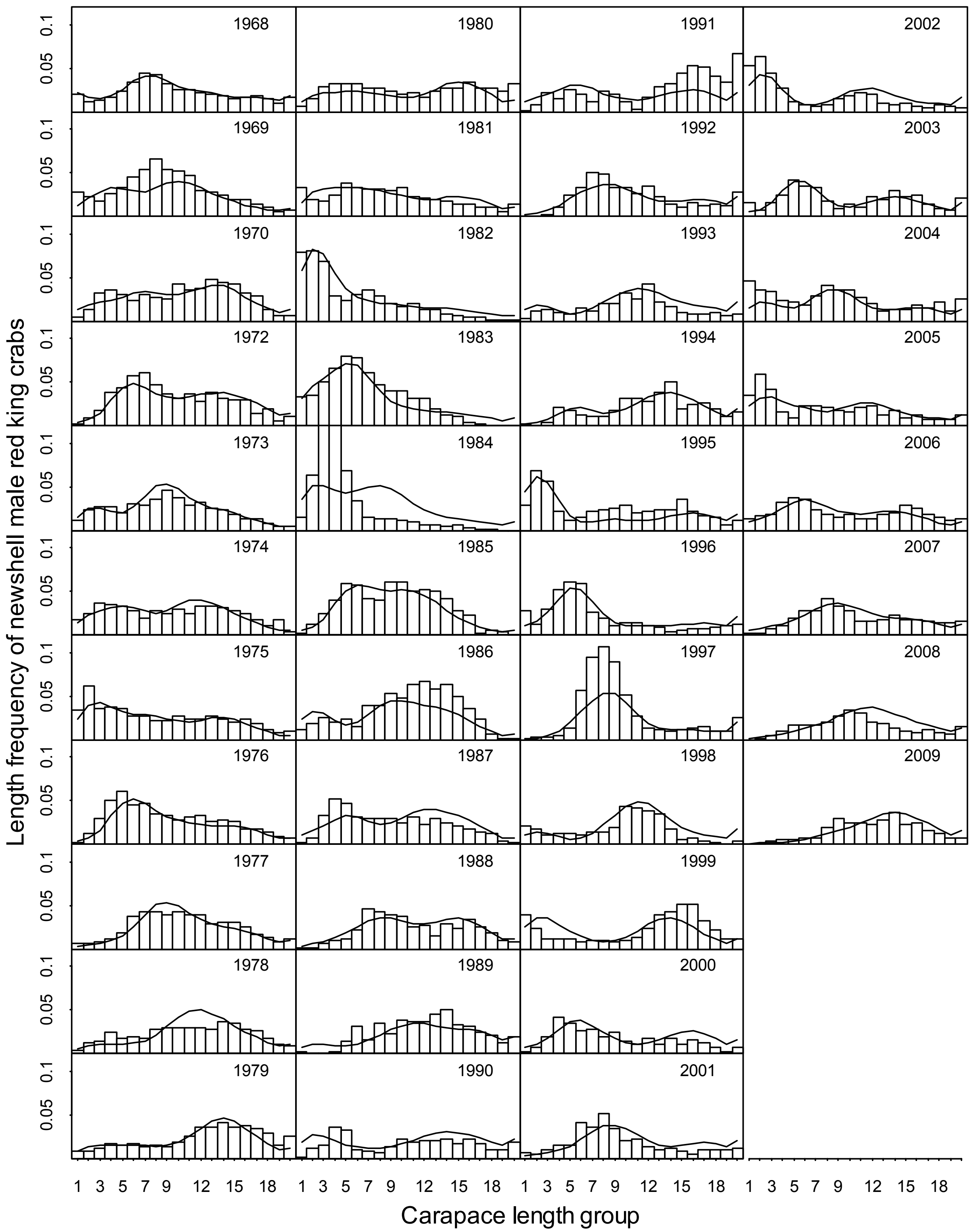


Figure 13. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay all-shell (before 1986) and newshell (1986-2009) male red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

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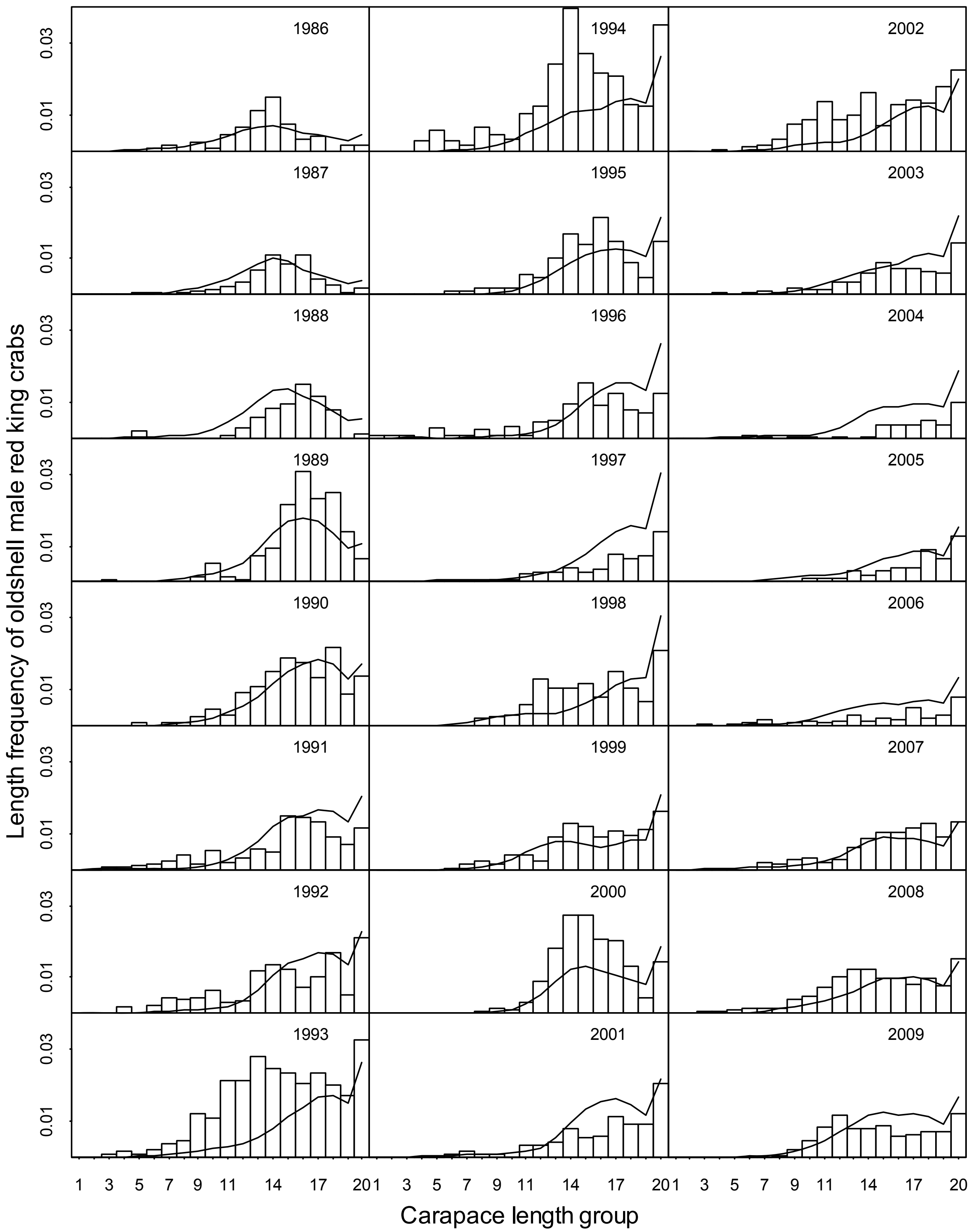


Figure 14. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay oldshell male red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

75

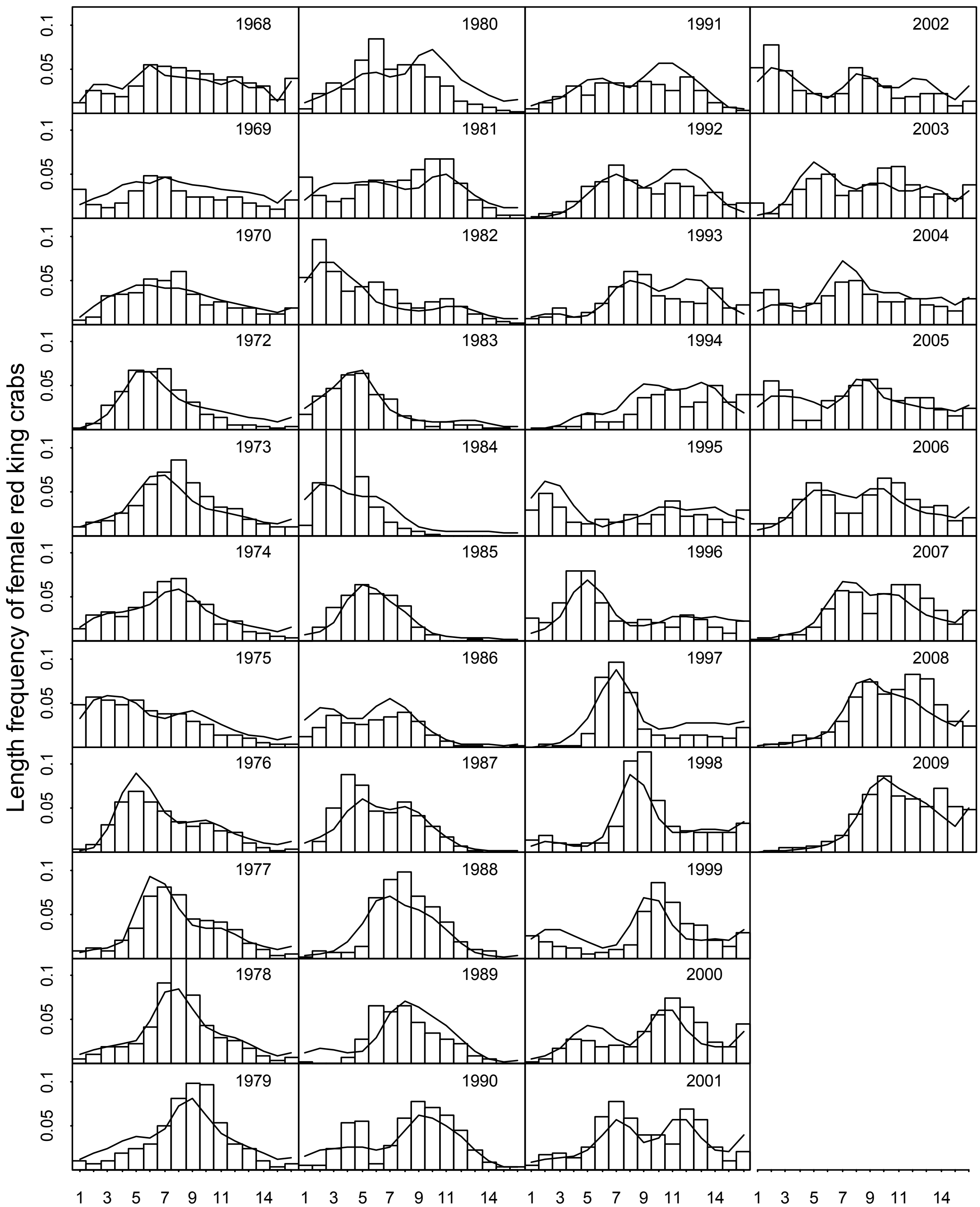


Figure 15. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crabs by year. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

76

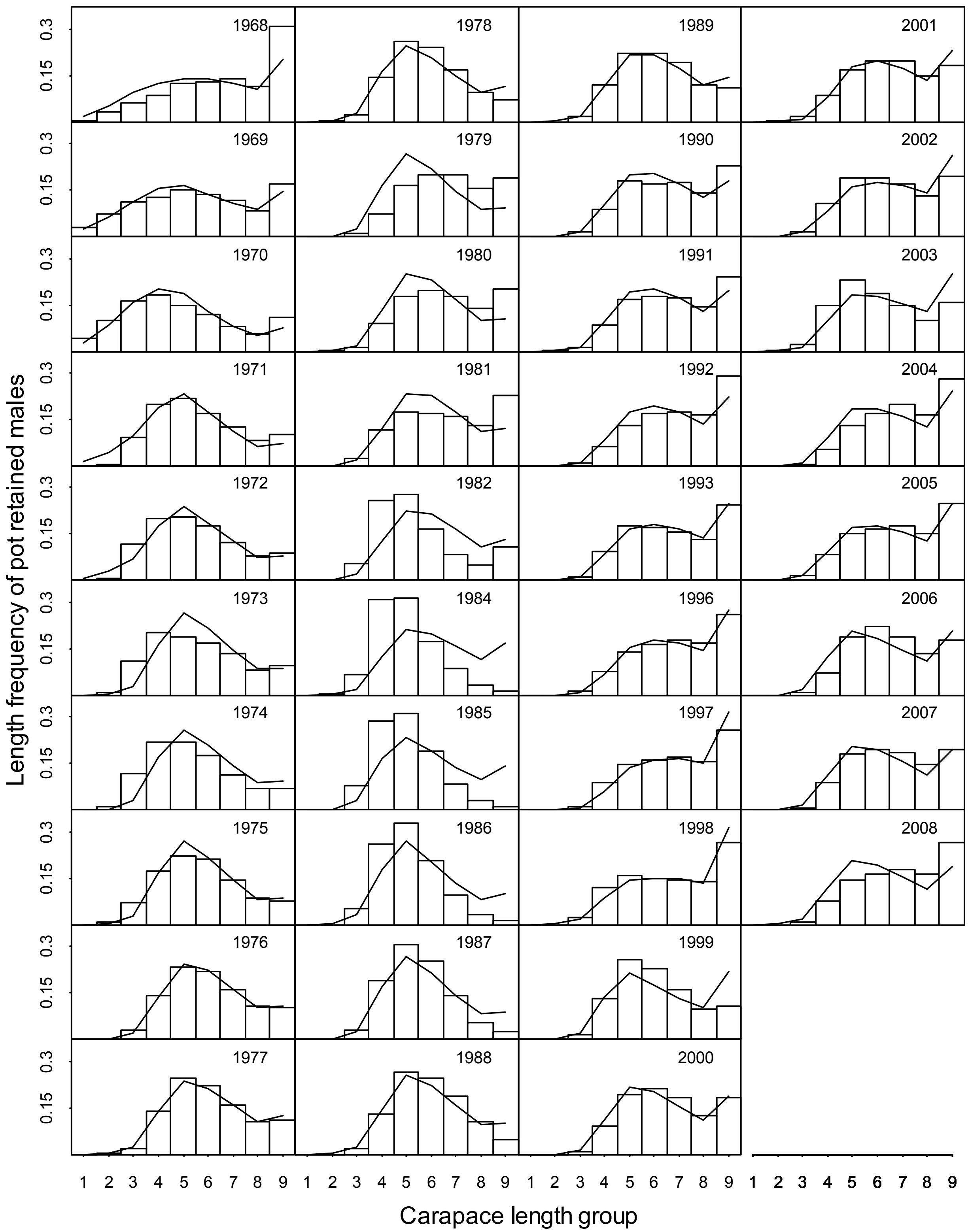


Figure 16. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 122.5 mm.

77

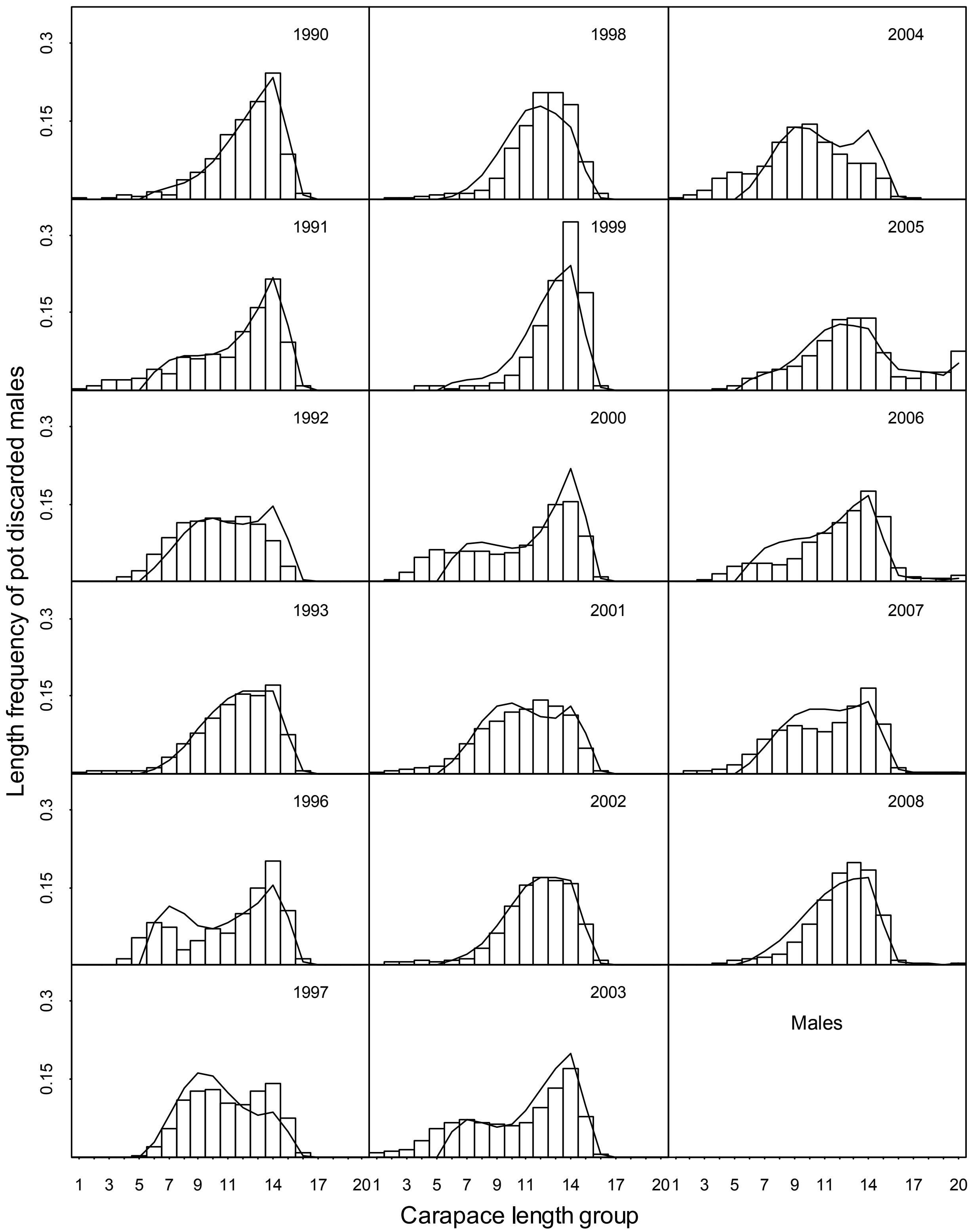


Figure 17. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

78

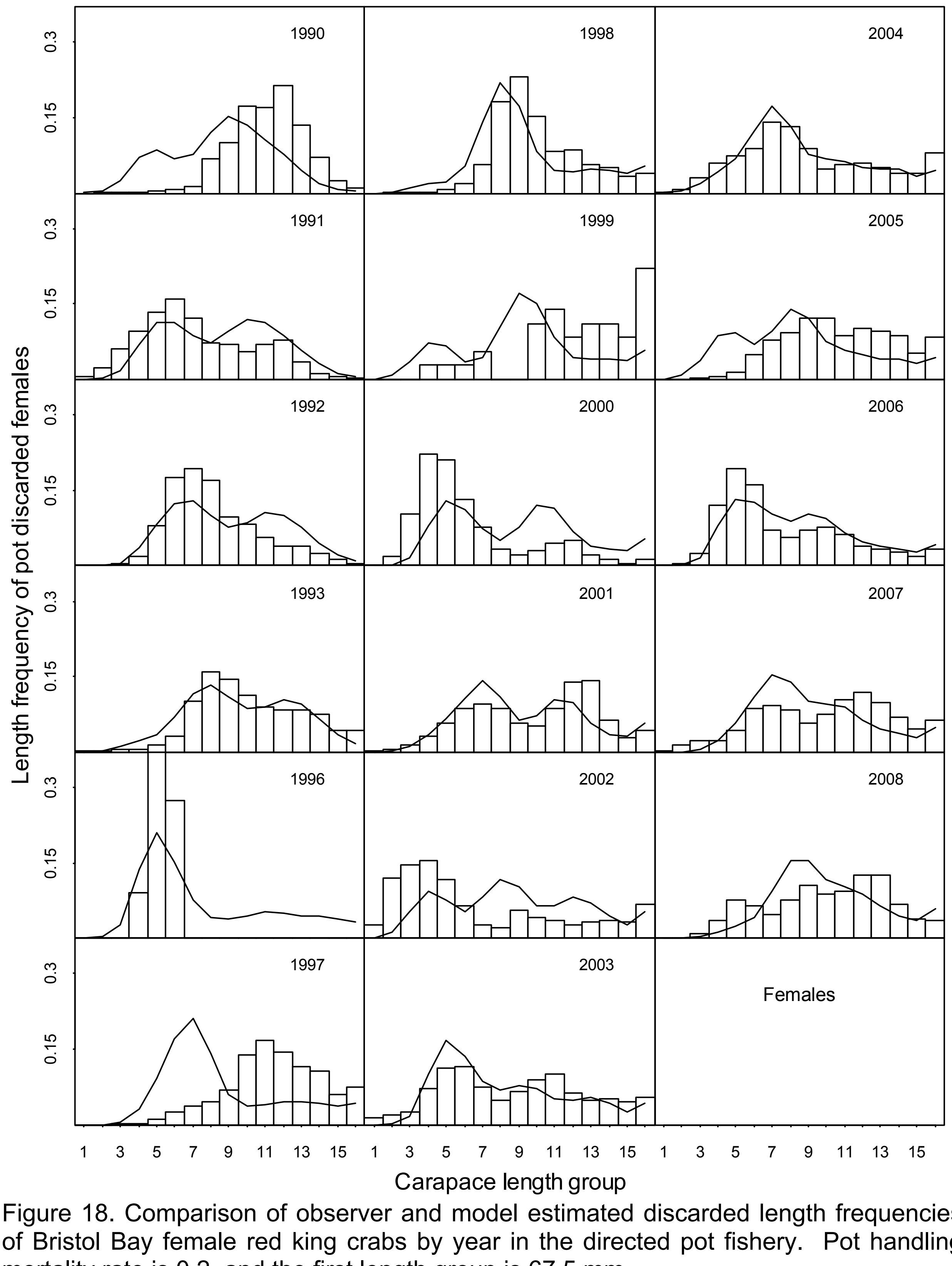


Figure 18. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the directed pot fishery. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

79

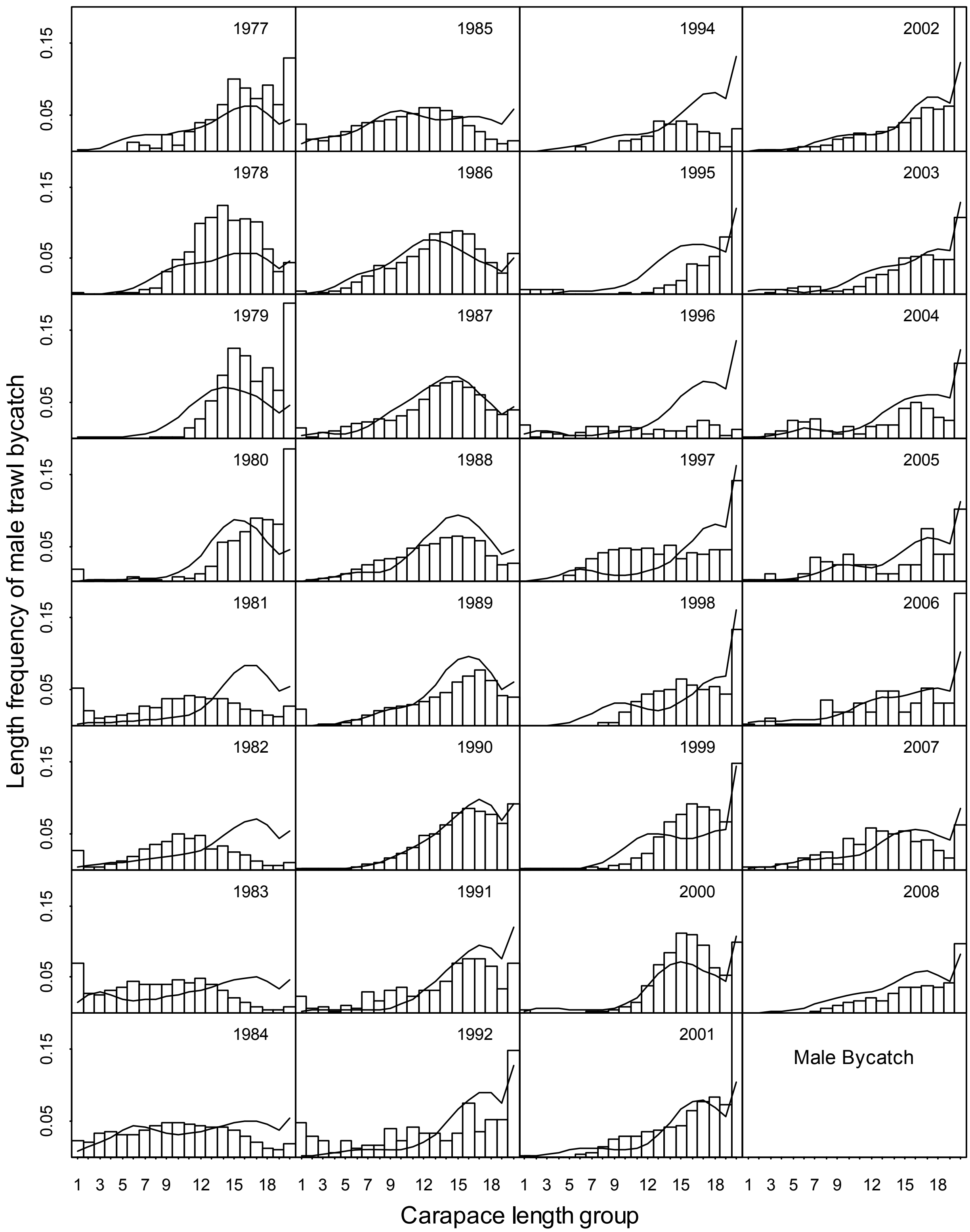


Figure 19. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

80

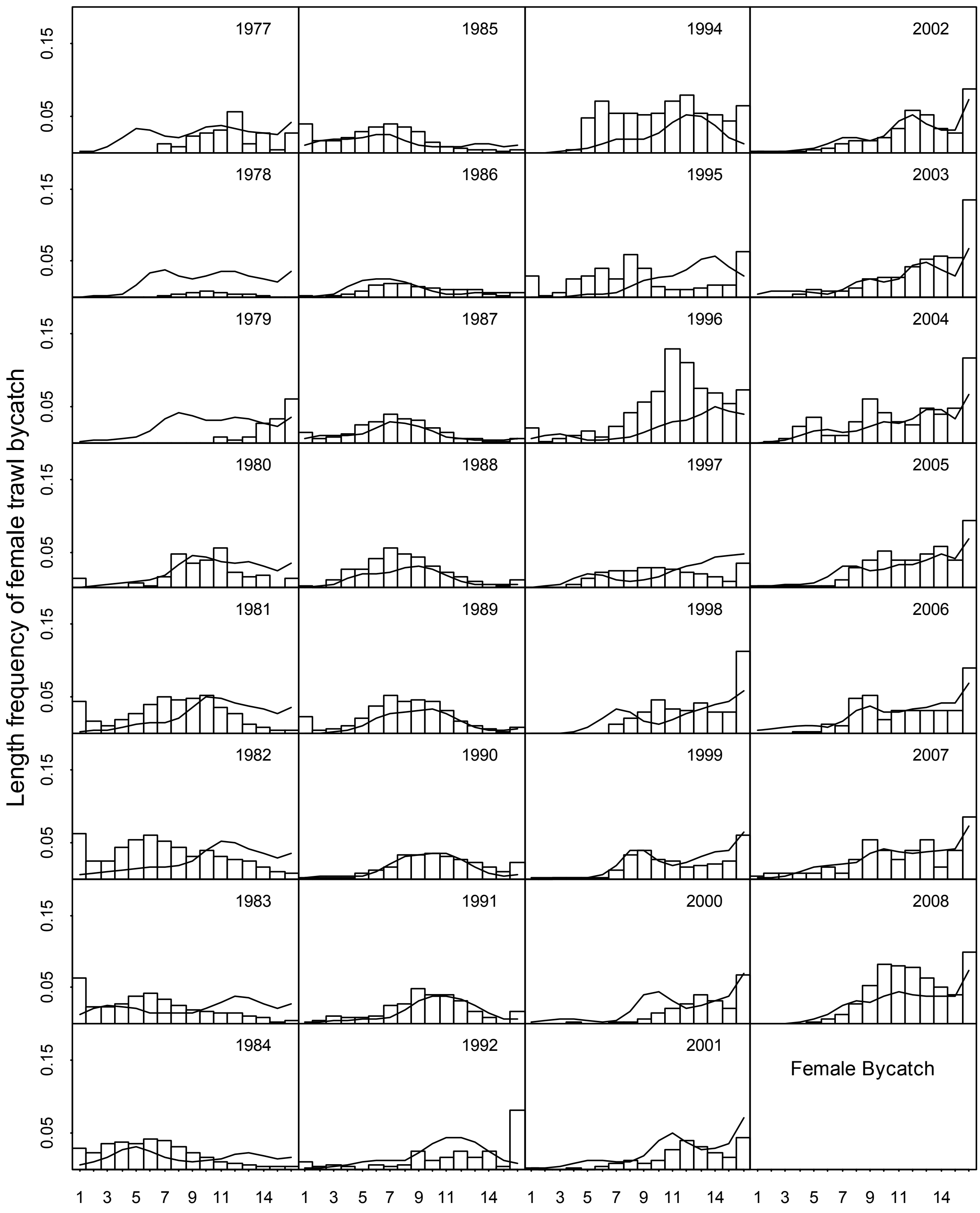


Figure 20. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crabs by year in the groundfish trawl fisheries. Pot handling mortality rate is 0.2, and the first length group is 67.5 mm.

81

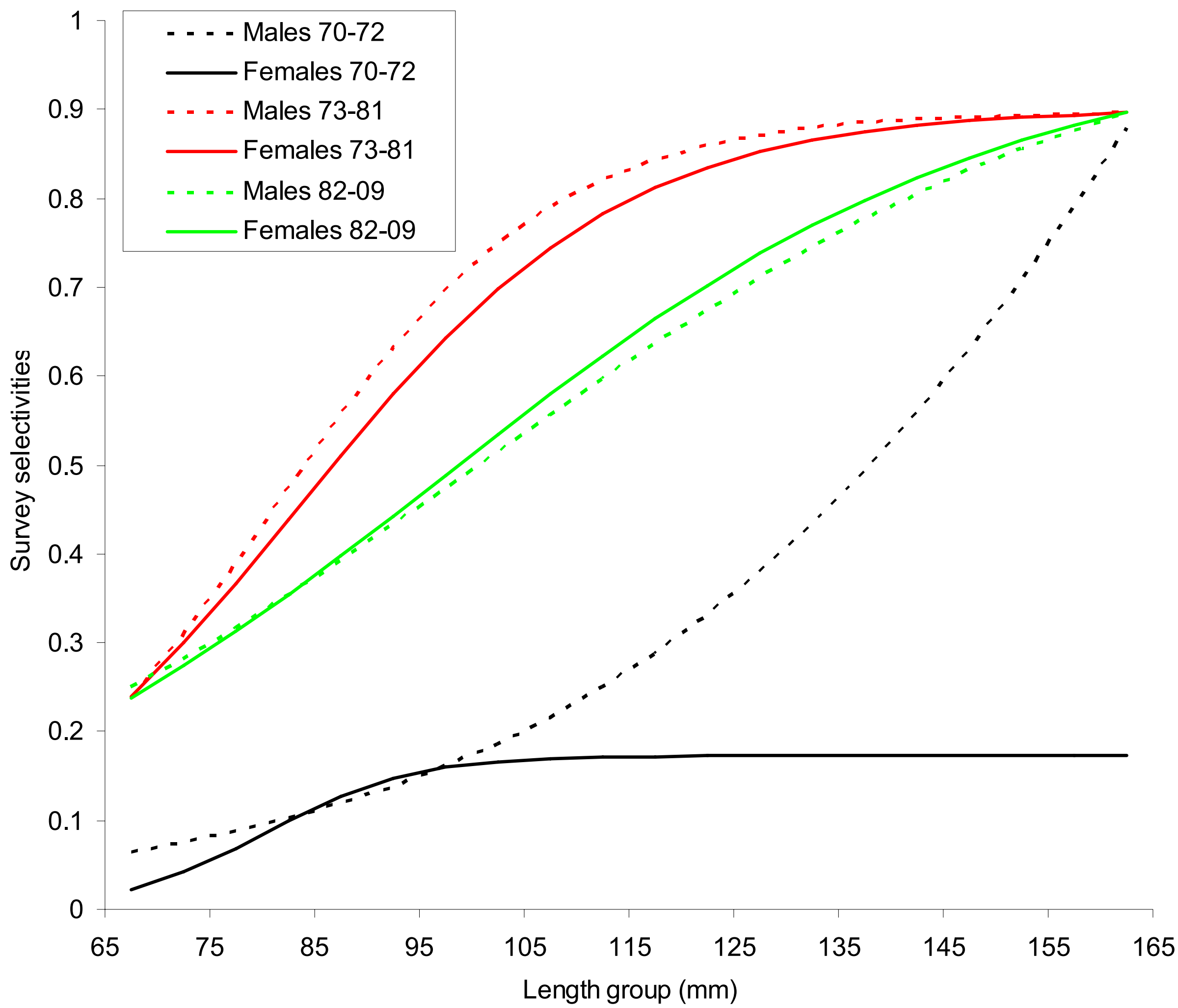


Figure 21a. Estimated trawl survey selectivities. Pot handling mortality rate is 0.2.

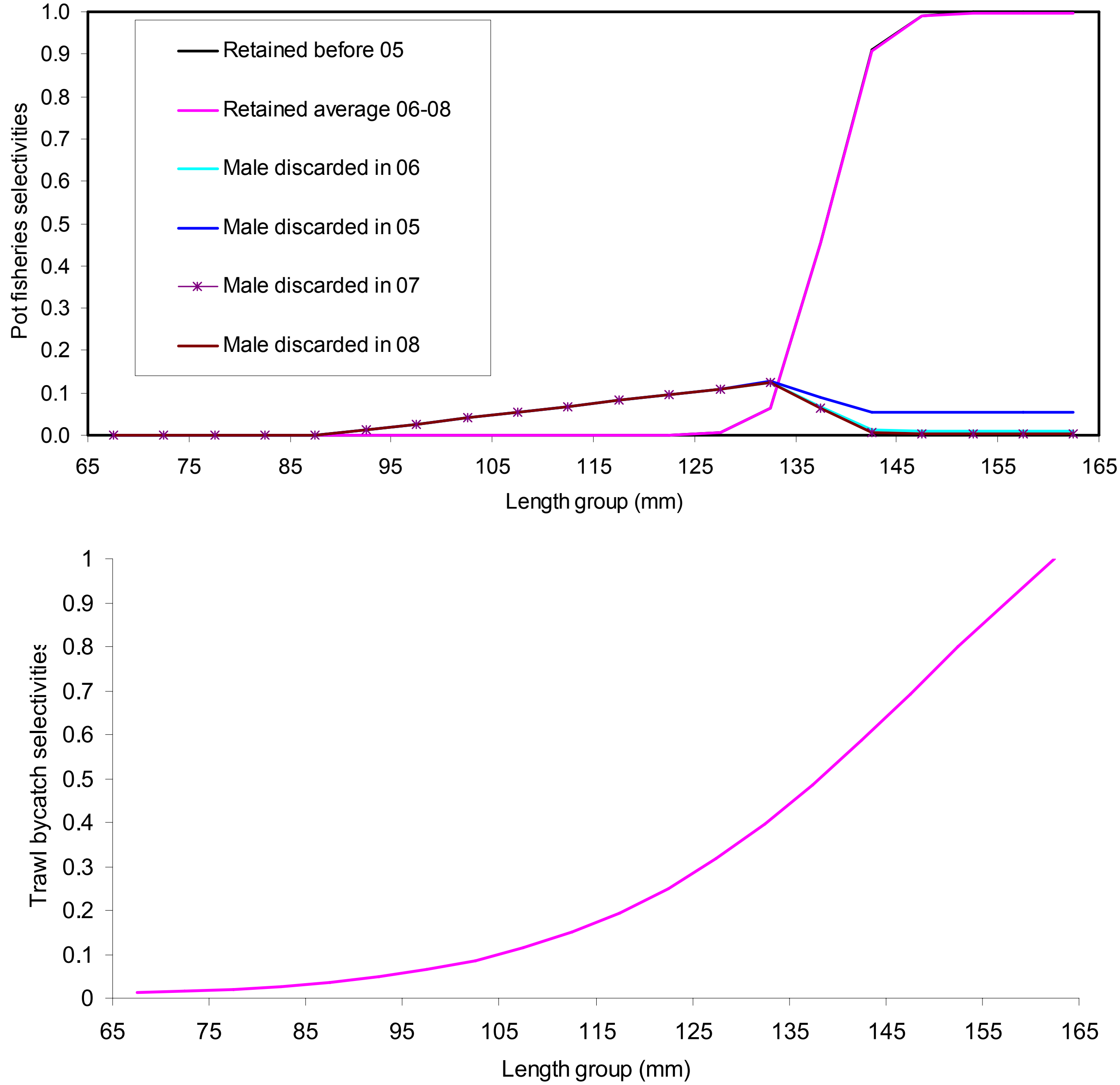


Figure 21b. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities. Pot handling mortality rate is 0.2.

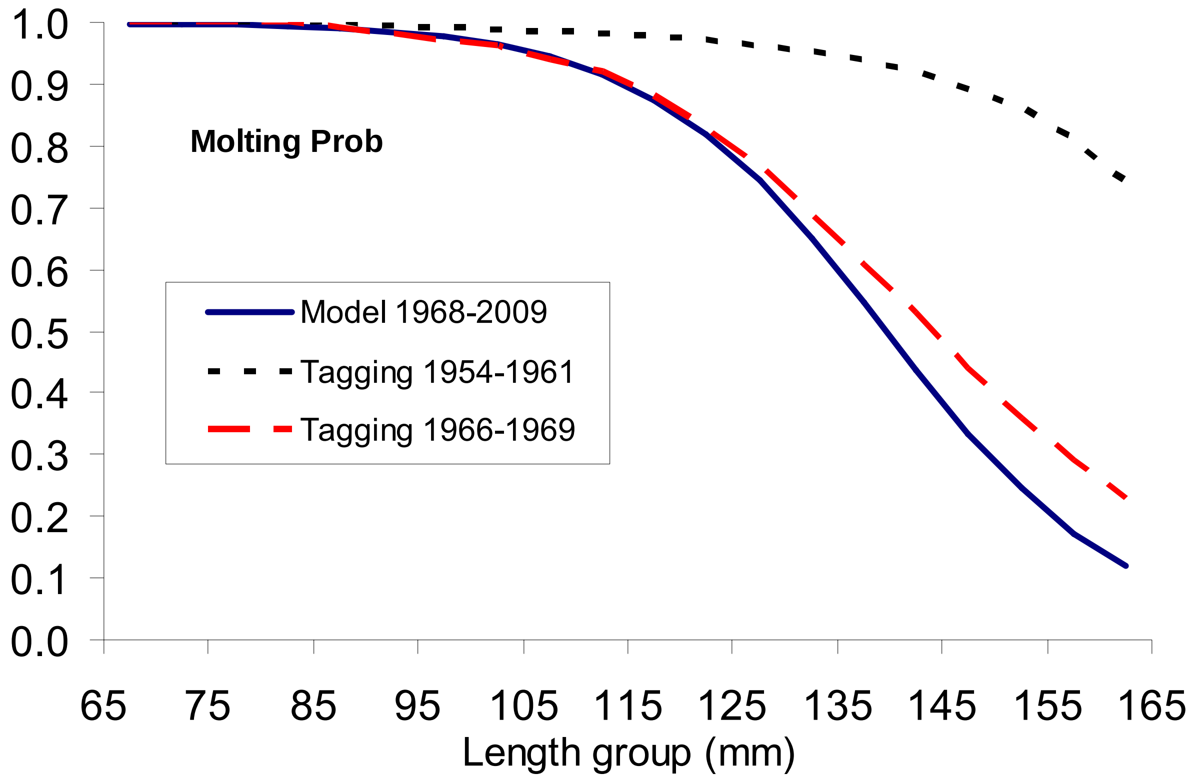


Figure 22. Comparison of estimated probabilities of molting of male red king crabs in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1968-2009 were estimated with a length-based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

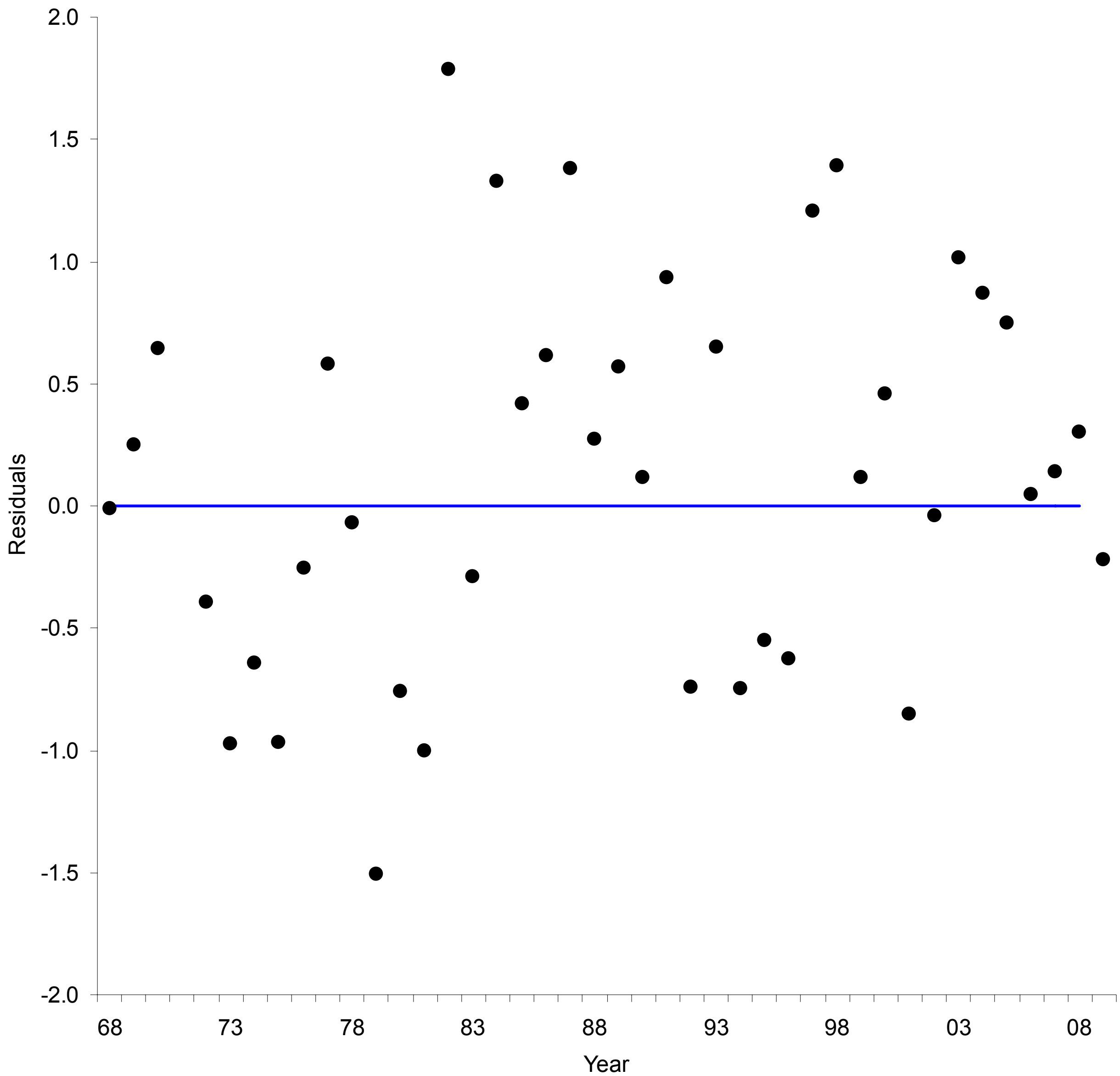


Figure 23. Standardized residuals of total survey biomass. Pot handling mortality rate is 0.2.

85

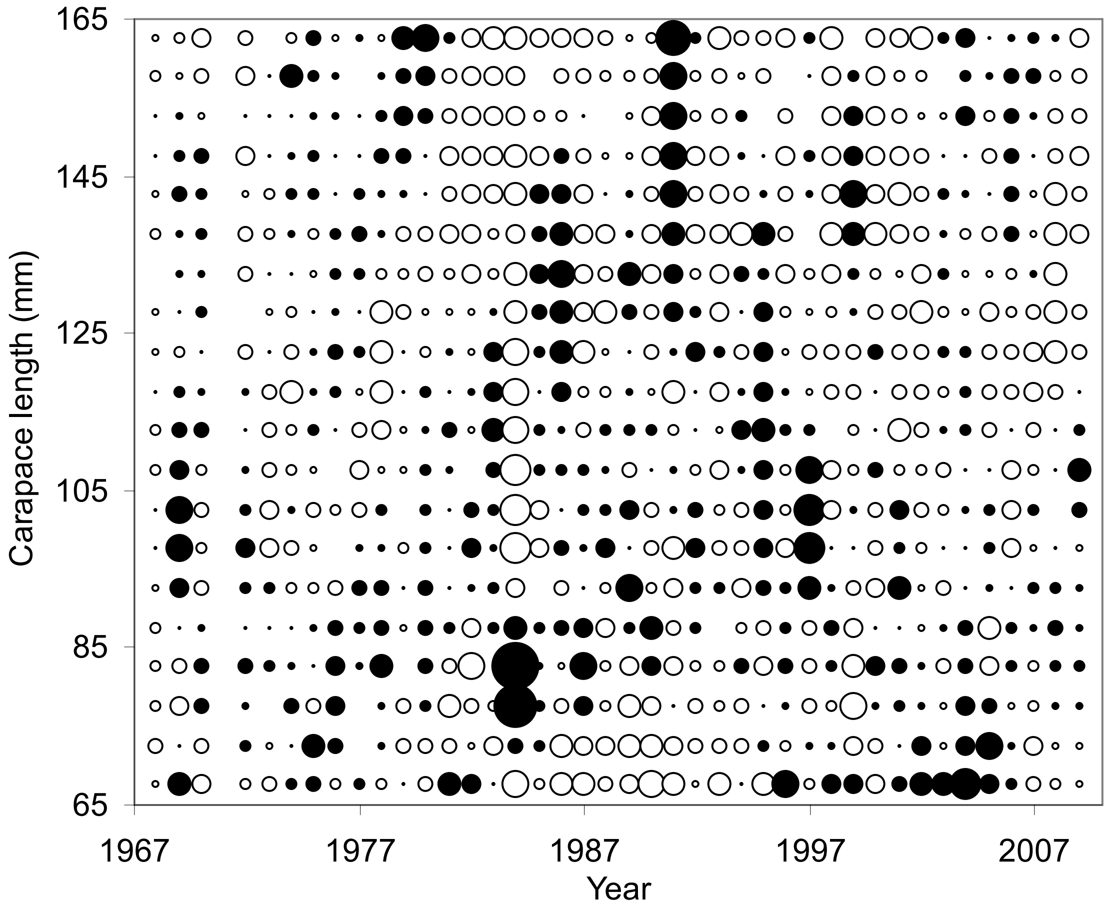


Figure 24. Standardized residuals of proportions of survey all-shell (1968-1985) and newshell (1986-2009) male red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.

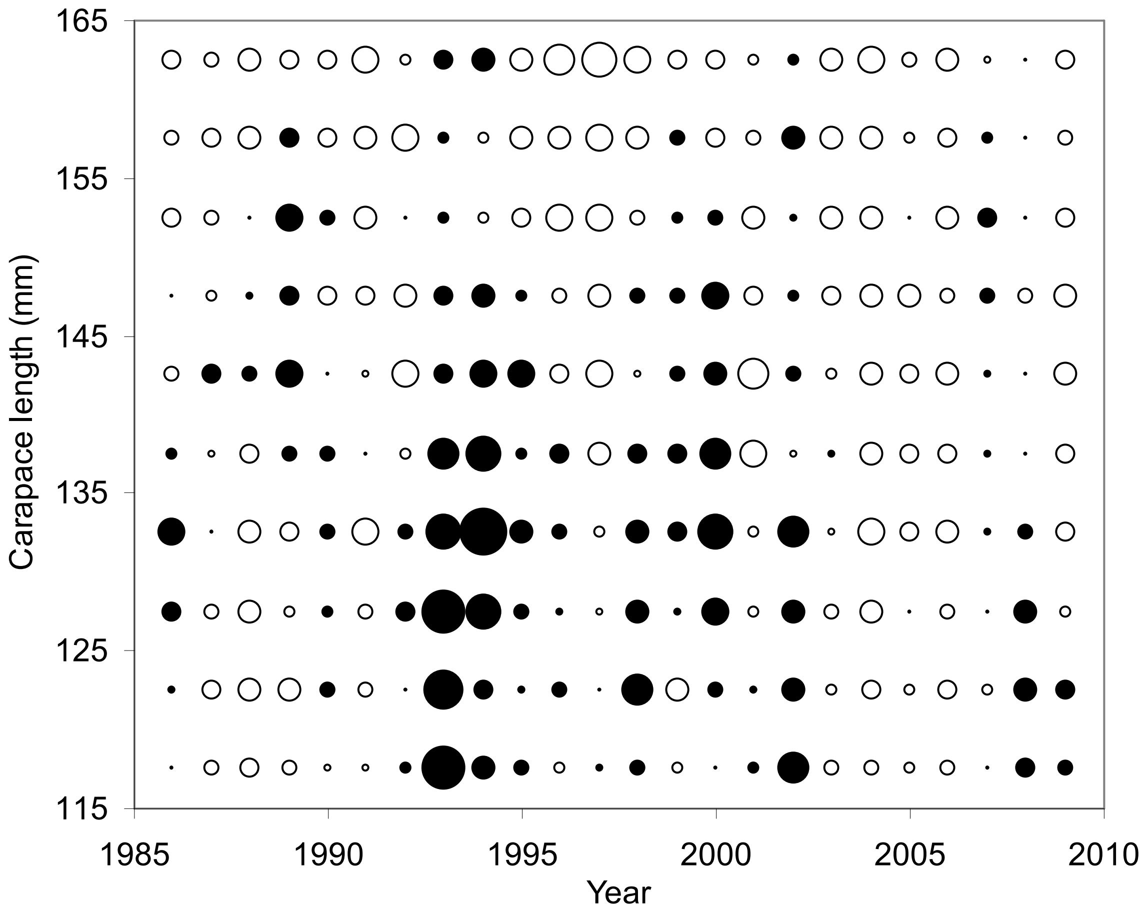


Figure 25. Standardized residuals of proportions of survey oldshell male red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.

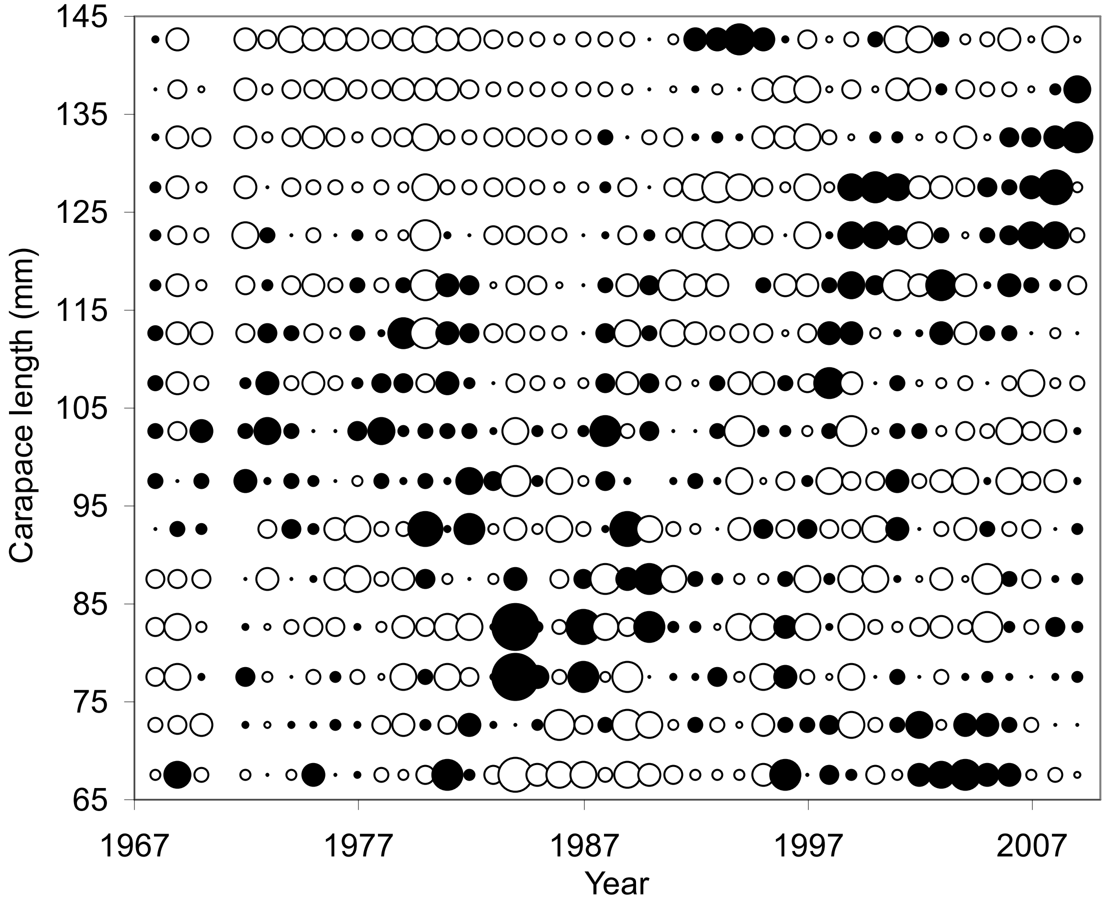
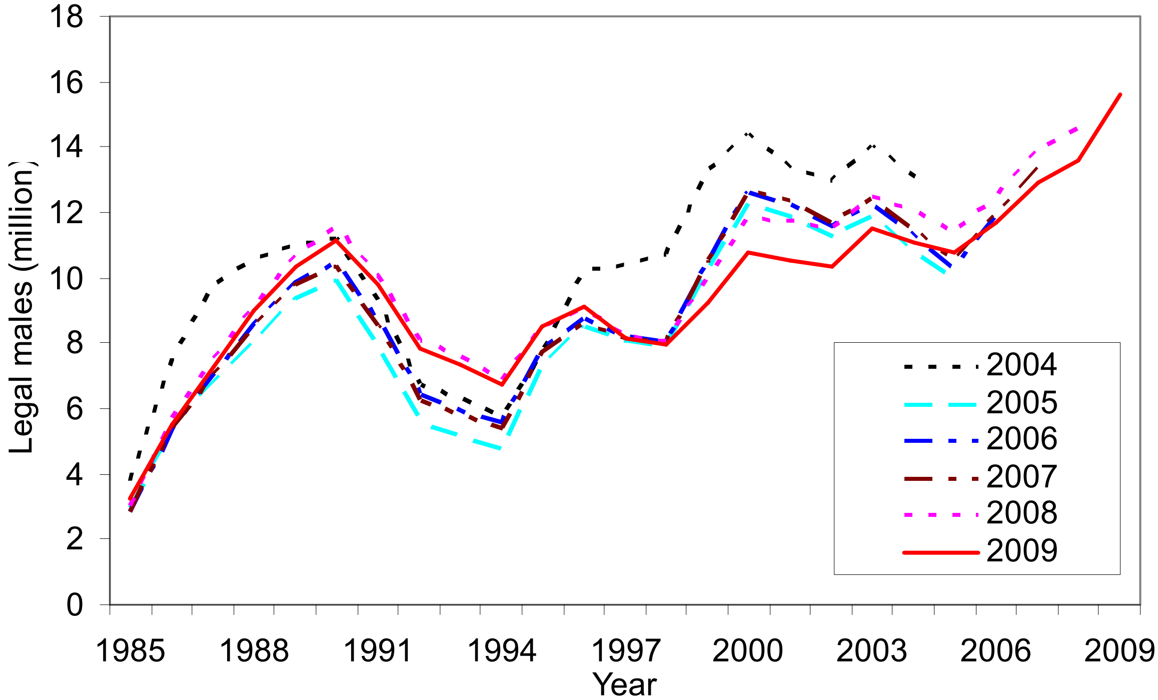


Figure 26. Standardized residuals of proportions of survey female red king crabs. Solid circles are positive residuals, and open circles are negative residuals. Pot handling mortality rate is 0.2.



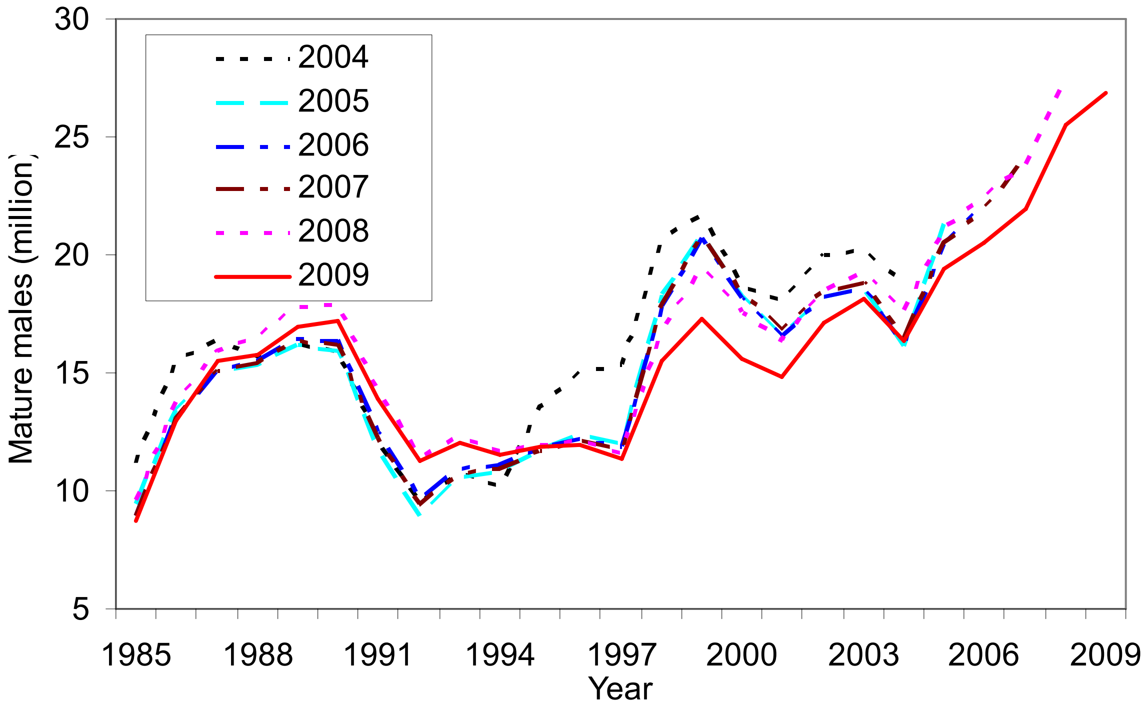
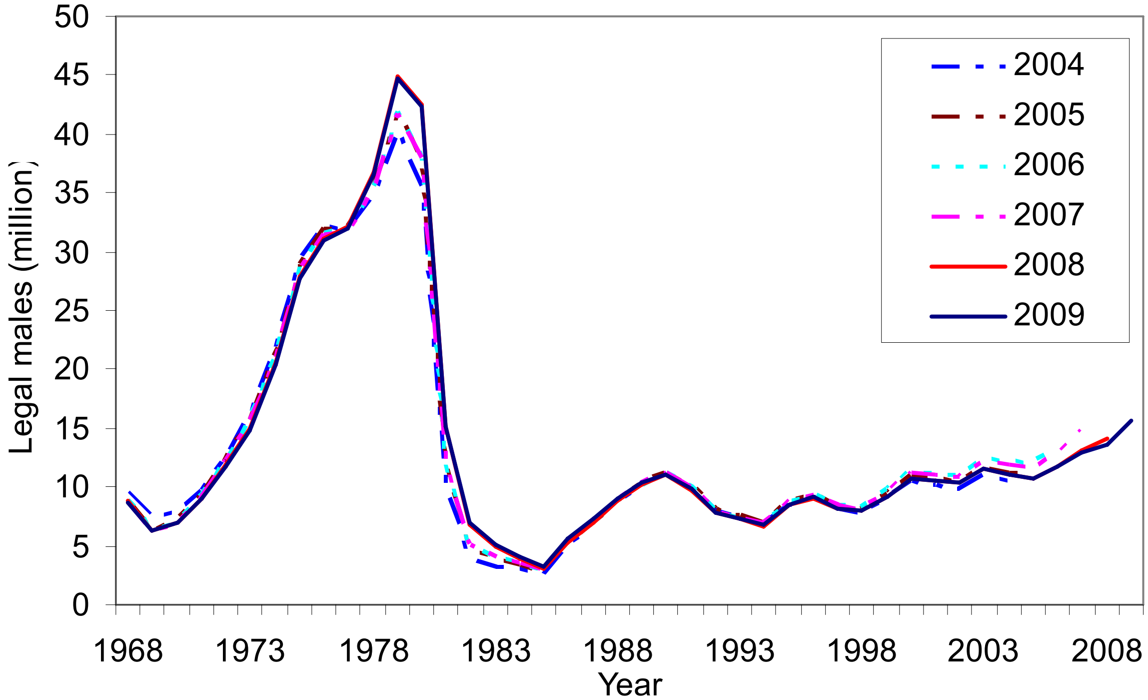


Figure 27. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1985 to 2009 made with terminal years 2004-2009 with scenario (3). These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot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



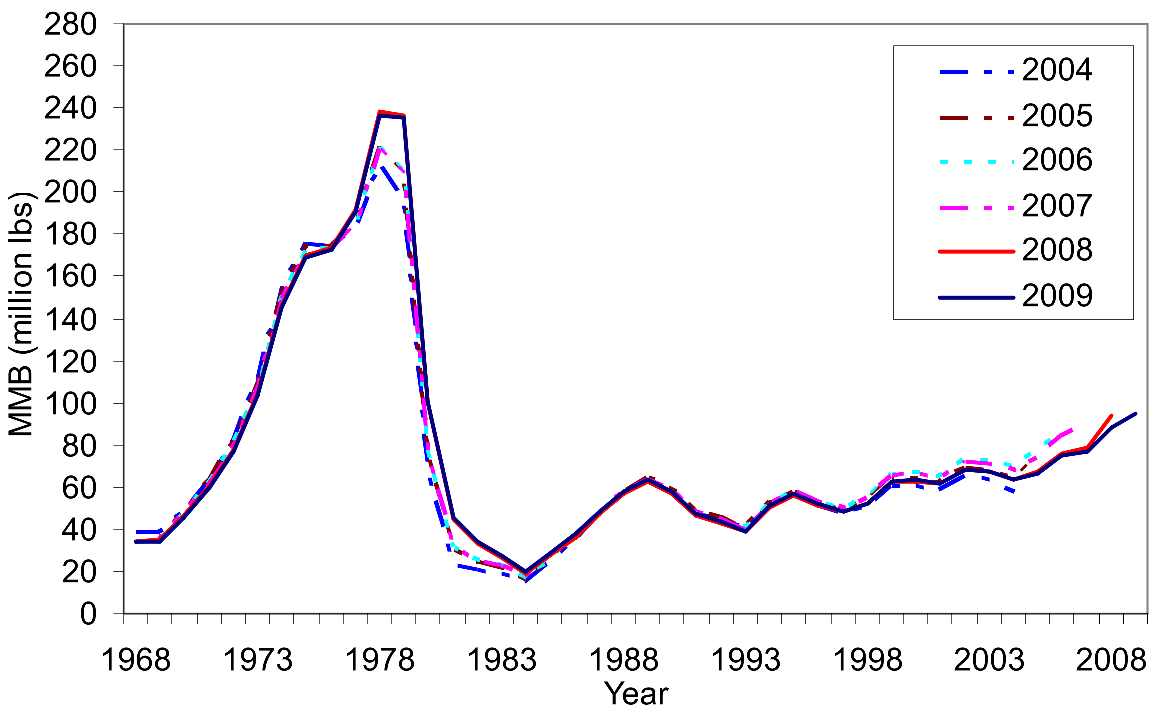
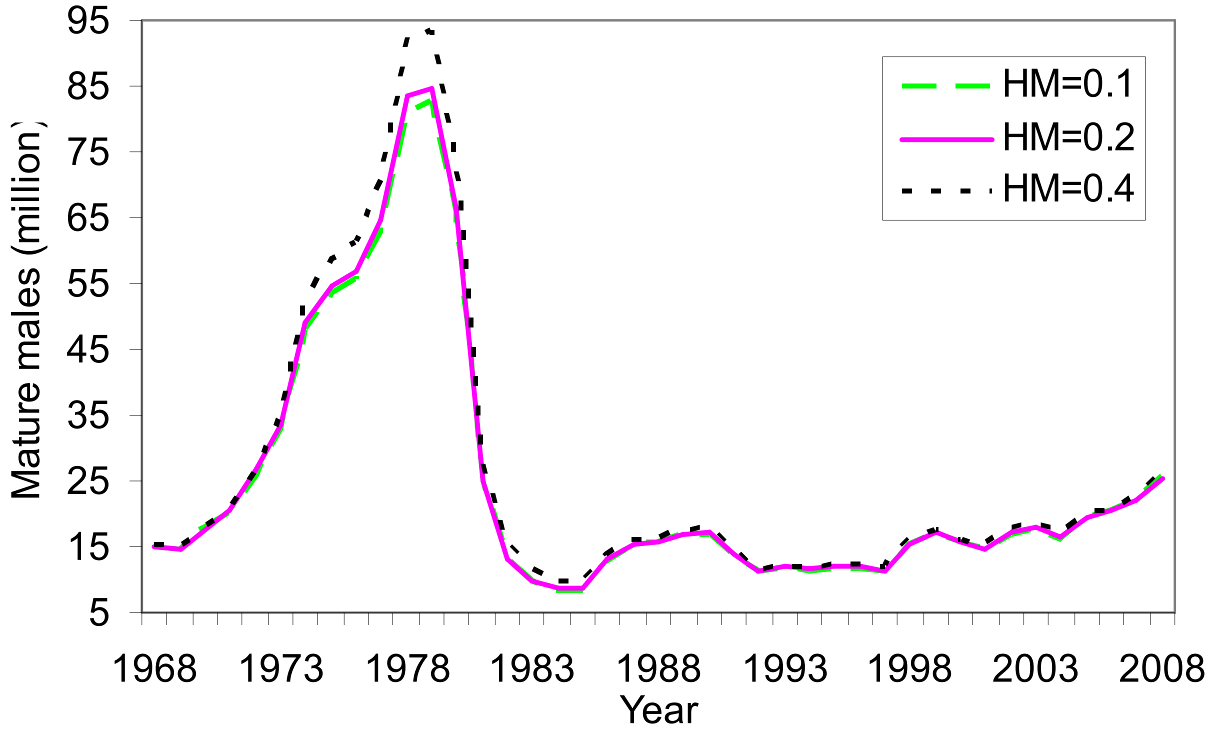


Figure 28. Comparison of estimates of legal male abundance (top) and mature male biomass (bottom) on Feb. 15 of Bristol Bay red king crab from 1968 to 2009 made with terminal years 2004-2009 with scenario (3). These are results of the 2009 model. Legend shows the year in which the assessment was conducted.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



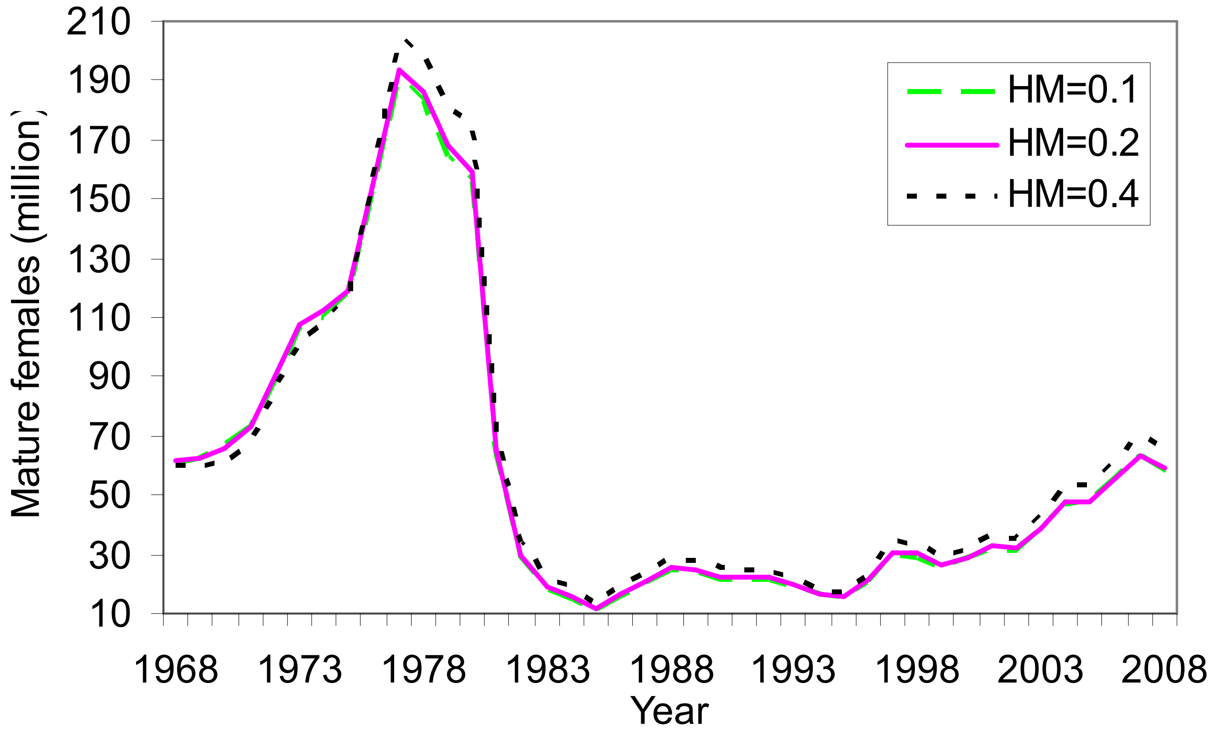


Figure 29. Comparison of mature abundance estimates for pot handling mortality rates of 0.1, 0.2 and 0.4. Mature females are for crabs >89 mm CL in this plot.

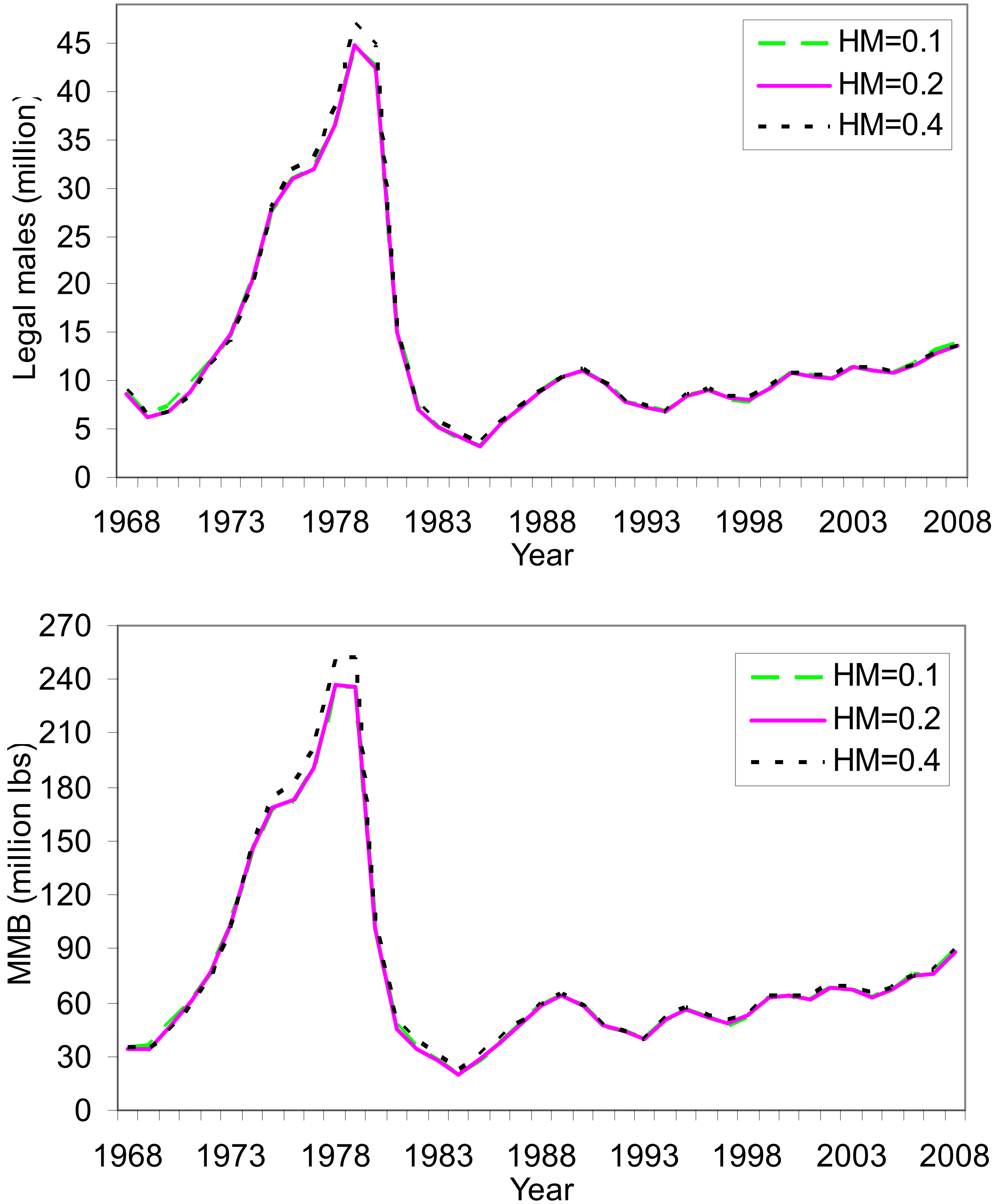


Figure 30. Comparison of legal male abundance estimates and mature male biomass on Feb. 15 for pot handling mortality rates of 0.1, 0.2 and 0.4.

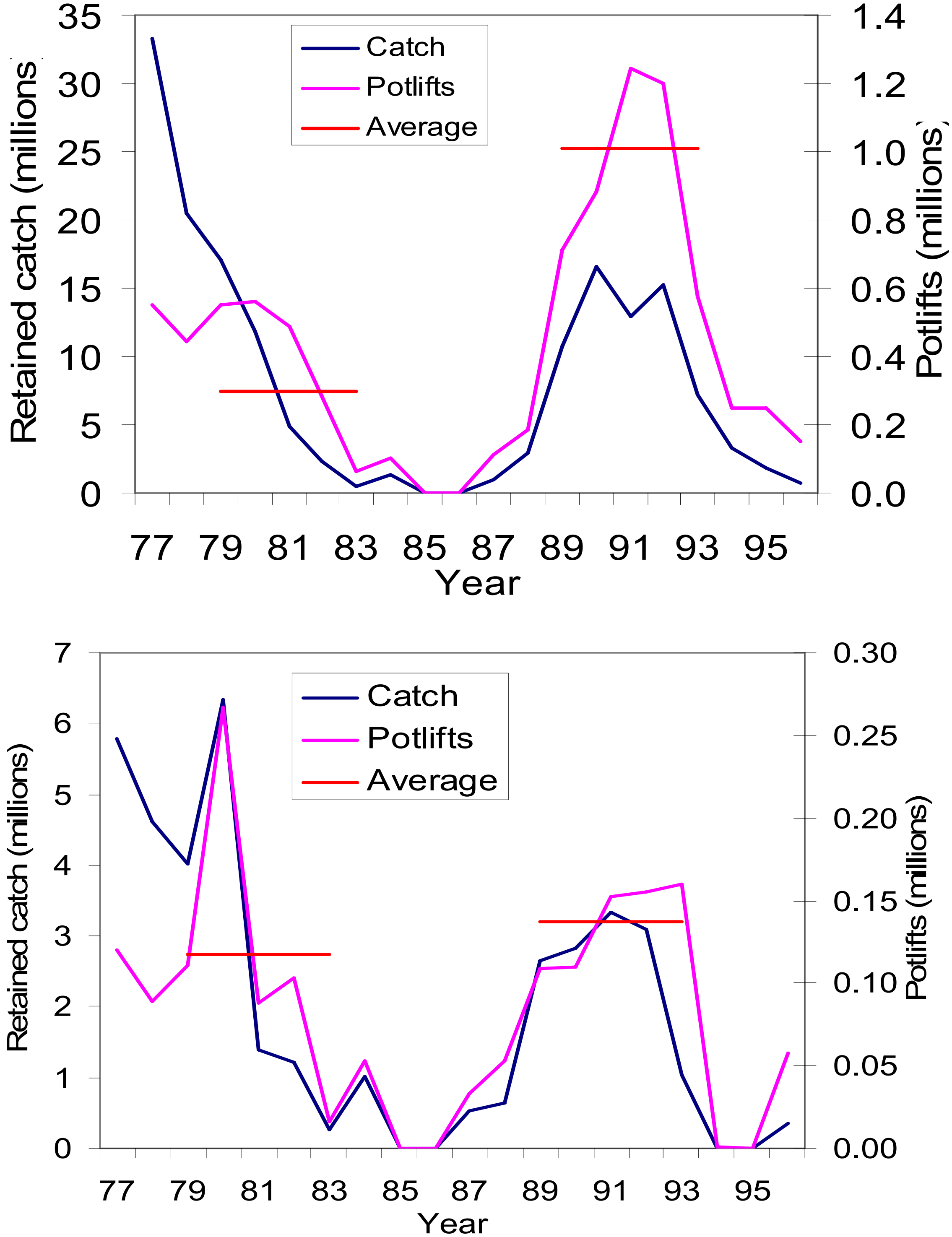


Figure 31. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

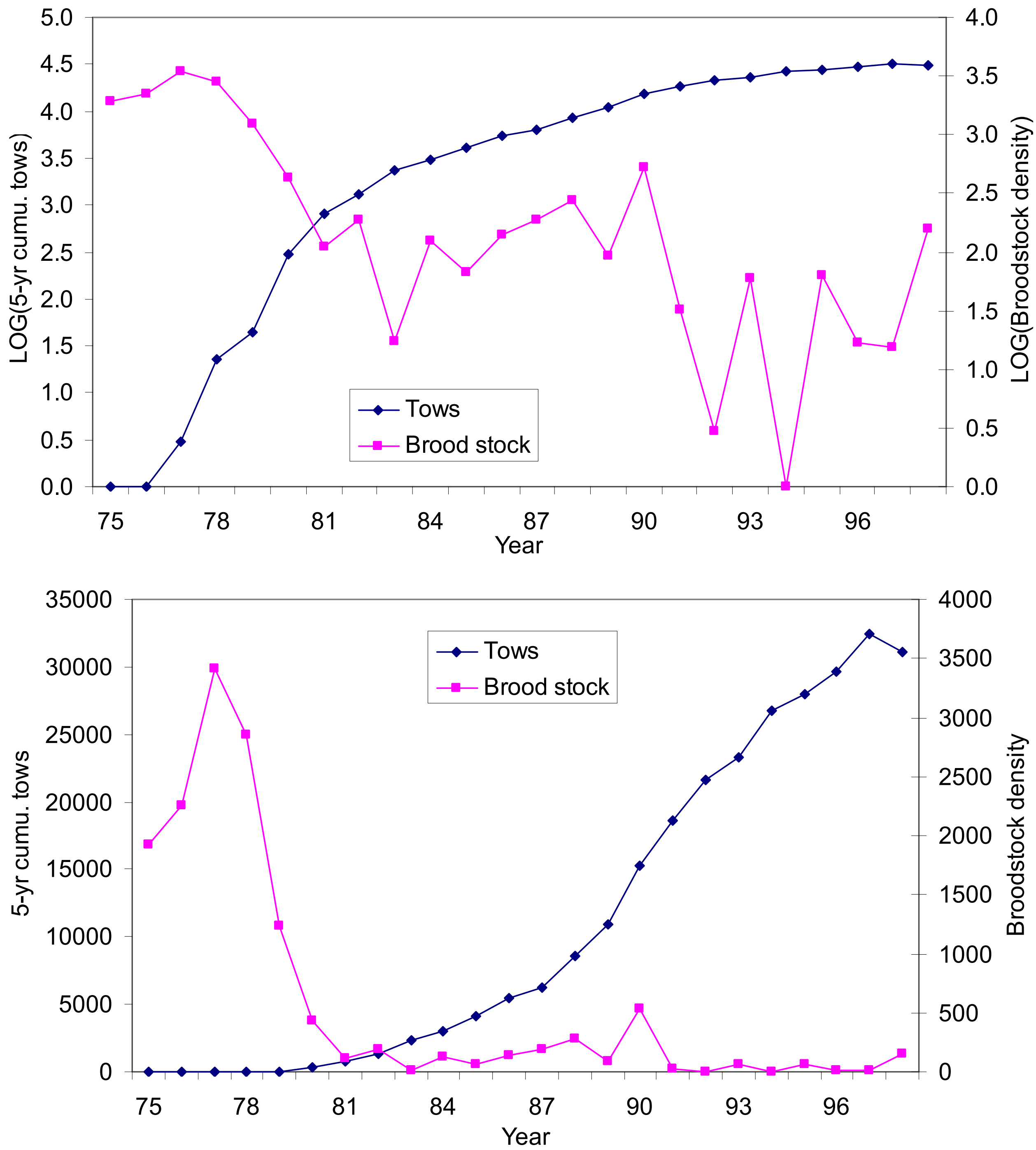


Figure 32a. Numbers of bottom trawl tows and red king crab brookstock density in heavily trawled Unimak and Amak of the southern Bristol Bay during 1975-1998. The upper plot is log-transformed data used by Dew and Mcconnaughey (2005), and the bottom plot is in a normal scale. All data are from Dew and Mcconnaughey (2005).

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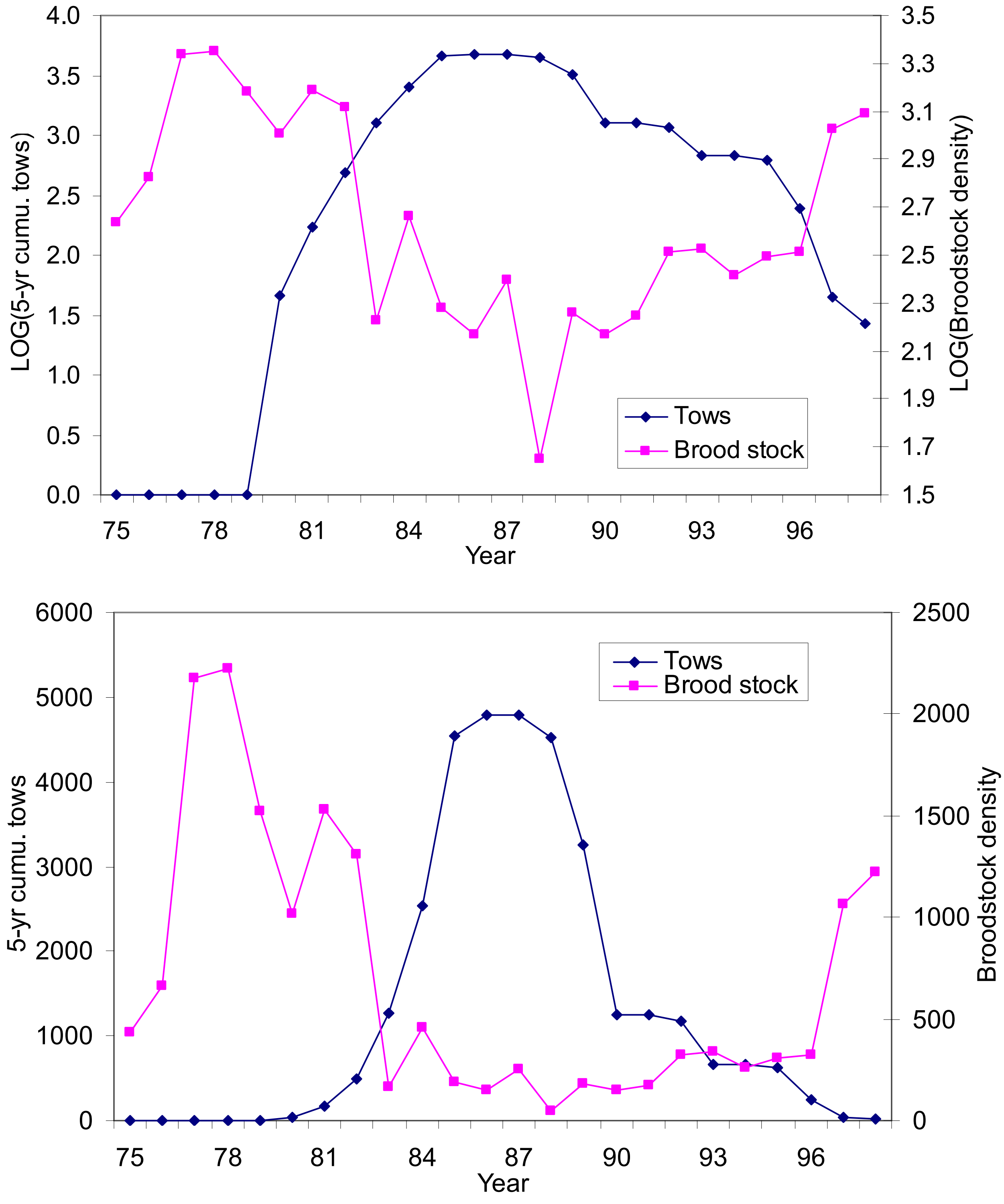

Figure 32b. Numbers of bottom trawl tows and red king crab brookstock density in lightly trawled north of Port Moller, Bristol Bay, during 1975-1998. The upper plot is log-transformed data used by Dew and Mcconnaughey (2005), and the bottom plot is in a normal scale. All data are from Dew and Mcconnaughey (2005).

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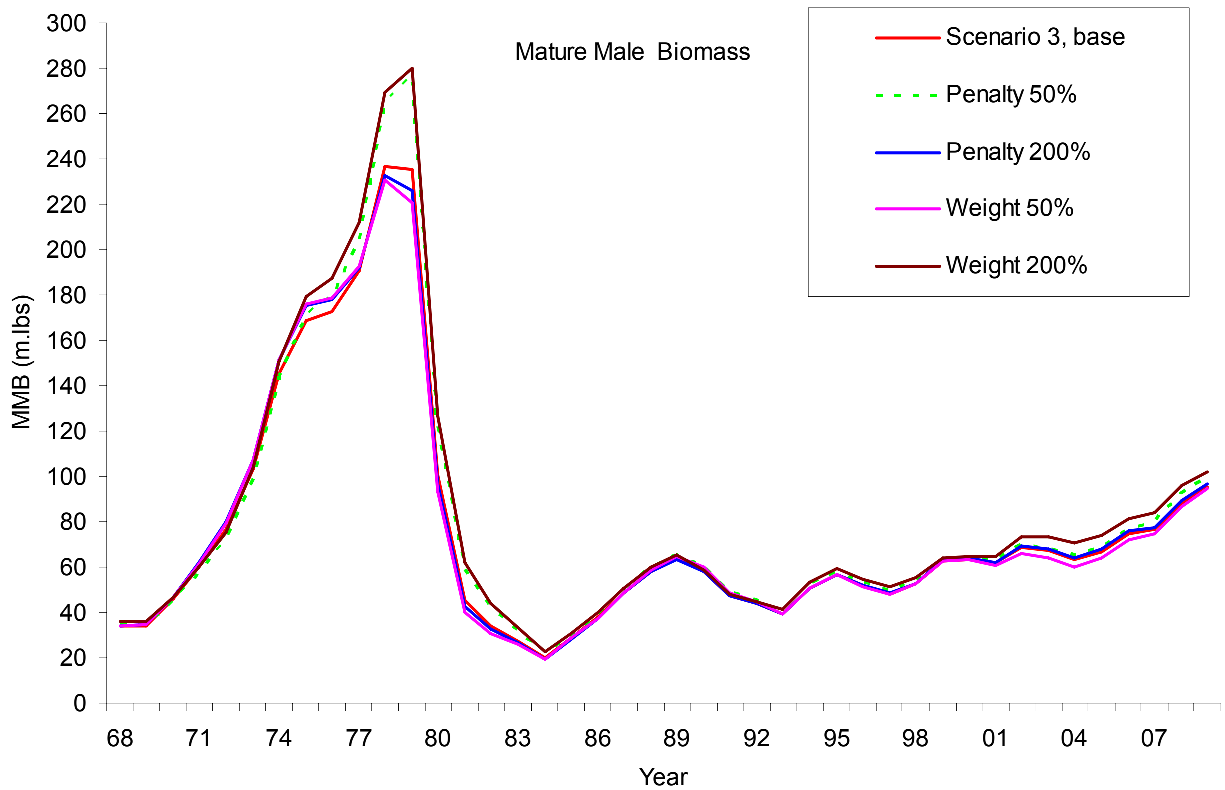


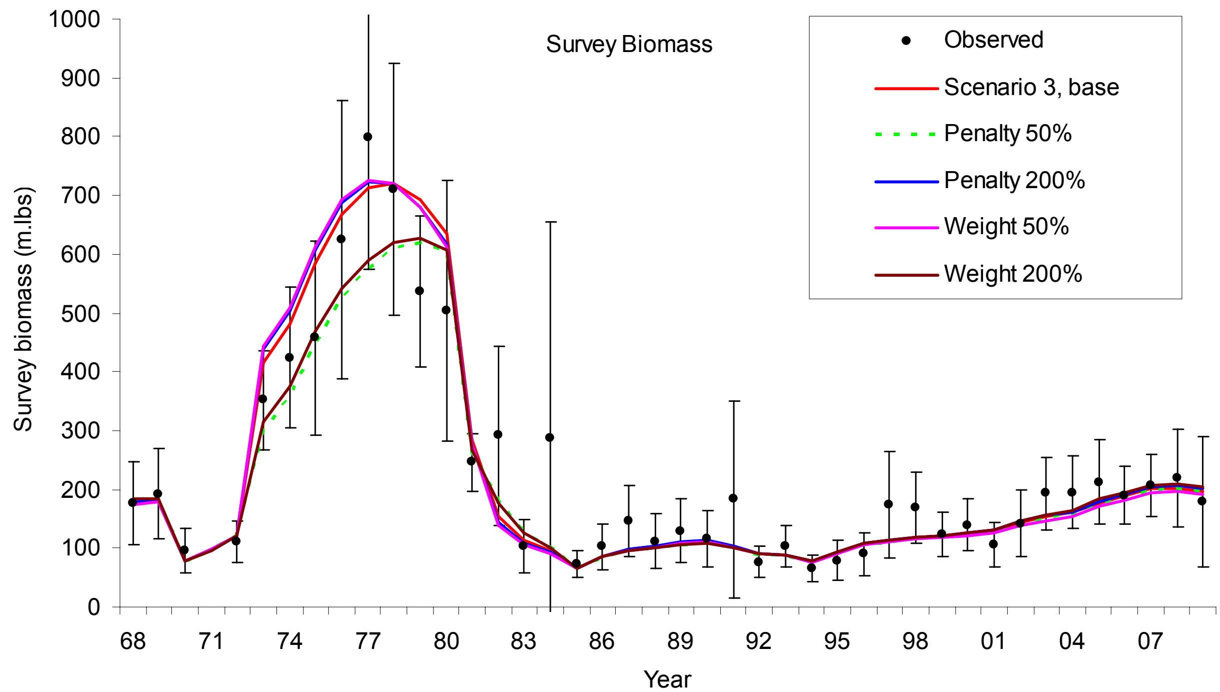
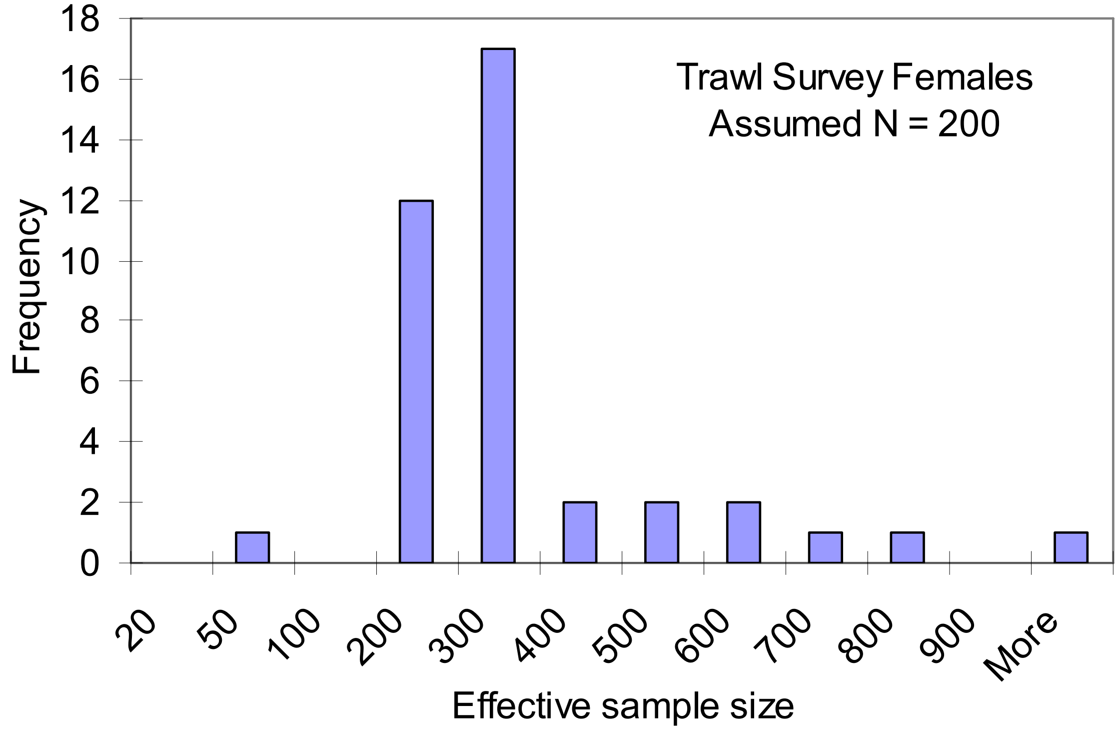


Figure 33. Comparison of estimated mature male biomasses and survey biomasses with alternative weights on biomass and penalty terms. The weights to all biomasses and penalty terms were reduced to 50% or increased to 200%.



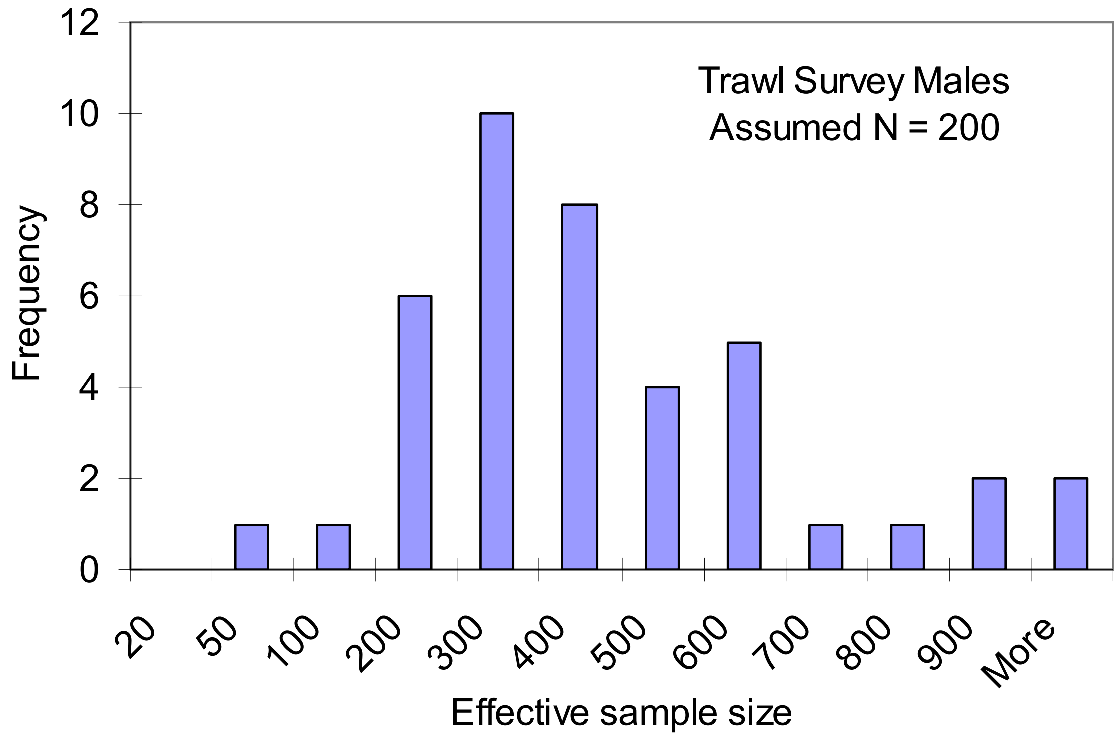


Figure 34a. Estimated effective sample sizes for length/sex composition data: trawl survey data.

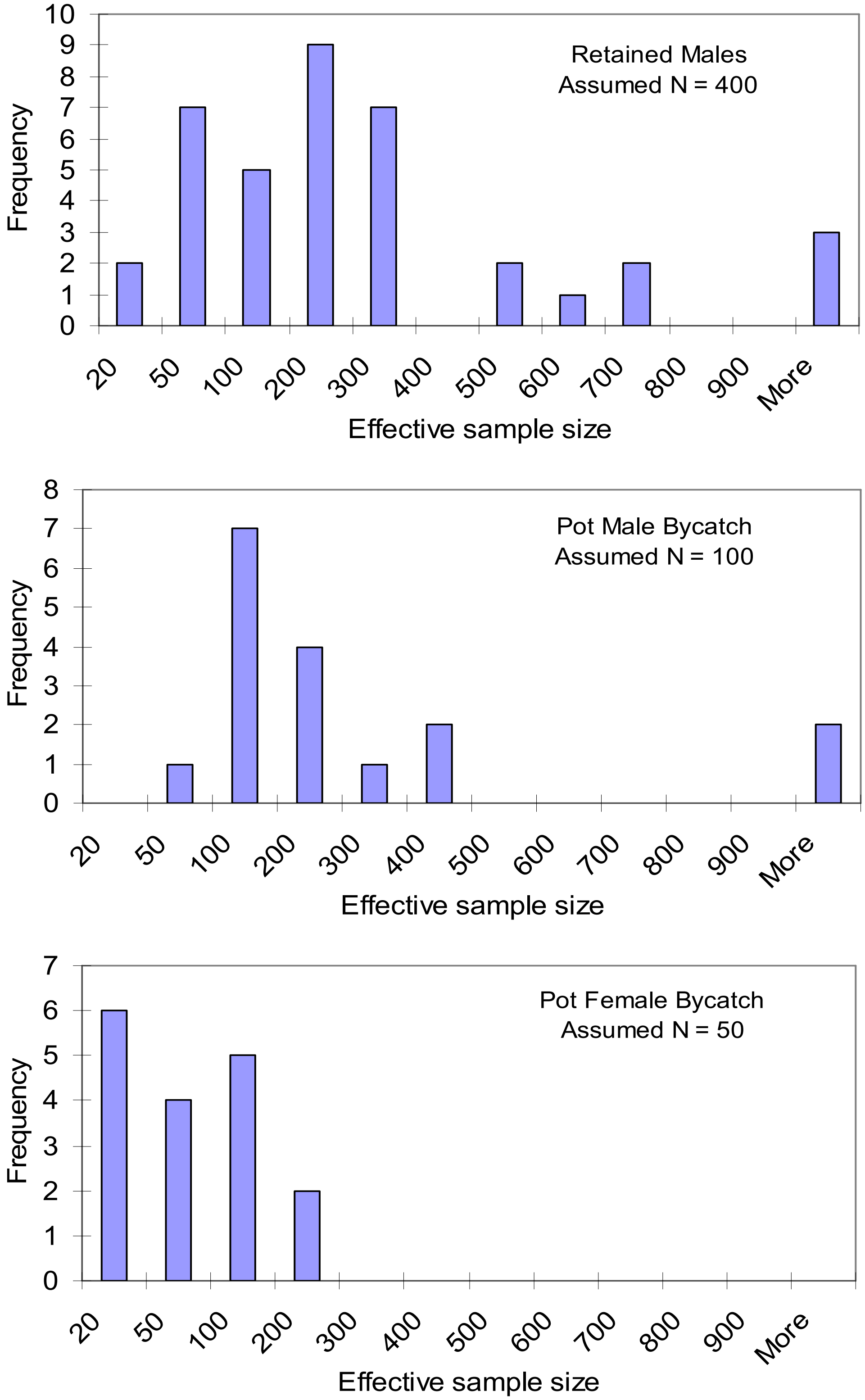


Figure 34b. Estimated effective sample sizes for length/sex composition data: directed pot fishery data

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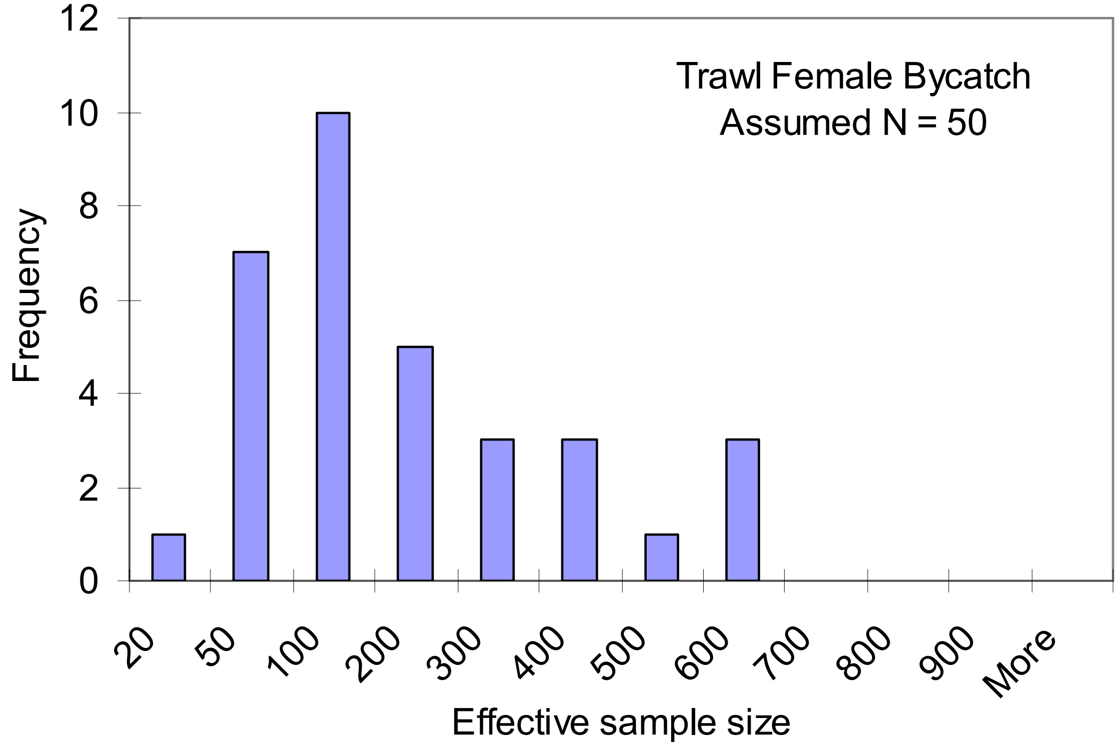

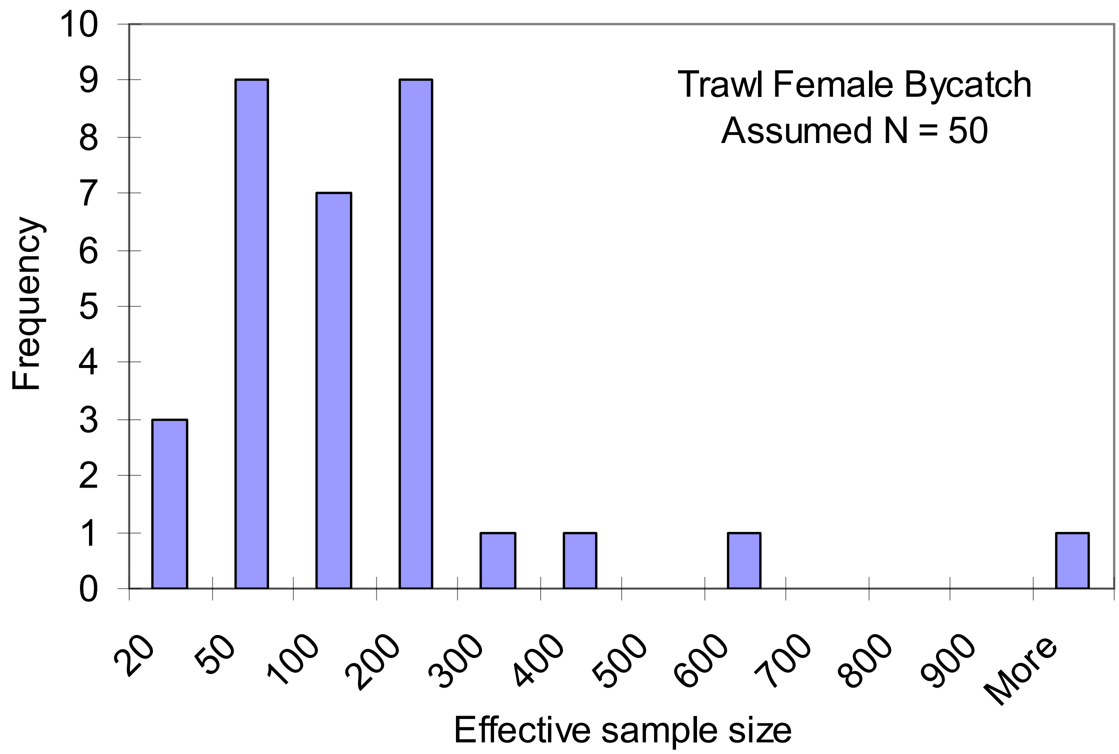

Figure 34c. Estimated effective sample sizes for length/sex composition data: trawl bycatch data.

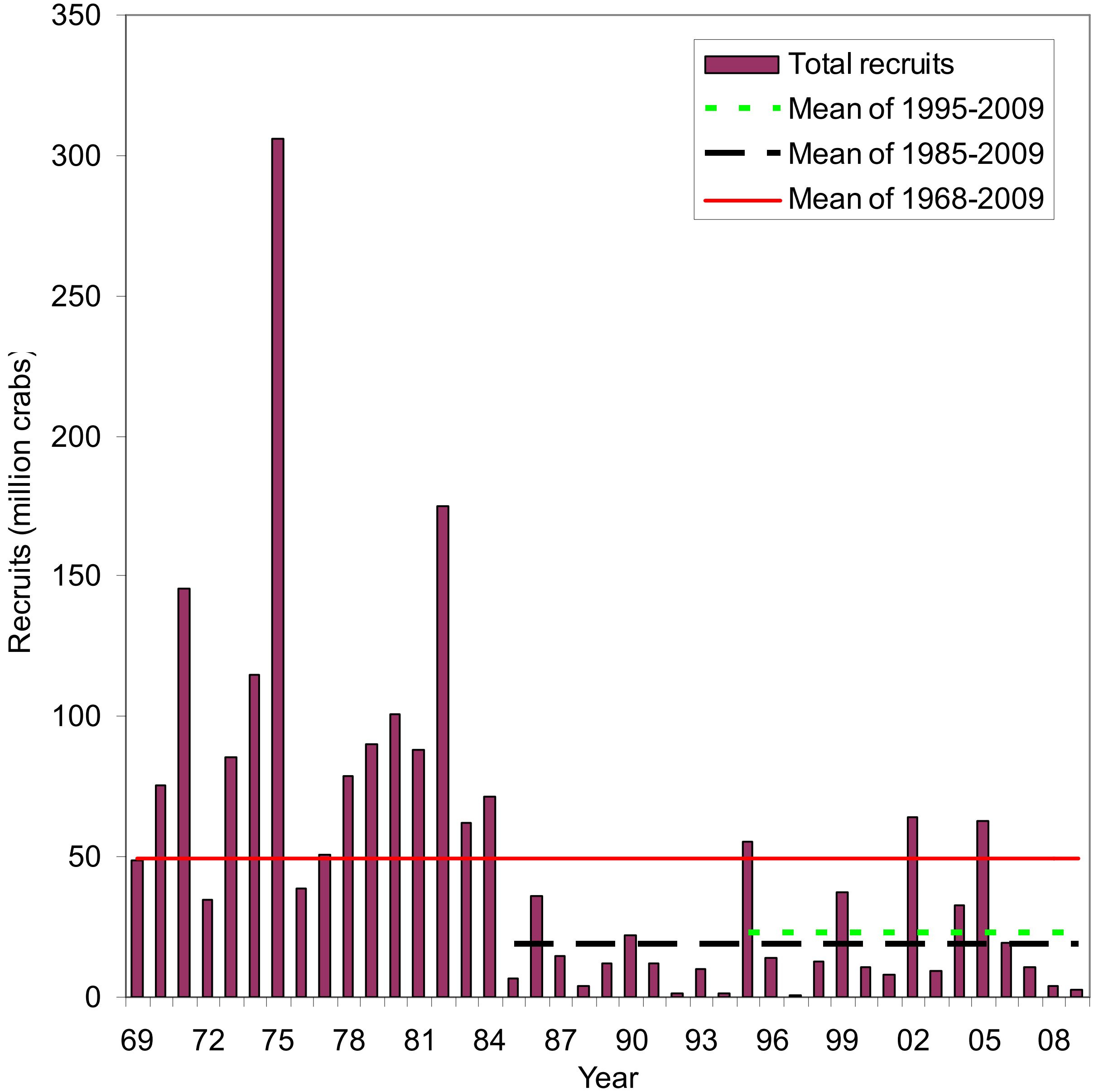

Figure 35. Estimated recruitment time series during 1969-2009 (occurred year) with scenario (3). Mean male recruits during 1995-2009 was used to estimate $B_{35\%}$.

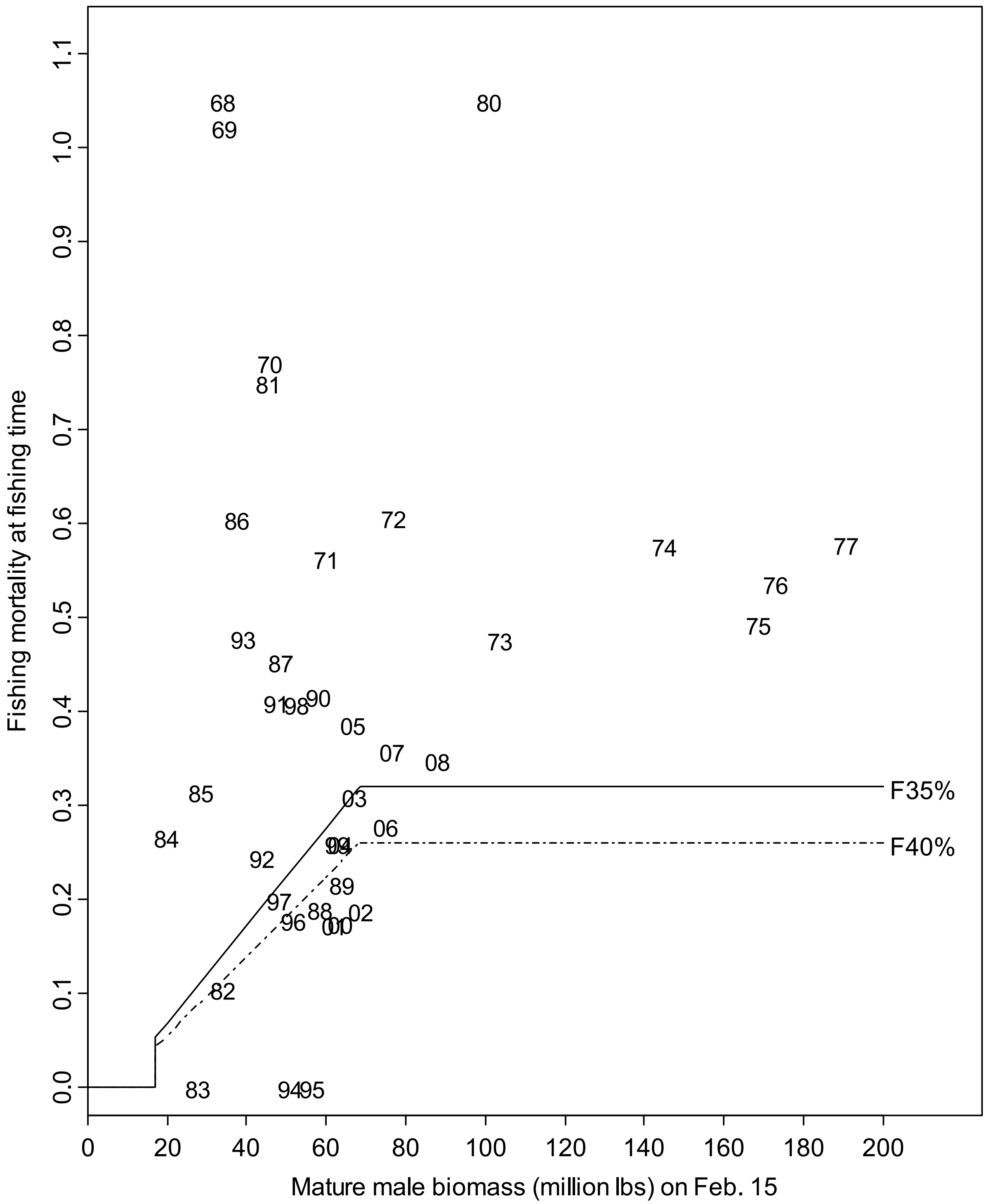

Figure 36. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1968-2008. Average of recruitment from 1995 to 2008 was used to estimate B_{MSY}. Pot handling mortality rate is 0.2.

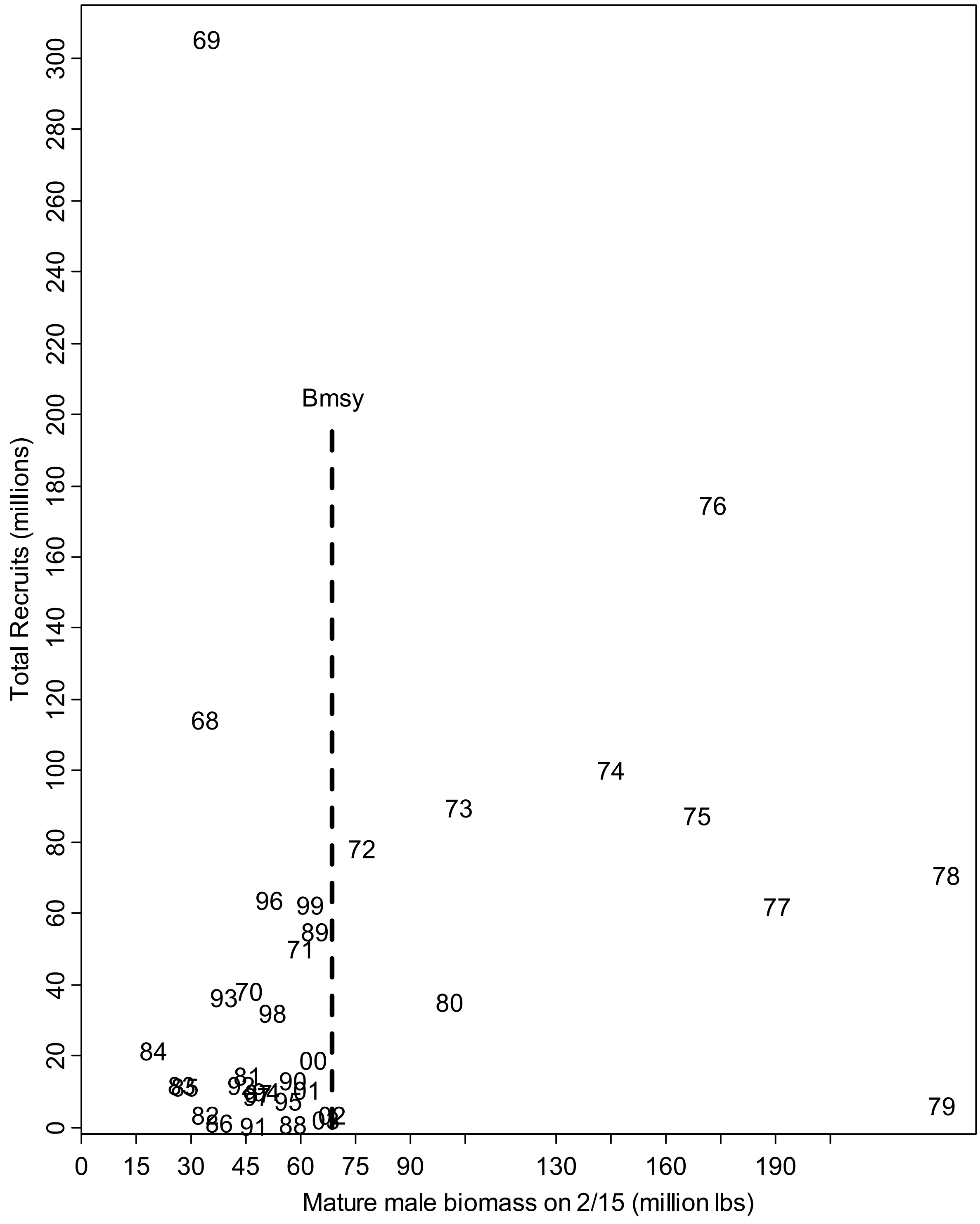

Figure 37a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate to be 0.2. Numerical labels are years of mating, and the vertical dotted lines are the estimated $B_{35\%}$ based on three different recruitment levels.

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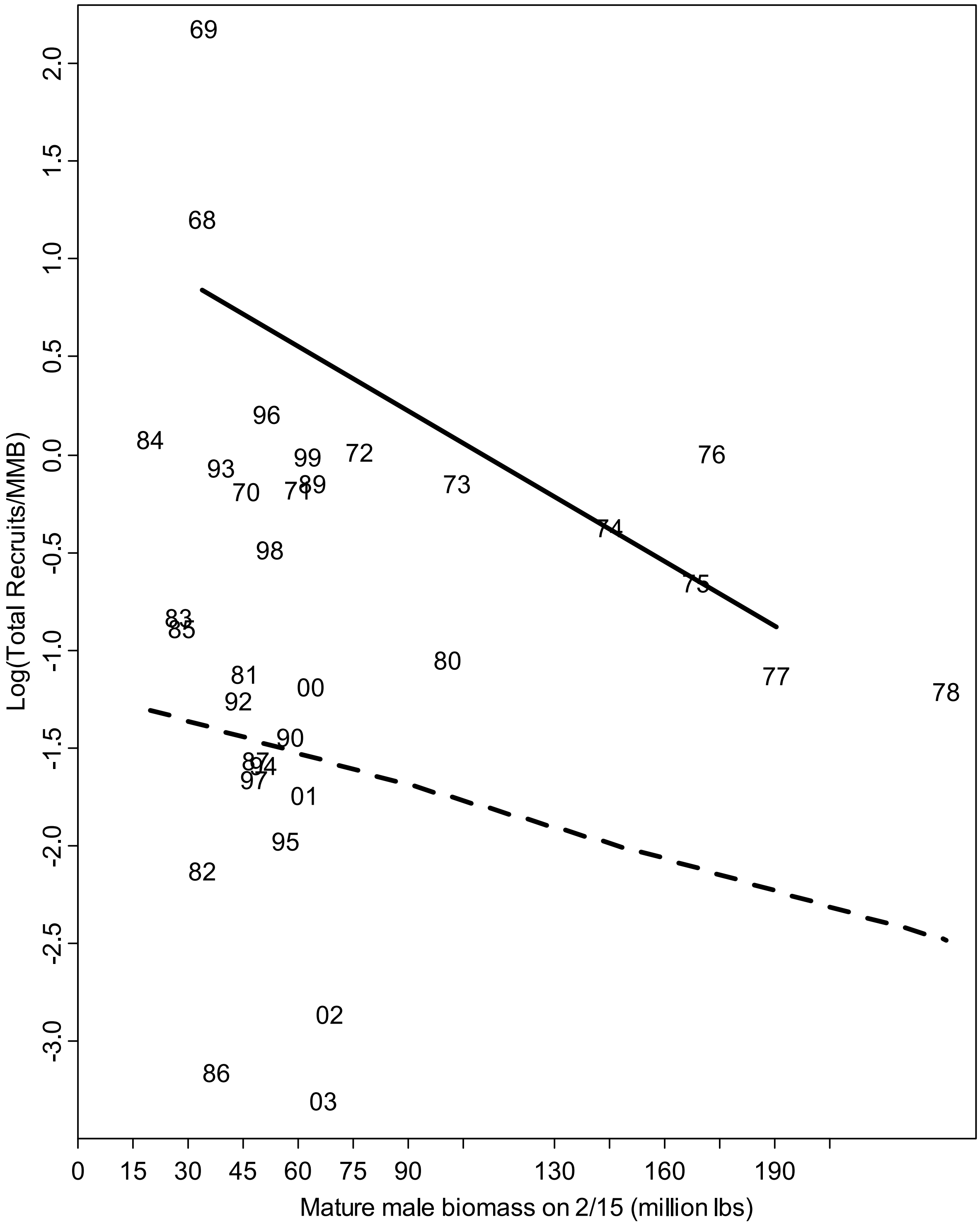

Figure 37b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate to be 0.2. Numerical labels are years of mating, the solid line is the regression line for data of 1968-1977, and the dotted line is the regression line for data of 1978-2003. estimated $B_{35\%}$ based on three different recruitment levels.

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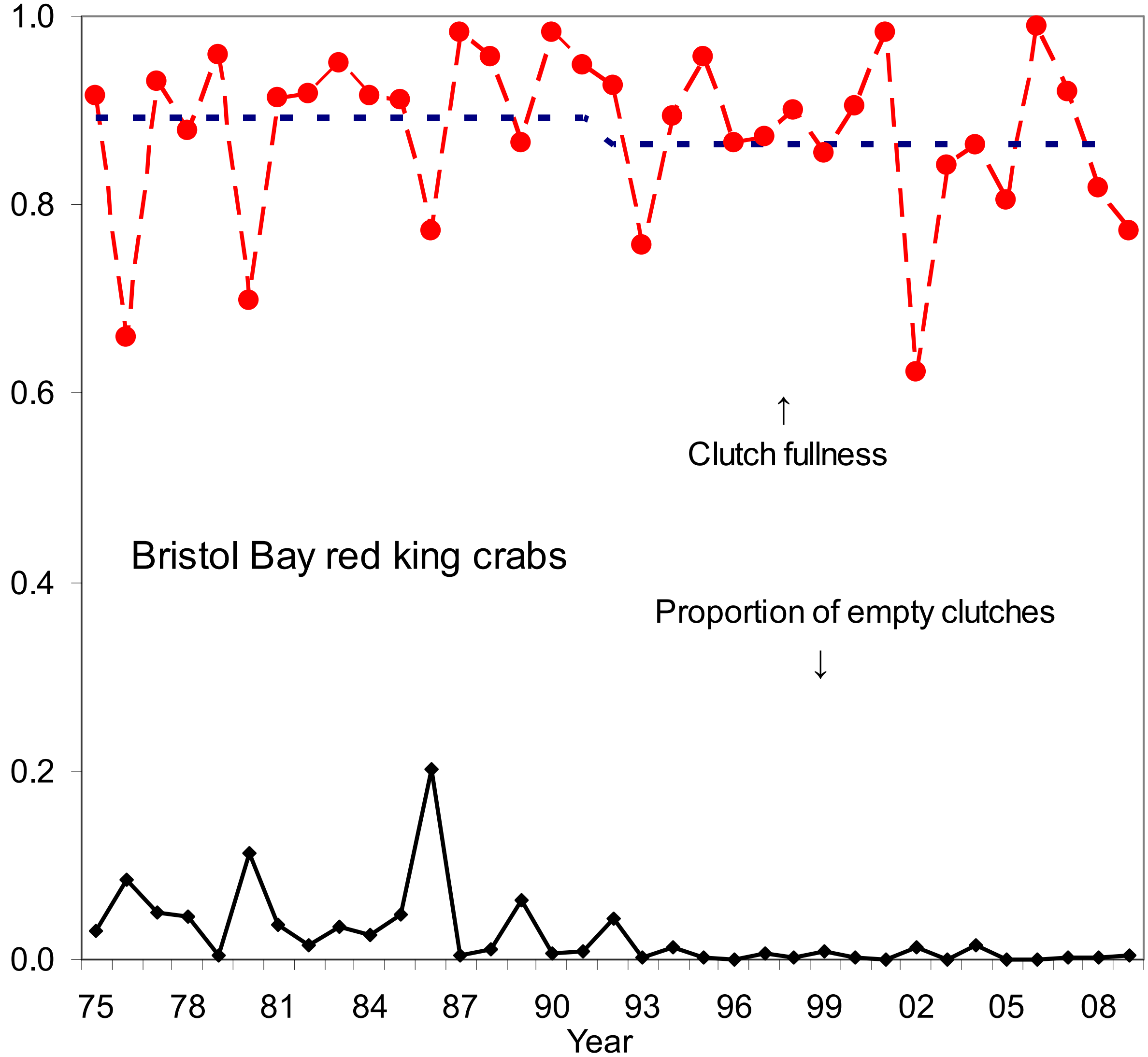

Figure 38. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crabs >89 mm CL from 1975 to 2009 from survey data. Oldshell females were excluded.

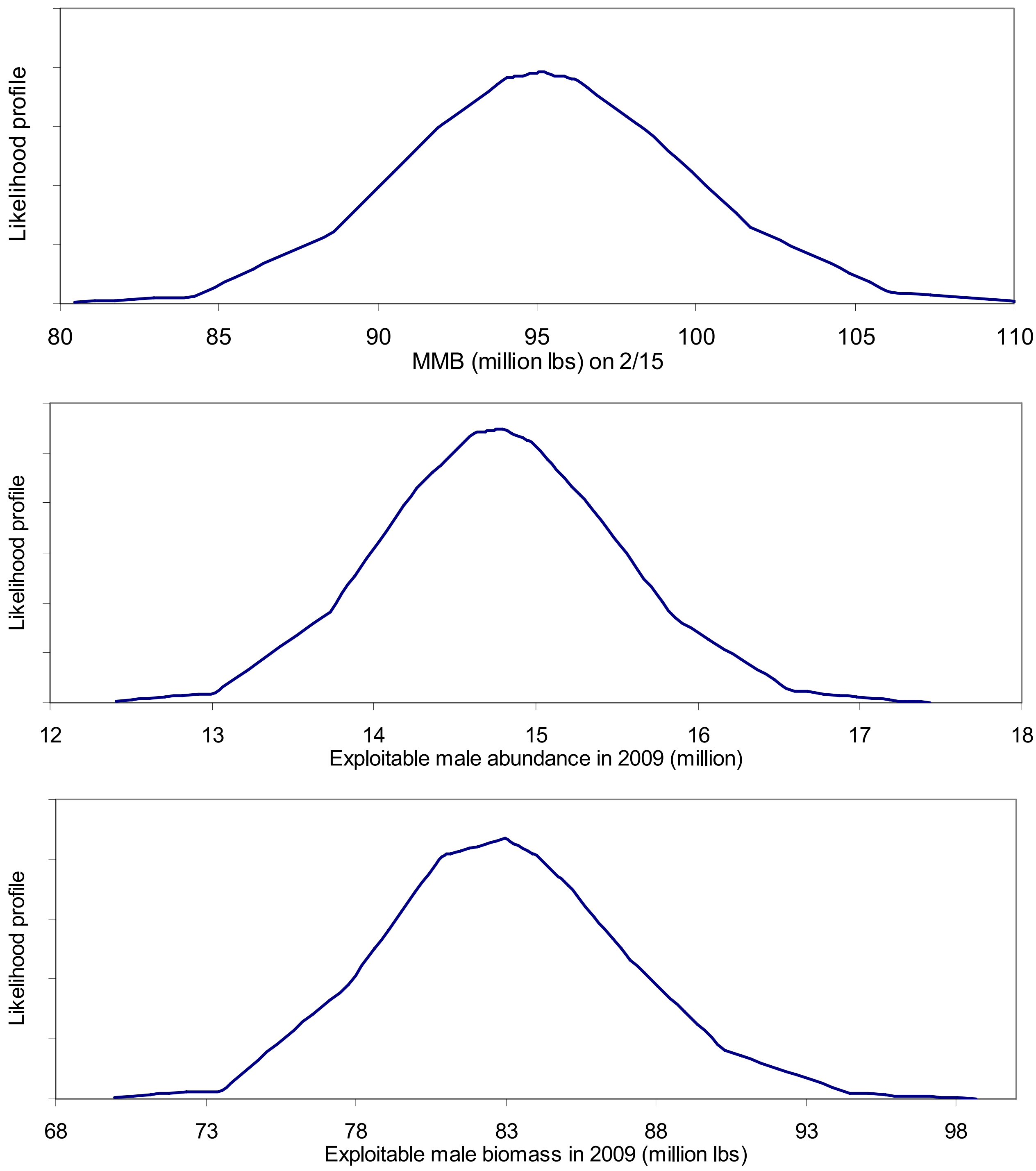

Figure 39. Likelihood profiles for estimated mature male biomass on Feb. 15 and exploitable male abundance and biomass at the fishing time for the 2009 season with $F_{35\%}$. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

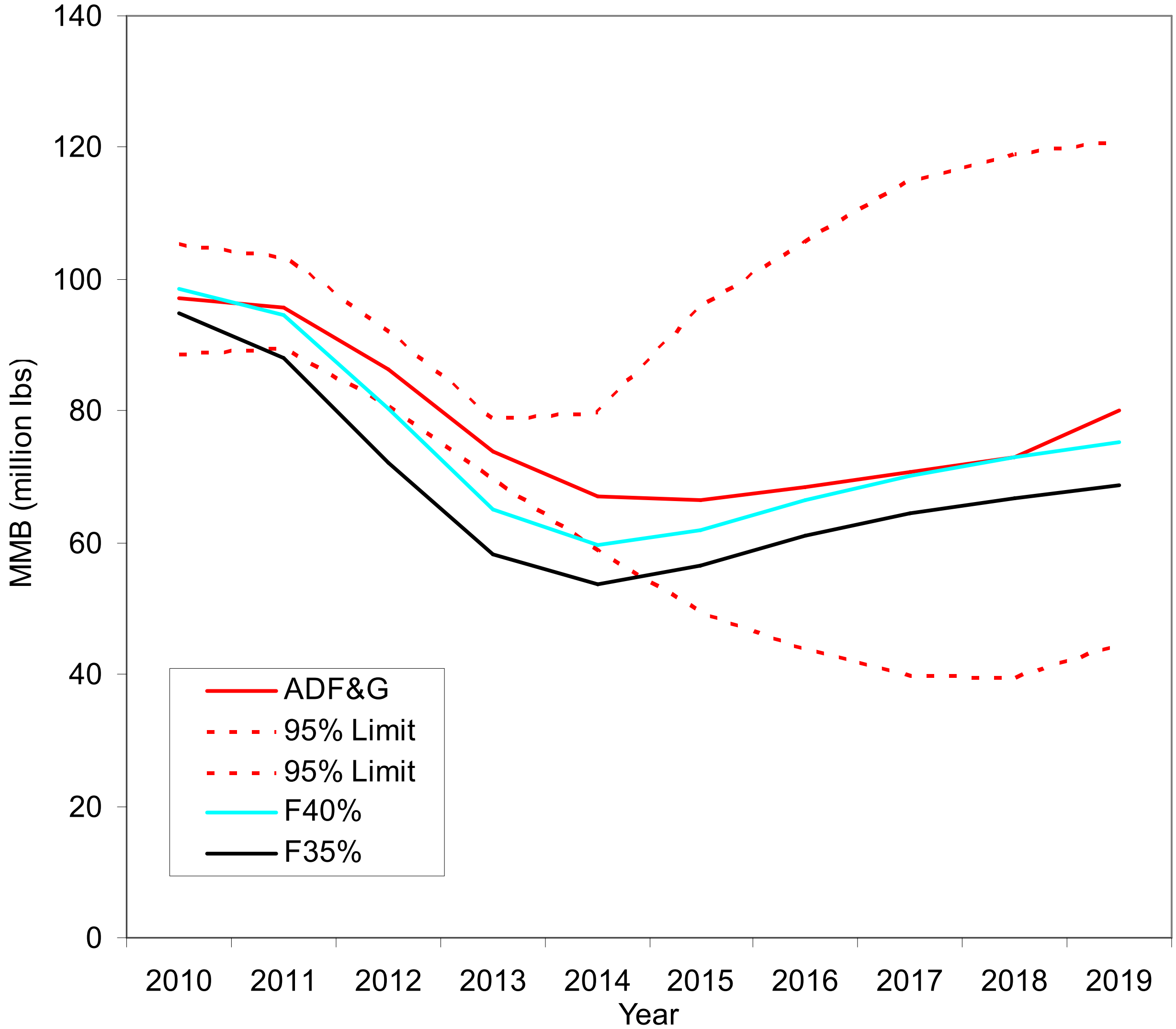

Figure 40. Projected mature male biomass on Feb. 15 with $F_{40\%}$, $F_{35\%}$ and the ADF&G harvest strategy with $F_{35\%}$ constraint during 2010-2119. Pot handling mortality rate is 0.2 and the confidence limits are for the ADF&G harvest strategy.

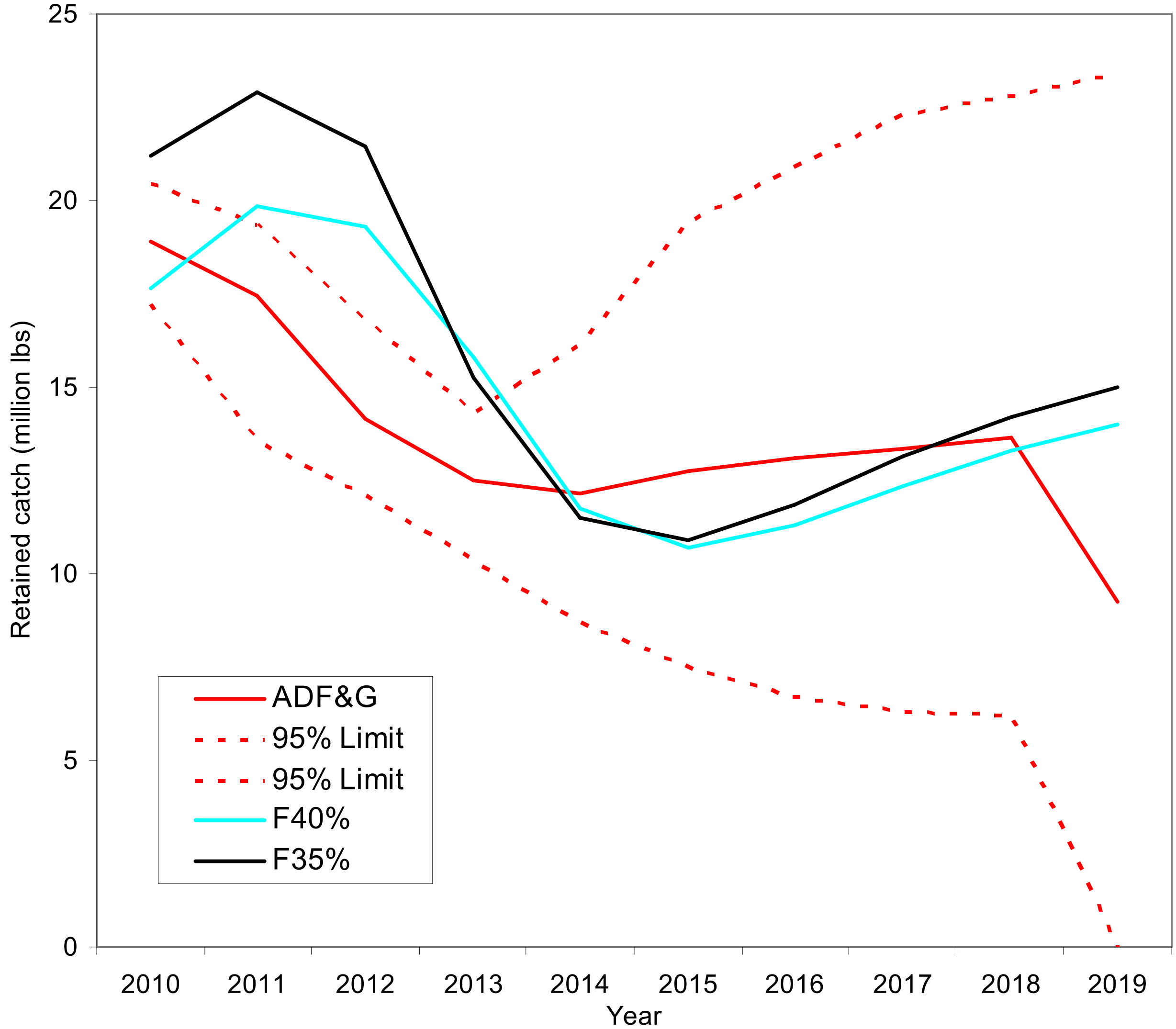

Figure 41. Projected retained catch biomass with $F_{40\%}$, $F_{35\%}$ and the ADF&G harvest strategy with $F_{35\%}$ constraint during 2010-2119. Pot handling mortality rate is 0.2 and the confidence limits are for the ADF&G harvest strategy.

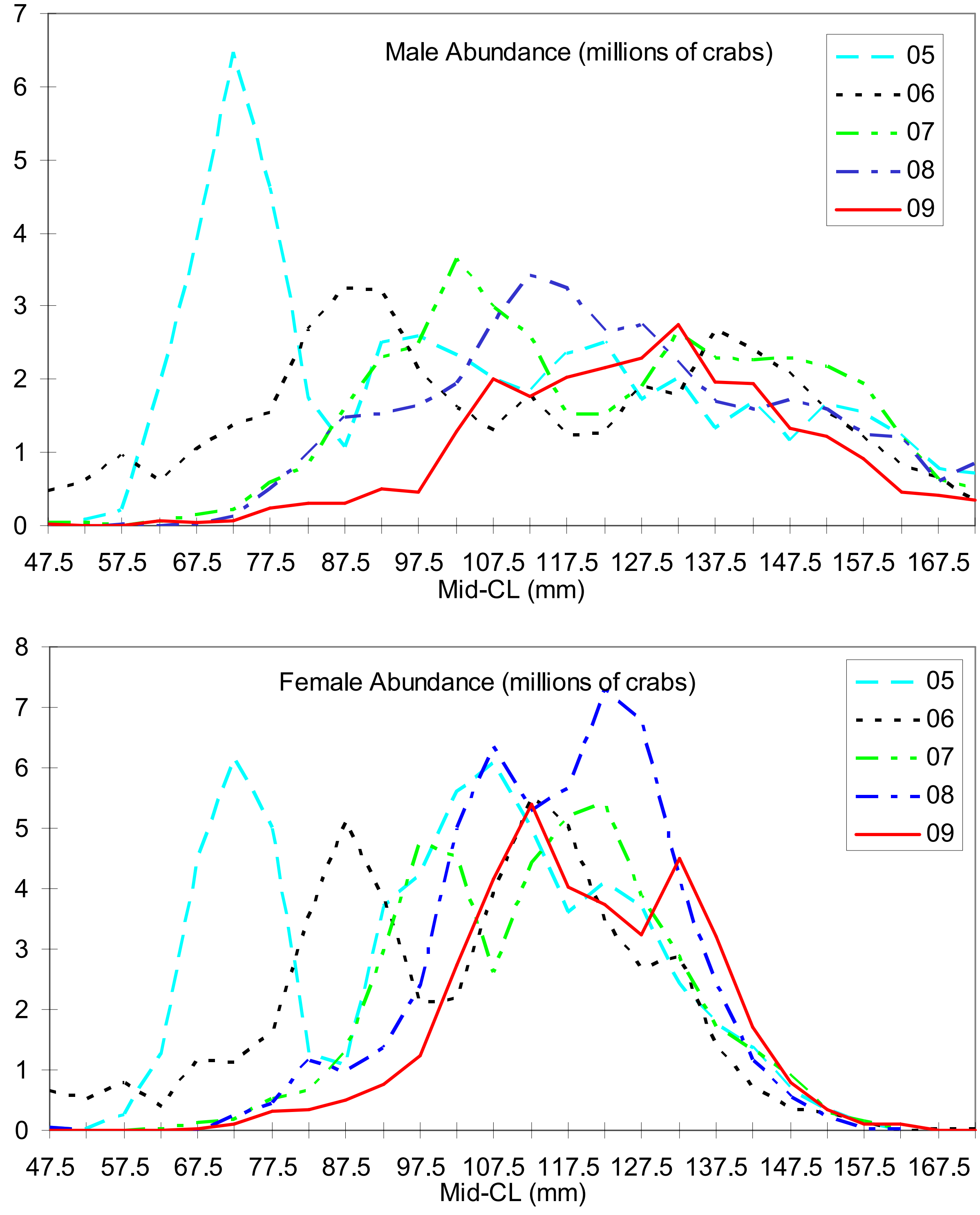

Figure 42. Length frequency distributions of male (top panel) and female (bottom panel) red king crabs in Bristol Bay from NMFS trawl surveys during 2005-2009. For purposes of these graphs, abundance estimates are based on area-swept methods.

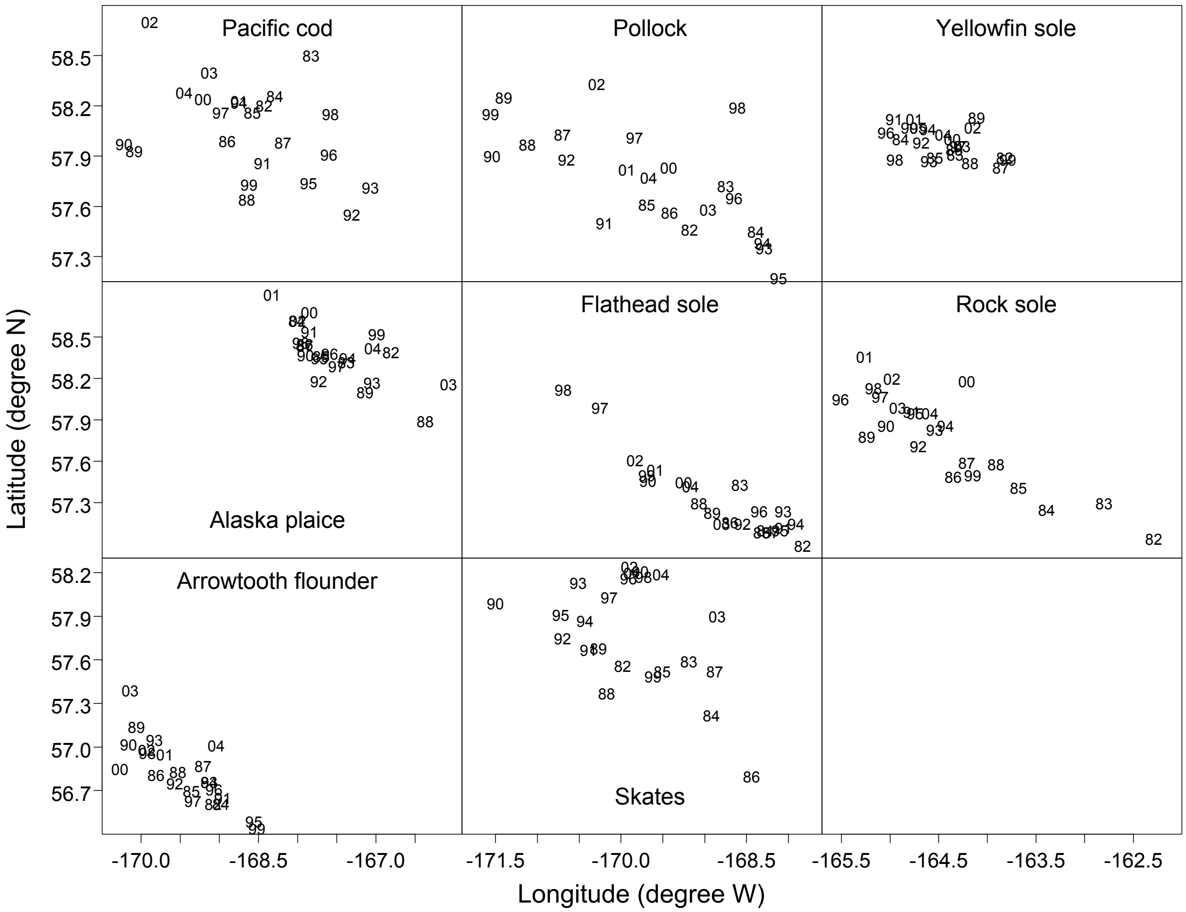

Figure 43. Biomass distribution centers of Pacific cod, walleye pollock, yellowfin sole, Alaska plaice, flathead sole, rock sole, arrowtooth flounder, and skates derived from NMFS summer trawl survey data in the eastern Bering Sea. (Source: Zheng and Kruse 2006).

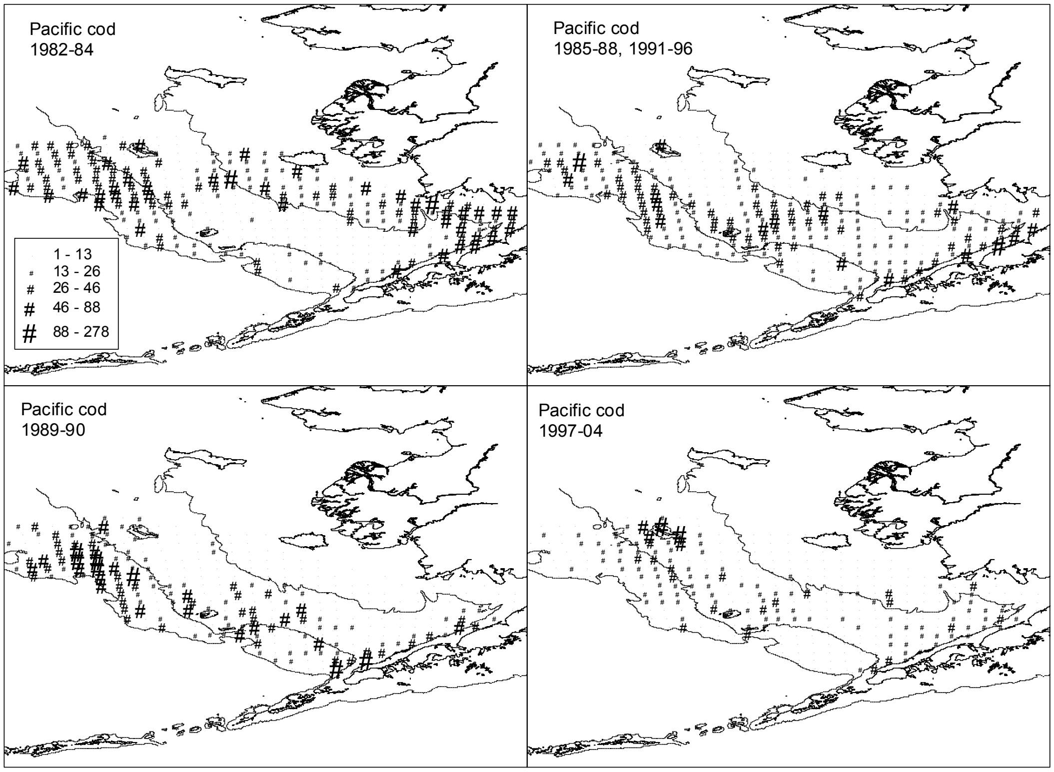

Figure 44. Distributions of relative biomass of Pacific cod in the eastern Bering Sea from 1982 to 2004 derived from NMFS summer trawl survey data. Relative biomass is expressed as kg/ha. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

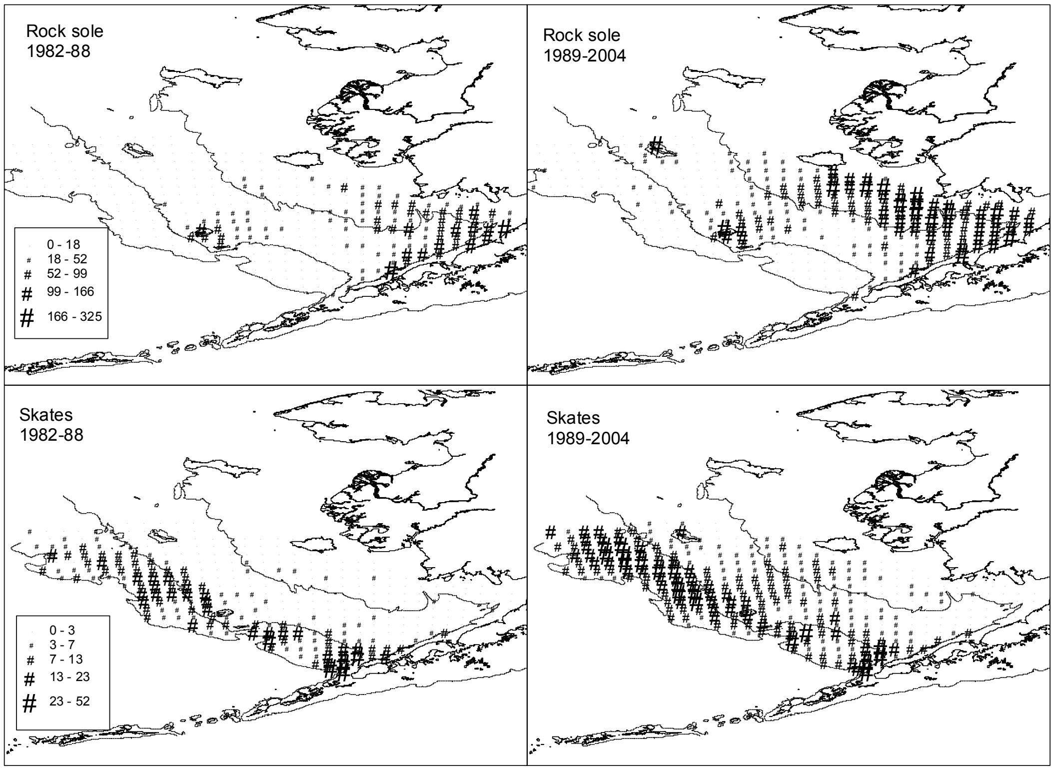

Figure 45. Distributions of relative biomass of rock sole and skates in the eastern Bering Sea from 1982 to 2004 derived from NMFS summer trawl survey data. Relative biomass is expressed as kg/ha. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

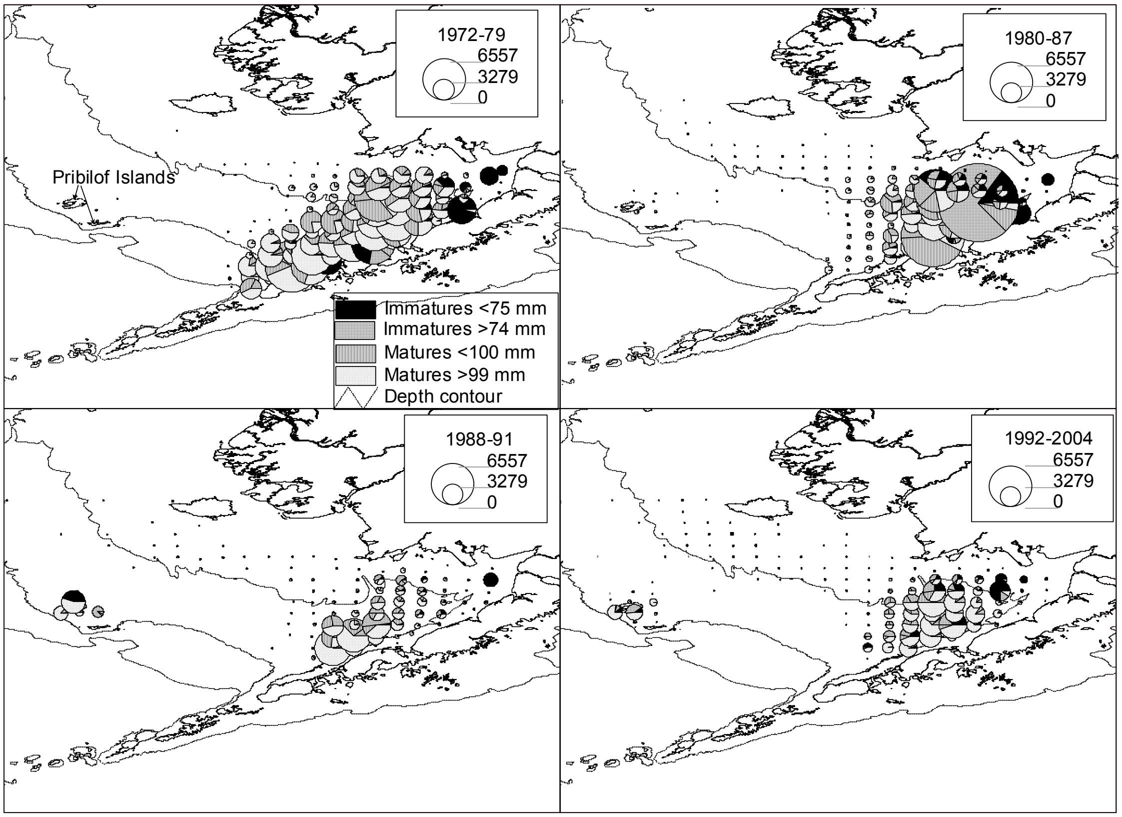

Figure 46. Geographic distributions of immature and mature female red king crabs from 1972 to 2004 in the eastern Bering Sea derived from NMFS summer trawl survey data. The diameter of each pie represents crab density expressed as the number of crabs per square nautical mile. Three depth contour lines are 50, 100, and 200 m. (Source: Zheng and Kruse 2006).

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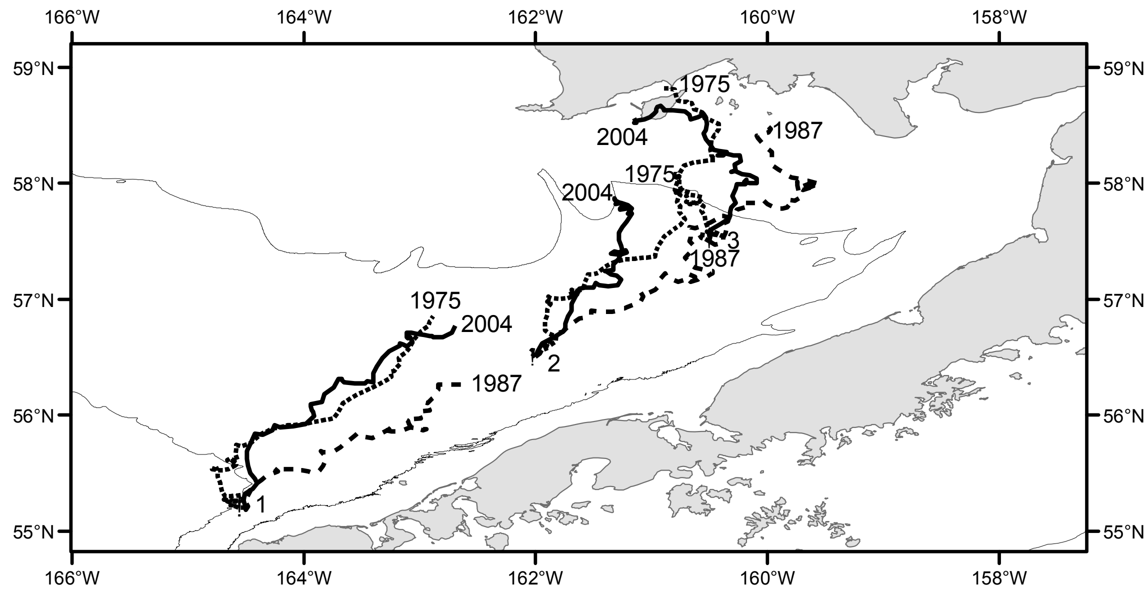

Figure 47. Larval movements after hatching on May 15, 1975, 1987, and 2004 from three different locations for Bristol Bay red king crab during two months. (Source: Zheng and Kruse 2008).

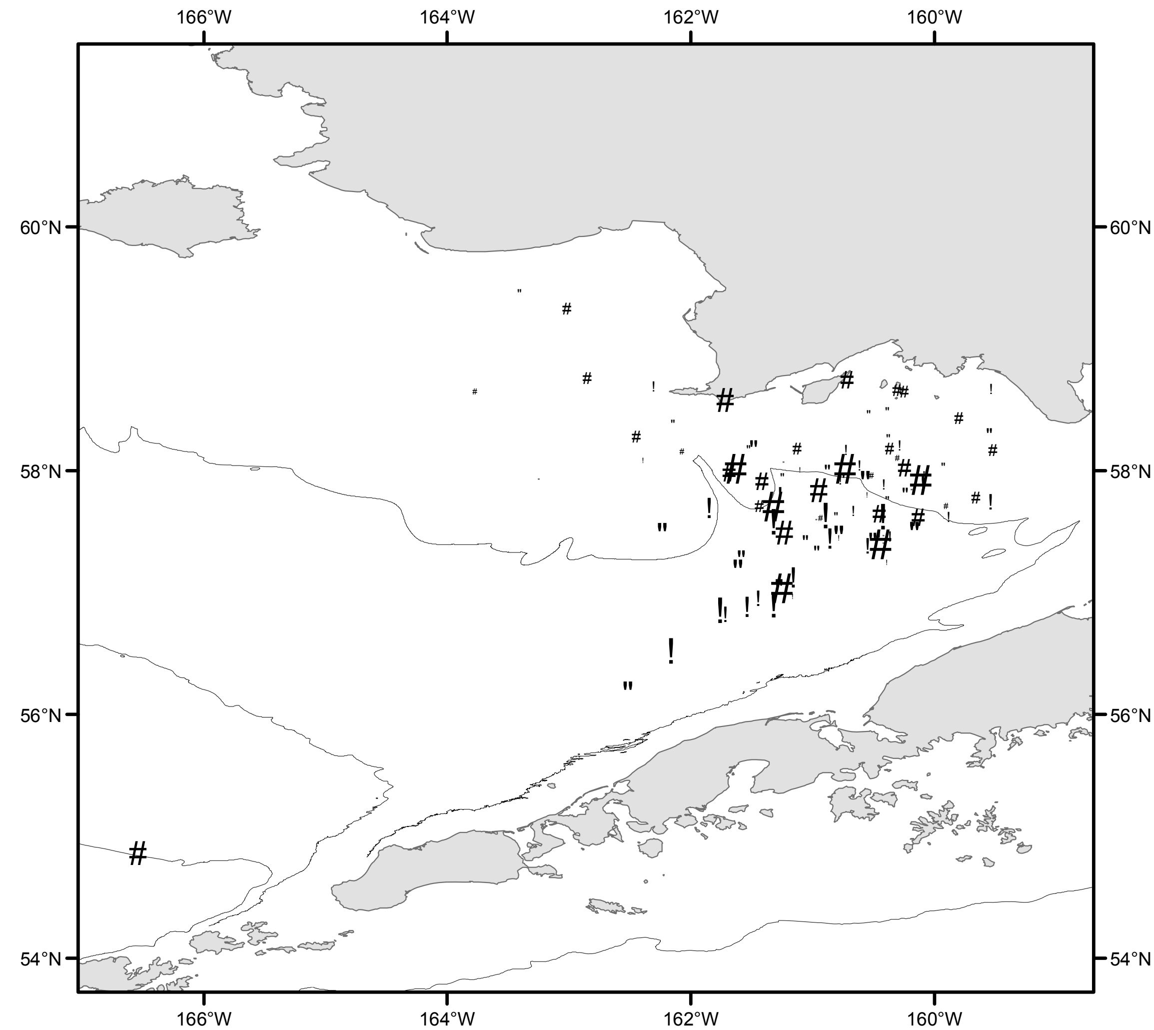

Figure 48. Estimated settling locations from the distribution centers of Bristol Bay mature female red king crabs >99 mm CL during 1967-1999. Hatching dates of April 15, May 15, and June 15 are triangles, squares, and circles, respectively. Symbol sizes are proportional to year-class strength.

Appendix

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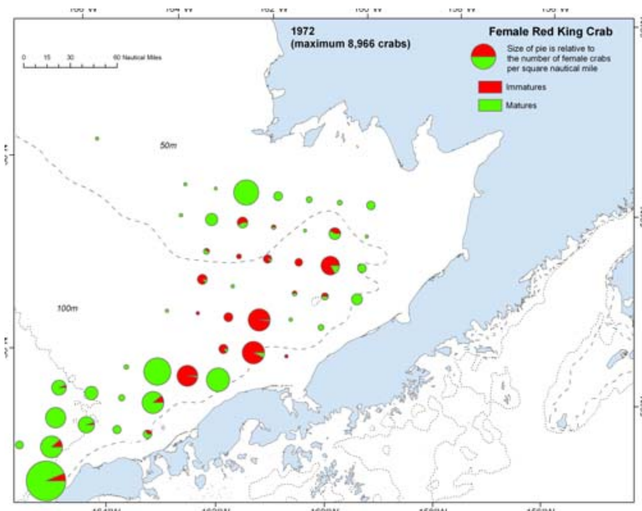
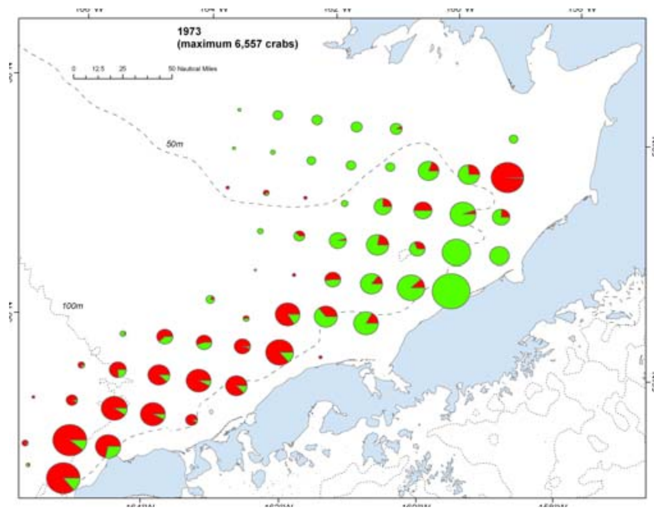
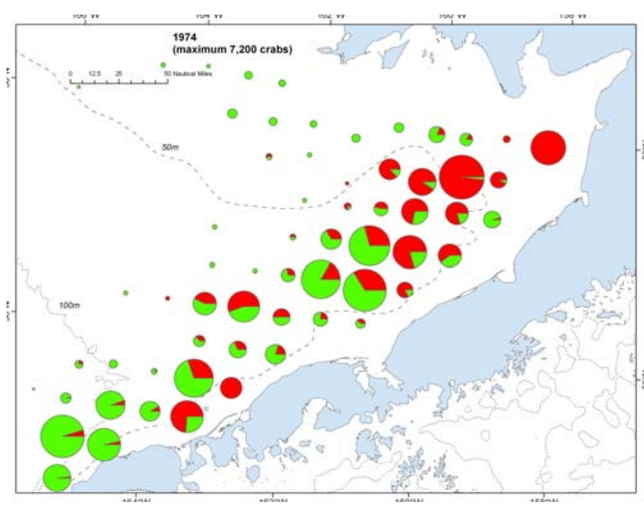
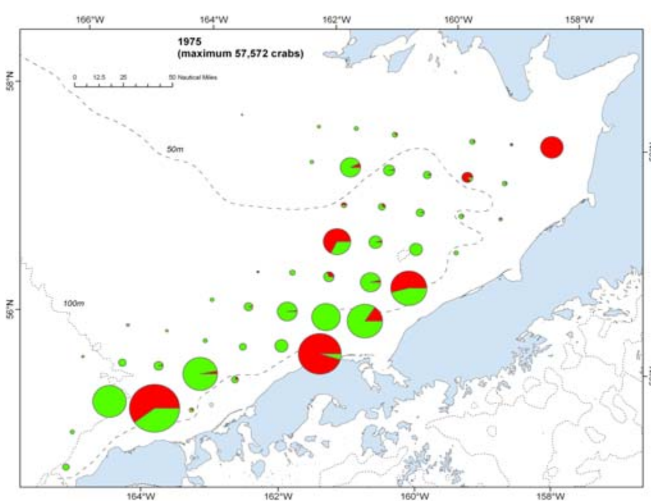
Spatial distributions of retained catch and female Bristol Bay red king crab, and number of bottom tows of groundfish fisheries in the eastern Bering Sea. The female data are from the NMFS and the bottom tow data are from the North Pacific (NORPAC) fishery-observer database from the Alaska Fisheries Science Center, NMFS, Seattle. The bottom tow data are summarized in a one degree longitude and 0.5 degree latitude.

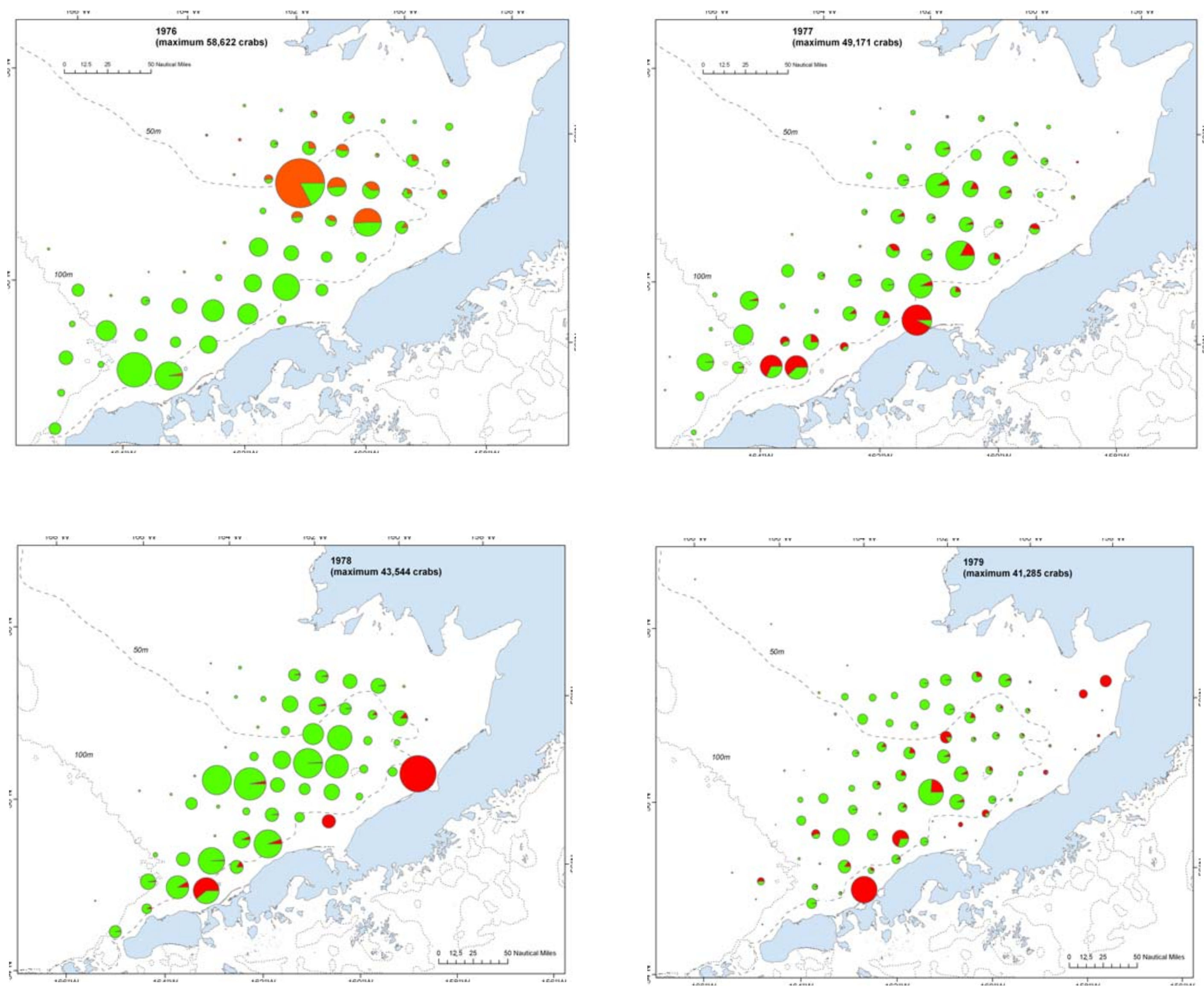

1972
(maximum 8,966 crabs)
Female Red King Crab
Size of pie is relative to the number of female crabs per square nautical mile
Immatures
Matures
50m
100m

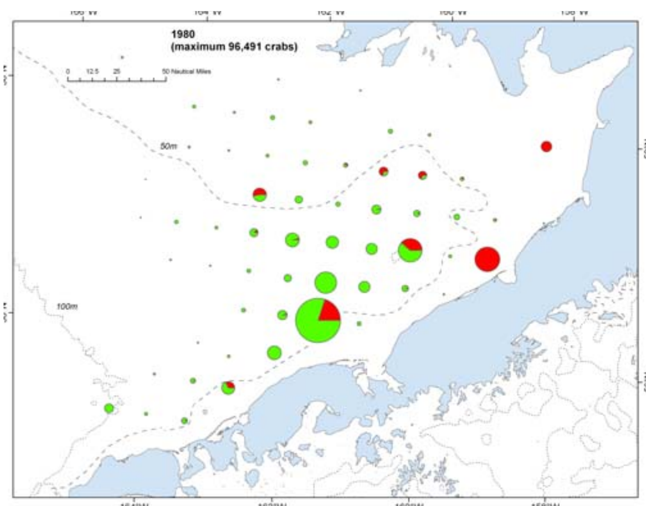

1973
(maximum 6,557 crabs)
50m
100m

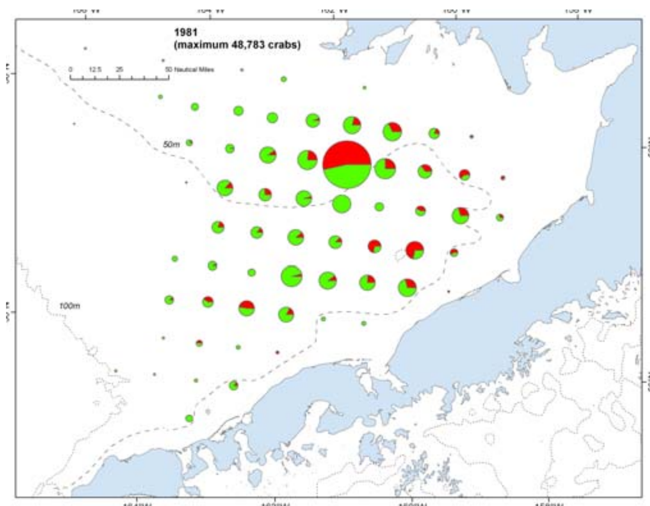

1974
(maximum 7,200 crabs)
50m
100m

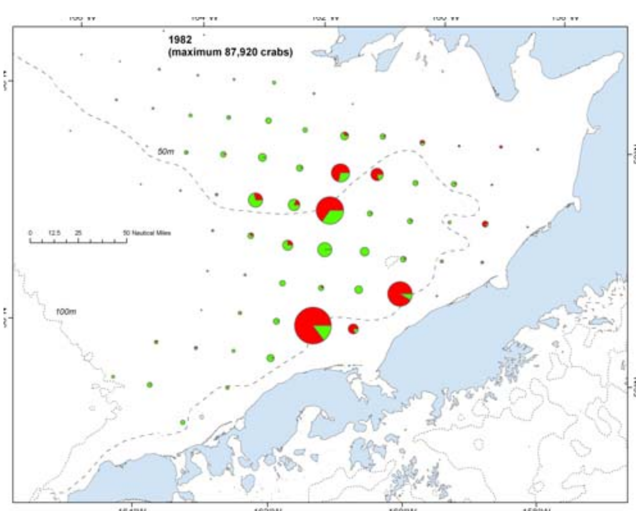

1975
(maximum 57,572 crabs)
166°W
164°W
162°W
160°W
158°W
58°N
56°N
50m
100m

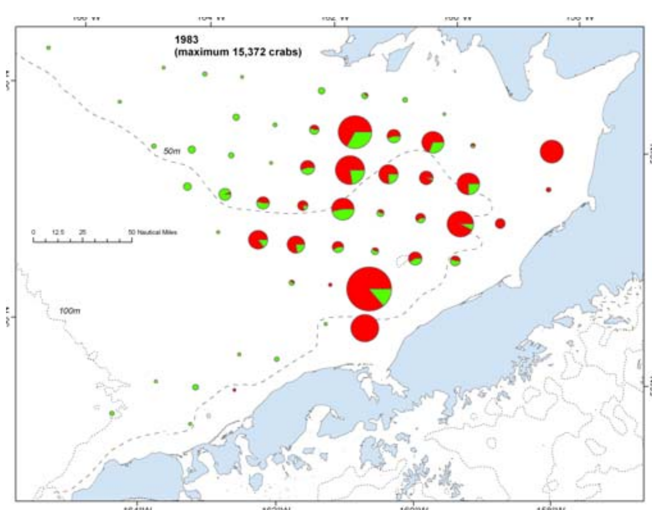
116

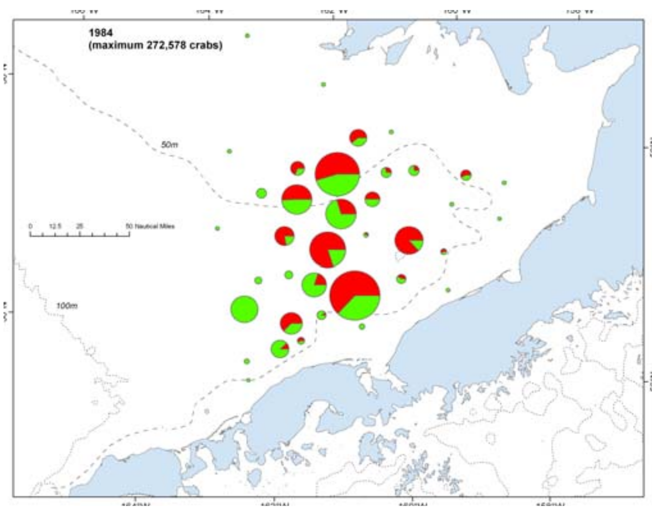

1976
(maximum 58,622 crabs)
0 12.5 25 50 Nautical Miles
50m
100m
1977
(maximum 49,171 crabs)
0 12.5 25 50 Nautical Miles
50m
100m
1978
(maximum 43,544 crabs)
50m
100m
0 12.5 25 50 Nautical Miles
1979
(maximum 41,285 crabs)
50m
100m
0 12.5 25 50 Nautical Miles

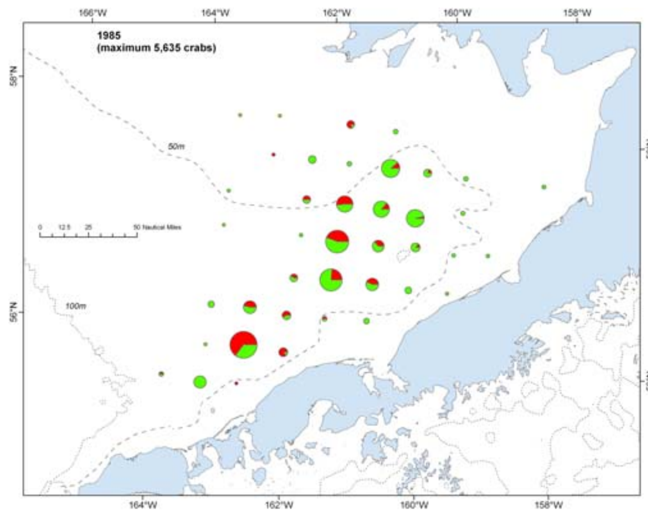

1980
(maximum 96,491 crabs)
50m
100m

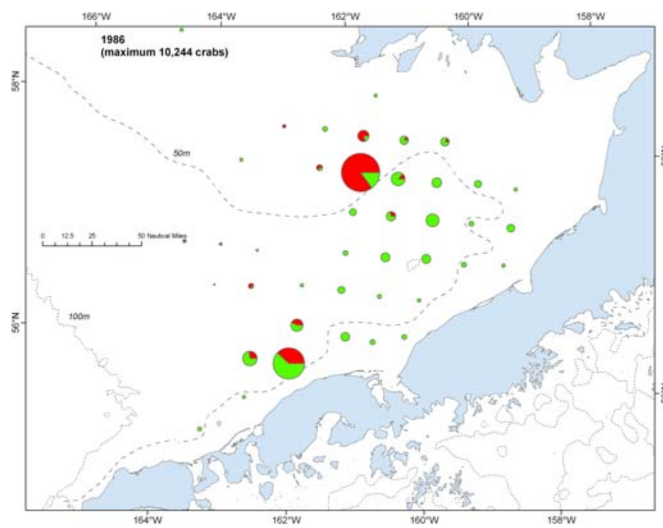

1981
(maximum 48,783 crabs)
50m
100m

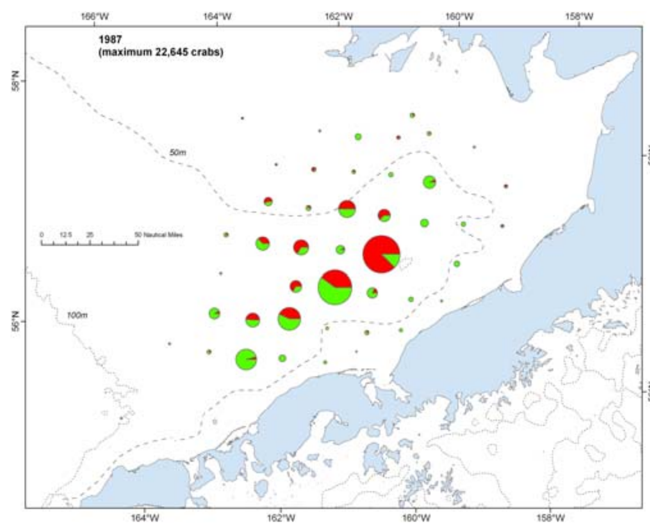

1982
(maximum 87,920 crabs)
50m
100m


1983
(maximum 15,372 crabs)
50m
100m

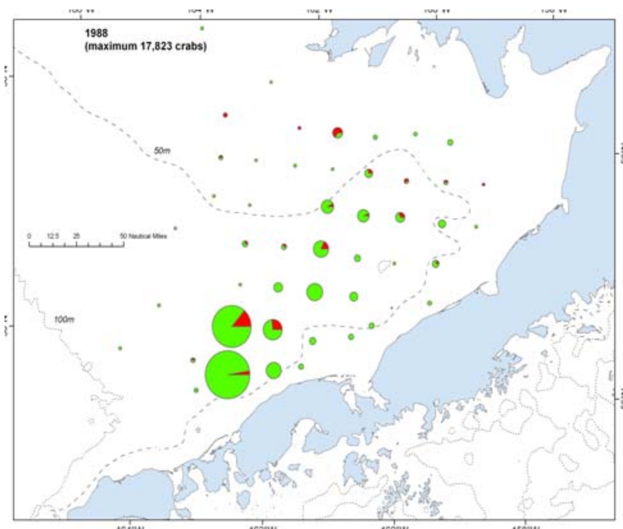

1984
(maximum 272,578 crabs)
50m
100m
0 12.5 25 50 Nautical Miles

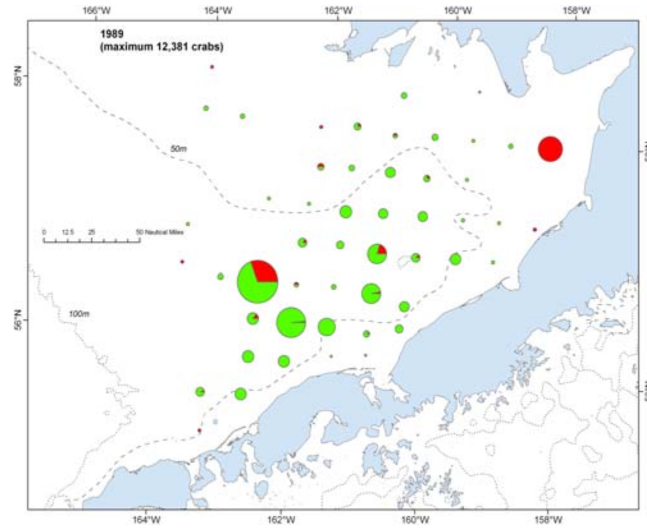

1985
(maximum 5,635 crabs)
50m
100m
0 12.5 25 50 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

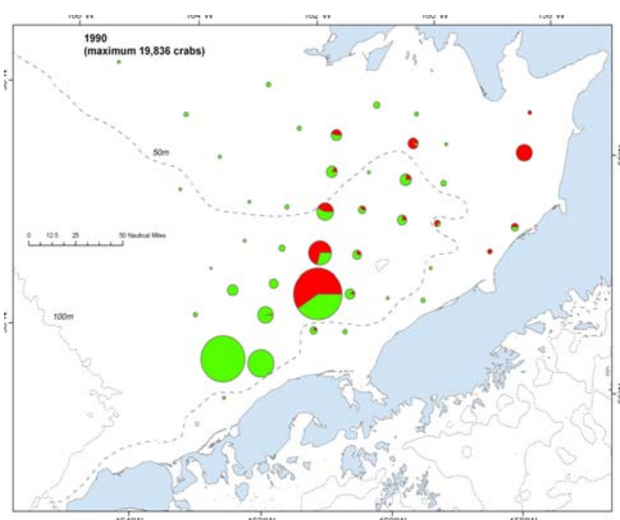

1986
(maximum 10,244 crabs)
50m
100m
0 12.5 25 50 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

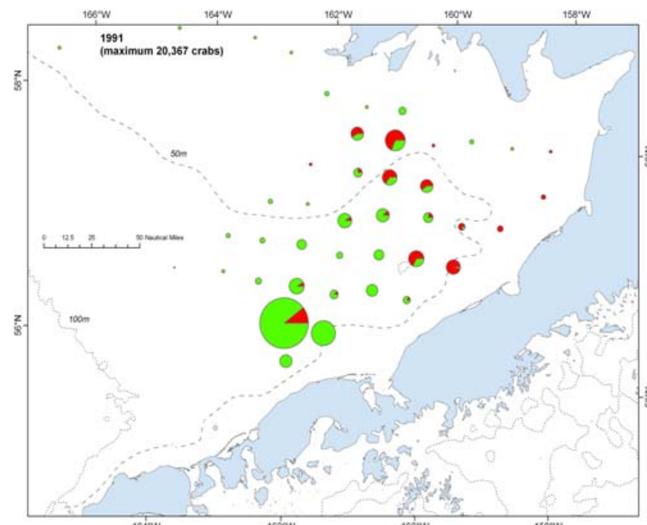

1987
(maximum 22,645 crabs)
50m
100m
0 12.5 25 50 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

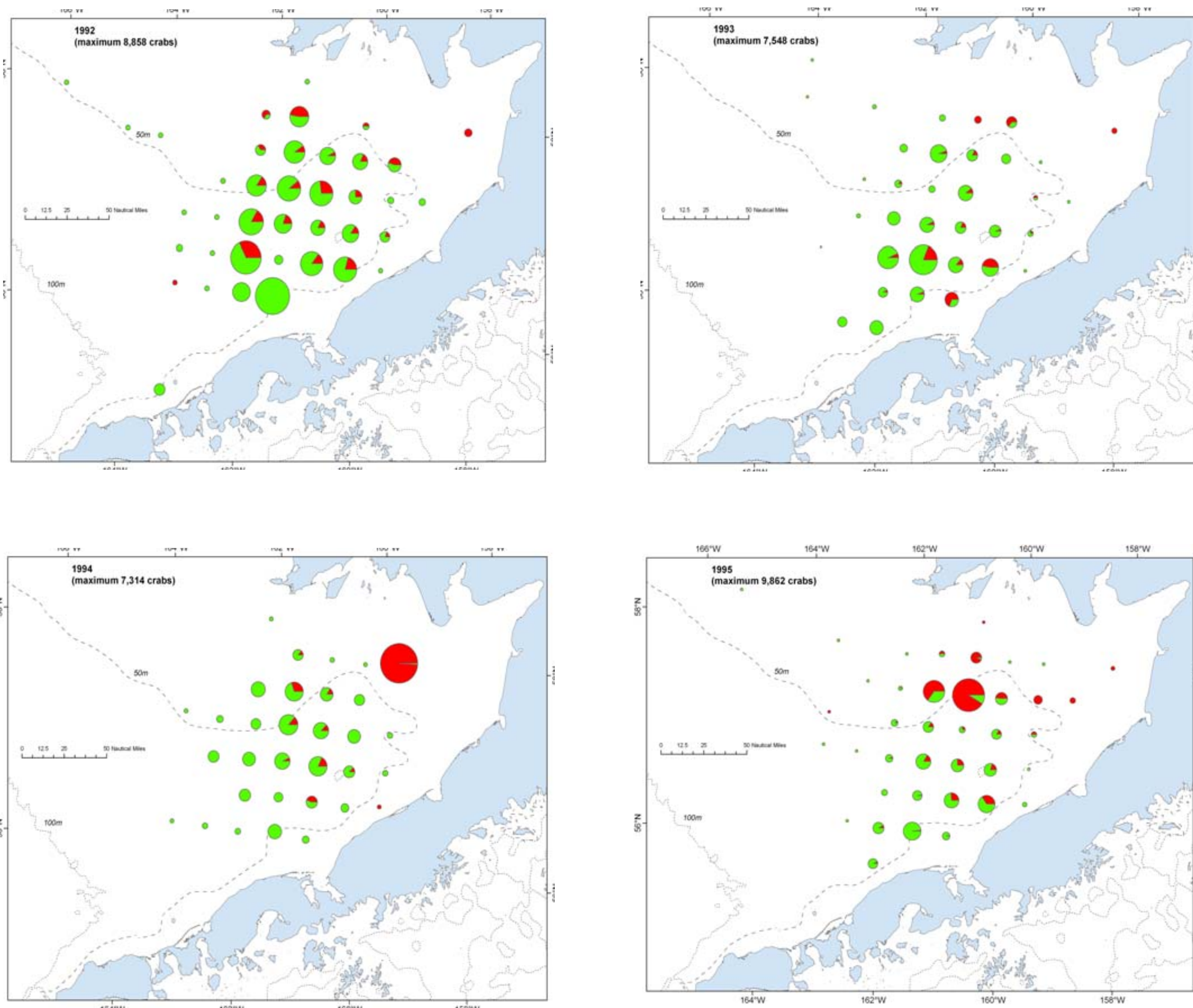
119


1988
(maximum 17,823 crabs)
50m
100m
0 12.5 25 50 Nautical Miles

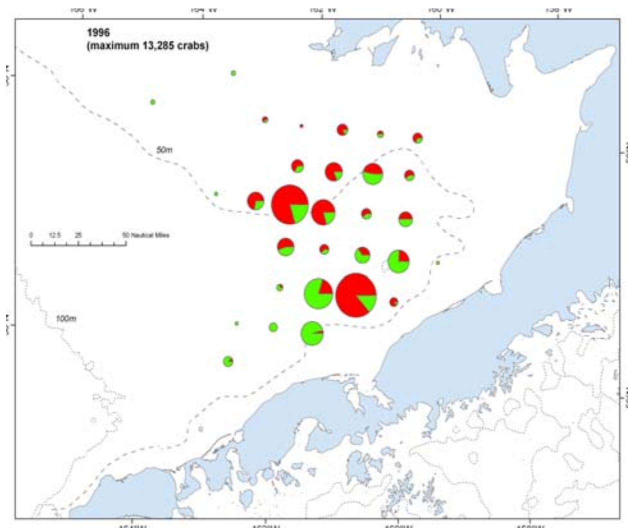

166°W
164°W
162°W
160°W
158°W
1989
(maximum 12,381 crabs)
58°N
56°N
50m
100m
0 12.5 25 50 Nautical Miles
164°W
162°W
160°W
158°W

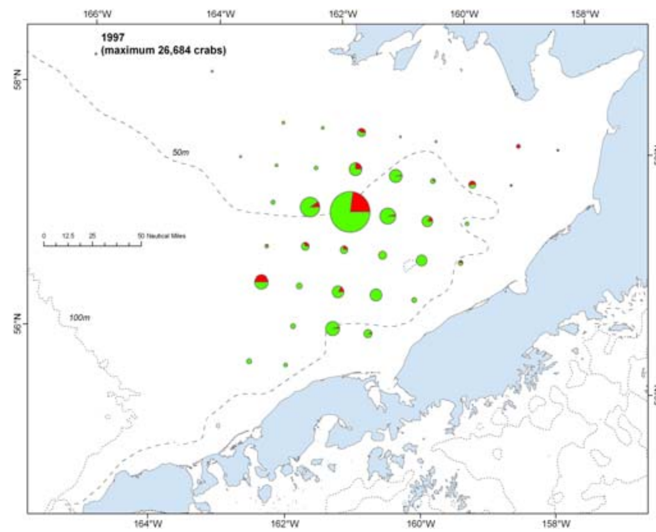

1990
(maximum 19,836 crabs)
50m
100m
0 12.5 25 50 Nautical Miles

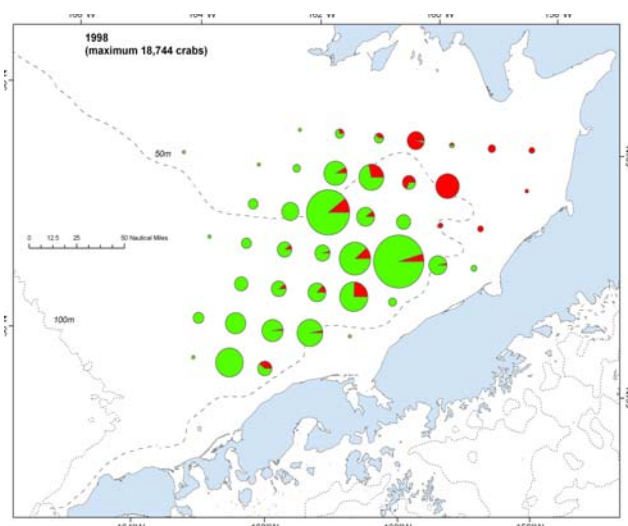

166°W
164°W
162°W
160°W
158°W
1991
(maximum 20,367 crabs)
58°N
56°N
50m
100m
0 12.5 25 50 Nautical Miles
164°W
162°W
160°W
158°W

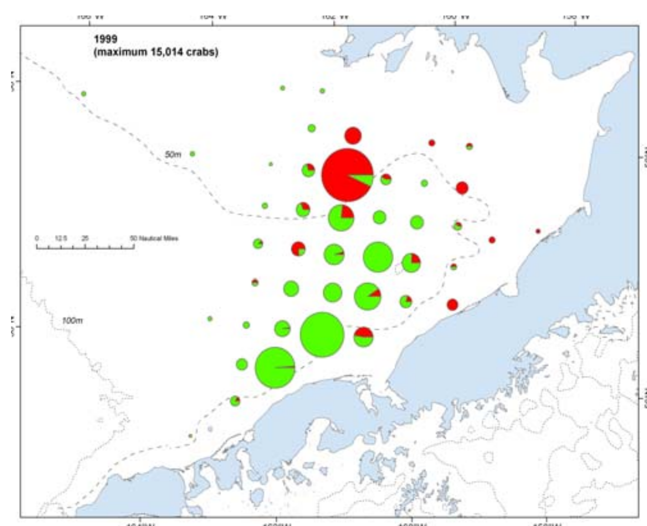

1992
(maximum 8,858 crabs)
1993
(maximum 7,548 crabs)
1994
(maximum 7,314 crabs)
1995
(maximum 9,862 crabs)
50m
100m
50 Nautical Miles
166°W
164°W
162°W
160°W
158°W
58°N
56°N

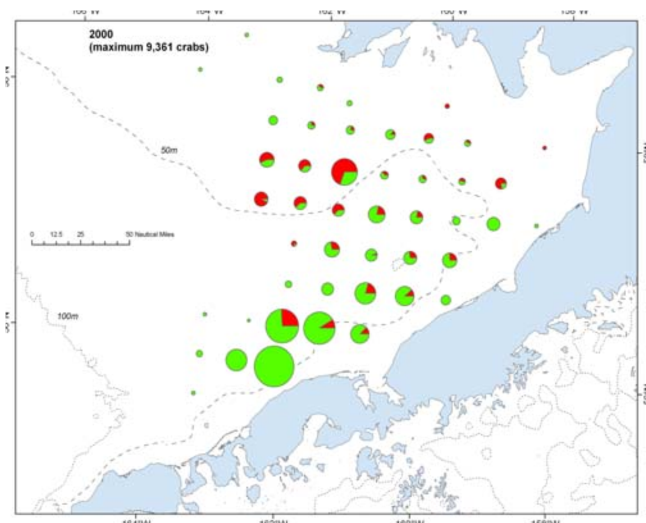
121

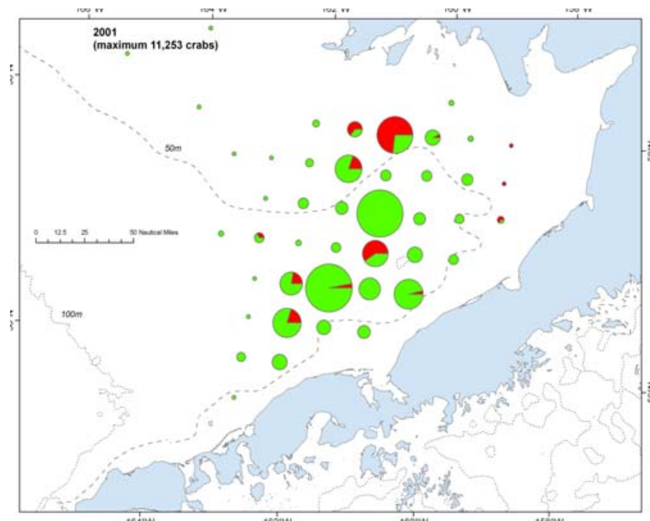

1996
(maximum 13,285 crabs)
50m
100m
0 12.5 25 50 Nautical Miles

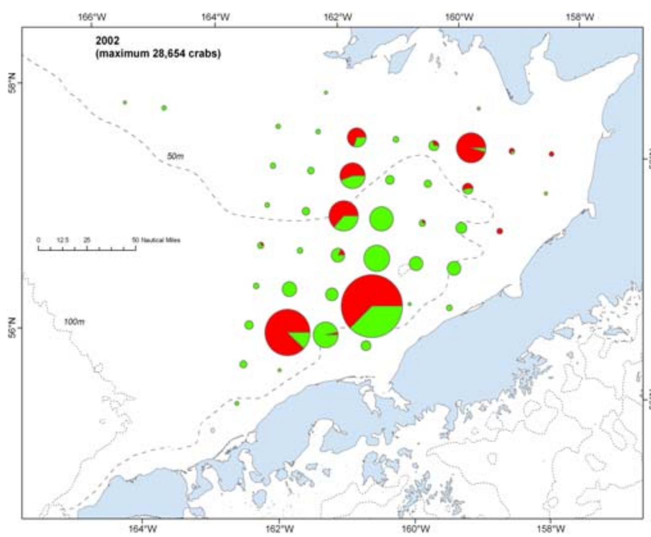

1997
(maximum 26,684 crabs)
166°W
164°W
162°W
160°W
158°W
58°N
56°N
50m
100m
0 12.5 25 50 Nautical Miles
164°W
162°W
160°W
158°W

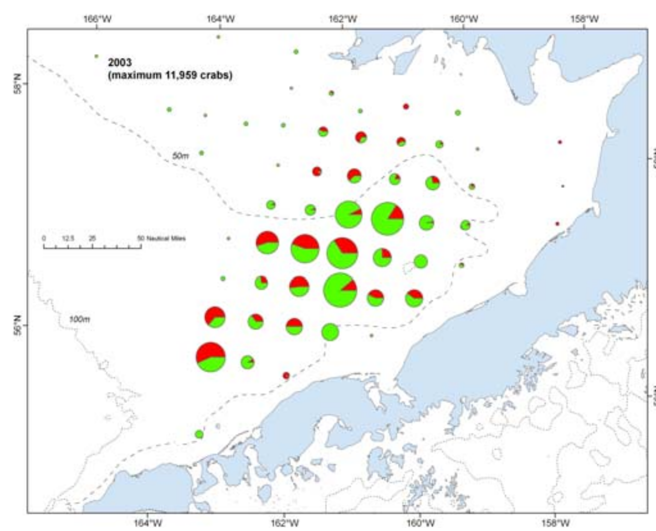

1998
(maximum 18,744 crabs)
50m
100m
0 12.5 25 50 Nautical Miles

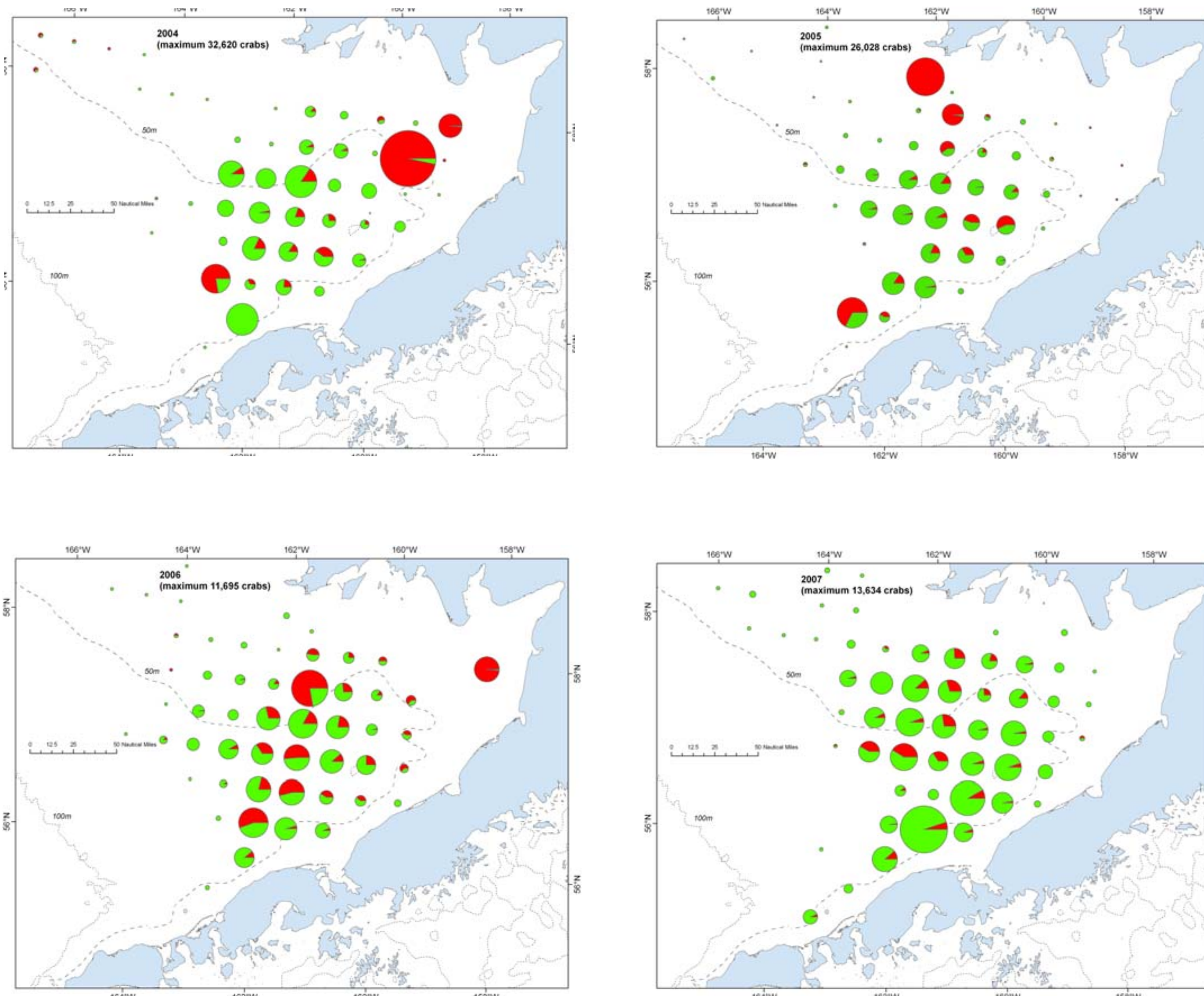

1999
(maximum 15,014 crabs)
50m
100m
0 12.5 25 50 Nautical Miles


2000
(maximum 9,361 crabs)
50m
100m
50 Nautical Miles

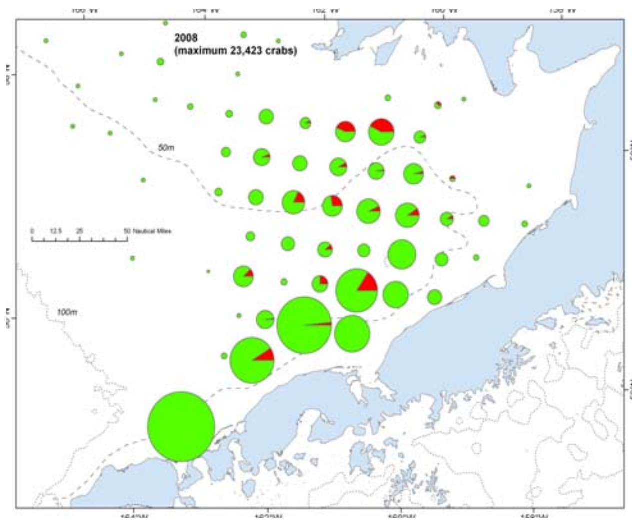

2001
(maximum 11,253 crabs)
50m
100m
50 Nautical Miles

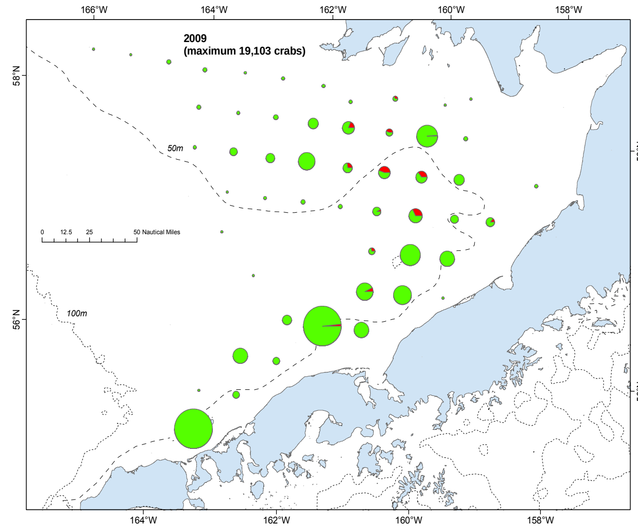

166°W
164°W
162°W
160°W
158°W
2002
(maximum 28,654 crabs)
58°N
56°N
50m
100m
50 Nautical Miles


166°W
164°W
162°W
160°W
158°W
2003
(maximum 11,959 crabs)
58°N
56°N
50m
100m
50 Nautical Miles

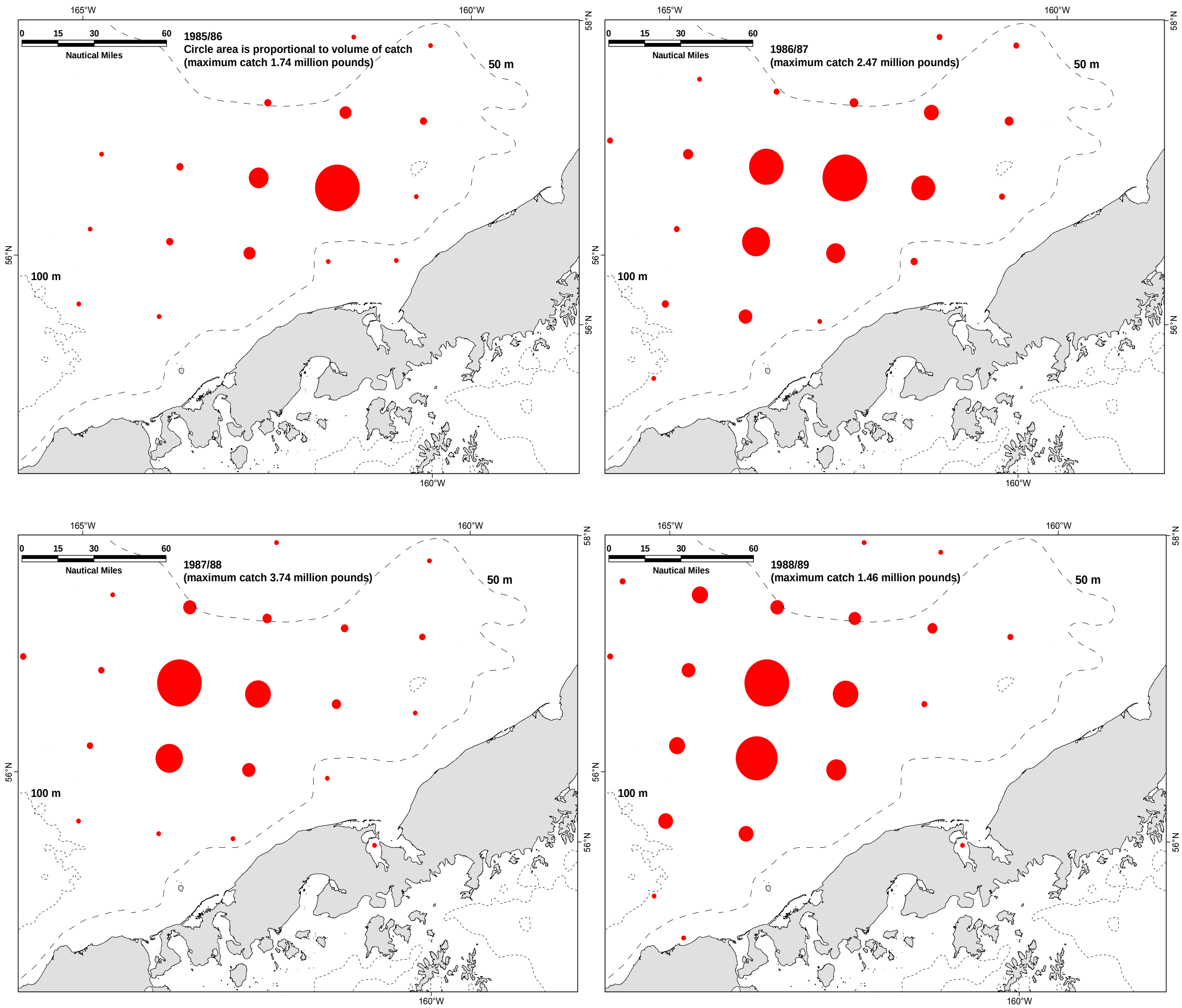

2004
(maximum 32,620 crabs)
2005
(maximum 26,028 crabs)
2006
(maximum 11,695 crabs)
2007
(maximum 13,634 crabs)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

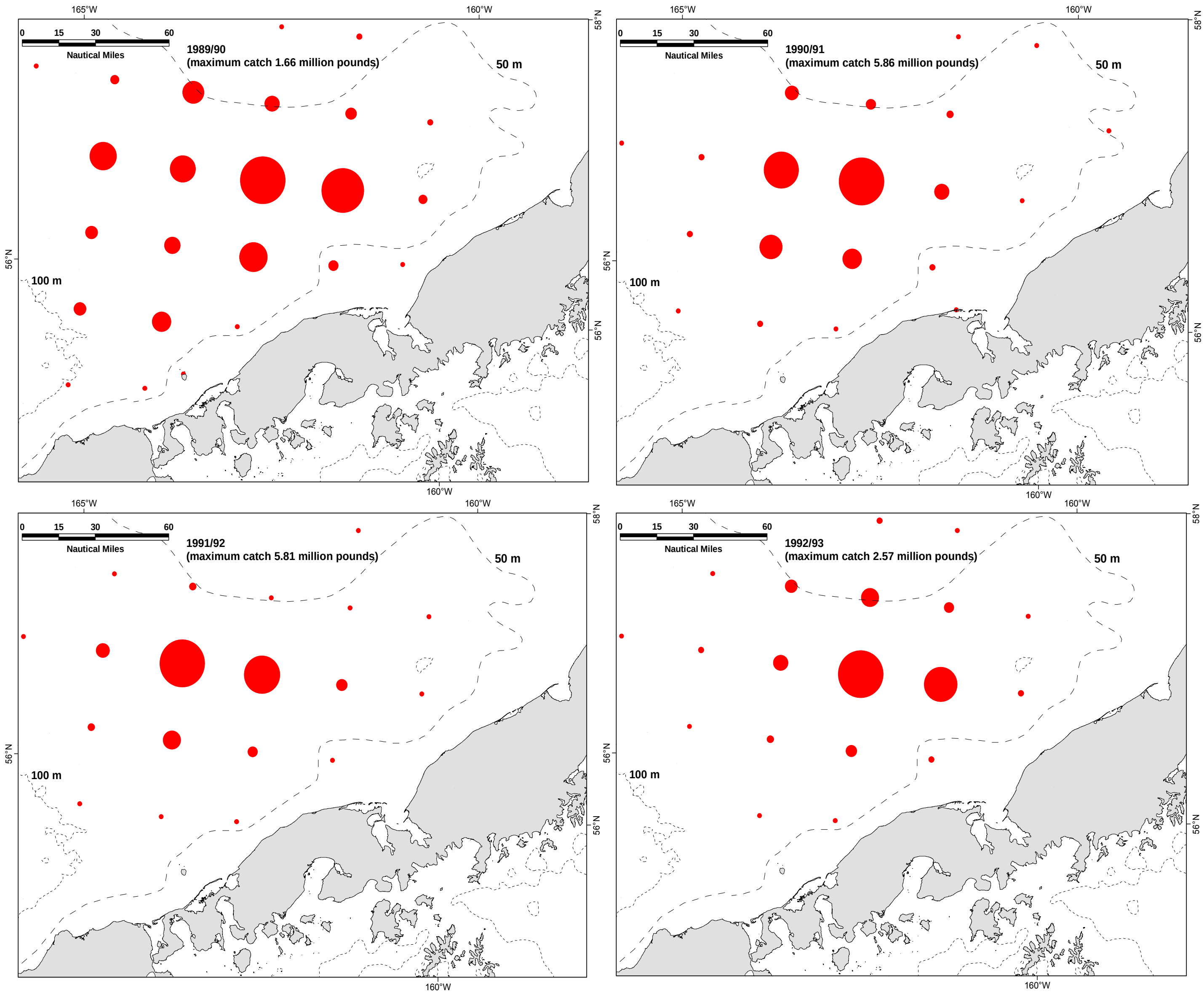
124


2008
(maximum 23,423 crabs)
50m
100m
0 12.5 25 50 Nautical Miles

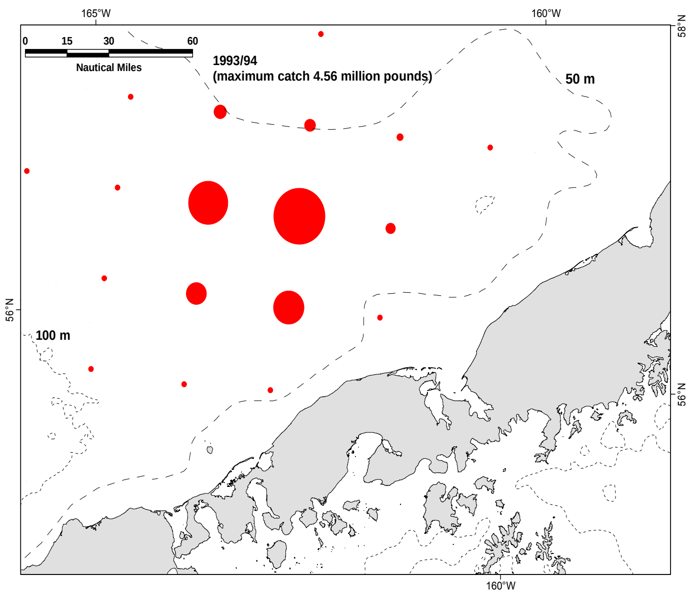

2009
(maximum 19,103 crabs)
166°W
164°W
162°W
160°W
158°W
58°N
56°N
50m
100m
0 12.5 25 50 Nautical Miles

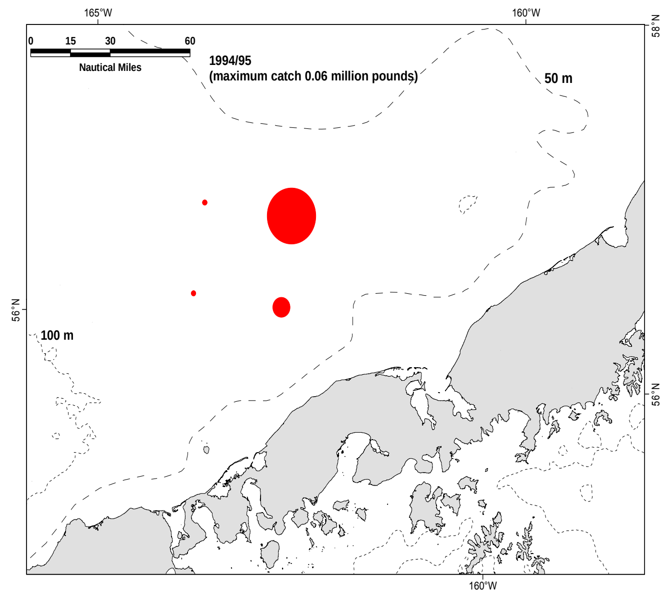
125

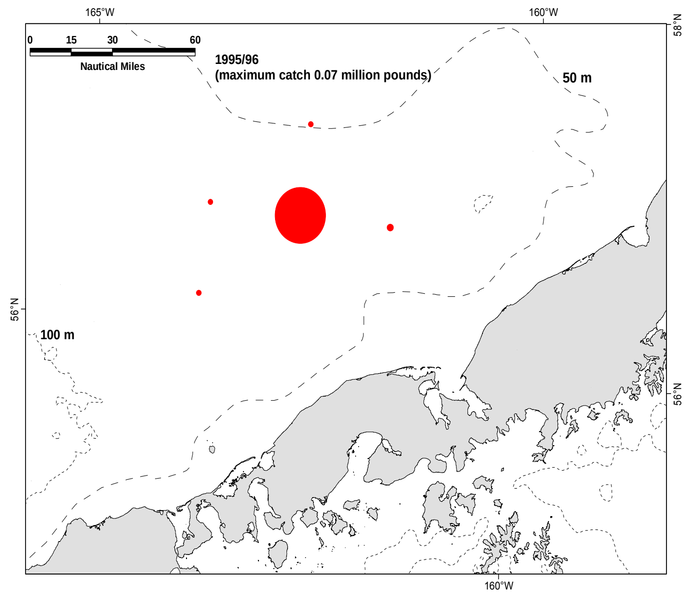

1985/86
Circle area is proportional to volume of catch
(maximum catch 1.74 million pounds)
1986/87
(maximum catch 2.47 million pounds)
1987/88
(maximum catch 3.74 million pounds)
1988/89
(maximum catch 1.46 million pounds)
Nautical Miles
0 15 30 60
50 m
100 m
165°W
160°W
58°N
56°N

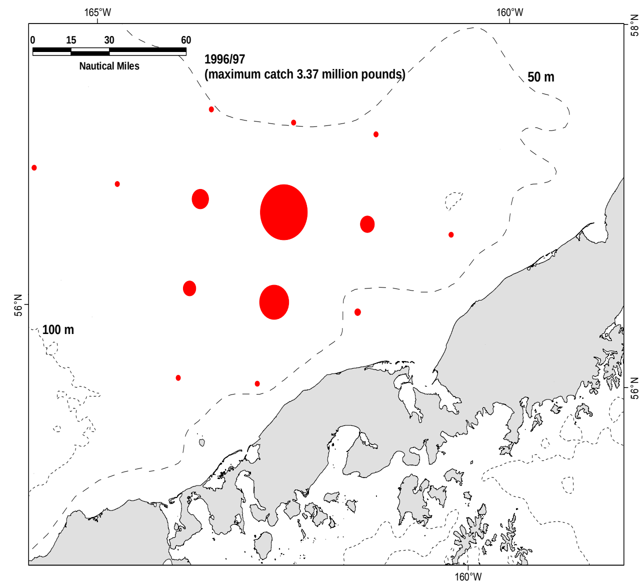

165°W
160°W
58°N
56°N
0 15 30 60
Nautical Miles
1989/90
(maximum catch 1.66 million pounds)
50 m
100 m
1990/91
(maximum catch 5.86 million pounds)
1991/92
(maximum catch 5.81 million pounds)
1992/93
(maximum catch 2.57 million pounds)

127

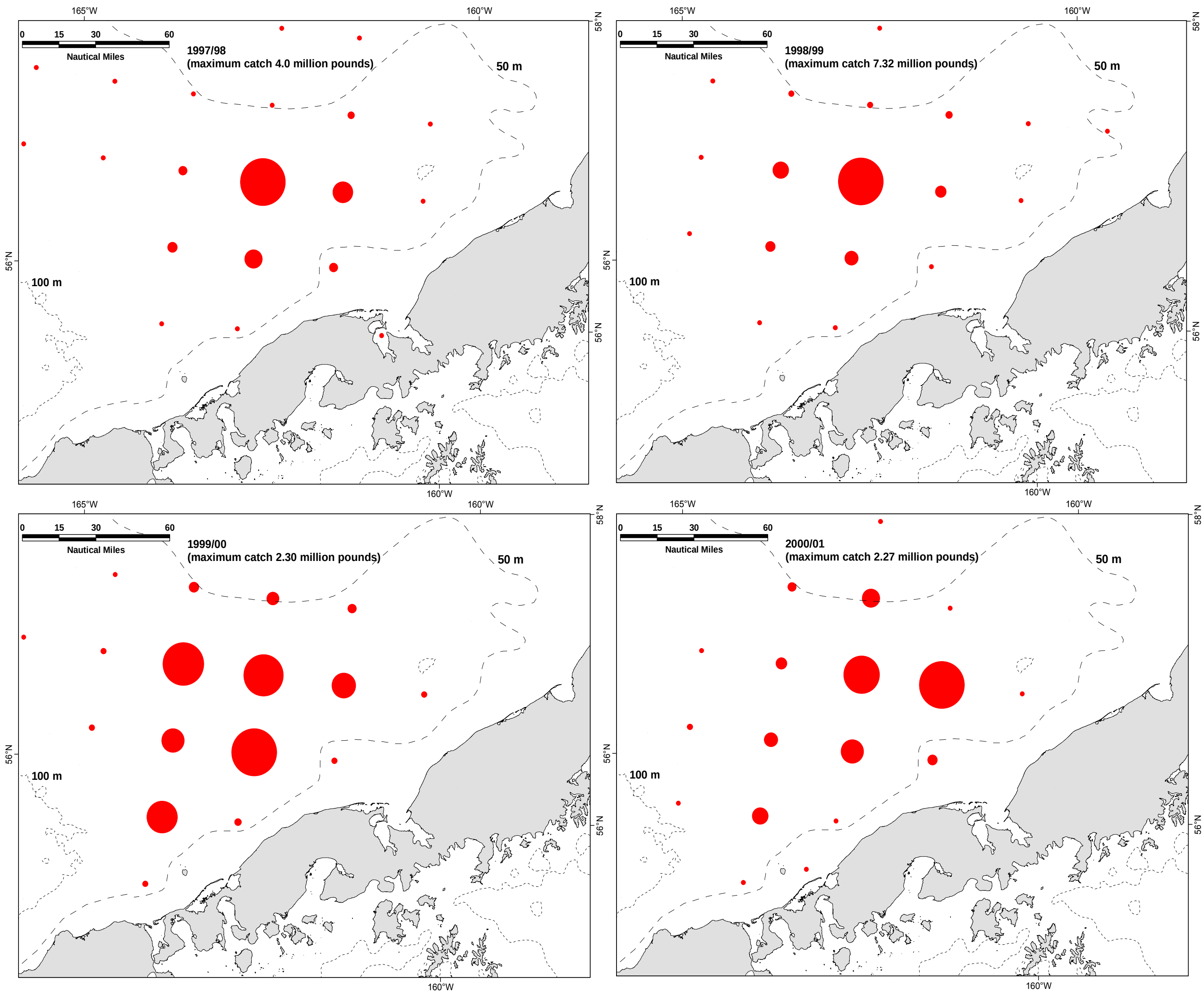

165°W
160°W
58°N
56°N
0 15 30 60
Nautical Miles
1993/94
(maximum catch 4.56 million pounds)
50 m
100 m

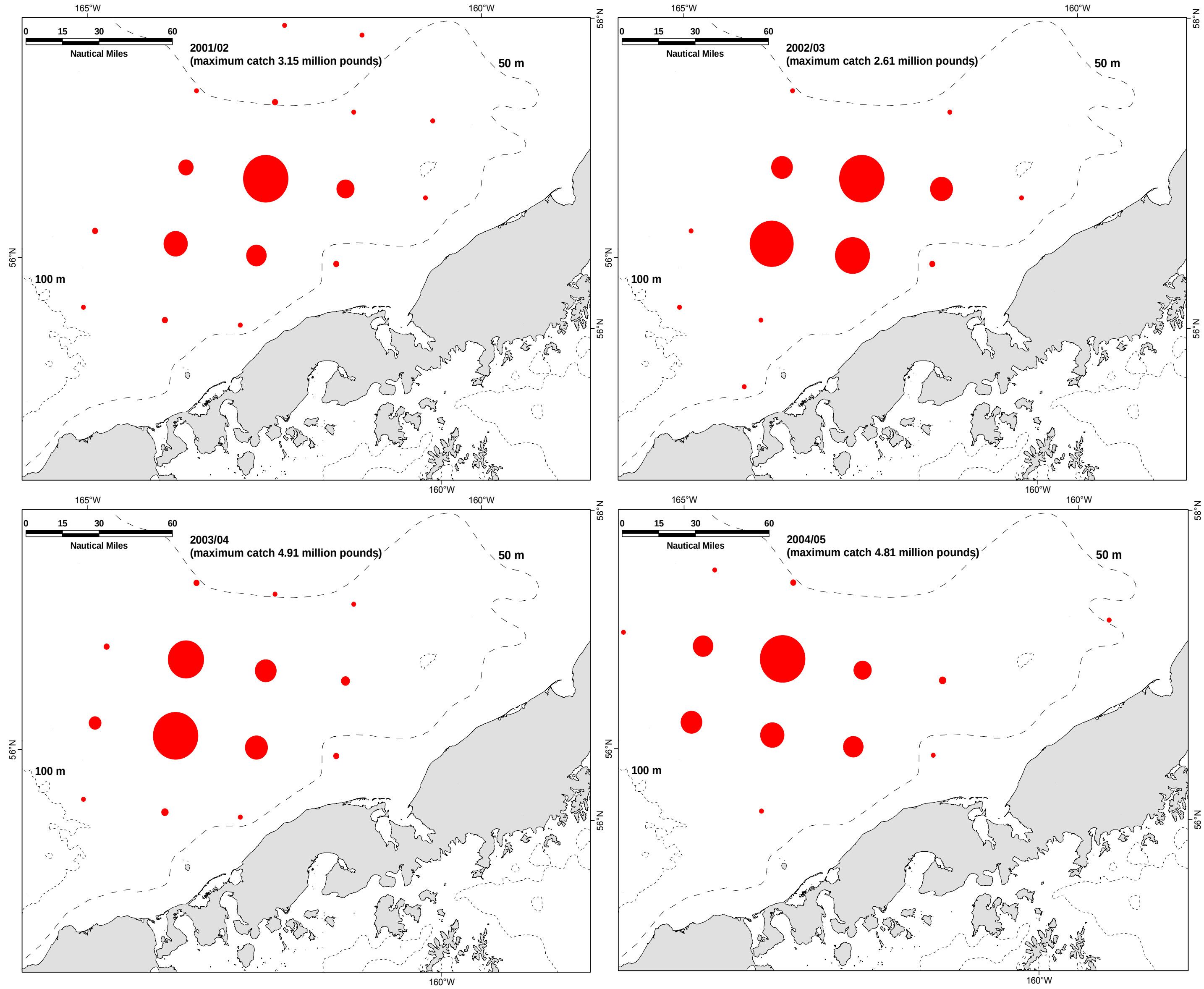

165°W
160°W
58°N
56°N
0 15 30 60
Nautical Miles
1994/95
(maximum catch 0.06 million pounds)
50 m
100 m

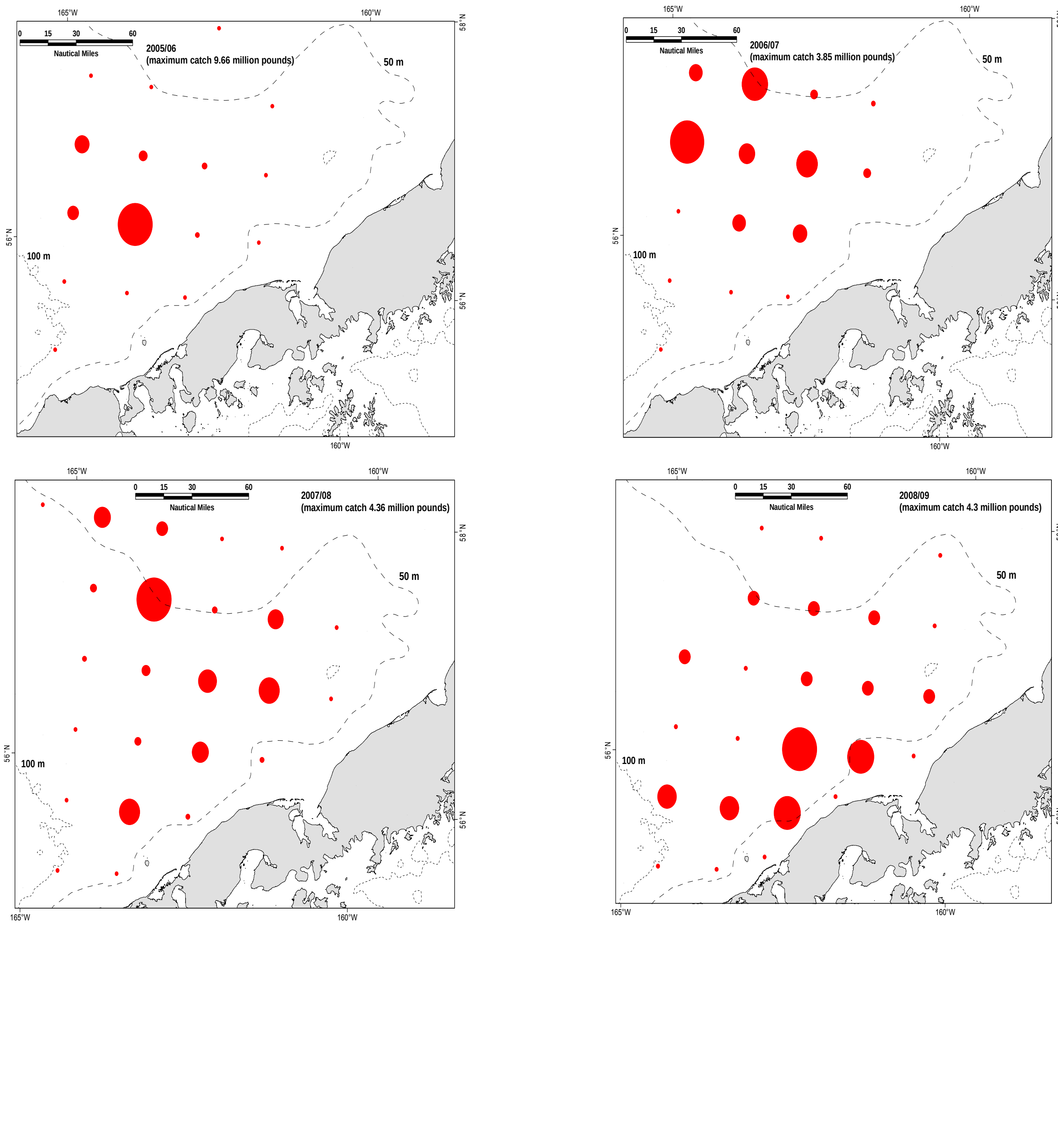

165°W
160°W
58°N
56°N
0 15 30 60
Nautical Miles
1995/96
(maximum catch 0.07 million pounds)
50 m
100 m

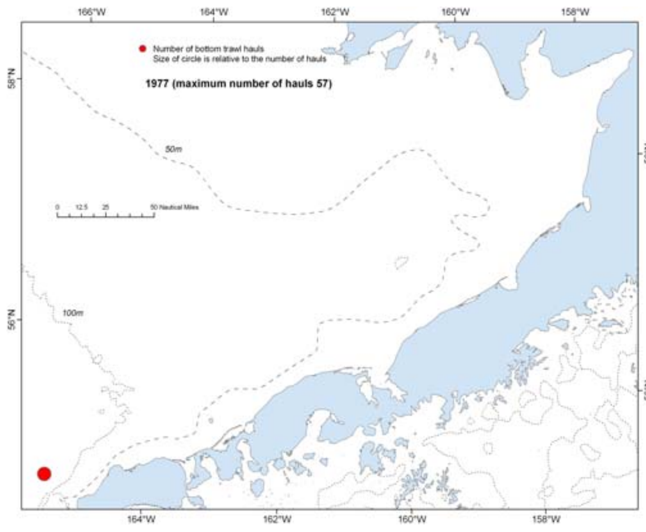

165°W
160°W
58°N
56°N
0 15 30 60
Nautical Miles
1996/97
(maximum catch 3.37 million pounds)
50 m
100 m

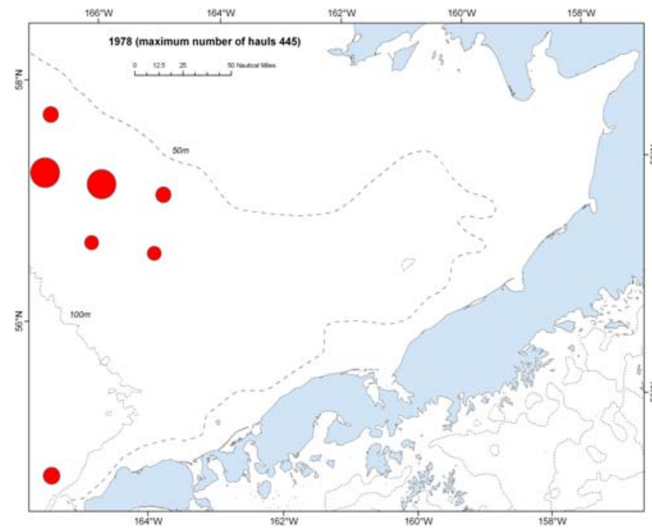
128

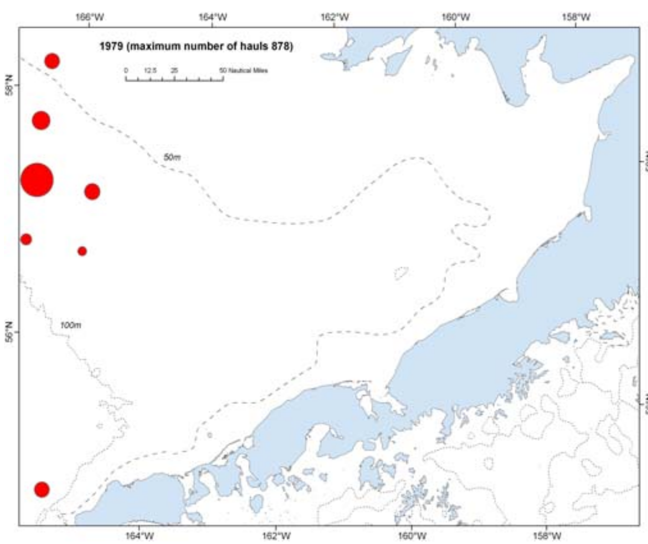

1997/98
(maximum catch 4.0 million pounds)
1998/99
(maximum catch 7.32 million pounds)
1999/00
(maximum catch 2.30 million pounds)
2000/01
(maximum catch 2.27 million pounds)
0 15 30 60
Nautical Miles
50 m
100 m
165°W
160°W
58°N
56°N

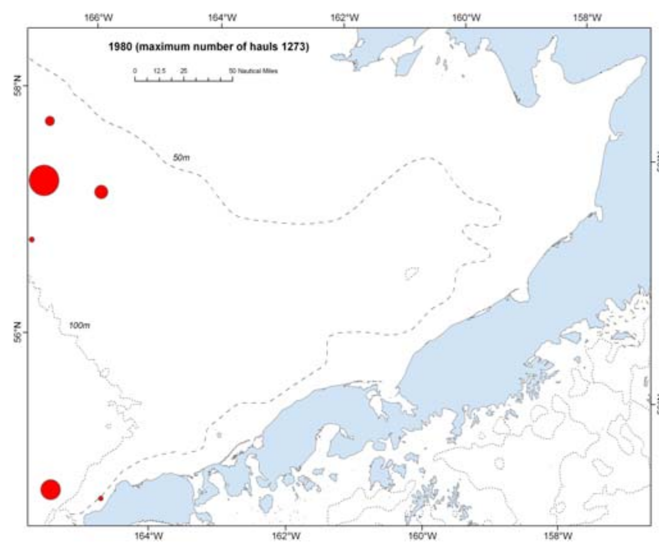

2001/02
(maximum catch 3.15 million pounds)
2002/03
(maximum catch 2.61 million pounds)
2003/04
(maximum catch 4.91 million pounds)
2004/05
(maximum catch 4.81 million pounds)
Nautical Miles
0 15 30 60
50 m
100 m
165°W
160°W
58°N
56°N

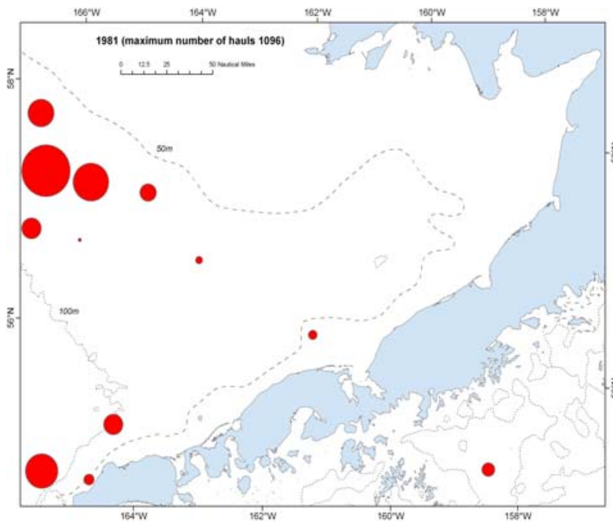

2005/06
(maximum catch 9.66 million pounds)
2006/07
(maximum catch 3.85 million pounds)
2007/08
(maximum catch 4.36 million pounds)
2008/09
(maximum catch 4.3 million pounds)
0 15 30 60
Nautical Miles
50 m
100 m
165°W
160°W
58°N
56°N

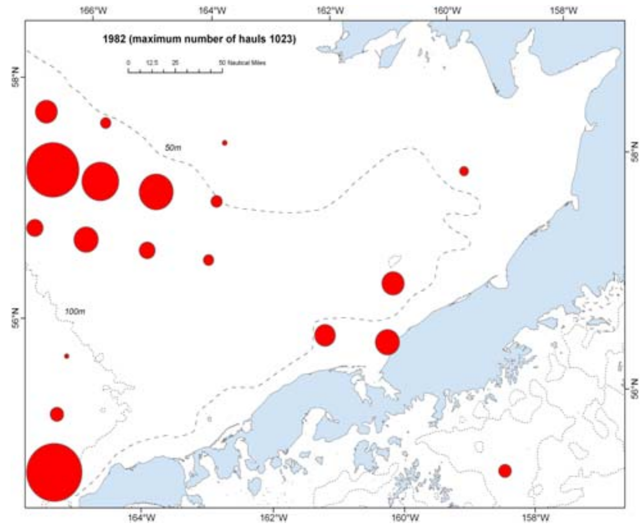

Number of bottom trawl hauls
Size of circle is relative to the number of hauls
1977 (maximum number of hauls 57)
50m
100m

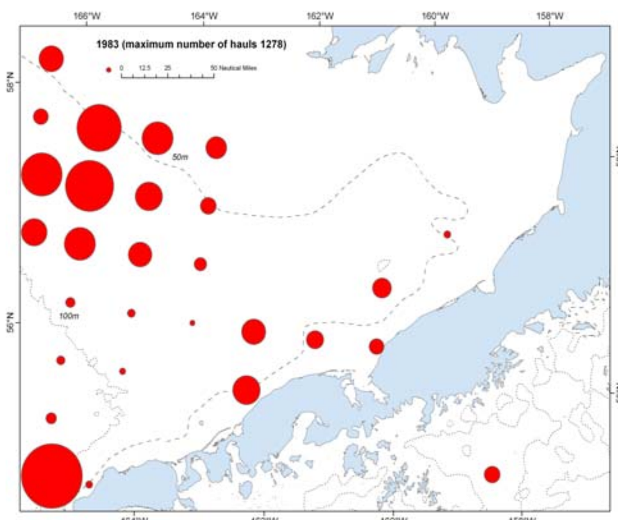

1978 (maximum number of hauls 445)
50m
100m

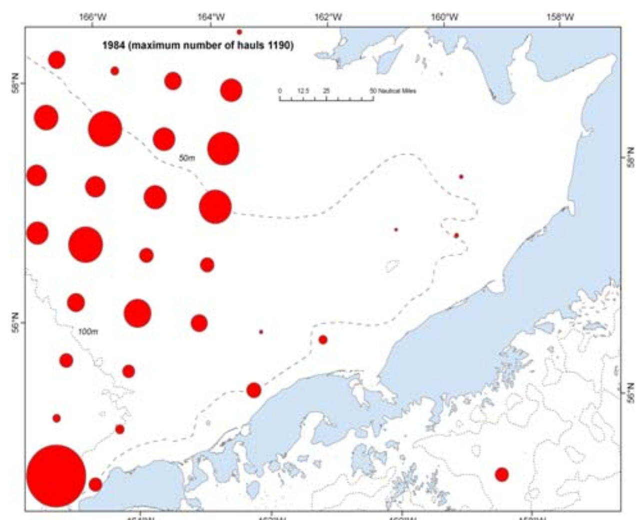

1979 (maximum number of hauls 878)
50m
100m


1980 (maximum number of hauls 1273)
50m
100m

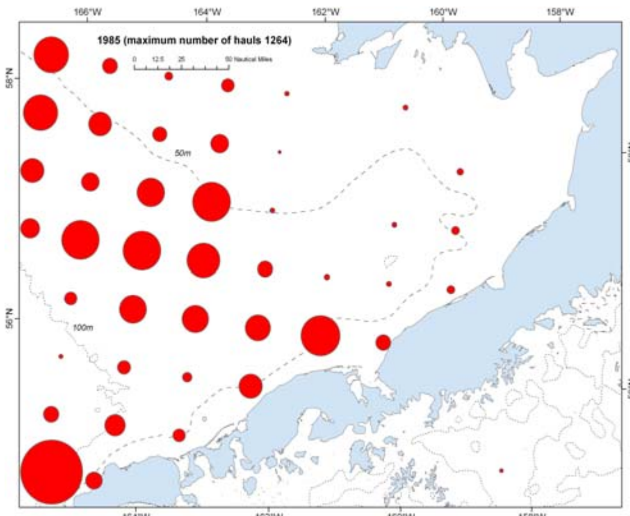

1981 (maximum number of hauls 1096)
50m
100m

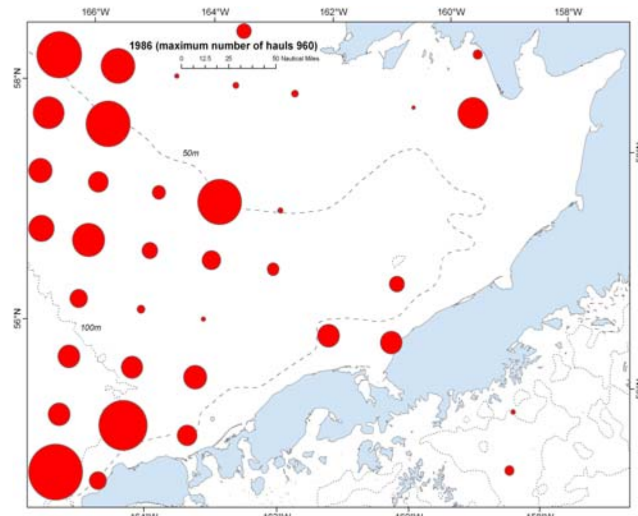

1982 (maximum number of hauls 1023)
50m
100m

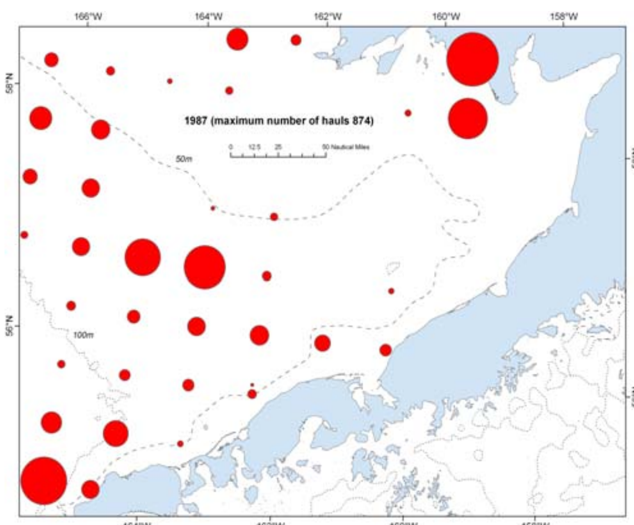

1983 (maximum number of hauls 1278)
50m
100m

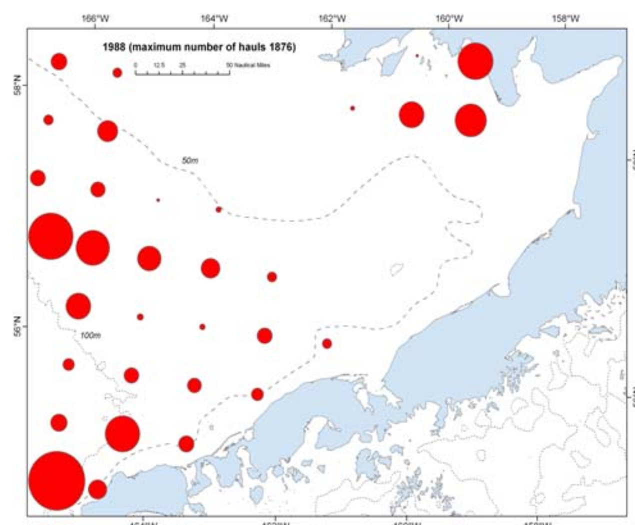

1984 (maximum number of hauls 1190)
50m
100m

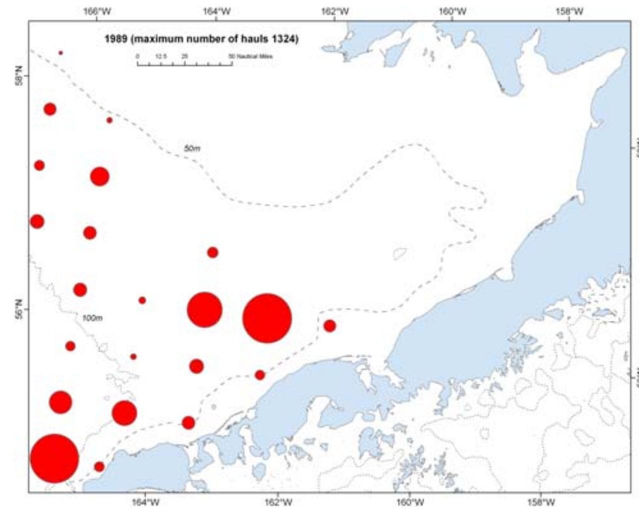
133

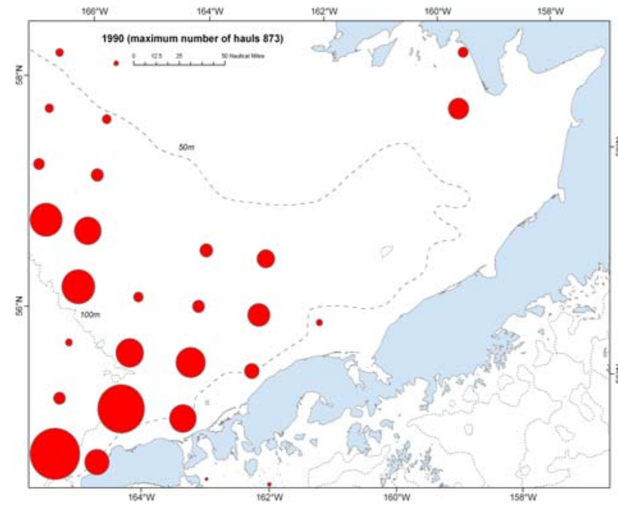

1985 (maximum number of hauls 1264)
50m
100m

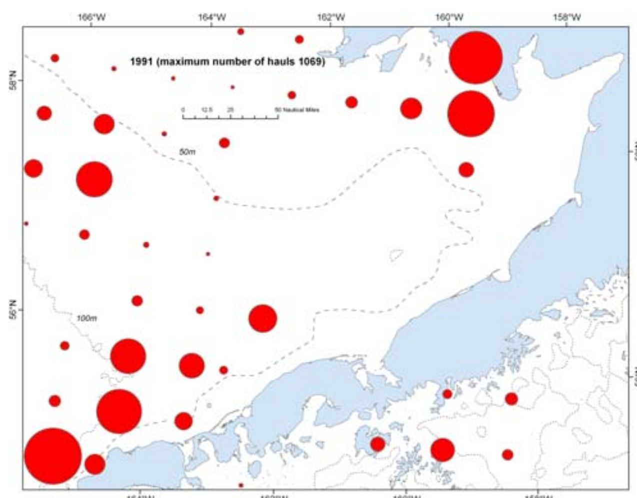

1986 (maximum number of hauls 960)
50m
100m

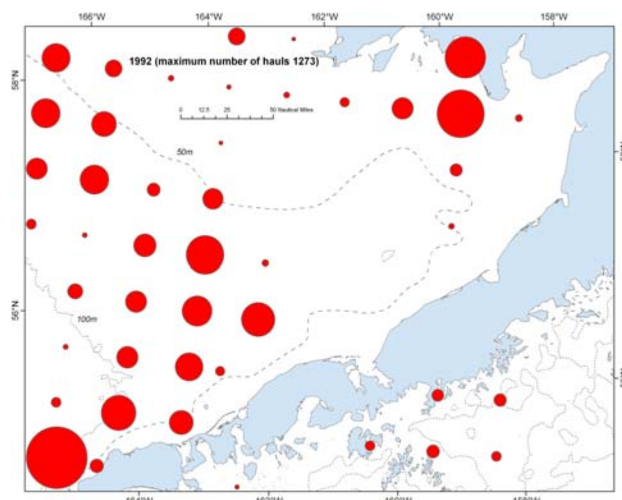

1987 (maximum number of hauls 874)
50m
100m

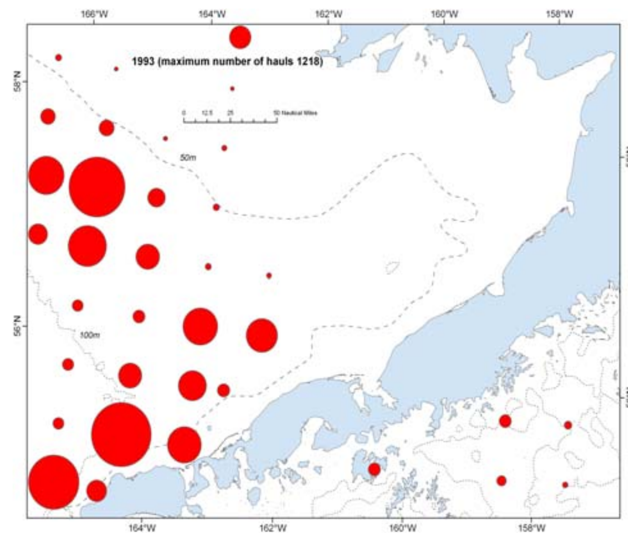

1988 (maximum number of hauls 1876)
50m
100m

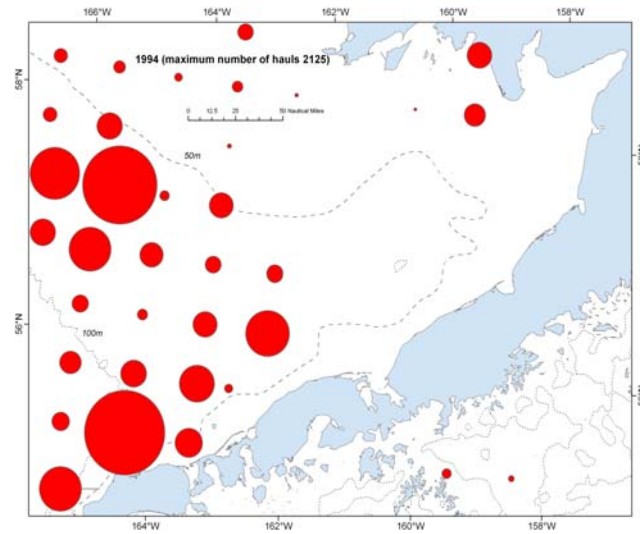

1989 (maximum number of hauls 1324)
166°W 164°W 162°W 160°W 158°W
58°N 56°N
50m
100m

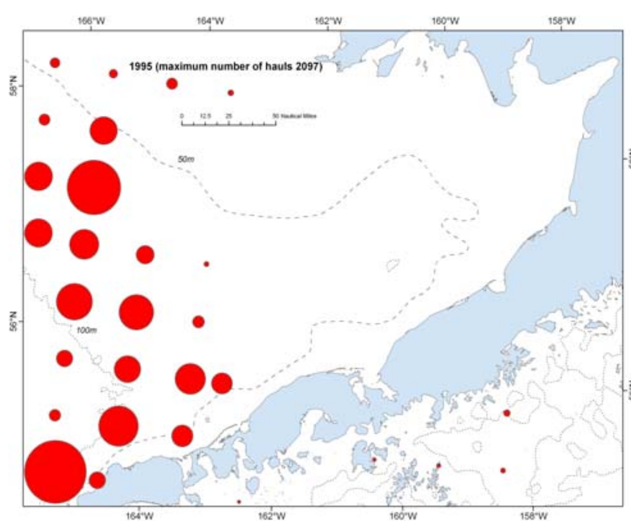

1990 (maximum number of hauls 873)
166°W 164°W 162°W 160°W 158°W
58°N 56°N
50m
100m

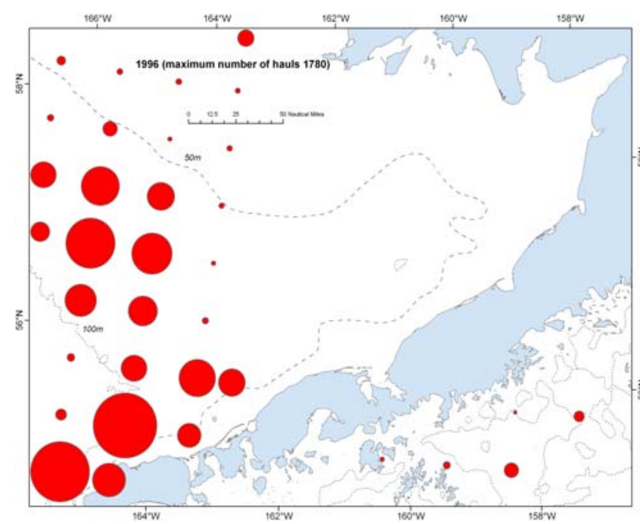

1991 (maximum number of hauls 1069)
166°W 164°W 162°W 160°W 158°W
58°N 56°N
50m
100m


1992 (maximum number of hauls 1273)
166°W 164°W 162°W 160°W 158°W
58°N 56°N
50m
100m

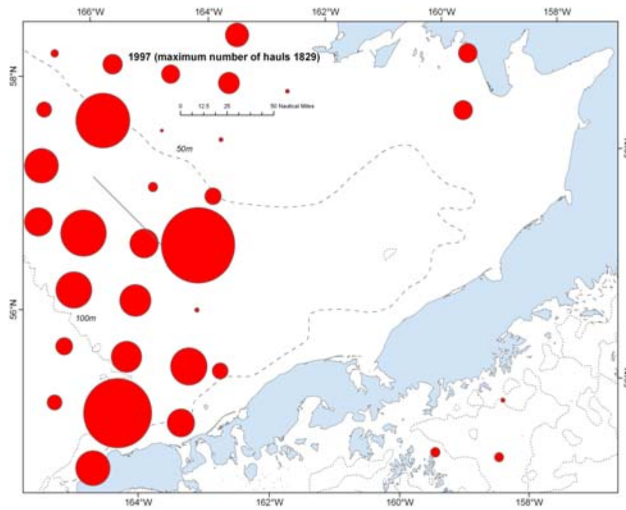

1993 (maximum number of hauls 1218)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

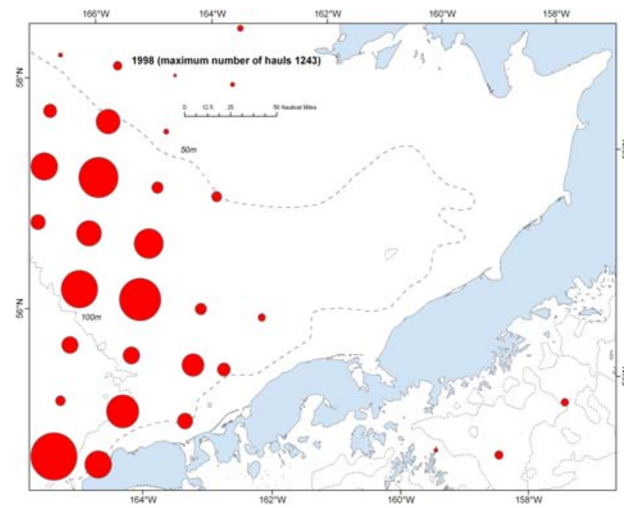

1994 (maximum number of hauls 2125)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

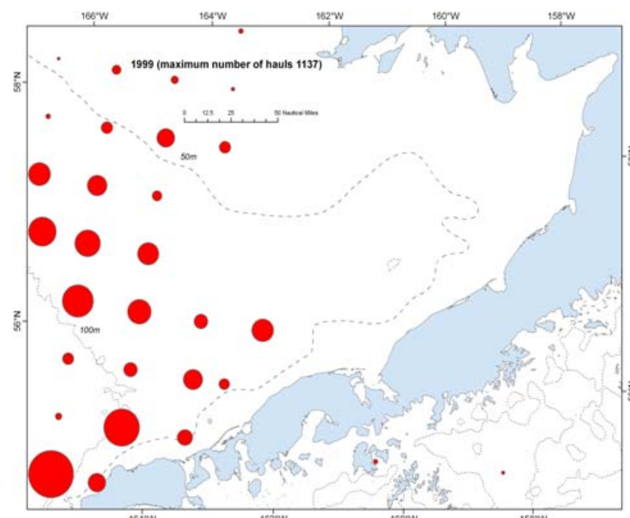

1995 (maximum number of hauls 2097)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

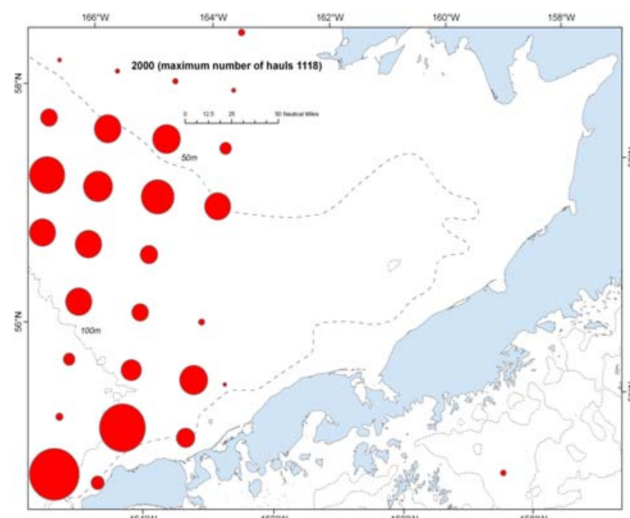

1996 (maximum number of hauls 1780)
50m
100m
166°W
164°W
162°W
160°W
158°W
58°N
56°N

136

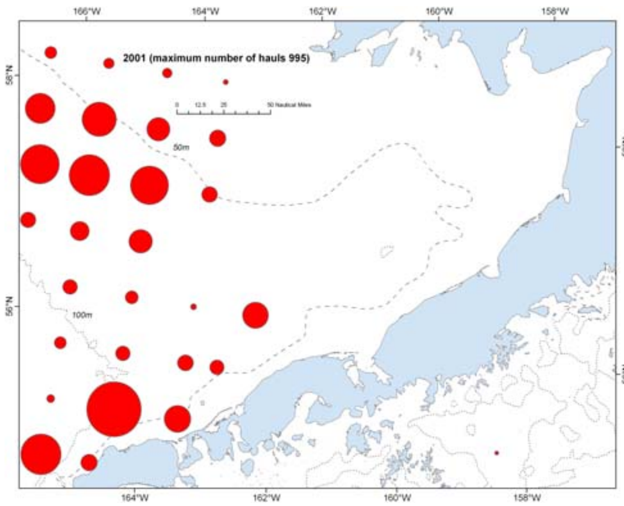

1997 (maximum number of hauls 1829)
50m
100m

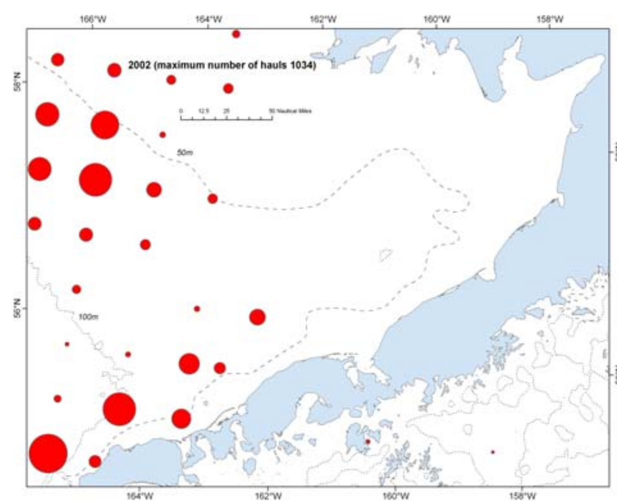

1998 (maximum number of hauls 1243)
50m
100m

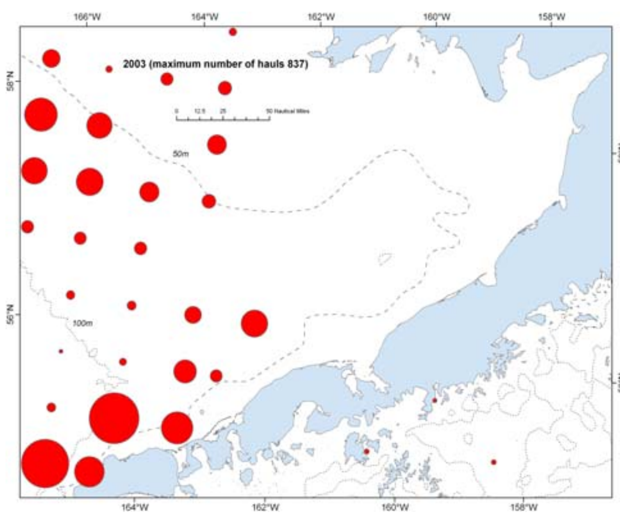

1999 (maximum number of hauls 1137)
50m
100m

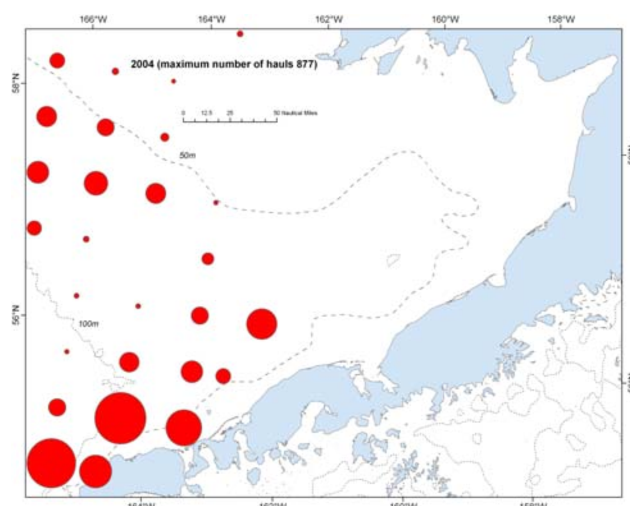

2000 (maximum number of hauls 1118)
50m
100m

137

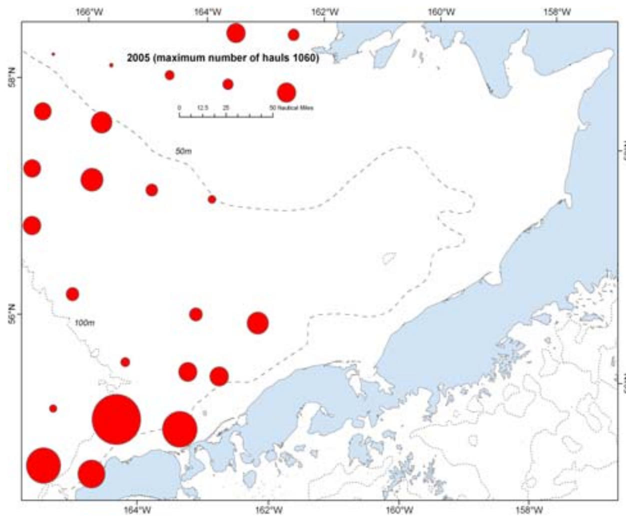

2001 (maximum number of hauls 995)
166°W
164°W
162°W
160°W
158°W
50m
100m

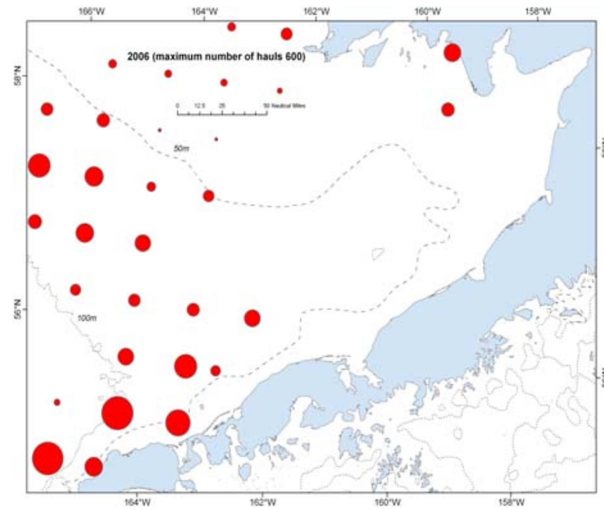

2002 (maximum number of hauls 1034)
166°W
164°W
162°W
160°W
158°W
50m
100m

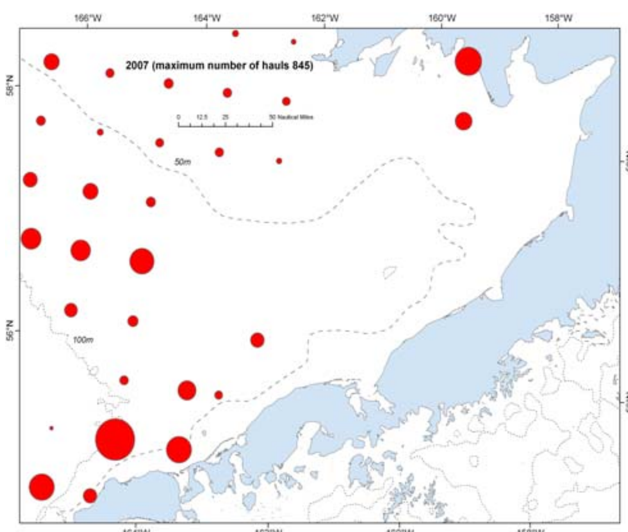

2003 (maximum number of hauls 837)
166°W
164°W
162°W
160°W
158°W
50m
100m


2004 (maximum number of hauls 877)
166°W
164°W
162°W
160°W
158°W
50m
100m

138


2005 (maximum number of hauls 1060)
50m
100m


2006 (maximum number of hauls 600)
50m
100m


2007 (maximum number of hauls 845)
50m
100m

139

140

2009 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

15 September 2009

Louis Rugolo and Jack Turnock
Alaska Fisheries Science Center
NOAA Fisheries

Executive Summary

In 2009, Tanner crab mature male biomass (MMB) at the time of the survey declined substantially and was projected to the time of mating in 2009/10 to be below the minimum stock size threshold (MSST). The status of the Eastern Bering Sea (EBS) Tanner crab stock in 2009/10 is projected to be overfished.

In 2009, Tanner crab MMB at the time of the survey was estimated at 87.6 million pounds. This was a 36.8% decrease in MMB relative to 2008. Legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southern Bristol Bay and northwest of the Pribilof Islands. The total abundance index for legal males decreased 40.3% to 7.9 million crabs between 2008 and 2009. Legal males were distributed 53.3% (4.2 million crabs) east and 46.7% (3.7 million crabs) west of 166^{o} west longitude which compared to 69.0% and 31.0% respectively in 2008. The abundance index for pre-recruit male crabs (110-137 mm cw) declined 33.7%, and that for small males (<110 mm cw) declined 11.0% relative to 2008. Total male abundance declined 18.7% between 2008 and 2009. Comparison of the 2007-2009 male size frequency distributions revealed a dramatic decline in male abundance above 60mm CL between 2008 and 2009 (Figure 12a), a general failure for modes to persist inter-annually (Figures 10a-d), and a relatively increasing percentage of old shell crabs in the mature male stock. A relatively strong recruit mode (20-40mm CL) is apparent in results of the 2009 survey.

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

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} for OFL-setting is the reference biomass (B_{REF})=189.76 million pounds MMB at the time of mating estimated as the average survey MMB_{mating} from 1969-80 inclusive. For Tier-4 stocks, the F_{OFL} is derived using an F_{OFL} Control Rule based on the relationship of current male mature biomass to B_{REF} as a proxy for B_{MSY}. Here, $F_{OFL}=\gamma M$**.** The Amendment 24 and its associated EA defines a default value of gamma=1.0. Gamma is allowed to be less than or greater than unity resulting in overfishing limits more or less biologically conservative than fishing at M. Amendment 24 also cautions that γ should not be set to a value that would provide less biological conservation and more risk-prone overfishing definitions without defensible evidence that the stock could support fishing at levels in excess of M. The resultant overfishing limit (F_{OFL}) for Tier-4 stocks is specified in terms of a Total Catch OFL that includes all stock losses (retained catch, discard and bycatch) for males and females combined.

The value of M is 0.23 for EBS Tanner crab. For this analysis, gamma is set to 1.0. The projected 2009 estimate of MMB at the time of mating is 70.16 million pounds. Relative to B_{REF} (189.76 million pounds), B/B_{REF}=0.370. Under the OFL Control Rule, the 2009 F_{OFL}=0.069.

For the 2009/10 Tanner crab fishery, we estimated the Total Catch OFL=5.57 million pounds for males and females combined. Total losses to MMB in the 2009/10 Total Catch OFL are 5.01 million pounds. Directed and non-directed discard losses to MMB in 2009 are estimated to be 1.04 and 2.42 million pounds, respectively. The retained part of the catch OFL of legal-sized crab is 1.55 million pounds. The retained legal catch would comprise 30.9% of the total MMB losses. A significant component of MMB losses therefore is attributed to non-targeted losses under current fishing practices.

Expected discard losses of female Tanner crab from the 2009/10 groundfish fishery and the directed pot fishery combined was estimated at 0.56 million pounds. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.135 and 0.064 respectively.

Status and catch specifications (10^6 lbs) for EBS Tanner crab.

Year	MSST	Biomass (MMB)	OFL	TAC [E+W]	Retained Catch	Total Catch
2005/06		86.60		1.60	0.95	3.56
2006/07		130.46		2.97	2.12	6.95
2007/08		151.58		5.62	2.11	8.00
2008/09	94.88	118.20	15.52	4.30	1.94	4.96
2009/10	94.88	70.16[1/]	5.57[2/]			

The 2008/09 stock was above MSST and hence not overfished. Overfishing did not occur during the 2008/09 fishing year. The stock is below MSST in 2009/10 and declared overfished.

Notes:
1/– Projected 2009/10 MMB at time of mating after extraction of the estimated total catch OFL.
2/– Projected total catch OFL for the 2009/10 fishery.

A. Summary of Major Changes

There are no major changes in assessment methodology this 2009 Tanner crab SAFE relative to the 2008 report (Rugolo et al. 2008) or the 2009 draft report (Rugolo et al. 2009) in terms of determining stock status or estimating the F_{OFL} and catch components comprising the Total Catch OFL. Two data inputs changed since the May CPT meeting and are included in the assessment: (1) revised groundfish fishery bycatch data of EBS crab for 1991-2008 provided by J.Mondragon (ARO, 08/07/09); and (2) revised EBS pot fishery discard data in the directed fishery and non-directed pot fisheries for 2006/07, 2007/08 and 2008/09 provided by D.Pengilly (ADF&G, 08/24/09). One change in method is included in this assessment for estimating expected discard losses of male and female Tanner crab in the directed pot fishery. We previously used the previous-most year (2007/08). The 2008/09 data were not available in May 2009. Here we used the average ratios of legal and sublegal male and female discards to the average retained catch in the 2006/07, 2007/08 and 2008/09 directed fisheries as the expected measures of performance to project discard losses in the terminal 2009/10 fishery.

B. Responses to SSC and CPT Comments

1. SSC Comments:

June 2009 Meeting:

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

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

The SSC made the following specific recommendations to assessment authors:

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

The revised groundfish fisheries bycatch data (J.Mondragon, 08/07/09) has been included in the 2009 SAFE report and OFL analysis. The revised EBS pot fishery discard data (D.Pengilly, ADF&G, 08/24/09) in the directed fishery and non-directed pot fisheries for 2006/07, 2007/08 and 2008/09 has been included in the 2009 SAFE report and OFL analysis.

The authors have estimated the 2009/10 MMB at mating using the revised EBS bottom trawl time series based on the measured footrope width. While the results of the OFL-setting analysis reported in the main body of this SAFE are shown using the trawl survey time series based on the fixed footrope width, the 2009/10 MMB at mating metric is compared to the 2009/10 MMB at mating based on the measured footrope data. The authors have developed the revised EBS bottom trawl time series based on the measured footrope width. Results of the OFL analysis using these data are presented in Appendix B. The SSC stated the importance of using these revised data for stock status determination and OFL-setting in the final 2009 assessment. The authors agree.

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

The authors agree with the SSC comments and recommendations.

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

The current stock assessment and OFL-setting Tier-4 analysis incorporates the entire stock area. A length-based Tanner Crab stock assessment model (TCSAM) for the EBS Tanner crab stock is in development. The author's goal is to present a progress report on model development to the CPT in May 2010 and to the SSC in June 2010. Having a final and approved Tanner crab stock assessment model for the 2010/11 assessment cycle is not anticipated given the normal review and approval process. Success in formulating TCSAM will depend on the historical time series survey data from 1969-2009 which are not yet available, as input to the model and to derive life-history metrics to parameterize the model. The goal is to promote the EBS Tanner crab stock to a Tier-3 management status, and formulate OFLs based on based the TCSAM. The assessment model will be specified for the unit stock distributed over the EBS shelf. The existing snow crab stock assessment model (COSAM) (Turnock and Rugolo 2009) is being evaluated as a candidate to modify in developing the TCSAM.

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

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

The authors agree with the SSC comments and recommendations. Results of our feasibility analysis for estimating Tanner crab OFL using $F_{35\%}$ and estimated fishery selectivities are presented in Appendix A. The rationale presented in the 'Analytical Approach' and 'OFL Setting Results' sections of this document also support gamma=1.0 for this stock.

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

The authors agree with the SSC comments and recommendations. Results of our feasibility analysis for estimating Tanner crab OFL using $F_{35\%}$ and estimated fishery selectivities are presented in Appendix A. The rationale presented in the 'Analytical Approach' and 'OFL Setting Results' sections of this document also support gamma=1.0 for this stock.

2. CPT Comments:

May 2009 Meeting:
In their review of the Draft 2009 Tanner crab SAFE report at their May 2009 meeting, the Crab Plan Team made the following comments concerning the EBS bottom trawl survey data and its use in 2009/10 stock assessments and OFL-setting:

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

The authors followed this recommendation from the CPT. In June 2009 the SSC recommended use of the revised time series for the final assessment in 2009. As directed by the SSC, the authors have estimated the 2009/10 MMB at mating using the revised bottom trawl time series data. The results of the OFL-setting analysis reported in the main body of this SAFE are based on unrevised (fixed footrope) time series data. The authors compare the estimated 2009/10 MMB at mating metric using measured footrope width data to the 2009/10 MMB at mating based on fixed footrope width. The authors have developed the revised EBS bottom trawl time series based on the measured footrope width. Results of the OFL analysis using these data are presented in Appendix B.

The authors agree with the SSC in its stated importance of using these revised data for stock status determination and OFL-setting in the final 2009 assessment.

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

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

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

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

A length-based Tanner Crab stock assessment model (TCSAM) is in development. The authors will present a progress report on a working model for review to the CPT in May 2010 and to the SSC in June 2010. Given the Council review and approval process, it's not anticipated that the TCSAM will be implemented for the 2010/11 assessment cycle but, rather, for the ensuing 2010/11 fisheries. Model development will depend on the historical time series survey data from 1969-2009 which are not yet available, as input to the model and to derive life-history metrics to parameterize the model. The goal of this work is to promote the EBS Tanner crab stock to a Tier-3 management status, and formulate OFLs based on based the TCSAM.

The assessment model will be specified for the unit stock distributed over the EBS shelf. The existing snow crab stock assessment model (COSAM) (Turnock and Rugolo 2009) is being evaluated as a candidate to modify in developing the Tanner crab stock assessment model (TCSAM). Despite the precedent of establishing operational management controls for this stock east and west of 166^{o} W longitude, the unit stock of Tanner crab in the EBS comprises crab throughout the geographic range of the NMFS trawl survey. No evidence supports partitioning the unit stock into discrete, non-interbreeding and non-mixing sub-populations which can be assessed and managed as separate units. If clinal differences in biological metrics (e.g., growth and maturity) exist and are essential to the status of stock determination and OFL-setting, these may be accommodated within the formulation of the model. Given requisite understanding of the geographic fidelity of the stock over its range, and its availability to the fisheries, partitioning of the Total Catch OFL may be possible to support operational decisions of setting TACs or issuing of IFQs for Eastern District and Western District fisheries.

iii. 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.

Following the recommendation of the SSC (October 2008 minutes quoted above) and consistent with that of the authors, a value of gamma=1.0 is adopted for OFL-setting. Use of a value of gamma greater than unity is unsupported by evidence that this stock can persist in the face of exploitation rates in excess of M. The rationale presented in subsections 1. History of Modeling Approaches, and 2. Model Selection of section E. The Analytical Approach, also support the use of gamma=1.0 for this stock. Consistent with precautionary management principles embodied in the MSFCMA and national standards, the CPT may recommend the use of a gamma<1.0 to achieve stock rehabilitation goals considering the uncertainty in current stock status.

iv. 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.

More complete documentation of data sources has been made. The calculations used for deriving the OFL are shown. The table specifying the Total Catch OFL and the various catch components has been modified.

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

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

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

The authors agree.

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

This draft Tanner crab SAFE report addresses the SSC comments from their October 2008 meeting.

viii. 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.

A retrospective re-analysis of the entire historical NMFS trawl survey database began in 2009. At the May 2009 meeting, an update on the progress of this work and the nature of data quality issues across the data record will be given to the CPT by the Stock Assessment Program. At the time of this September 2009 CPT meeting, the authors don't have the complete survey time series data needed as input to the assessment model, or required to derive life-history metrics required to parameterize a full assessment model. The length-based stock assessment model being developed for the EBS Tanner crab stock will use the newly derived time-series survey data. The authors will attempt to more fully describe the fishery data used in the OFL-setting where they may affect the results.

C. 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 found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a) where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break where water temperatures are generally warmer (Figures 1 and 2). The southern range of the cold water congener the snow crab, *C. opilio*, 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).

Stock structure
Tanner crabs in the EBS are considered to be a separate stock distinct stock from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998**.** The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit. Clinal differences in some biological characteristics may exist across the range of the unit stock (Somerton 1981a).

D. Data
1. The Survey
The NMFS conducts an annual trawl survey in the EBS to determine the distribution and abundance of commercially-important crab and groundfish fishery resources. The survey has been conducted since 1968 by the Resource Conservation and Engineering (RACE) Division of the Alaska Fisheries Science Center. It's been conducted annually since 1975 when it was also expanded into Bristol Bay and the majority of the Bering Sea continental shelf. Since 1988, 376 standard stations have been included in the survey covering a 150,776 nm^2 area of the EBS with station depths ranging from 20 to 150 meters depth. The annual collection of data on the distribution and abundance of crab and groundfish resources provides fishery-independent estimates of population metrics and biological data used for the management of target fishery resources. Crustacean resources targeted by this survey and enumerated annually by NMFS are red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), hair crab (*Erimacrus isenbeckii*), Tanner crab (*Chionoecetes bairdi*) and snow crab *(C. opilio*). The sampling methodology specifies the majority of tows made at the centers of squares defined by a 20 x 20 nmi (37 x 37 km) grid (Figures 2 and 3). Near St. Matthew Island and the Pribilof Islands, additional tows were made at the corners of squares that define high density sampling strata for blue king crab and red king crab.

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

Stock Biomass

Tanner crab male mature biomass (MMB) and legal male biomass (LMB) exhibited periods of peak biomass in the early to mid-1970s and the early to mid-1990s (Table 5, Figures 4b and 6). LMB data are currently available for 1980-2009. MMB estimates currently date to 1969. Retrospective analysis of the historical NMFS trawl survey data is in progress which will complete the time series record and provide a consistent estimate of stock metrics between 1968 to present. The components of MMB and LMB at the time the survey, at the time of the fishery and at the time of mating are shown in Table 5 and Figure 6. The historical bimodal distribution in male biomass (Figure 4) reflects that of the attendant directed fisheries with peak modes in the mid-1960s through mid-1970s and in the early-1990s (Table 5, Figure 5), and collapsed stock status following those modes. MMB at the survey revealed an all-time high of 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 87.6 million pounds in 2009. Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the B_{MSY} level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt.

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

The combined Eastern and Western Districts abundance index (23.8 million crabs) of large females ($\geq$ 85 mm cw) showed a 25.7% decrease over 2008, and these were dominated (68.3%) by old shell females. (Figure 9). Among all female Tanner crab in 2009, 25.3% were old shell in all categories combined and 74.7% were comprised of molting, new-soft and new-hard shell (71.9%) categories (collectively, new shell females). Among this new shell female group, 89.8% were immature and 10.2% mature. Of all mature new shell females, 19.3% were barren and 80.7% ovigerous, among which 10.2%, 67.1% and 21.8% brooded ¾ full, ½ full and full clutches, respectively, while the remainder carried partial clutches less than ½ full. The small (<85 mm cw) female Tanner crab abundance estimate in 2009 (152.0 million crab) increased 21.0% relative to 2008. Total 2009 female abundance (175.8 million crab) increased 11.5% from 2008 to 2009, and the total abundance of male and female combined (401.4 million crab) declined 7.8% (Figure 9). Ovigerous females were sparsely distributed from southern Bristol Bay where at relatively highest abundance westward to south of St. Matthew Island (Figure 2). Immature female Tanner crab displayed a similar distribution to mature females although they were slightly more densely distributed relative to matures along the southeast-northwest cline from southwestern Bristol Bay, north of the Pribilof Islands to west and south of St. Matthew Island (Figure 2). The survey length frequency distributions of female Tanner crab from 2007-2009 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11a-d). The prominent length mode between 65-75 mm cw seen in 2006 did not persist through 2007, 2008 or 2009 but revealed consistently declining abundance through 2009. The mode of mature females in 2008 at 75 mm cw declined in abundance in 2009 and is dominated by old and very old shelled females. A modest mode of new shell recruits is seen in 2009 at 25-30 mm cw, and new shell females dominate the 2009 length frequency distribution below 65 mm cw. A significant portion (73.4%) of mature female Tanner crab 75 mm cw and larger in 2009 are comprised of old shell females, and 25.1% of this length group were in the new-hard shell condition class (Figure 11d). As seen for male Tanner crab, female abundance above 60mm CL declined sharply between 2008 and 2009 (Figure 11d).

2. The Fishery

Management Unit

Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the EBS is managed under a federal fisheries management plan (NPFMC 1998). The plan defers certain management controls for Tanner crab to the state of Alaska with federal oversight (Bowers et al. 2008). The state manages Tanner crab based on registration areas, divided into districts. Under the plan, the state can adjust or further subdivide these districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 1998).

The Bering Sea District of Tanner crab Registration Area J (Figure 3) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36' N lat. and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173° W long. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168° W long. and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

The domestic Tanner crab (*C. bairdi*) pot fishery rapidly developed in the mid-1970s (Table 2, Figures 5). For stock biomass and fishery data tabled in this document, we adopted the convention that 'year' refers to the survey year, and fishery data are those subsequent to the survey, through prior to the survey in the following year. Other notation is explicit – e.g., 2008/09 is the 2008 summer survey and the winter 2009 fishery. United States landings were first reported for Tanner crab in 1968 at 1.01 million pounds taken incidentally to the EBS red king crab fishery (Table 2). Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early-1970s, reaching a high of 66.6 million pounds in 1977 (Table 2, Figure 5). Landings fell precipitously after the peak in 1977 through the early 1980s, and domestic fishing was closed in 1985 and 1986 as a result of depressed stock status. In 1987, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990 at 40.1 million pounds, and then fell sharply through the mid-1990s (Figure 5). The domestic Tanner crab fishery closed between 1997 and 2004 as a result of severely depressed stock condition. The domestic Tanner crab fishery re-opened in 2005 and has averaged 1.7 million pounds retained catch between 2005-2007 (Table 2). Landings of Tanner crab in the foreign Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 44.0 million pounds in 1969 (Table 2, Figure 5). 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, non-directed pot fisheries (notably, for snow crab and red king crab), and the groundfish trawl fisheries (Table 3). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for trawl fishery bycatch (NPFMC 2008). Total Tanner crab discard and bycatch losses by sex are shown in Table 3 for 1965-2008. The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 2). These losses were persistently high during the late-1960s through the late-1970s; male losses peaked in 1970 at 44.5 million pounds (Table 3). A subsequent peak mode of discard/bycatch losses occurred in the late-1980s through the early-1990s which, although briefer in duration, revealed higher losses for males than the earlier mode, peaking at 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 3). Total Tanner crab retained catch plus non-directed losses of males and females (Table 4, Figure 4a) reflect the performance patterns in the directed and non-directed fisheries. Total male catch rose sharply with fishery development in the early 1960s and reveals a bimodal distribution between 1965 and 1980 with peaks of 104.7 million pounds in 1969 and 115.5 million pounds in 1977 (Table 4, Figure 4a). 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 losses by all pot and trawl fisheries combined to retained catch shifted significantly relative to that between 1980-1996 (Tables 2 and 3). For 2005-2008, the ratio of total male discard losses to retained catch was 4.3, 3.8, 4.6, and 2.4, respectively, and averaged 3.8 (se=0.5). The majority of these male losses are sub-legal sized crab, and a principal contributor to these non-retained losses is the directed Tanner crab fishery (Table 7a). This contrasts the pre-closure performance of the domestic fishery between 1980-1996 which averaged 1.1 (se=0.1) pounds of non-retained male losses to each pound of retained catch. These ratios in terms of numbers of non-retained male losses to retained legal crab are more striking due to the contribution of sub-legal sized crab to total male discards. Discard and bycatch losses of male and female Tanner crab (Table 3) during the closures of the directed domestic fishery (1985-1986 and 1997-2004) reflect losses due to non-directed EBS pot fisheries and the domestic groundfish trawl fishery.

Exploitation Rates
The historical patterns of fishery exploitation on LMB and MMB were derived (Table 6, Figures 7a and 7b). The exploitation rate on LMB was estimated as the proportion of retained catch to LMB at the time of the fishery, while that on MMB as the proportion of total male catch to MMB at the time of the fishery. Estimates of LMB are currently available only for 1980-2008. When the re-analysis of the NMFS trawl survey database is completed, MMB estimates will be available for the time series record, 1968 to present. During 1980-2008, exploitation rate (μ) on LMB was highest in 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 7b). These rates of exploitation on LMB are less than the equivalent value of M=0.23 for this stock; the EBS Tanner crab stock did not persist at sustainable or healthy stock levels under these rates. The pattern of μ on MMB from 1969-2008 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) is attributed to early biomass estimates which will be replaced by a new biomass time-series biomass in 2010. Exploitation rates on MMB during the 1990s peaked at 0.42 in 1990, averaged 0.21 between 1986-1997, and closely followed the build up in stock biomass during that period.

3. Life-History

Reproduction
In most majid crabs, the molt to maturity is the final or terminal molt. For *Chionoecetes bairdi* specifically it is now generally accepted that both males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo terminal molt at maturity. Females terminally molt from their last juvenile, or pubescent, instar usually while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding their clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using stored sperm from the spermathacae (Adams and Paul 1983, Paul and Paul 1992). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to self-fertilize the new clutch (Paul 1982, Adams and Paul 1983), however, egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically. Physiological maturity refers to the presence or absence of spermataphores in the 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 (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 Prince William Sound. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the EBS egg condition for multiparous Tanner crabs assessed between April and July 1976 also suggested that hatching and extrusion of new clutches for this maturity status began in April and ended sometime in mid June (Somerton 1981a).

Fecundity
A variety of factors affect female Tanner crab fecundity including female size, maturity status (primiparous vs multiparous), age post terminal molt, and egg loss (NMFS 2004a). Of these factors, female size is the most important, with estimates of 89 to 424 thousand eggs for EBS females 75 to 124 mm carapace width (cw) respectively (Haynes et al. 1976). Maturity status is another significant factor affecting fecundity with primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent females often carry small clutches or no eggs (i.e., barren) suggesting that female Tanner crab reproductive output is a declining function of age (NMFS 2004a).

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 >=80 mm cw (Bowers et al. 2008). For male Tanner crab during the same survey years, the estimated size at 50% maturity was 117.0 mm cw and 108.9 mm cw east and west of 167° 15’ W longitude, respectively (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. Somerton postulated that because of net selectivity of the survey sampling gear, age five Tanner crab (mean cw=95 mm) were the first cohort to be fully recruited to the gear; he estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using 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. The natural mortality rate (M) of EBS Tanner crab is set at 0.23 for the purpose of assessing stock status and OFL-setting based on the current expectation of longevity of at least 15 y.

Growth and Age
Somerton (1981a) studied growth of Tanner crab in the EBS 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 1). Radiometric ageing has suggested that age after the terminal molt to maturity may be 6 to 7

years (Nevisi et al. 1996). If mean age at maturity is 7-8 y, these results suggest that maximum age of an exploited stock is 13-15 y.

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 Tanner crab. Only clean shell 2 or 3 crab were selected with no missing or regenerating appendages. The fitted equation for male weight at carapace width is: $W=0.00019(CW)^{3.09894}$.

E. The Analytic Approach

1. History of Modeling Approaches

Tier-4 OFL Control Rule

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} for management is the reference biomass (B_{REF})=189.76 million pounds MMB at the time of mating estimated as the average survey MMB_{mating} from 1969-80 inclusive. In 2009, survey MMB of Tanner crab (87.6 million pounds) declined 38.8% relative to 2008 (143.1 million pounds). MMB projected to the time of mating in 2009/10 (70.16 million pounds) represents 37.0% of B_{REF} after accounting for projected total losses to MMB in the 2009/10 Total Catch OFL=5.01 million pounds. MMB at mating in 2009/10 is below the minimum stock size threshold (MSST=94.88 million pounds). The status of the Eastern Bering Sea (EBS) Tanner crab stock in 2009/10 is projected to be overfished. Per the SSC request in June 2009, we estimated 2009/10 survey MMB based on the revised EBS bottom trawl survey data at 77.1 million pounds which is approximately 12.0% lower than that derived using the unrevised data. Results of the full OFL analysis using revised EBS bottom trawl survey data based on measured footrope widths for 1976-2009 are presented in Appendix B.

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 may be available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Such modeling approaches can serve the basis for estimating the annual status determination criteria to assess stock status and to establish harvest control rules.

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

For Tier-4 stocks, the F_{OFL} is derived using and F_{OFL} Control Rule (Figure 8) according to whether current mature stock biomass metric (B_t) belongs to stock status levels a, b or c in the algorithm below. The stock biomass level beta (β) represents a minimum threshold below which directed fishing mortality is set to zero. The F_{OFL} Control Rule sets β=0.25. The parameter alpha moderates the slope of the non-constant portion of the control rule. For biomass levels where $\beta < B_t \leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B_t/B_{MSY}.

The value of M is 0.23 for eastern Bering Sea Tanner crab. In the analysis of Tier-3 for snow crab, *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 is specified consistent with the expectation of a measure of equilibrium stock biomass (B_{MSY}) capable of yielding MSY to the fisheries operating at F_{MSY}.

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

2. Model Description

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

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

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

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

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

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

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 ($1-e^{-Fofl}$) and the male mature biomass at the time of the fishery ($MMB_{survey}e^{-2M/3}$). The time from survey to the mean fishery period is 8 months.

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

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) equals that estimated in equation (4).

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

$$C_{dir\text{-}dsc,MMB\ 09} = C_{ret,LMB\ 09}\ (DSC,MMB_{06\text{-}08} / C_{ret,LMB\ 06\text{-}08})\ HM_{pot} \quad (6)$$

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 a lesser extent. In this analysis, we used data from the previous three fishing seasons (2006, 2007 and 2008) to estimate of the average ratio of combined Tanner crab mature male discards ($C_{non\text{-}dsc\text{-}pot,MMB\ 06\text{-}08}$) to average snow crab retained catch ($C_{ret,Opilio\ 06\text{-}08}$) (Table 7b). $C_{ret,opilio\ 2009}$ is the projected 2009 retained catch OFL (Turnock, pers. Comm.). Using this ratio, projected non-directed pot fishery discard losses to MMB in the terminal fishery ($C_{non\text{-}dsc\text{-}pot,MMB}$) is given by:

$$C_{non\text{-}dsc\text{-}pot,MMB} = C_{ret,Opilio\ 2009}\ (C_{non\text{-}dsc\text{-}pot,MMB\ 06\text{-}08} / C_{ret,opilio\ 06\text{-}08})\ HM_{pot} \quad (7)$$

Discard losses to MMB ($C_{non\text{-}dsc\text{-}gf,MMB\ 09}$) resulting from bycatch in the groundfish trawl fisheries was estimated using the average groundfish bycatch of Tanner crab over 2003-08 (Mean $_{03\text{-}08,dsc,gf}$) (Table 7c) supplied by J. Mondragon (ARO, 08/07/09) We assumed that this average (6 y) bycatch of Tanner crab would occur in the terminal 2009 fishery. Reported bycatch are for males and females combined. The sex distribution of this bycatch is unavailable for this analysis. The proportion of males in the bycatch ($Porportion_{male}$) was estimated assuming a sex ratio of 1:1 in the bycatch and apportioning the catch based on the ratio of mean weights of 120 mm cw male crab to 87.5 mm cw female crab resulting in a 60.2% v. 39.8% male to female split.

For all trawl discards, a post-release handling mortality rate of 80% was used (HM_{gf}=0.80). Groundfish trawl fishery discard losses to MMB is given by:

$$C_{non\text{-}dsc\text{-}gf,MMB\ 09} = Mean_{03\text{-}08,dsc,gf}\ Porportion_{male}\ HM_{gf} \quad (8)$$

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

3. Model Selection

In May 2008, the CPT requested that the authors examine the feasibility of estimating $F_{35\%}$ for the Tanner crab stock using fishery selectivity. The SSC had recommended using fishery selectivity and maturity to estimate $F_{35\%}$ as the proxy F_{OFL}, and to estimate gamma as the ratio of $F_{35\%}$ to M. Results of that study are presented in Appendix A, which the SSC reviewed in October 2008. Fishery selectivity for Tanner crab used in the EA analysis were estimated based on historical fishery performance prior to the 1997 closure. We estimated selectivity for the contemporary Tanner crab fishery following its reopening in 2005 and found that the current selectivity patterns for both the directed and non-directed pot fisheries differed profoundly from those used in the EA analysis. While it's desirable for Tier-4 stocks to employ the $F_{35\%}$ proxy for F_{MSY} where reliable data and understanding on fishery performance exist, we considered it premature to employ this approach for Tanner crab given the changes in the directed and non-directed pot fisheries performance observed from 2005-2007 relative to those of the pre-1997 closure. Since the EA selectivity patterns no longer applied, their use in estimating $F_{35\%}$ and a factor in estimating gamma, may provide misleading and incorrect results in terms of management controls. The SSC concurred with this assessment and recommended the $F_{35\%}$ not be used in OFL-setting and to set gamma=1.0. An EBS Tanner crab stock assessment model is being developed in which fishery selectivity will be estimated across the time-series record.

For this analysis, we set gamma at 1.0. We accounted for discard mortalities from the directed and non-directed pot fisheries and the groundfish trawl fisheries. Even if pot fishery selectivities were equivalent pre-1997 and post-reopening in 2005, the EA simulations which suggest that $F_{35\%}$ may be a suitable F_{MSY} proxy for snow crab and Bristol Bay red king crab did not equivalently account for non-retained losses. Thus, it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. Further confounding specification of gamma for EBS Tanner crab is the fact that the MMB measure derived in this analysis employs a maturity schedule, whereas the EA simulations employed knife-edge sex-specific maturity at size. The EA guidance prescribes that gamma should not be set to a level that would provide for more risk-prone overfishing definitions without defensible evidence that the stock could support levels in excess of M. Examination of the historical performance of the fishery (Figure 4a) and stock biomass (Figure 6) reveals that the Tanner crab stock has not maintained itself in dynamic equilibrium over any sustained period, nor persisted in the face of exploitation rates (Table 6, Figures 7and 7b) in excess of M. The difference between fishery selectivity and maturity in EBS crab stocks has been suggested as a reason to allow gamma to exceed unity. Notwithstanding the technical challenges noted in estimating current fishery selectivity, this relies on theoretical population dynamic considerations in mature male biomass which are violated given the unique reproductive dynamic features of this stock (e.g., male-female size dependencies for successful copulation, male guarding and competition). Since a fundamental precept of precautionary fishery management is that the stock should not be exploited at a rate in excess of the F_{OFL}, we find no evidence that would justify a gamma in excess of 1.0 or fishing at an F_{OFL} rate greater than M on this stock.

4. Results

For the EBS Tanner crab stock and OFL-setting for the terminal 2009/10 fishery, the proxy B_{MSY} is B_{REF}=189.76 million pounds of male mature biomass estimated as the average MMB at mating from 1969-1980 inclusive. The SSC (October 2008) recommended using these 12 y of MMB estimates to specify B_{REF} despite both the author's and CPT's concerns about the quality and availability of survey biomass data prior to 1975. We note that the use of the average 1969-1980 MMB at mating estimates as a proxy for B_{MSY} is confounded by contemporaneous and antecedent high exploitation rates (Table 6, Figure 7a). This B_{REF} benchmark may underestimate the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries. The authors will revisit the choice of a proxy B_{MSY} once the retrospective analysis of the historical trawl survey is completed and consistent estimates of stock metrics are available.

From 1980-2009, the EBS Tanner crab stock collapsed twice resulting in two periods of fishery closures and the imposition of a rebuilding plan by the NPFMC. During this period, the stock experienced exploitation rates in excess of current F_{MSY} estimates - specifically, at approximately three times that rate in the late-1970s, and twice that in the late-1980s preceding the collapses. During 1980-2009, the stock has not maintained itself at a level that could be reasonably construed as in dynamic equilibrium, or at a level indicative of B_{MSY} capable of providing MSY to the fisheries. In 2009, Tanner crab MMB at mating declined below the MSST threshold and is deemed to be in an overfished state. The finding of this status determination criterion will necessitate the development and implementation of a new rebuilding plan by 2011 at the latest under the provisions of the Magnuson-Stevens Fishery Conservation and Management Act.

F. Calculation of the 2009/10 OFL

For the 2009/10 Tanner crab fishery, we estimated the Total Catch OFL=5.57 million pounds for males and females combined (Table 8). Relative to B_{REF}=189.76 million pounds, projected 2009/10 MMB at mating (70.16 million pounds) represents B/B_{REF}=0.370. Under the OFL Control Rule at this level of mature stock biomass, the full selection F_{OFL}=0.069.

Total losses to MMB in the 2009/10 Total Catch OFL are 5.01 million pounds. Directed and non-directed discard losses to MMB in 2009 are estimated to be 1.04 and 2.42 million pounds, respectively. The retained part of the catch OFL of legal-sized crab is 1.55 million pounds. The retained legal catch would comprise 30.9% of the total MMB losses. A significant component of the MMB losses therefore is attributed to non-targeted losses under current fishing practices.

Expected discard losses of female Tanner crab from the 2009/10 groundfish fishery and the directed pot fishery combined was estimated at 0.56 million pounds. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.135 and 0.064 respectively.

G. Rebuilding Analyses

The EBS Tanner crab stock is not under a rebuilding plan. No rebuilding analyses have been conducted.

H. Data Gaps and Research Priorities

A length-based stock assessment model (TCSAM) for this stock has been conceptualized and is in initial stages of development. Success in formulating TCSAM will depend on the historical time series survey data from 1969-2009 and directed study data which are collectively required as inputs to the model, and to derive life-history survey performance metrics to parameterize the model. The TCSAM will employ the new bottom trawl survey data based on measured footrope width measurements. The early years of this survey time series is particularly important in estimating the overfished threshold B_{REF}. Survey data for years 1969-1974 are not yet available.

Antecedent analyses using these data are required to derive model inputs, parameters and schedules. For males and females, these include the estimation of growth, maturity schedule, , survey selectivity, length frequency distributions and spatial splits, biomass and fishing power. From recent collections of a set of refined data on biometrics, we will formulate the carapace width-weight relationships by sex. From refined chela height-carapace width data collections recently made on the survey, we will calculate the functional relationship of male maturity to determine the probability of molting at size. These refined length-weight and carapace width-chela height data are not yet available to the authors.

An essential requirement to a successful TCSAM is a consistent time series of survey population metrics, life-history parameters and schedules for modeling.

I. Ecosystem Considerations

1. Ecosystem Effects on Stock

Prey Availability or Abundance Trends

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

Predator Population Trends

Pacific cod (*Gadus macrocepahalus*) are documented as predators of Tanner crab in the eastern Bering Sea as well as Pacific halibut (*Hippoglossus stenolepis*) and skates (*Raja* sp.) (Livingston 1989, Livingston et al. 1993, Lang et al. 2005). Pacific cod biomass increased steadily from 1978 through 1983, remained relatively constant thereafter through 1988, fluctuated slightly from 1988 through 1994 (peak observed) and has steadily declined since then with 2007 estimates being the lowest on record (Thompson et al. 2007). Halibut biomass was lowest in 1982, fluctuated from 1983 through 1988 (peak), and increased from 1990 through 1996 (peak observed) (pers comm. Steven Hare, IPHC). Biomass estimates of all skate species in the EBS are not reported with the exception of that for Alaska skate (*Bathyraja parmifera*) which has been estimated since 1982. Alaska skate biomass fluctuated from 1982 through 1986, increased from 1986 through 1990 (peak), decreased from 1991 through 1999, and demonstrated an increasing trend from 1999 to present (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. (Meyers et al. 1990). BCS has been detected in EBS Tanner crab for 20 years with no clear trends in prevalence. The long-term effect of this syndrome on crab populations is not well understood (Workshop on "Hematodinum Associated Diseases: Research Status and Future Directions", Prince Edward Island, Canada, 2007). Another disease detected in EBS Tanner crab is black mat syndrome (BMS); a systemic fungal infection caused by *Trichomaris invadens.* BMS is thought lethal to crab by preventing (Sparks 1982). However, BMS is not considered to be an issue of concern in the EBS (pers comm. F. Morado, NOAA Fisheries).

Changes in Habitat Quality

The EBS ecosystem reorganization following the 1976/77 regime shift and, to a lesser degree, the 1998/1999 shift (Connors et al. 2002, Litzow 2006) are believed not to favor decapod stocks, however, mechanisms of action impacting EBS crabs are conjectural and the exact nature of the biological response to such changes is poorly understood (Litzow 2006). It's hypothesized that future temperature increases and ocean acidification, if any, may affect the growth and survival of larval EBS crab (unpublished data, M. Litzow, NOAA Fisheries), or result in changes to the phytoplankton community in the EBS (Hare et al. 2007) upon which larval Tanner crab depend (Incze et al. 1987, Incze and Paul 1983). The current effects of temperature change and ocean acidification on Tanner crab population dynamics or stock status, and/or on phytoplankton community structure are unknown.

2. Fishery Effects on Ecosystem

Fishery Contribution to Bycatch

Bycatch data from the directed Tanner crab fishery in the EBS were examined for the 2005/06 and the 2006/07 fisheries (Table 9). Non-targeted sublegal male and female Tanner crab comprised the largest component of bycatch followed by snow crab. Fish species are also a component of Tanner crab fishery bycatc and include a number of crab predators, notably, Pacific cod, Pacific halibut, yellowfin sole, and sculpin (*Myoxocephalus* spp.) (Barnard and Burt 2007, Barnard and Burt 2008). The invertebrate component of bycatch included sea stars, snails, hermit crabs and lyre crab.

Handling Mortality
It's generally accepted that a certain amount of mortality is inflicted on the non-target species captured and released during fishing operations. MacIntosh et al. (1996) examined handling-induced injuries on survival on EBS Tanner crab and found that subsequent mortality was low and not significantly greater than controls. Stress due to windchill causes mortality to EBS Tanner crab (Carls 1989), and can result in leg loss or immediate mortality. Stevens and MacIntosh (1992) observed an mortality of 11% for Tanner crab caught on one commercial crab vessel. Tracy and Byersdorfer (2000) and Byersdorfer and Barnard (2002) observed a relatively high incidence of pre-discard injuries in snow crab and Tanner crab during their respective directed fisheries, however, there is poor understanding of the magnitude of post-release mortality in EBS crabs (NMFS 2004).

Mortality to fish and non-target invertebrates from ghost pot fishing in the EBS is not well studied. The ADFG requires the use of a biodegradeable twine panel in each crab pot intended to disable ghost fishing in lost pots approximately 30 days. Recent work indicates that even biodegradeable twine may remain intact for up to 89 days in lost pots (Barnard 2008), or 3 times the length of time (30 d) found to cause irreversible starvation in crabs (Paul et al. 1994).

Benthic Sspecies and Habitat Impacted by Pot Gear
In the final Environmental Impact Statement (EIS) for the BSAI crab fisheries, the impact of pot gear on benthic EBS species is discussed (NMFS 2004). Benthic species examined included fish, gastropods, coral, echinoderms (sea stars and sea urchins), non-target crab, and invertebrates (sponges, octopuses, anemones, tunicates, bryozoans, hydroids, and jellyfish). Physical damage to the habitat by pot gear depends on habitat type. Sand and soft sediments where the Tanner crab pot fishing occurs are less likely to be impacted, whereas coral, sponge, and gorgonian habitats are more likely to be damaged by commercial crab pot fishing (Quandt 1999, NMFS 2004). The total portion of the EBS impacted by commercial pot fishing may be less than 1% of the shelf area (NMFS 2004). The report concludes that BSAI crab fisheries have an insignificant effect on benthic habitat. Considering that bycatch species impacted by the Tanner crab pot fishery are widespread across the EBS shelf, the impacts of pot gear on benthic populations should be minimal.

ESA and non-ESA Marine Mammals and Seabirds
As noted in the Endangered Species Act EIS report, crab fisheries do not adversely affect ESA listed species, destroy or modify their habitat, or comprise a measurable portion of the diet (NMFS 2004), including listed marine mammals or seabirds although the possibility of strikes of listed seabirds with crab fishing vessels does exist (NMFS 2000).

Of non-listed marine mammals, bearded seals (*Erignathus barbatus*) are the only marine mammal potentially impacted by crab fisheries insofar as crab are a measurable portion of their diet (Lowry et al. 1980, NMFS 2004). For non-listed seabirds, the Alaska Groundfish Fisheries Final Programmatic SEIS (NMFS 2004b) provides life history, population biology and foraging ecology for marine birds. The SEIS concluded that crab stocks under the NPFMC fishery management plan (NPFMC 1998), including Tanner crab, have very limited interaction with non-listed seabirds.

Fishery Contribution to Discards and Offal Production
The EIS for the BSAI Crab Fisheries summarizes some of the effects of discards and offal production (NMFS 2004). Returning discards, process waste, and the contents of used bait containers to the sea provides energy to scavenging birds and animals that may not otherwise have access to those energy resources. The total offal and discard production as a percentage of the unused detritus already going to the bottom has not been estimated.

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Table 1. Age (months), mean size (mm cw) and instar number for male Tanner crab in Kodiak and the eastern Bering Sea.

	Kodiak		EBS
Instar Number	Mean Size (mm cw)	Mean Age (months)	Mean Size (mm cw)
1	3.4	1.8	-
2	4.5	4.5	-
3	6.0	3.5	-
4	7.9	4.9	-
5	10.4	6.6	-
6	13.7	8.9	-
7	18.1	11.9	17.2
8	23.9	15.9	24.4
9	31.6	21.1	33.5
10	41.7	28.1	45.9
11	53.6	37.3	60.7
12	67.8	47.2	79.3
13	84.6	59.0	98.5
14	106.3	73.1	112.5
15	129.5	85.3	126.8
16	154.3	106.2	141.8
17	180.8	124.5	157.2

Table 2. Eastern Bering Sea *Chionoecetes bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965-2009.

Eastern Bering Sea Chionoecetes bairdi Retained Catch (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	12.0	29.95	8.73	39.69
1969	1.02	29.0	43.98	15.61	60.60
1970	0.17	8.0	41.73	14.31	56.20
1971	0.11	10.0	35.04	10.51	45.66
1972	0.23	6.0	37.04		37.27
1973	5.04	115.0	23.67		28.72
1974	7.03	72.0	26.58		33.60
1975	22.30	63.0	16.62		38.92
1976	51.50	68.0	14.67		66.17
1977	66.60	51.0	11.72		78.32
1978	42.50	42.0	4.00		46.50
1979	36.60	30.0	5.30		41.90
1980	29.60	21.0			29.60
1981	11.00	10.0			11.00
1982	5.27	8.0			5.27
1983	1.21	8.0			1.21
1984	3.15	12.0			3.15
1985	0	0			0
1986	0	0			0
1987	2.20	8.0			2.20
1988	7.01	16.0			7.01
1989	24.50	15.0			24.50
1990	40.10	19.0			40.10
1991	31.80	10.0			31.80
1992	35.10	13.0			35.10
1993	16.90	13.0			16.90
1994	7.80	13.0			7.80
1995	4.23	8.0			4.23
1996	1.81	5.0			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			0.95
2006	2.12	13.8			2.12
2007	2.11	17.0			2.11
2008	1.94	12.6			1.94

Table 3. Eastern Bering Sea *Chionoecetes bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish fisheries, 1965-2008.

Eastern Bering Sea *Chionoecetes bairdi* Discard and Bycatch Losses (10^6 lb)
[HMPot=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	2.70	1.79	48.15	8.50
1992	27.25	2.41	2.93	1.94	30.18	4.35
1993	14.86	2.72	1.87	1.23	16.72	3.95
1994	7.74	2.34	2.22	1.47	9.97	3.81
1995	5.33	2.61	1.62	1.07	6.95	3.68
1996	1.21	0.36	1.69	1.12	2.90	1.48
1997	2.11	0.25	1.25	0.83	3.36	1.08
1998	2.32	0.20	0.99	0.66	3.32	0.85
1999	0.85	0.16	0.67	0.44	1.52	0.61
2000	0.23	0.03	0.79	0.52	1.02	0.55
2001	0.40	0.01	1.26	0.83	1.66	0.85
2002	0.68	0.04	0.76	0.51	1.45	0.55
2003	0.27	0.03	0.45	0.30	0.72	0.33
2004	0.14	0.02	0.72	0.47	0.86	0.49
2005	1.43	0.08	0.66	0.44	2.09	0.52
2006	3.01	0.55	0.76	0.50	3.77	1.05
2007	4.44	0.23	0.74	0.49	5.18	0.72
2008	2.00	0.08	0.57	0.37	2.57	0.45

Table 4. Eastern Bering Sea *Chionoecetes bairdi* total catch in the directed (retained) and non-directed fisheries, 1965-2008.

Eastern Bering Sea *Chionoecetes bairdi* Total Catch 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	79.95	8.50	88.45
1992	65.28	4.35	69.63
1993	33.62	3.95	37.57
1994	17.77	3.81	21.58
1995	11.19	3.68	14.86
1996	4.71	1.48	6.18
1997	3.36	1.08	4.44
1998	3.32	0.85	4.17
1999	1.52	0.61	2.13
2000	1.02	0.55	1.57
2001	1.66	0.85	2.51
2002	1.45	0.55	1.99
2003	0.72	0.33	1.05
2004	0.86	0.49	1.35
2005	3.04	0.52	3.56
2006	5.90	1.05	6.95
2007	7.28	0.72	8.00
2008	4.51	0.45	4.96

Table 5. Eastern Bering Sea *Chionoecetes bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1965-2009. (2009 MMB and LMB at mating are based on extraction of respective 2009/10 catch OFLs).

	Eastern Bering Sea *Chionoecetes bairdi* Survey Biomass					
	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	77.50	69.08	36.88
1981	158.07	140.90	116.68	35.00	31.20	19.02
1982	113.32	101.01	88.11	25.25	22.51	16.39
1983	65.70	58.56	53.23	16.75	14.93	13.16
1984	45.41	40.48	32.63	14.50	12.92	9.29
1985	26.01	23.19	20.87	11.00	9.81	9.44
1986	35.49	31.64	28.30	7.75	6.91	6.65
1987	63.93	56.99	47.59	14.75	13.15	10.45
1988	139.55	124.39	100.95	35.75	31.87	23.65
1989	231.48	206.34	148.28	84.00	74.87	47.56
1990	240.30	214.20	116.87	112.75	100.50	56.62
1991	255.73	227.95	139.43	87.75	78.22	43.48
1992	246.92	220.09	146.53	104.50	93.15	54.54
1993	144.40	128.71	90.25	51.50	45.91	27.28
1994	95.02	84.70	63.74	38.50	34.32	25.23
1995	71.65	63.87	50.28	25.00	22.28	17.21
1996	58.64	52.27	45.60	23.00	20.50	17.92
1997	25.13	22.40	18.20	8.50	7.58	7.29
1998	25.35	22.60	18.43	5.50	4.90	4.72
1999	43.87	39.11	36.12	5.25	4.68	4.50
2000	39.24	34.98	32.64	12.50	11.14	10.72
2001	43.65	38.91	35.78	16.25	14.48	13.94
2002	44.53	39.70	36.76	17.50	15.60	15.01
2003	61.29	54.63	51.85	18.50	16.49	15.87
2004	65.48	58.36	55.31	13.50	12.03	11.58
2005	104.50	93.15	86.60	28.50	25.40	23.50
2006	158.95	141.68	130.46	36.38	32.42	29.08
2007	185.19	165.07	151.58	26.53	23.65	20.65
2008	143.08	127.54	118.23	29.39	26.20	23.28
2009	87.62	78.10	*70.16*	17.54	15.63	*12.94*

Table 6. Eastern Bering Sea *Chionoecetes bairdi* fishery exploitation rate on male mature biomass (MMB) and legal mature biomass (LMB), 1965-2008. Exploitation rates are based on biomass; μ on MMB uses total catch losses while μ on LMB uses total retained legal catch.

Eastern Bering Sea *Chionoecetes bairdi* Exploitation Rate @ Time Fishery		
Year	MMB	LMB
1965		
1966		
1967		
1968		
1969	0.19	
1970	0.74	
1971		
1972		
1973	0.32	
1974	0.21	
1975	0.12	
1976	0.35	
1977	0.38	
1978	0.45	
1979	0.60	
1980	0.27	0.43
1981	0.13	0.35
1982	0.09	0.23
1983	0.05	0.08
1984	0.16	0.24
1985	0.06	0.00
1986	0.07	0.00
1987	0.13	0.17
1988	0.15	0.22
1989	0.24	0.33
1990	0.42	0.40
1991	0.35	0.41
1992	0.30	0.38
1993	0.26	0.37
1994	0.21	0.23
1995	0.18	0.19
1996	0.09	0.09
1997	0.15	0
1998	0.15	0
1999	0.04	0
2000	0.03	0
2001	0.04	0
2002	0.04	0
2003	0.01	0
2004	0.01	0
2005	0.03	0.04
2006	0.04	0.07
2007	0.04	0.09
2008	0.04	0.07

Table 7. Data used to estimate discard and bycatch losses in the terminal 2009/10 OFL fishery: (a) average Tanner crab fishery performance, (b) Tanner crab discards in the snow and red king crab pot fisheries and snow crab retained catch, and (c) 2003-08 Tanner crab bycatch in the EBS groundfish fisheries.

(a)

Average Tanner Crab Discard and Retained Catch
In the Tanner Crab Directed Fishery
[2006/07, 2007/08, & 2008/09]

Discard:		LB	Ratio:
	S.Legal ♂:	2,716,383	1.32102
	Legal ♂:	56,818	0.02763
	All ♀:	320,118	0.15568
Retained:		2,056,272	1.0
	Total:	5,149,591	

(b)

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

Year	Opilio Retained (10^6 LB)	Bairdi Discard (10^6 LB)	Ratio
2006/07	37.00	3.28	0.088678
2007/08	63.03	4.25	0.067454
2008/09	58.55	3.06	0.052279
2009/10	50.50 *		
		Average:	0.069470
		Projected Bairdi Discard (10^6 LB):	3.508253

* Projected retained catch OFL for 2009/10 @ 0.75F35%.

(c)

Trawl Fishery Tanner Crab Bycatch
(Male + Female Combined)

Year		Bycatch (10^6 LB)
2003		0.9343
2004		1.4882
2005		1.3694
2006		1.5810
2007		1.5320
2008		1.1748
	Average:	1.3810

Table 8. Catch overfishing limits, stock and fishery metrics for the 2009/10 Eastern Bering Sea *Chionoecetes bairdi* fishery. (B_{REF}=mean 1969-1980 MMB at the time of mating, inclusive; µ on MMB is Total Catch OFL/MMB at the time of the fishery).

2009/10 Eastern Bering Sea *Chionoecetes bairdi*
Catch OFL, Stock and Fishery Metrics

Metrics (10^6lb):	
B_{REF}:	189.76
MMB @ Mating:	70.16
B/B_{REF}:	0.37
F_{OFL}:	0.07
Catch Components (10^6lb):	
Total ♂ Catch OFL:	5.01
Directed Discard Losses MMB:	1.04
Non-Directed Discard Losses MMB:	2.42
Retained Part of Total ♂ Catch OFL:	1.55
Discard + Bycatch Losses ♀:	0.56
Total ♂ Catch OFL + ♀ Losses:	5.57
Rates:	
µ on MMB @ Fishery:	0.064

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

Table 9. Total observed bycatch (#) in pot lifts in the directed EBS Tanner crab fisheries sampled during 2005/06 (n=160) and the 2006/07 (n=141) (Barnard and Burt 2007; Barnard and Burt 2008). A total of 29,693 and 49,192 pots were lifted during the 2005/06 and 2006/07 fisheries respectively (Bowers et al. 2008).

Species	Total Catch		Species	Total Catch	
	2005/06	2006/07		2005/06	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
Snow crab			Flatfish (unidentified)	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			

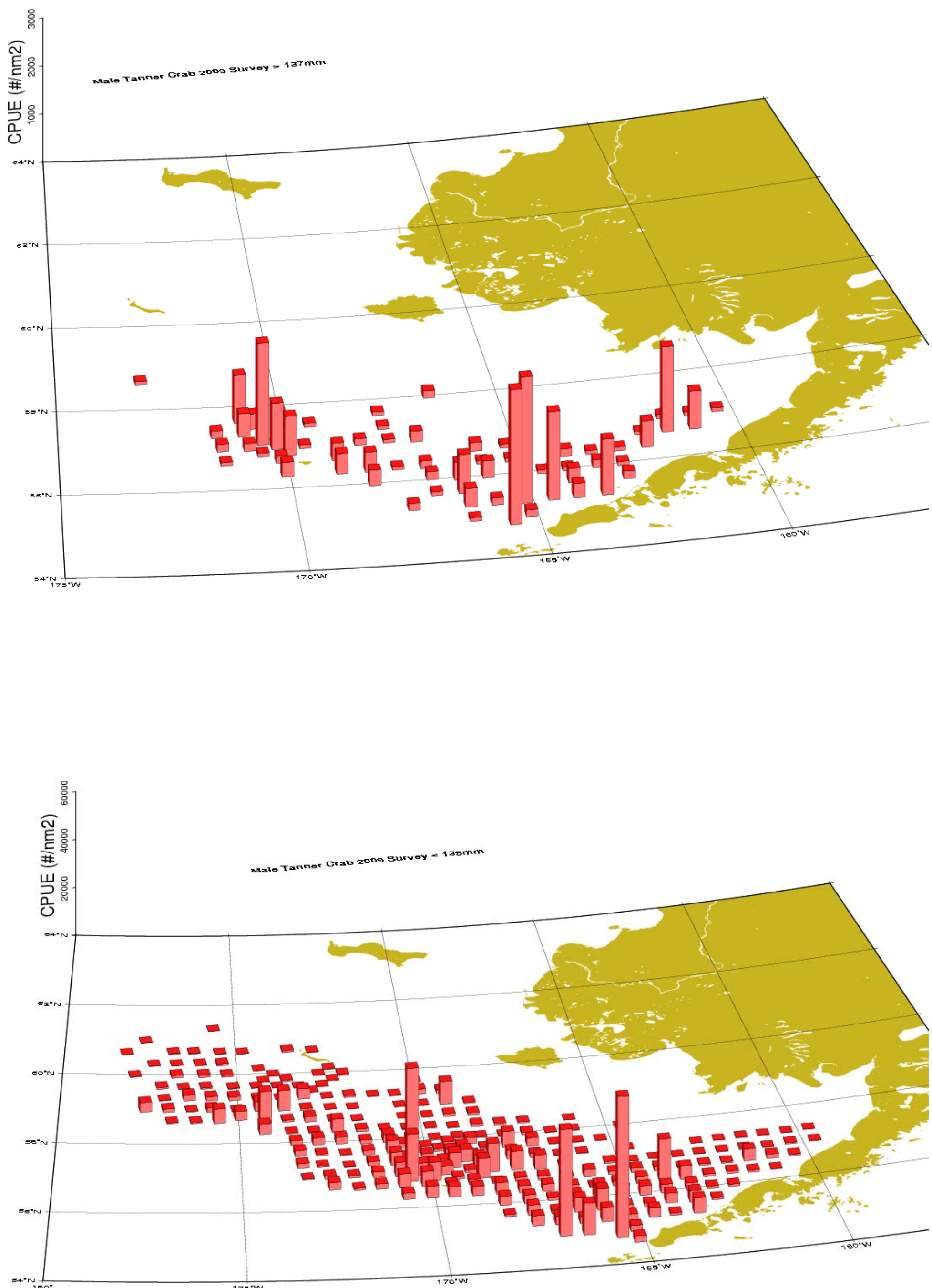


Figure 1. Distribution and abundance of legal (>= 138 mm cw) and sublegal (< 138 mm cw) male Tanner crab in the summer 2009 NMFS EBS trawl survey.

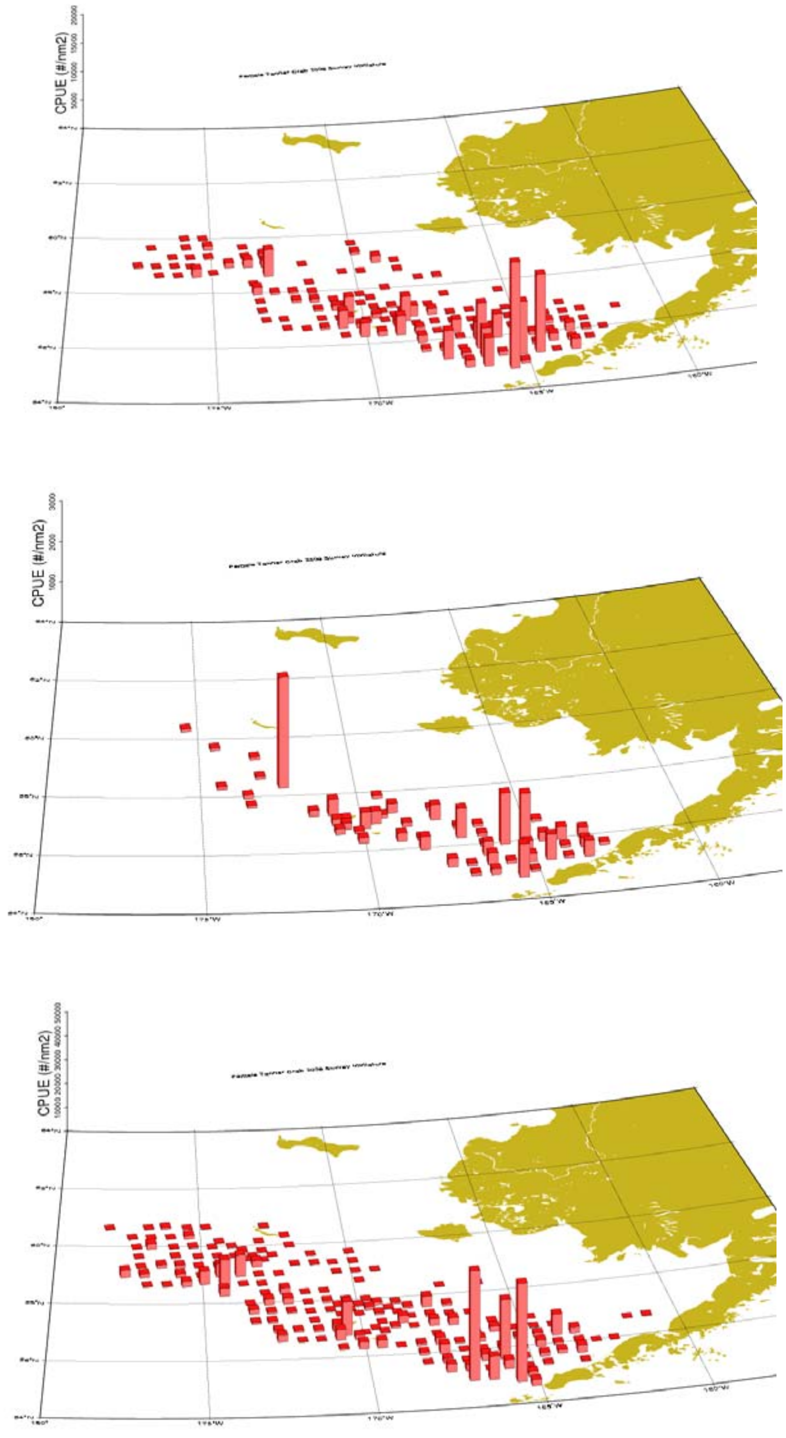


Figure 2. Distribution and abundance of ovigerous, barren mature, and immature female Tanner crab in the summer 2009 NMFS EBS trawl survey.

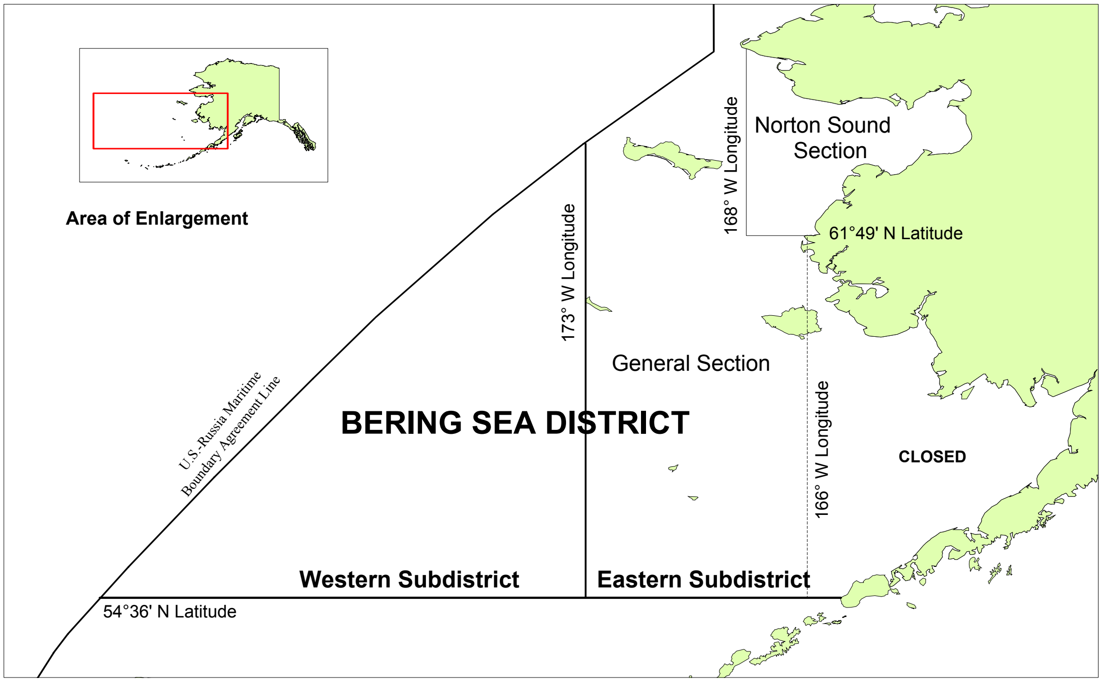
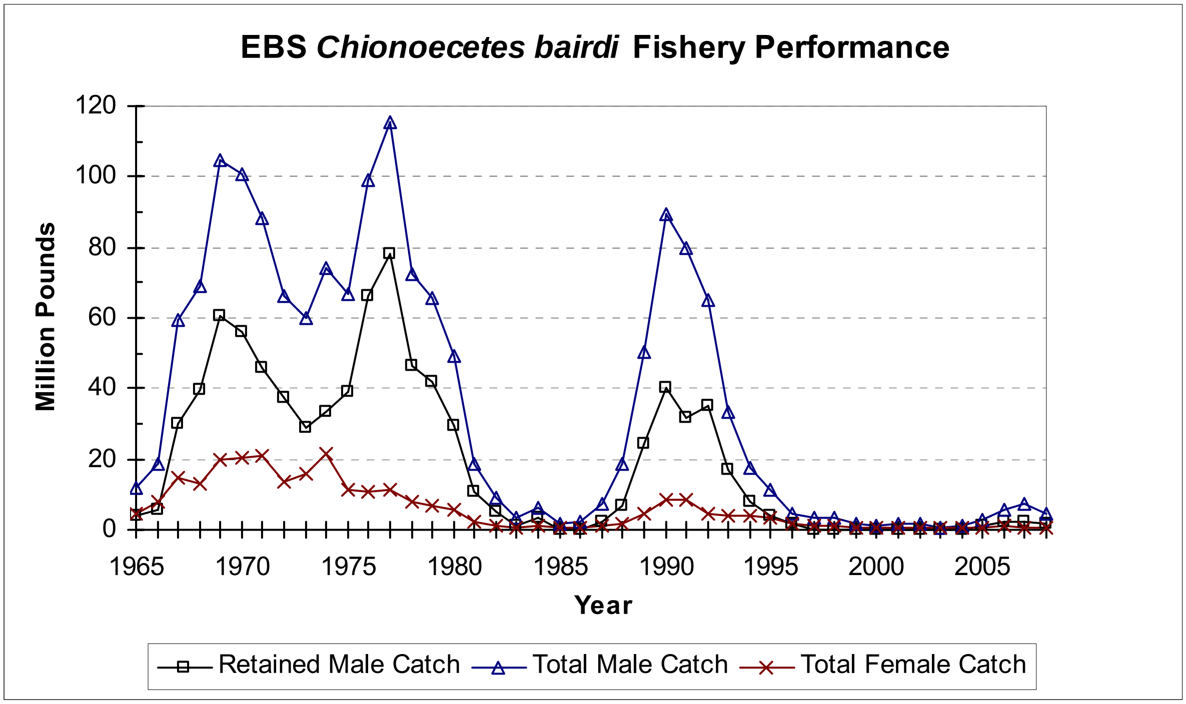


Figure 3. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)



(b)

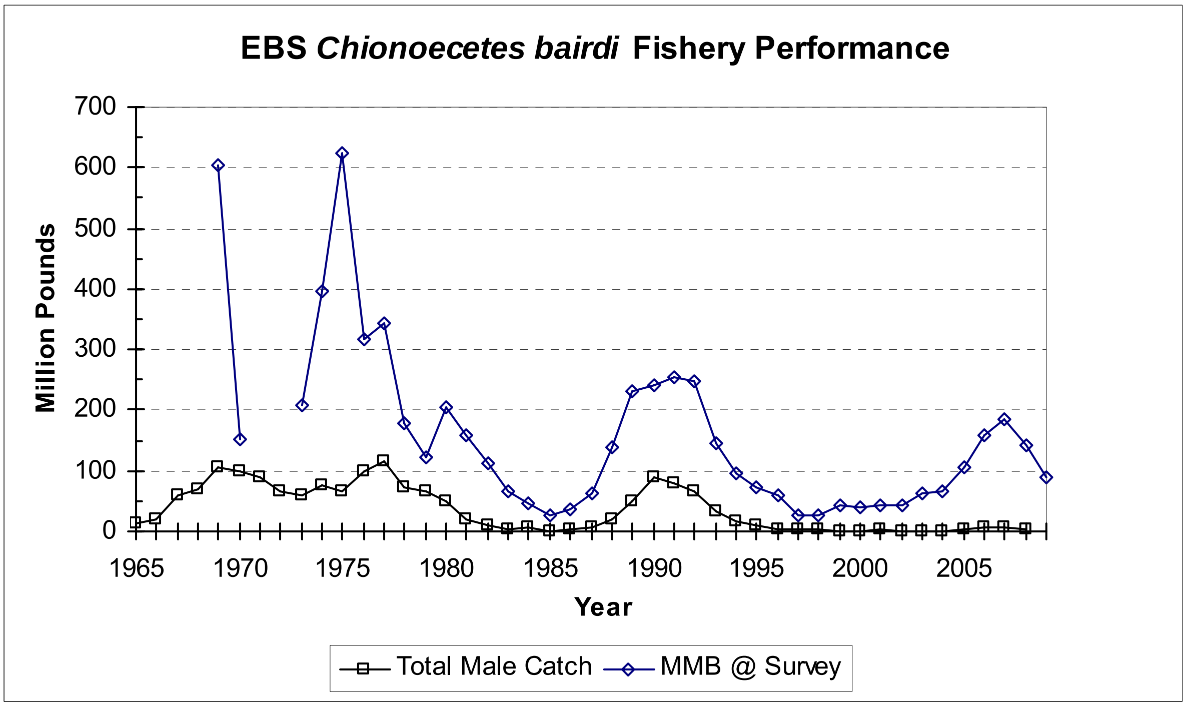


Figure 4. Eastern Bering Sea *Chionoecetes bairdi* retained male catch, total (retained + discard/bycatch) male catch and total female catch (a), and total male catch vs male mature biomass at the time of the survey (b), 1965-2009.

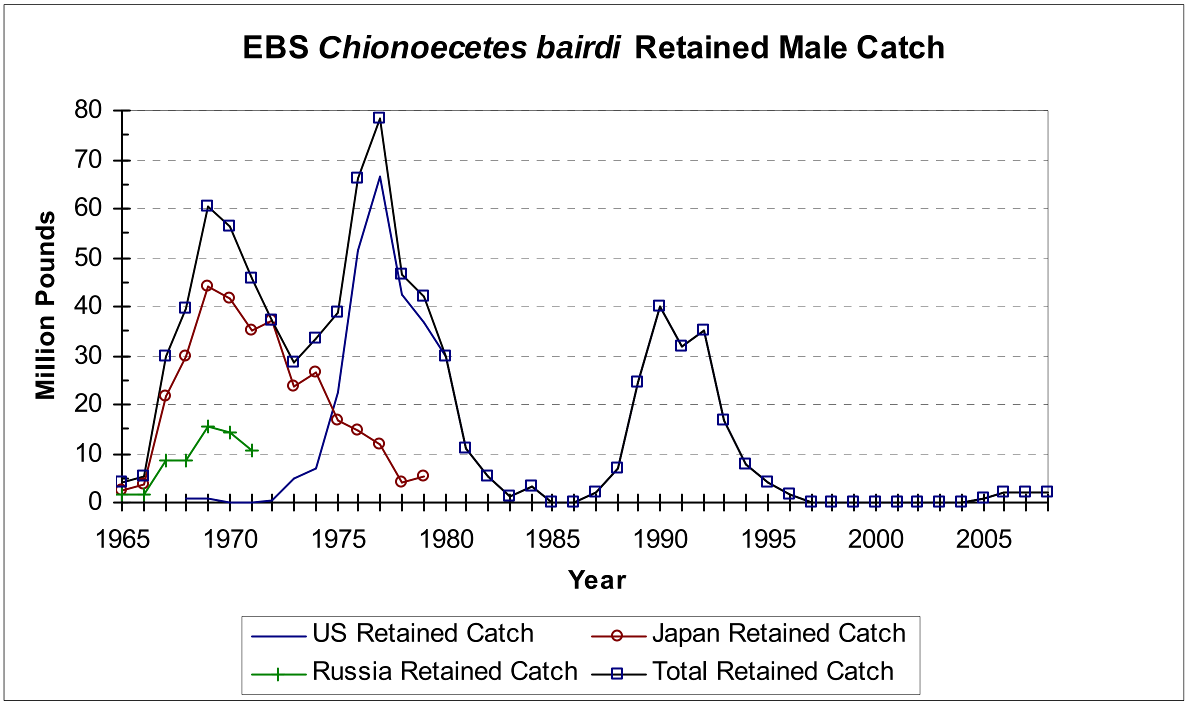


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965-2009.

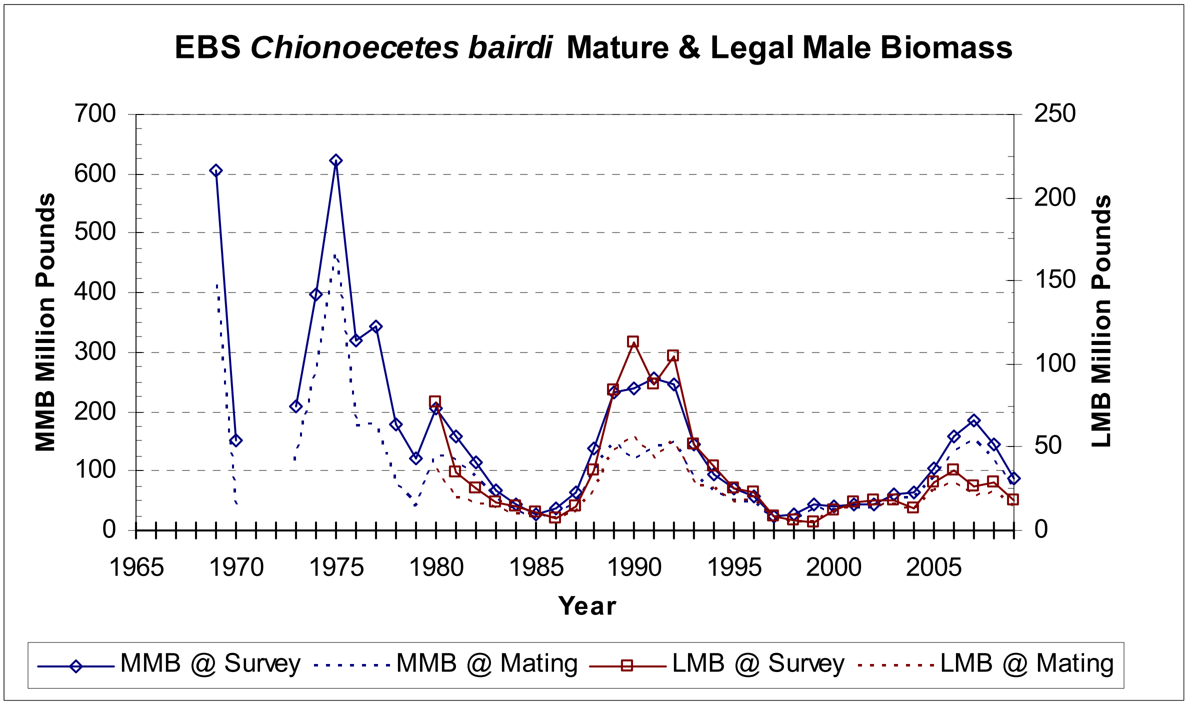
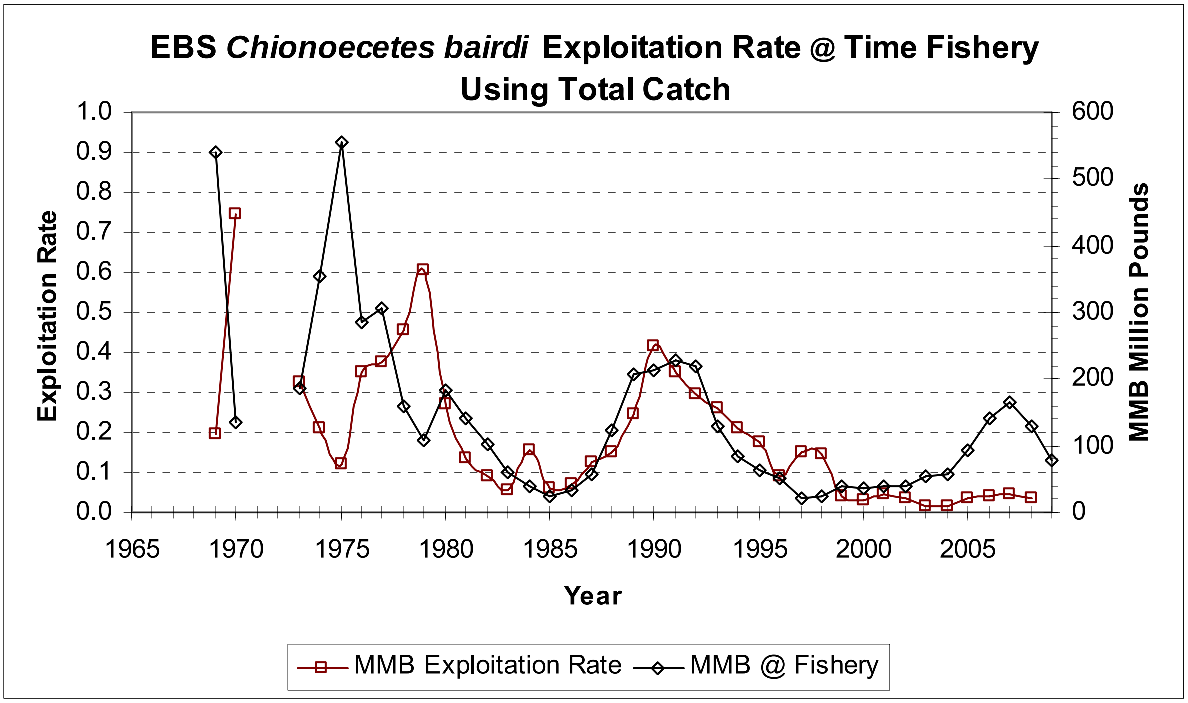


Figure 6. Eastern Bering Sea *Chionoecetes bairdi* mature and legal male biomass at time of the survey and subsequent mating, 1965-2009. (Note: 2009/10 MMB and LMB at time of mating are estimates based on extraction of respective 2009/10 catch OFLs).

(a)



(b)

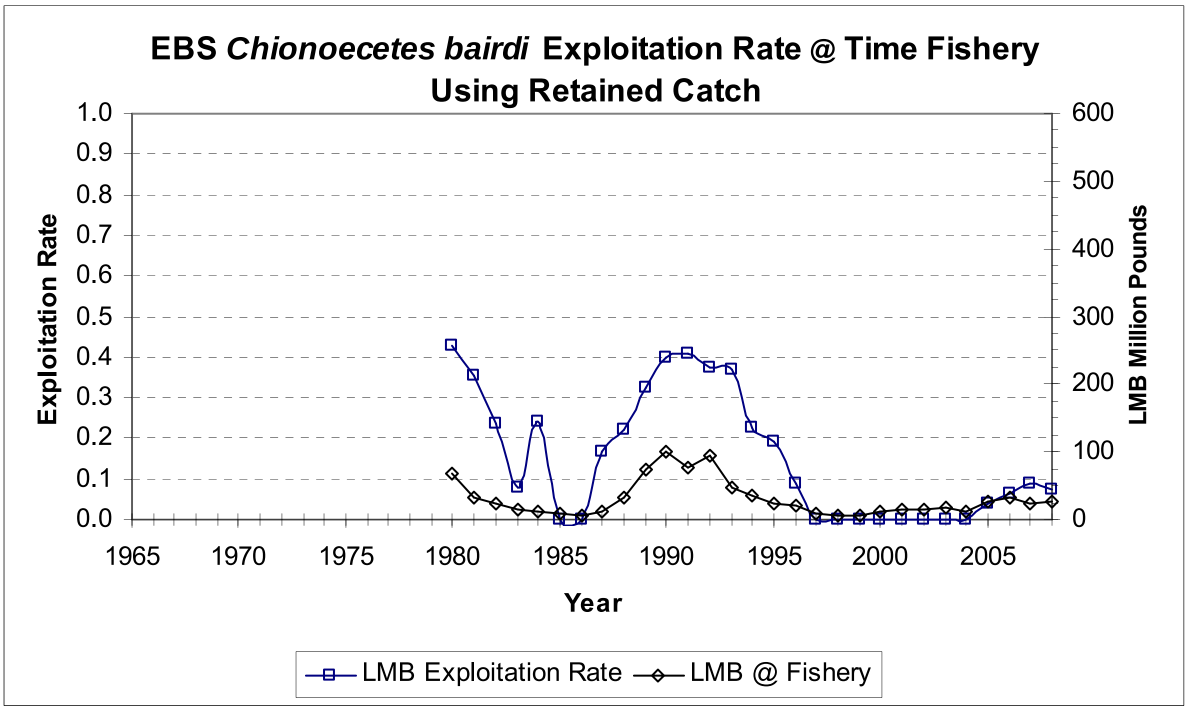


Figure 7. Eastern Bering Sea *Chionoecetes bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1965-2009.

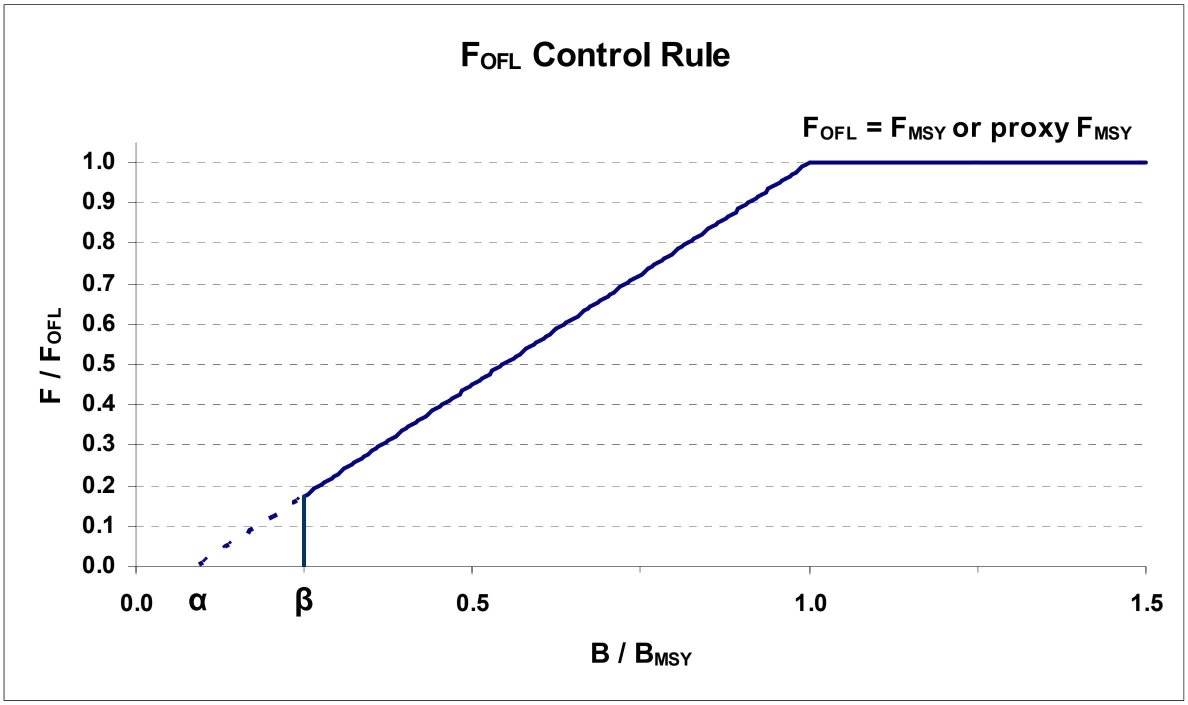


Figure 8. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

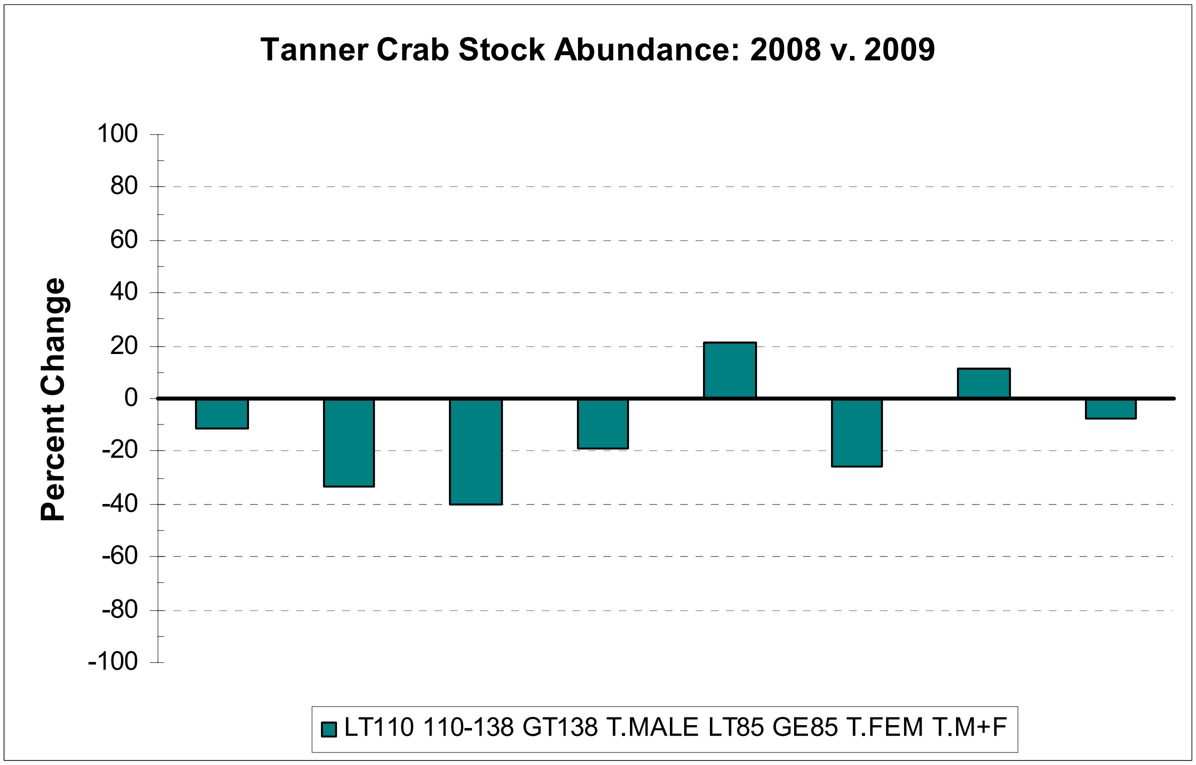
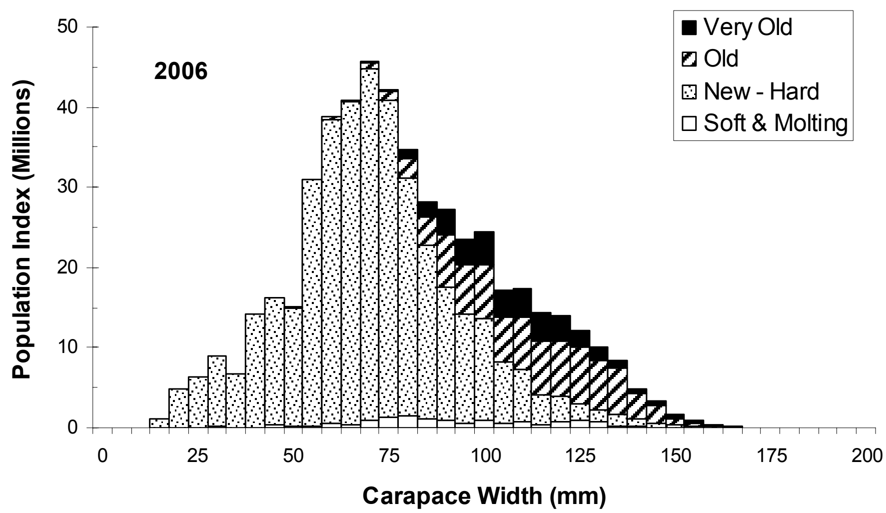


Figure 9. Percent change in Tanner crab stock abundance between 2008 and 2009 for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.

(a)



(b)

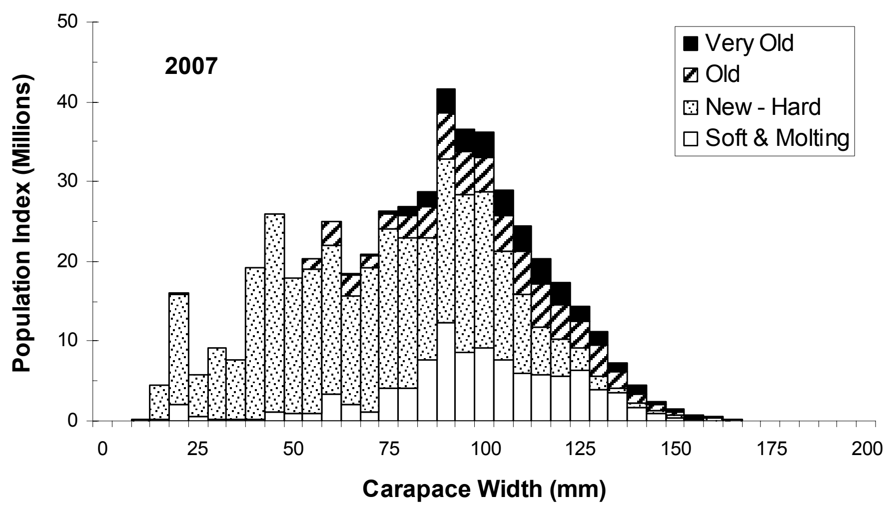
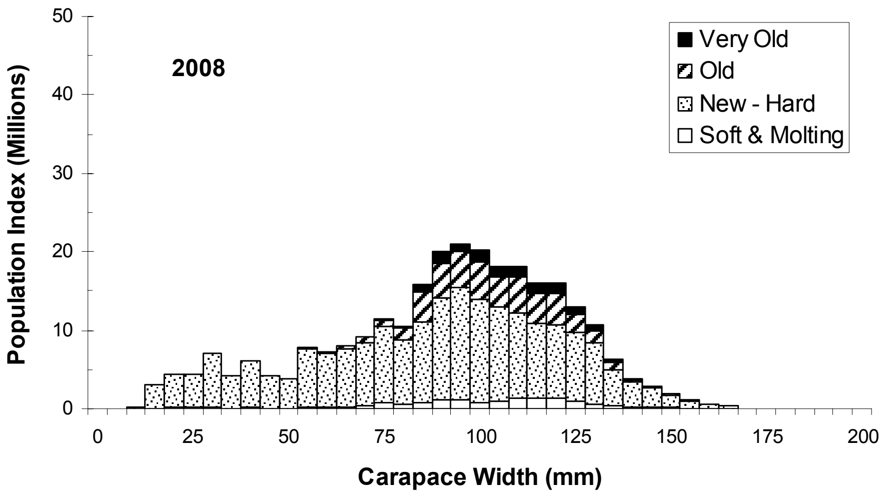


Figure 10 (a-b). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2007.

(a)



(b)

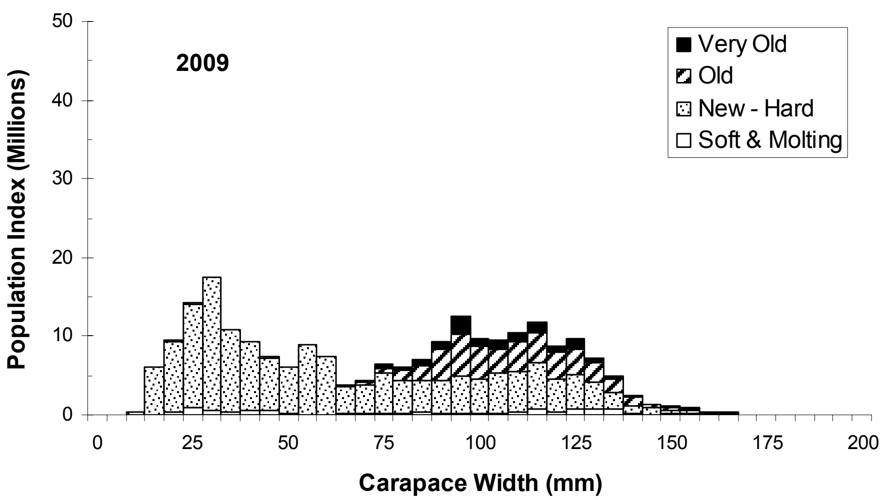
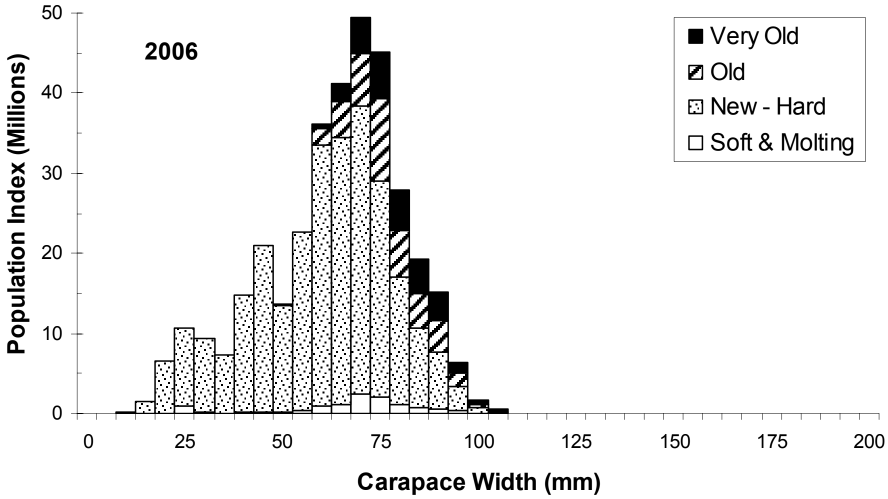


Figure 10 (c-d). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008-2009.

(a)



(b)

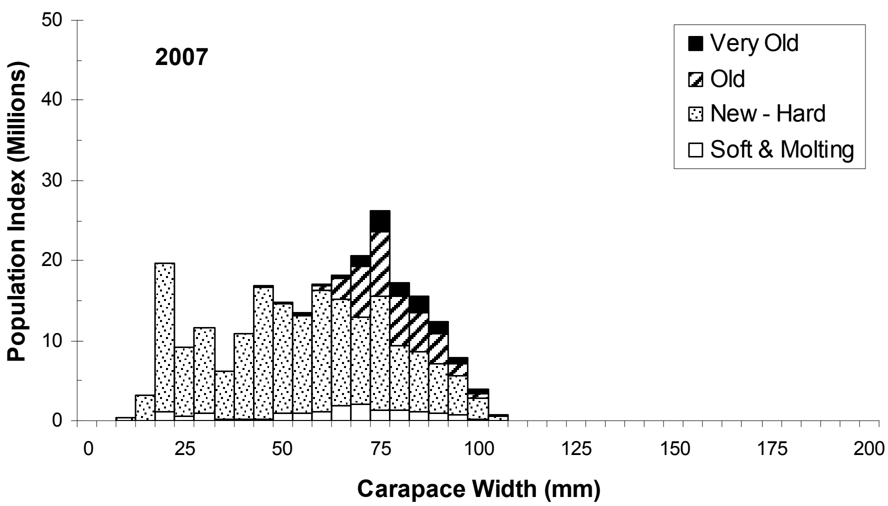
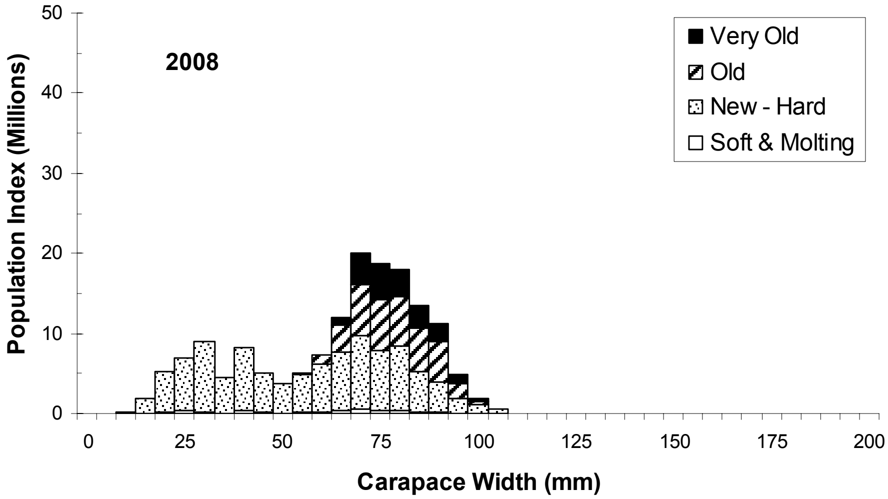


Figure 11 (a-b). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2007.

(a)



(b)

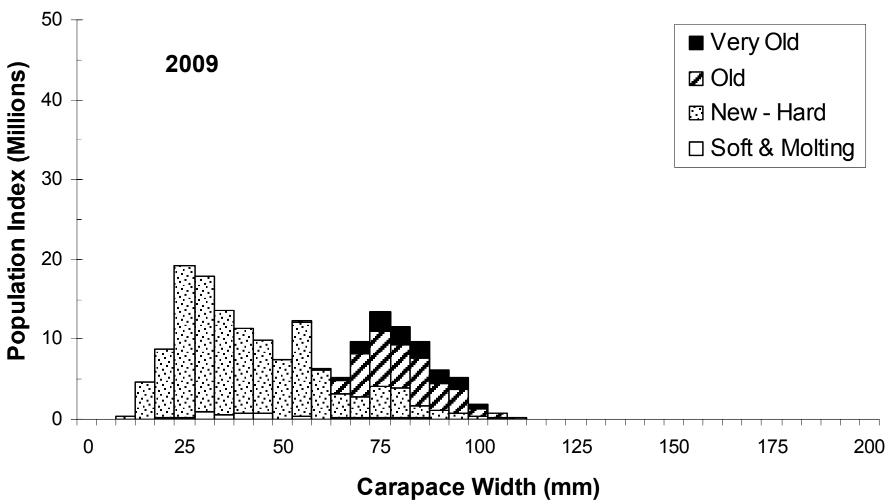
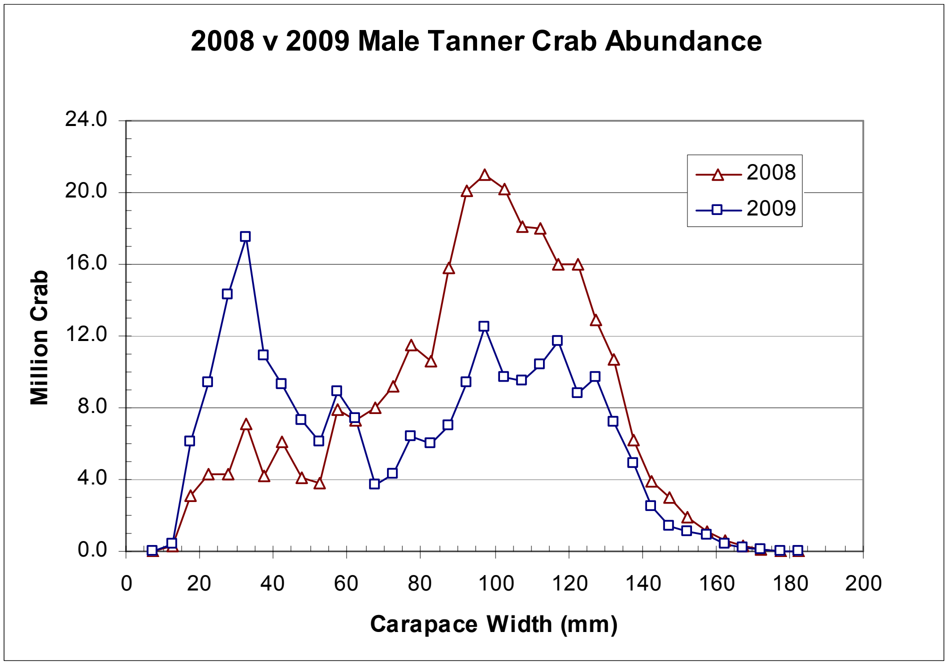


Figure 11 (c-d). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008-2009.

(a)



(b)

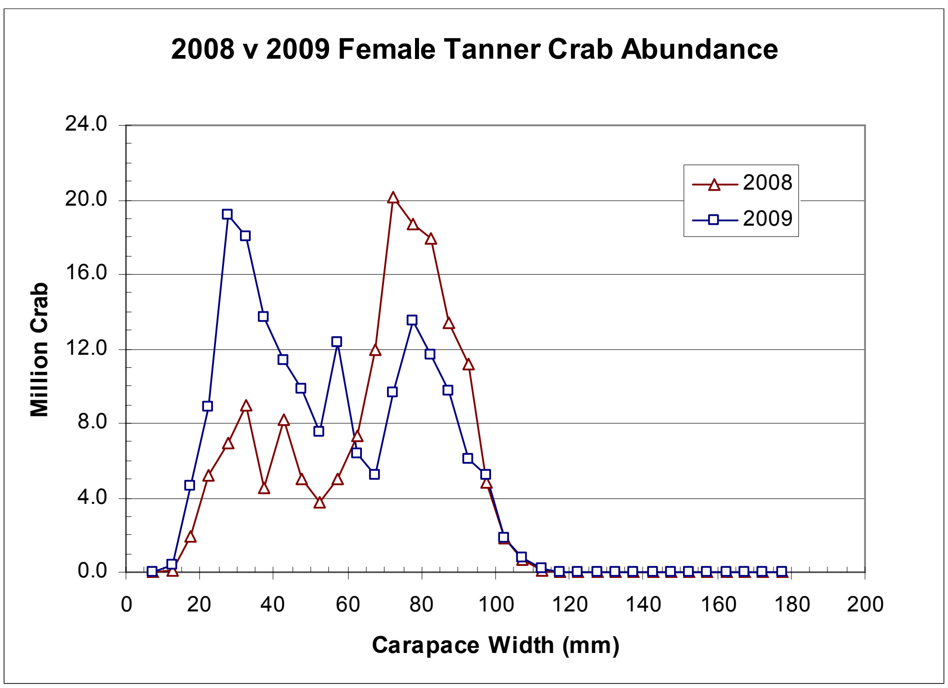


Figure 12. Male (a) and female (b) Eastern Bering Sea *Chionoecetes bairdi* total abundance in 2008 and 2009 by 5 mm carapace width.

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

The calculation of the OFL in this study follows the method proposed by the SSC at their June 2008 meeting. The SSC recommended using fishery selectivities taken from the Environmental Assessment (EA) on new OFL definitions for EBS crab stocks to derive an $F_{35\%}$ proxy for F_{MSY} (Figure A-5) due to the lack of recent data on selectivities. The F_{MSY} proxy was recommended as a scaler multiple of the instantaneous mortality rate (M) derived as $F_{35\%}$ / M and estimated as 2.1 x M from the analysis presented in June 2008. The same method is used here, except that new fishery selectivity curves are estimated from the most recent year of fishery data and $F_{35\%}$ is calculated using these newly estimated fishery selectivities. The F_{MSY} proxy for the control rule would be:

$$\text{Proxy } F_{MSY} = \gamma M \quad (1)$$

The SSC proposed that gamma might be estimated as $F_{35\%}$ / M, therefore,

$$\text{Proxy } F_{MSY} = (F_{35\%} / M) \cdot M = F_{35\%} \quad (2)$$

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

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

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

The 2008 survey abundance by length was projected forward to estimate catch and MMB using $F_{35\%}$ and the estimated fishery selectivities (Table A-1). The total catch OFL for scenario 1 (0.5 selectivity size>145 mm cw) was 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>140 mm cw) 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.

Metric:	Scenario 1	Scenario 2
	Retained sel >145mm = 0.5	Retained sel >140 mm = 1.0
Directed Legal Catch	5.62	5.57
Retained Directed Legal Catch	5.27	5.21
Directed Discard	7.13	6.75
Non-Directed Discard (snow crab + groundfish trawl)	3.35	3.36
Total Male Catch OFL	16.10	15.67
MMB	106.03	106.47
B_{REF}	178.2	178.2
MMB/ B_{REF} (%)	59.49	59.75
Directed $F_{35\%}$	0.585	0.411
Directed Control Rule F 2008/09	0.322	0.227
F Snow Crab Fishery	0.105	0.09

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

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

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

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

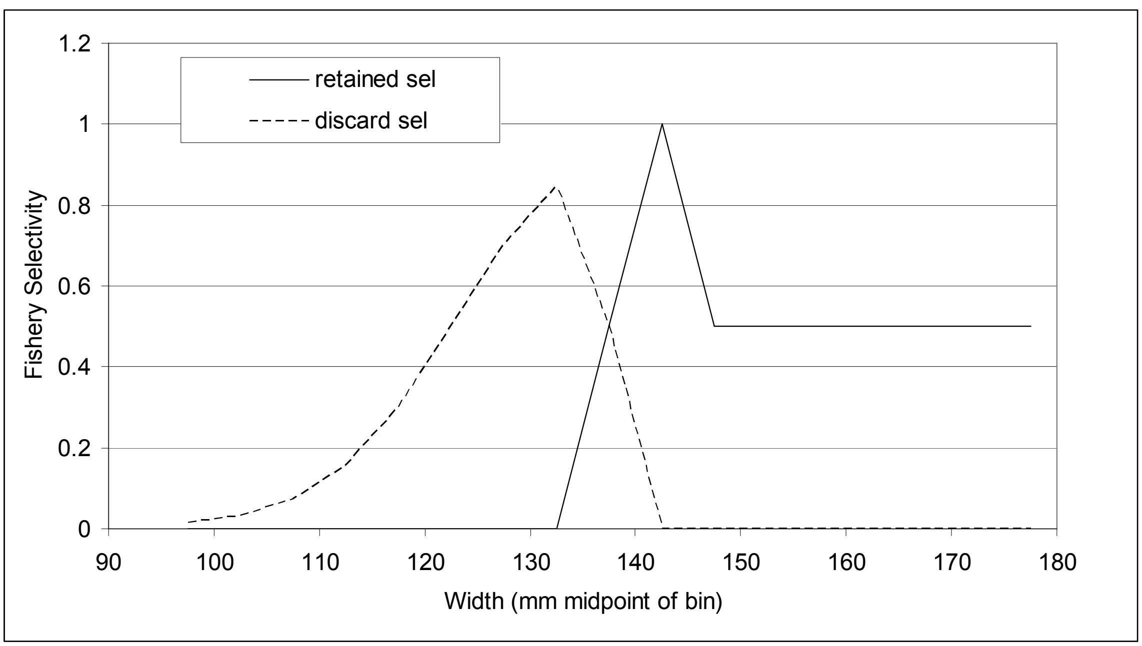


Figure A-1. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery before discard mortality is applied.

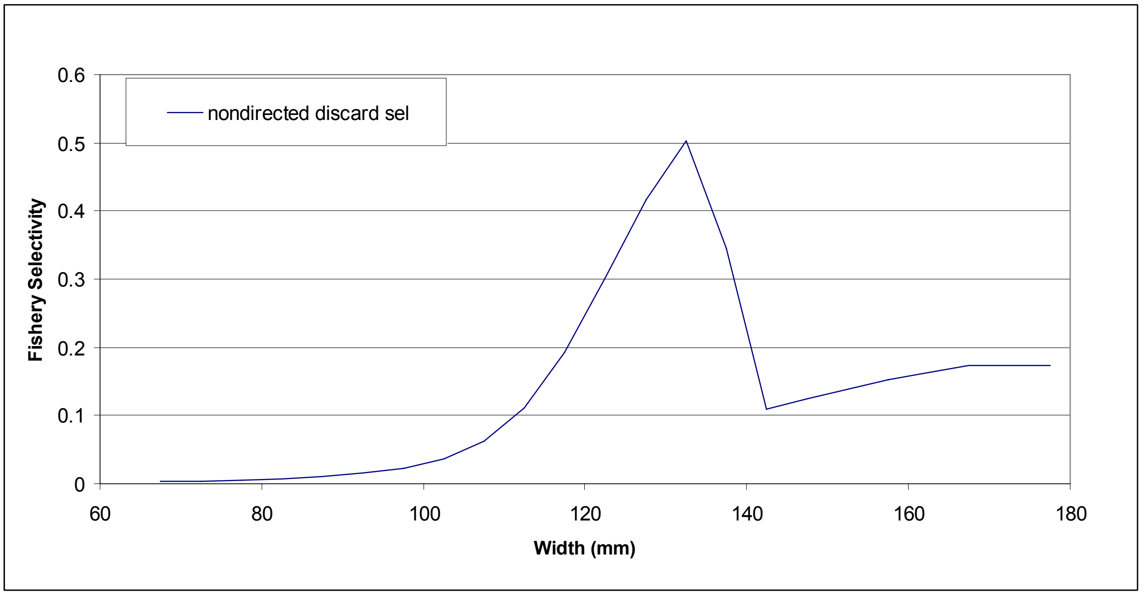


Figure A-2. Non-directed discard fishery selectivities with 50% mortality in the snow crab fishery and 80% mortality from trawl fisheries. The directed Tanner crab discard selectivity was used for snow crab fishery discards. Selectivity for the trawl discard is from the EA on overfishing analysis.

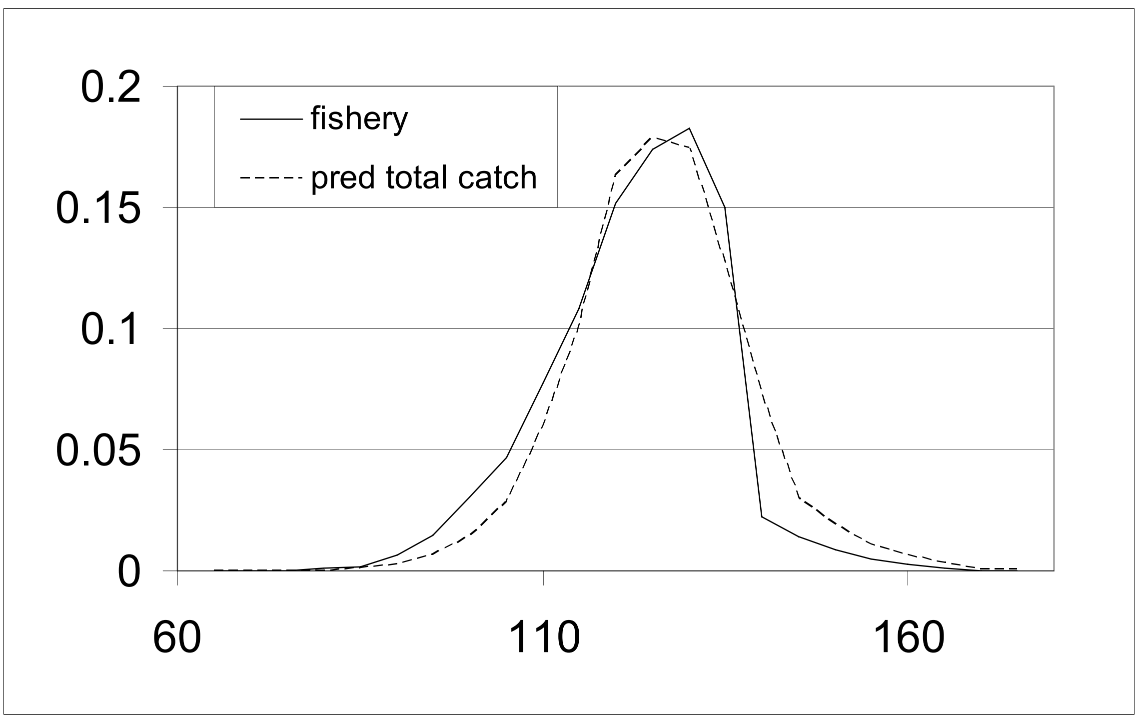


Figure A-3. Length frequency of total directed Tanner fishery catch (fishery) and predicted total directed Tanner fishery catch with estimated discard and retained fishery selectivities (Figure A-1) using the 2007 survey data and 2007/8 fishery observer data.

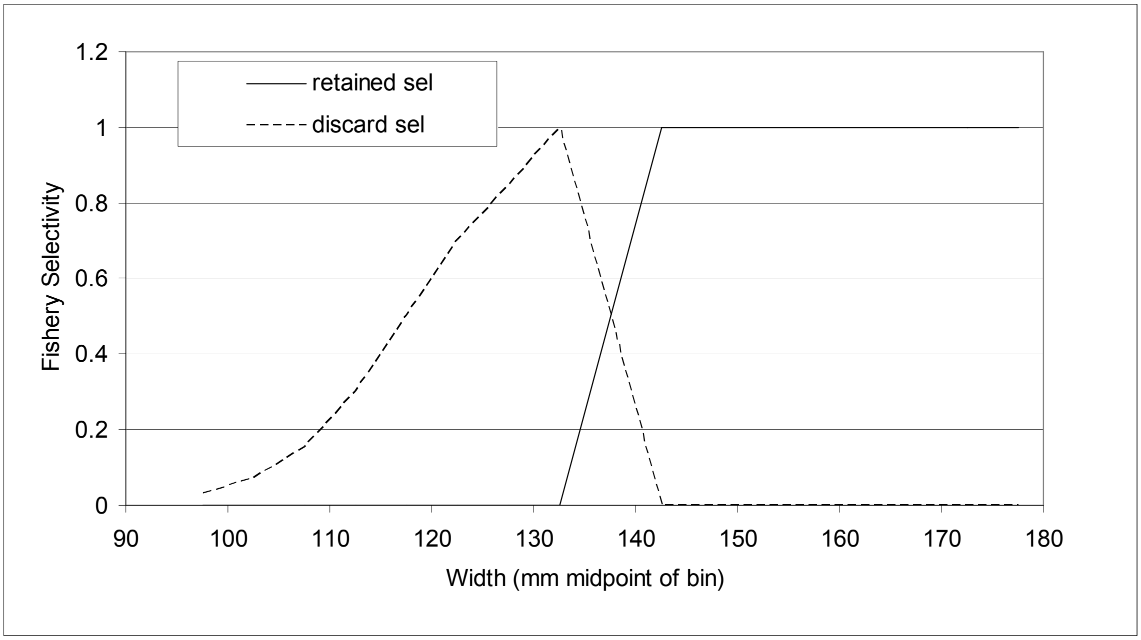


Figure A-4. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery (before discard mortality is applied), with retained selectivity of crab >140 mm cw fixed at 1.0.

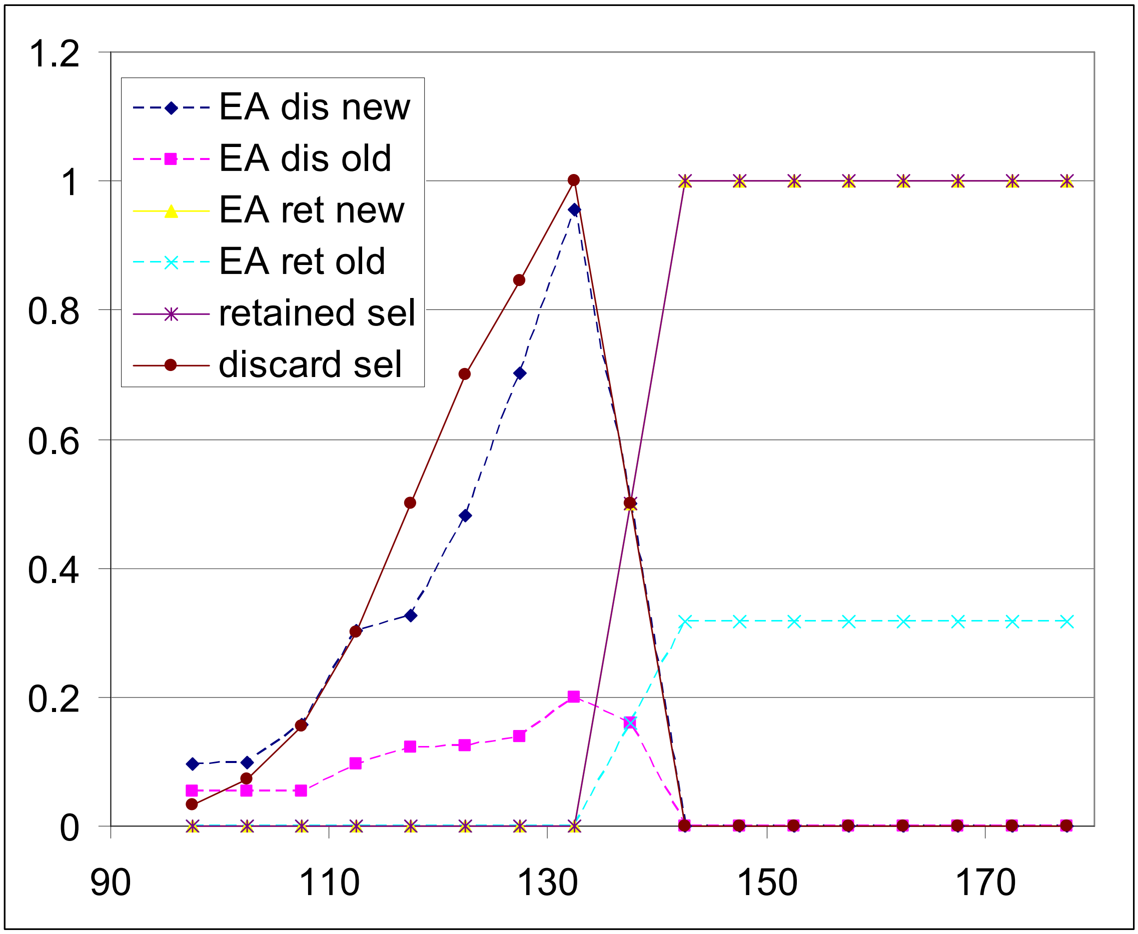


Figure A-5. Retained and discard directed Tanner fishery selectivities estimated for the 2007/8 fishery shell condition combined, before discard mortality is applied. Selectivities on discard and retained split by new and old shell from the EA analysis.

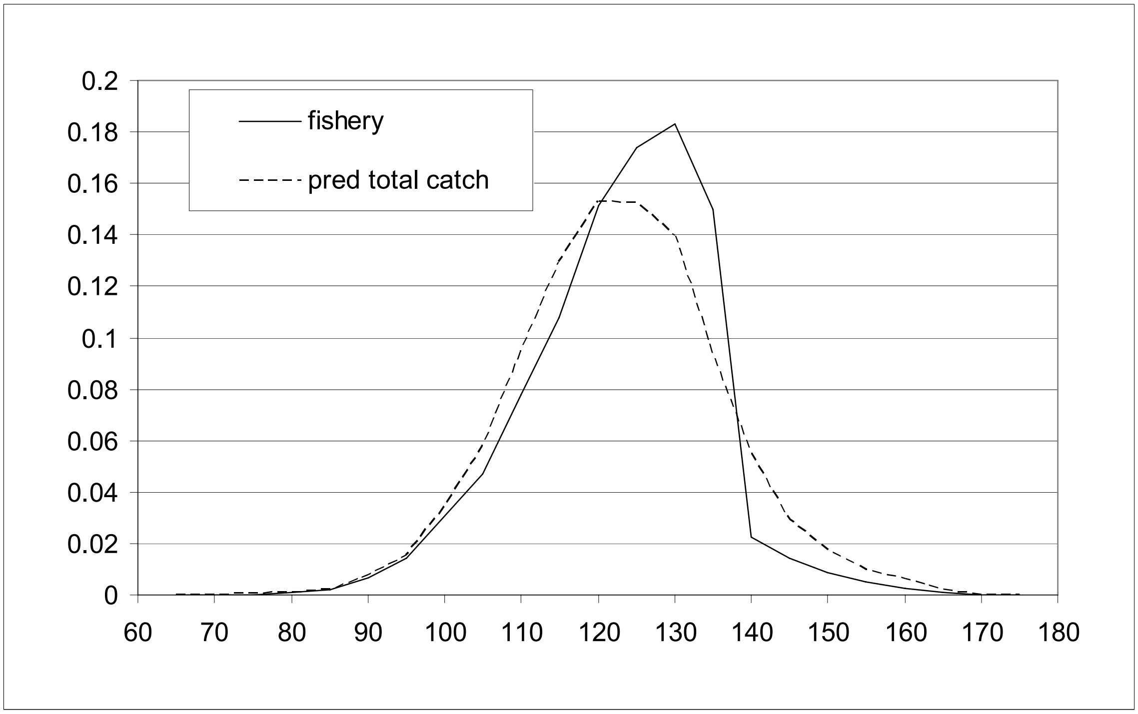


Figure A-6. Fit to total catch length frequency using retained selectivity at 1.0.

Appendix B. Eastern Bering Sea Tanner crab MMB at mating, stock status determination and 2009/10 OFLs based on revised NMFS bottom trawl survey data.

Introduction

Revised EBS Bottom Trawl Survey

The NMFS EBS bottom trawl survey data from 1975 to 2008 was revised in 2009 and reported to the Crab Plan Team at its 11-12 May 2009 meeting (Robert Foy; *see* Crab Plan Team Report). Principal changes to the time series included data error fixes, and the inclusion of area swept estimates based on measured net widths for each tow. Previous trawl survey abundance estimates for crab were made using a fixed 50 ft net width for all tows in lieu of measured net widths. Revisions to these data result in differences in biomass estimates relative to fixed net width estimates. Tanner crab MMB at the time of the survey based on non-revised and revised trawl survey data are shown in Figure B1. The percent difference between non-revised and revised survey MMB estimates ranged from +12.5% (1984) to -35.7% (1999). The mean percent difference over 1976 to 2009 was -9.1% (se=1.4). Differences in MMB estimated using revised data relative to non-revised data ranged from -58.2 million pounds in 1977 to +15.8 million pounds in 1976 in which the percent difference in those years was -16.9% and +5.0% respectively. The mean change in survey MMB estimates over 1976 to 2009 was -9.2 million pounds (se=2.2). The time series of mature and legal male biomass at the time of the survey, the time of the fishery and at the time of mating based on revised survey data are shown in Table B1.

Status of Stock

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} for management is the reference biomass (B_{REF})=184.85 million pounds MMB at the time of mating estimated as the average survey MMB_{mating} from 1969-80 inclusive. In 2009, survey MMB of Tanner crab (77.1 million pounds) declined 43.2% relative to 2008 (135.8 million pounds). MMB projected to the time of mating in 2009/10 (62.1 million pounds) represents 33.6% of B_{REF} accounting for a directed fishery retained catch of 0.96 million pounds. MMB at mating in 2009/10 is below the minimum stock size threshold (MSST=92.4 million pounds). The status of the EBS Tanner crab stock in 2009/10 is projected to be overfished.

Status and catch specifications (10^6 lbs) for EBS Tanner crab.

Year	MSST	Biomass (MMB)	OFL	TAC [E+W]	Retained Catch	Total Catch
2005/06		77.15		1.60	0.95	3.56
2006/07		116.50		2.97	2.12	6.95
2007/08		131.83		5.62	2.11	8.00
2008/09	92.42	111.99	15.52	4.30	1.94	4.96
2009/10	92.42	62.28[1/]	4.40[2/]			

Notes:
1/– Projected 2009/10 MMB at time of mating after extraction of the estimated total catch OFL.
2/– Projected total catch OFL for the 2009/10 fishery.

Calculation of the 2009/10 OFL

For the 2009/10 Tanner crab fishery, we estimated the Total Catch OFL=4.40 million pounds for males and females combined (Table B2). Relative to B_{REF}=184.85 million pounds, projected 2009/10 MMB at mating (62.28 million pounds) represents B/B_{REF}=0.337. Under the OFL Control Rule at this level of mature stock biomass, the full selection F_{OFL}=0.061.

Total losses to MMB in the 2009/10 Total Catch OFL are 3.89 million pounds. Directed and non-directed discard losses to MMB in 2009 are estimated to be 0.59 and 2.42 million pounds, respectively. The retained part of the catch OFL of legal-sized crab is 0.88 million pounds. The retained legal catch would comprise 22.6% of the total MMB losses. A significant component of the MMB losses therefore is attributed to non-targeted losses under current fishing practices.

Expected discard losses of female Tanner crab from the 2009/10 groundfish fishery and the directed pot fishery combined was estimated at 0.51 million pounds. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.103 and 0.057 respectively.

Table B1. Eastern Bering Sea *Chionoecetes bairdi* male mature and legal (≥ 138mm cw) male biomass at time of the survey, fishery and mating based on revised (1976-2009) NMFS bottom trawl survey data incorporating measured net widths. (2009 MMB and LMB at mating are based on extraction of respective 2009/10 catch OFLs).

Eastern Bering Sea *Chionoecetes bairdi* Survey Biomass						
	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	334.21	297.91	187.83			
1977	285.77	254.73	129.63			
1978	174.57	155.60	77.07			
1979	106.14	94.61	25.65			
1980	210.87	187.96	131.43	68.25	60.83	28.94
1981	122.37	109.07	86.05	22.93	20.44	8.67
1982	103.26	92.05	79.49	14.89	13.27	7.50
1983	60.02	53.50	48.36	9.69	8.64	7.11
1984	51.11	45.56	37.52	14.12	12.59	8.96
1985	24.27	21.63	19.37	8.40	7.49	7.21
1986	30.29	27.00	23.84	5.50	4.91	4.72
1987	59.00	52.59	43.35	12.76	11.38	8.75
1988	143.35	127.78	104.21	35.54	31.68	23.47
1989	232.92	207.62	149.52	71.45	63.69	36.80
1990	228.39	203.58	106.65	100.30	89.40	45.94
1991	238.85	212.91	124.95	77.50	69.08	34.68
1992	230.02	205.03	132.04	87.29	77.81	39.78
1993	129.54	115.47	77.50	41.45	36.94	18.65
1994	88.45	78.84	58.11	33.54	29.90	20.97
1995	65.31	58.21	44.84	20.87	18.60	13.67
1996	53.53	47.72	41.22	18.99	16.93	14.49
1997	22.99	20.49	16.36	7.33	6.53	6.29
1998	22.03	19.64	15.58	4.45	3.97	3.82
1999	28.22	25.15	22.68	4.72	4.20	4.05
2000	35.11	31.30	29.10	9.68	8.63	8.31
2001	39.21	34.95	31.98	13.00	11.59	11.15
2002	37.62	33.53	30.83	13.54	12.07	11.61
2003	51.12	45.56	43.13	14.56	12.98	12.49
2004	54.52	48.60	45.91	10.66	9.50	9.14
2005	93.48	83.32	77.15	22.66	20.20	18.49
2006	142.68	127.18	116.50	28.15	25.09	22.03
2007	162.16	144.55	131.83	23.10	20.59	17.71
2008	135.80	121.05	111.99	31.94	28.47	25.46
2009	77.14	68.76	*62.27*	15.49	13.81	*11.86*

Table B2. Catch overfishing limits, stock and fishery metrics for the 2009/10 Eastern Bering Sea *Chionoecetes bairdi* fishery based on revised NMFS bottom trawl survey data incorporating measured net widths. (B_{REF}=mean 1969-1980 MMB at the time of mating, inclusive; μ on MMB is Total Catch OFL/MMB at the time of the fishery).

2009/10 Eastern Bering Sea *Chionoecetes baridi*
Catch OFL, Stock and Fishery Metrics

Metrics (10^6lb):	
B_{REF}:	184.85
MMB @ Mating:	62.28
B/B_{REF}:	0.34
F_{OFL}:	0.06
Catch Components (10^6lb):	
Total ♂ Catch OFL:	3.89
Directed Discard Losses MMB:	0.59
Non-Directed Discard Losses MMB:	2.42
Retained Part of Total ♂ Catch OFL:	0.88
Discard + Bycatch Losses ♀:	0.51
Total ♂ Catch OFL + ♀ Losses:	4.40
Rates:	
μ on MMB @ Fishery:	0.057

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

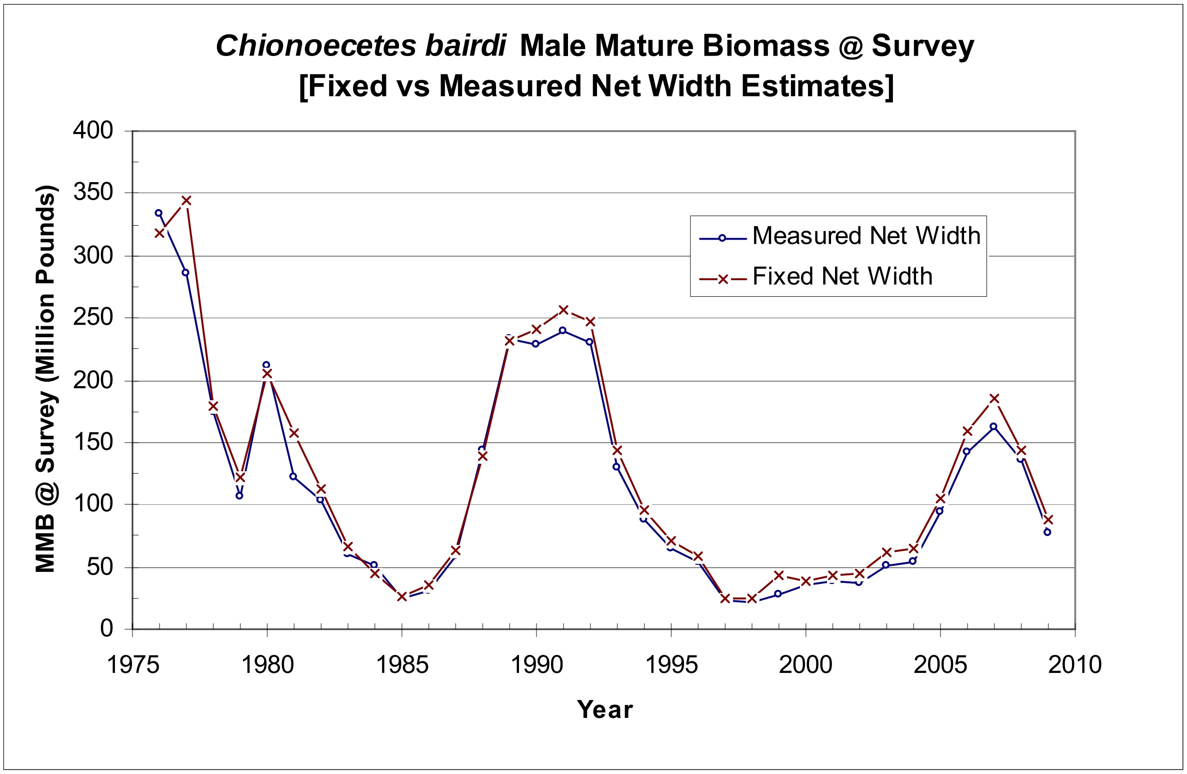


Figure B1. Eastern Bering Sea *Chionoecetes bairdi* male mature biomass estimated at the time of the survey based on fixed net width and measured net width-based calculations of area swept from the NMFS bottom trawl survey, 1976-2009.

Appendix C. Tanner crab stock assessment model (TCSAM) structure.

A length-based stock assessment model for the EBS Tanner crab stock is in development. The authors will present a progress report on model development to the CPT in May 2010 and to the SSC in June 2010. Having a final and approved TCSAM for the 2010/11 assessment cycle is not anticipated considering model development, as well as the Council review and approval process. Success in formulating TCSAM will depend on the historical time series survey data from 1969-2009 as input to the model, and which are required to derive life-history metrics to parameterize the model. The length-based stock assessment model developed for the EBS Tanner crab stock will use the newly derived time-series survey data. It will be specified for the unit stock distributed over the EBS shelf. The goal of this research is to promote the EBS Tanner crab stock to a Tier-3 management status. The existing snow crab stock assessment model (COSAM) (Turnock and Rugolo 2009) is evaluated as a candidate to modify in developing the TCSAM.

The dynamics of the Tanner crab stock will be modeled using the following conceptual approaches:

Recruitment is determined from the estimated mean recruitment, the yearly recruitment deviations and a gamma function that describes the proportion of recruits by length bin,

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

where,

R_0 Mean recruitment
pr_l proportion of recruits for each length bin
τ_t Recruitment deviations by year.

Recruitment is estimated equal for males and females in the model.

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

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

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

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

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

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

PM^s_l Fraction of immature crab that become mature for sex s and length bin l

l'	Premolt length bin
l	Postmolt length bin

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

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

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

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

The Gamma distribution is,

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

Where x is length, β for both males and females was set equal to 0.75, which was estimated from growth data on Bering Sea Tanner.

The probability of an immature crab becoming mature by size is applied to the post-molt size. Crab that mature and reach their terminal molt in year t then are mature new shell during their first year of maturity ($NMN^{s}_{t,l}$),

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

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

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

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

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

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

Where,

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

l Length bin,

Lbins number of length bins in the model,

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

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

W_l weight of a male crab for length bin l.

Catch of male snow crab was estimated as a pulse fishery 0.62 yr after the beginning of the assessment year (July 1),

$$catch = \sum_l (1 - e^{-(F * Sel_l + Ftrawl * TrawlSel_l)}) w_l N_l e^{-M * .62}$$

F Full selection fishing mortality determined from the control rule using biomass including implementation error
$Sel_{,l}$ Fishery selectivity for length bin l for male crab
Ftrawl Fishing mortality for trawl bycatch fixed at the average F
$TrawlSel_l$ Trawl bycatch fishery selectivity by length bin l
W_l weight by length bin l
N_l Numbers by length for length bin l
M Natural Mortality

Selectivity

The selectivity curve total catch were estimated as two-parameter ascending logistic curves,

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

The probability of retaining crabs by size with combined shell condition was estimated as an ascending logistic function. The selectivities for the retained catch were estimated by multiplying a two parameter logistic retention curve by the selectivities for the total catch.

$$S_{ret,l} = \frac{1}{1+e^{-a(l-b)}} \frac{1}{1+e^{-c_{ret}(l-d_{ret})}}$$

The selectivities for the survey and trawl bycatch were estimated with two-parameter, ascending logistic functions,

$$S_{surv,l} = q \frac{1}{1+e^{-a_{surv}(l-b_{surv})}}$$

Likelihood Equations

Catch biomass is assumed log-normal,

$$\lambda \sum_{t=1}^{T} \left[\log(C_{t,fishery,obs}) - \log(C_{t,fishery.pred}) \right]^2$$

There are separate likelihood components for the retained and total catch.

The robust multinomial likelihood is used for length frequencies from the survey and the catch (retained and total) for the fraction of animals by sex in each 5mm length interval. The number of samples measured in each year is used to weight the likelihood. However, since thousands of crab are measured each year, the sample size was set at 200.

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

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

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

A smoothness constraint is also added to the numbers at length by sex in the first year,

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

The survey biomass assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

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

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

Recruitment deviations likelihood equation is,

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

Fishery cpue in average number of crab per pot lift.

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

2009 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

1. Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years to current levels near 0.02 million pounds.
3. Stock biomass: Stock biomass in recent years has decreased since the 2007 survey with a substantial decrease in all size classes in 2009.
4. Recruitment: Recruitment indices are not well understood for Pribilof red king crab. Pre-recruit have remained relatively consistent in the past 10 years although may not be well assessed with the survey.
5. Management performance:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL
2006/07		13.84[A]	0	0	0.077	
2007/08	4.33	14.69[B]	0	0	0.015	
2008/09	4.39	11.06[C]	0	0	0.021	3.32
2009/10		4.46[D]				0.50

All units are in million pounds of crabs and the OFL is a total catch OFL for each year. The stock was above MSST in 2008/09 and is hence not overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2006 and updated with 2006/2007 catches
B – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
C – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
D – Based on survey data available to the Crab Plan Team in September 2009

6. Basis for OFL:

Year	Tier	B_{MSY} 10^6 lbs	Current MMB_{mating} 10^6 lbs	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}
2009/10	4b	8.78	4.46	0.51	1.0	1991/1992-2008/2009	0.18

7. Rebuilding analyses results summary: not applicable

Summary of Major Changes:

1. Management: There were no major changes to the 2008/2009 management of the fishery.
2. Input data: The new survey time series data incorporating data error fixes and variable net width calculations was used (Appendix 2). The new time series for groundfish discards incorporating new calculations for unmeasured crabs was used. The crab fishery retained and discard catch time series was updated with 2008/2009 data.

3. Assessment methodology: There were no changes to assessment methodology.
4. Assessment results: The projected MMB and subsequent OFL declined substantially in this assessment. Total catch in 2008/2009 was 0.021 million pounds.

Responses to SSC and CPT Comments

SSC comments October 2008:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The SSC appreciates the SAFE authors' response to our request to see an estimate of a proxy BMSY based on the 1980-2007 time period for comparison to the value estimated using the 1991-2007 period. The SSC does not disagree with the CPT and SAFE authors' choice of the 1991-2007 base period.

Responses to SSC Comments: Based on June 2008 SSC comments above, the 1980 to 2008 time series will remain as an output of this assessment in 2009 for additional comparison

SSC comments June 2009:

General remarks pertinent to this assessment

- *As reiterated from our June 2008 report, "future stock assessments should provide analyses to support the choice of γ…" in Tier 4. Currently, analysts have used and the Crab Plan Team and the SSC have supported a value of 1 for γ in the calculation $F_{OFL} = \gamma M$, in which M is natural mortality, which results in a proxy for F_{MSY}. The SSC recommends that analysts provide rationale for the selection of γ=1. The value of 1 for γ is the default value used in Tier 5 for groundfish and should be conservative for crab stocks, since only the legal male component of the adult stock is harvested. However, analysis in the Environmental Assessment for Amendment 24 to revise overfishing definitions for crab showed that values of γ between 2 and 3 might be appropriate for F_{msy} estimation for some Bering Sea crab stocks. Therefore, it is desirable to investigate whether alternative approaches can be developed. Some suggestions for doing this will be forthcoming from the crab data weighting and stock assessment workshop held in Seattle during the May Crab Plan Team meeting. A report from that workshop will be available in time for the September Crab Plan Team meeting.*

- *The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number of years that are common across groups of species or areas.*

Specific remarks pertinent to this assessment

The SSC agrees with the Plan Team recommendations for management of Pribilof Islands Red King Crab under Tier 4, setting γ=1, M=0.18, using the 1991 - 2009 period to determine the average mature male biomass as a proxy for B_{MSY}, once the 2009 bottom trawl survey results for this area are available. The SSC appreciates the inclusion of estimates of B_{MSY} proxies for the two time periods, 1980 – 2009 and 1991-2009, and *looks forward to the results of the final analysis in October. The Plan Team's rationale for beginning the time series at 1991 was based on the observation that red king crab were relatively uncommon in the area prior to 1991. The SSC would like to see this rationale included in the final SAFE report. The SSC also looks forward to seeing the implementation of the catch-survey analysis in next year's iteration of the assessment.*

The SSC notes that there is a possibility that the abundance trends of red king crab are related to those of blue king crab, in that red king crab may be replacing blue king crab in the Pribilof Islands area. Given this possibility, it would be valuable to include interactions between these crab species as a factor in any future development of population dynamics models. This might take the form of a single king crab model with partitioning of size class abundances between the two species, or of two separate models with a factor in each to account for the interaction.

In regards to ecosystem considerations, the SSC would like to see consideration given to time trends in the abundance and potential influence of major fish predators, including arrowtooth flounder. Also, the SSC suggests that calculations of the impact of pot gear on the substrate should be based on the area inhabited by the Pribilof Islands red king crab population, rather than the entire area of the Bering Sea shelf.

Responses to CPT Comments: The choice for gamma was discussed at the May 13-14, 2009 assessment workshop with guidance that will be used for the May 2010 assessment cycle. The discussion for specific shifts in recruitment has occurred briefly in previous meetings. This will be a focused topic in 2010. Rationale for using the 1991 time series was included in the assessment. The particulars of the CSA model are included in this SAFE for discussion and recommendation of the CPT for specific analyses so that the model can be implemented in 2010. Options to include interactions between blue and red king crab in the Pribilofs will be considered as catch-survey models are developed. Expanded ecosystem sections were not considered during this assessment cycle to focus efforts on model development, ACL implementation, and survey data. A general Ecosystems Chapter will be developed for May 2010 for all crab stocks.

<u>CPT comments September 2008:</u>

General remarks pertinent to this assessment

- *The team agreed that assessment documents presented to September meetings should be the "track changes" version of the May assessment, to facilitate evaluating changes from that version.*
- *A checklist of the items which should be included in stock assessments on which OFL determinations are based should be developed. This checklist would include a table of survey estimates (and their associated CVs) by year. Having a standard approach to reporting assessment results will help the review process as well as how the work of the team is documented.*
- *Whenever possible survey estimates of abundance should be accompanied by measures of their precision because it is hard to assess model performance without this information.*

Specific remarks pertinent to this assessment

- *The team requested additional information for the next year's assessment which further evaluates the individual fishery contributions to the bycatch. The team also requests the addition of CVs for all historical estimates from the survey.*

Responses to CPT Comments: Track changes were not used due to the volume of changes made to standardize this years assessments. Future assessments will use track changes. Standard format was used for this assessment. Confidence intervals were included for survey estimates. Bycatch was broken out by specific fishery information.

CPT comments May 2009:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The team agreed with the author's recommendation for the basis for the B_{msy} proxy as well as for the model parameters.

Responses to CPT Comments:

None

Introduction

1. **Red king crabs, *Paralithodes camtschaticus*** (Tilesius, 1815)

2. **Distribution -** Red king crabs are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58° 39' N lat.), west of 168° W long., east of the United States – Russian convention line of 1867 as amended in 1991, north of 54° 36' N lat. between 168° 00' N and 171° 00' W. long and north of 55° 30'N lat. between 171° 00' W. long and the U.S.-Russian boundary (Figure 2).

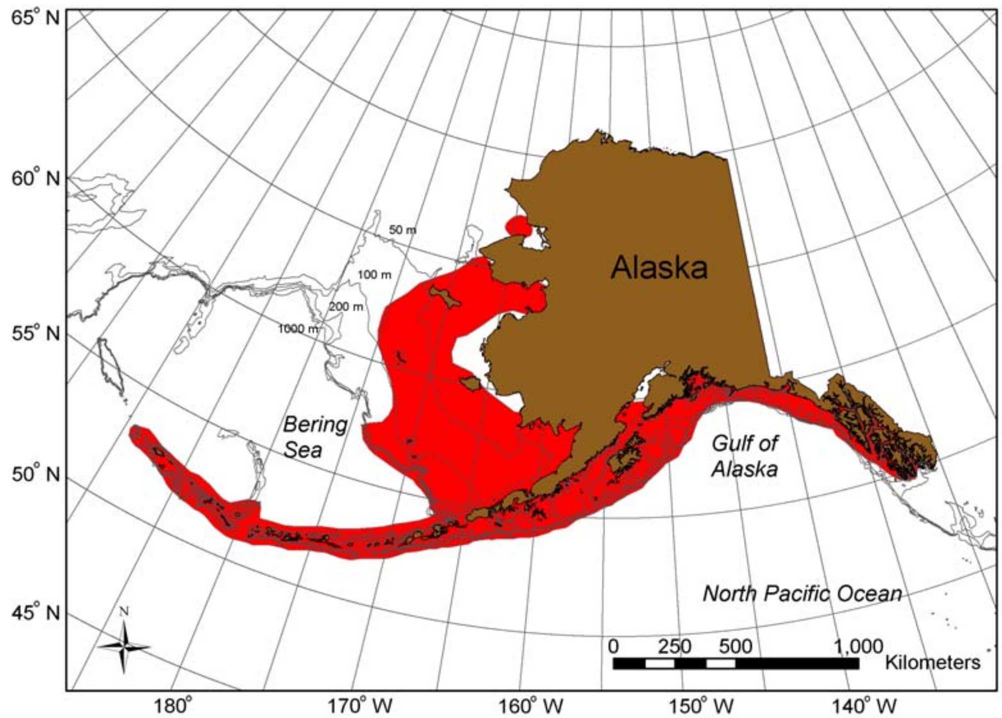

Figure 1. Red king crab distribution.

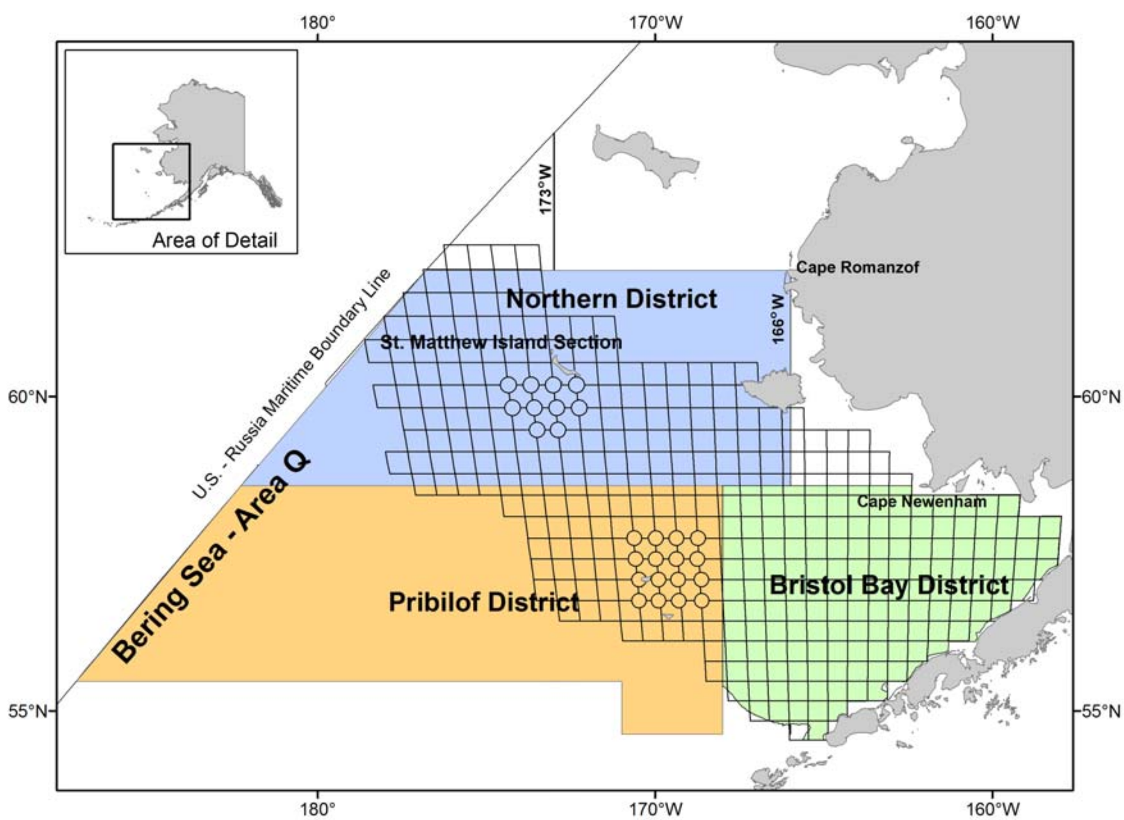

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

3. **Stock structure** - Stock structure of red king crabs in the North Pacific is largely unknown.

4. **Life History** - Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Unlike brachyurans, red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts and copulation occurs within hours. During copulation, the male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female's gonopores. After copulation, eggs are fertilized as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).
   Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006) and estimates vary. Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data range from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males range from 0.54 to 0.70, however the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, with higher mortality for crabs <125 mm CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24.

   The reproductive cycle of Pribilof Islands red king crabs has not been established, however in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous Bristol Bay red king crab females (brooding their first egg clutch) extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (brooding their second or subsequent egg clutch) females (Stevens and

Swiney 2007a, Otto et al. 1990) resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for eastern Bering Sea red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age, during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment is on average 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

5. **Management history** - Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the Sate of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crabs *Paralithodes platypus* being targeted (Figure 3). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof red and blue king crab fisheries which was implemented in 1998. From 1999 to 2008/2009 the Pribilof fishery was not open due to low blue king crab abundance,

uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof blue king crab was declared overfished in September of 2002 and is still considered overfished. (see Bowers et al. 2008 for complete management history).

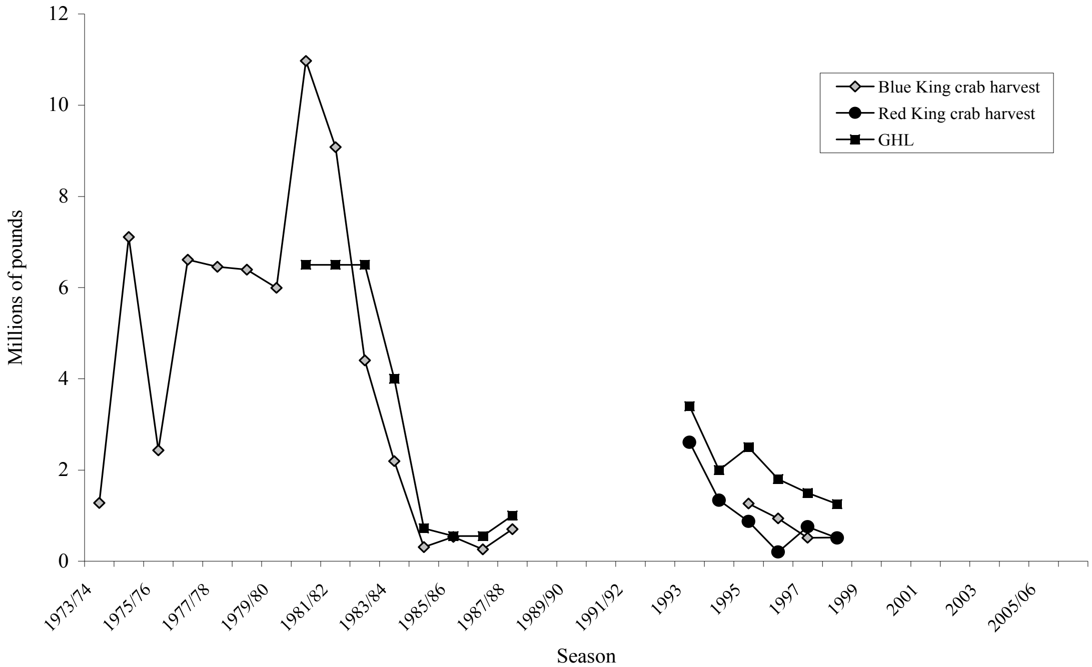

Figure 3. Historical harvests and GHLs for Pribilof Island red king crab (Bowers et al. 2007).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

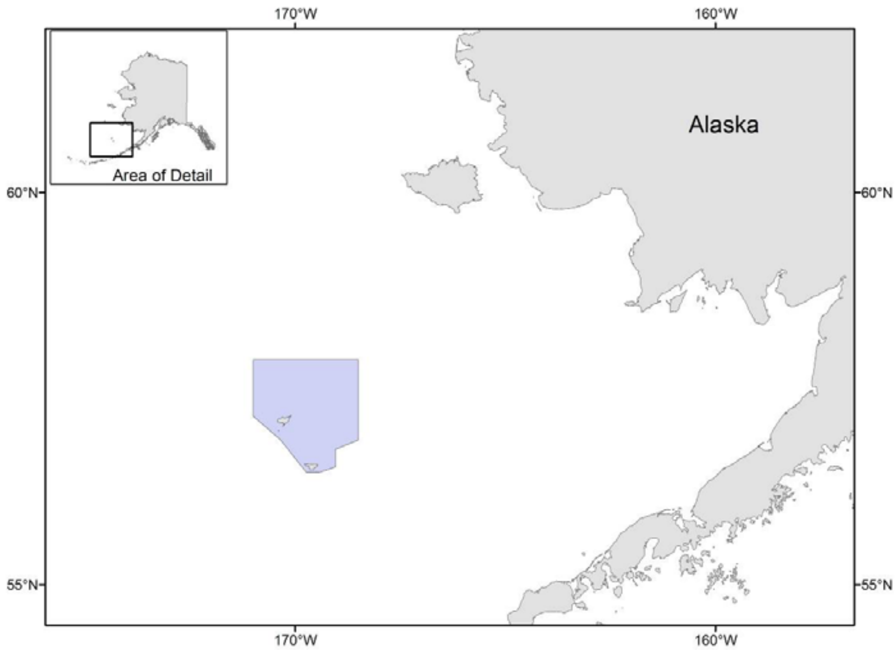

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area

Pribilof red king crabs occur as bycatch in the eastern Bering Sea snow crab (*Chionocetes opilio*), eastern Bering Sea Tanner crab (*Chionocetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof blue king crab fisheries. Many of these fisheries have been closed or recently re-opened so the opportunity to catch Pribilof red king crab is limited. Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries.

Data

1. The new survey time series data incorporating data error fixes and variable net width calculations was used (Appendix 2). The new time series for groundfish discards incorporating new calculations for unmeasured crabs was used. The crab fishery retained and discard catch time series was updated with 2008/2009 data.

2. a. Total catch:
   <u>Crab pot fisheries</u>
   Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (Table 1 and 2), the seasons when red king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons red king crab and blue king crab were fished under the same Guideline Harvest Level (GHL). There was no GHL and therefore zero retained catch in the 2008/2009 fishing season.

Table 1. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2008; D. Pengilly, ADF&G, personal communications).

year	Total 10^6 lbs
1979/1980	0
1980/1981	0
1981/1982	0
1982/1983	0
1983/1984	0
1984/1985	0
1985/1986	0
1986/1987	0
1987/1988	0
1988/1989	0
1989/1990	0
1990/1991	0
1991/1992	0
1992/1993	0
1993/1994	2.608
1994/1995	1.339
1995/1996	0.898
1996/1997	0.200
1997/1998	0.757
1998/1999	0.544
1999/2000	0
2000/2001	0
2001/2002	0
2002/2003	0
2003/2004	0
2004/2005	0
2005/2006	0
2006/2007	0
2007/2008	0
2008/2009	0

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, 1993-2007/08 (Bowers et al. 2008)

Season	Number of Vessels	Number of Landings	Number of Pots Registered	Number of Pots Pulled
1993	112	135	4,860	35,942
1994	104	121	4,675	28,976
1995	117	151	5,400[a]	34,885
1996	66	90	2,730[a]	29,411
1997	53	110	2,230[a]	28,458
1998	57	57	2,398[a]	23,381
1999-2008/09	Fishery Closed			

b. Bycatch and discards:

<u>Crab pot fisheries</u>

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight (lbs) was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was calculated from length frequency tables where the CL (mm) was converted to g (see equation 1: males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * CL(mm)^B \quad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (2)$$

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

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 3) although data may be incomplete for some of these fisheries. Prior to 1998 limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here.

In 2008/2009, 452 lbs of legal males were incidentally caught in the crab fisheries (Table 3).

<u>Groundfish pot, trawl, and hook and line fisheries</u>

The 2008/2009 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 2008 to June 2009. 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 2009 catches, sex ratios by size and sex from the 2009 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 2008/2009, 0.026 million lbs of male and female red king crab were caught in groundfish fisheries which is 0.01 more than the 0.016 million lb estimate of non-retained crab catch in 2007/2008 pot, trawl, and hook and line groundfish fisheries. The catch was mostly in non-pelagic trawls (73%) followed by pot (23%) and longline (4%) fisheries. The targeted species in these fisheries were yellowfin sole (40%), Pacific cod (34%), flathead sole (16%), and rock sole (9%).

Table 3. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2008; D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Crab Pot Fisheries			Groundfish Fisheries	
	Legal non-retained 10^6 lbs	Sublegal male 10^6 lbs	All Female 10^6 lbs	All Pot 10^6 lbs	All Trawl 10^6 lbs
1991/1992				0.001	0.101
1992/1993				0.036	0.388
1993/1994				0.001	0.291
1994/1995				0.001	0.034
1995/1996				0.011	0.014
1996/1997				0.004	0.005
1997/1998				0.010	0.017
1998/1999		0.002	0.025	0.023	0.015
1999/2000	0.003		0.018	0.027	0.007
2000/2001				0.005	0.010
2001/2002		0.000007		0.006	0.015
2002/2003				0.001	0.020
2003/2004				0.002	0.022
2004/2005				0.007	0.008
2005/2006		0.0004	0.004	0.010	0.054
2006/2007	0.003	0.0003	0.002	0.015	0.047
2007/2008	0.002	0.0001	0.0002	0.004	0.006
2008/2009	0.0002			0.004	0.015

c. Catch-at-length: NA

d. Survey biomass:
The 2009 NOAA Fisheries EBS bottom trawl survey results (Chilton et al. in press) are included in this SAFE report. Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock (Figure 5). Weight (equation 3) and maturity (equation 4) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass (million lbs).

$$\text{Weight (kg)} = 0.00036 * \text{CL(mm)}^{3.16}/1000 \qquad (3)$$

$$\text{Proportion mature} = 1/(1 + (5.842 * 10^{14}) * e^{(\text{CL(mm)} * -0.288)} \qquad (4)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 4, Figure 6).

Table 4. Pribilof Islands District red king crab abundance, mature biomass, and legal male biomass (million lbs), and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature males @ survey 10^6 LB	Mature males @ mating 10^6 LB	Legal Males @ survey 10^6 LB	Total males @ survey 10^6 LB	Total females @ survey 10^6 LB	Total Crab @ survey 10^6 LB
1980/1981	5.82	3.89	5.82			
1981/1982	5.82	4.69	5.82			
1982/1983	2.98	2.59	2.98			
1983/1984	0.77	0.68	0.70			
1984/1985	0.81	0.72	0.67			
1985/1986	0.22	0.19	0.22			
1986/1987	0.27	0.24	0.27			
1987/1988	0.09	0.08	0.09			
1988/1989	0.28	0.25	0.08			
1989/1990	3.11	2.76	1.77			
1990/1991	2.40	2.13	0.13			
1991/1992	8.11	7.14	2.45			
1992/1993	6.81	5.82	5.22			
1993/1994	16.84	12.18	15.72			
1994/1995	16.34	13.13	14.46			
1995/1996	8.51	6.63	7.65			
1996/1997	4.43	3.72	4.37			
1997/1998	11.60	9.51	10.76			
1998/1999	5.07	3.93	3.79			
1999/2000	0.02	0.00	0.02			
2000/2001	8.73	7.73	7.76			
2001/2002	17.44	15.45	11.51			
2002/2003	14.88	13.19	14.84			
2003/2004	11.05	9.78	10.85			
2004/2005	8.55	7.58	8.55			
2005/2006	2.98	2.60	2.95			
2006/2007	15.65	13.84	14.97			
2007/2008	16.58	14.69	15.98	17.01	5.99	23.00
2008/2009	12.49	11.06	11.64	13.76	7.61	21.37
2009/2010	5.43	4.46	4.66	5.56	1.22	6.77

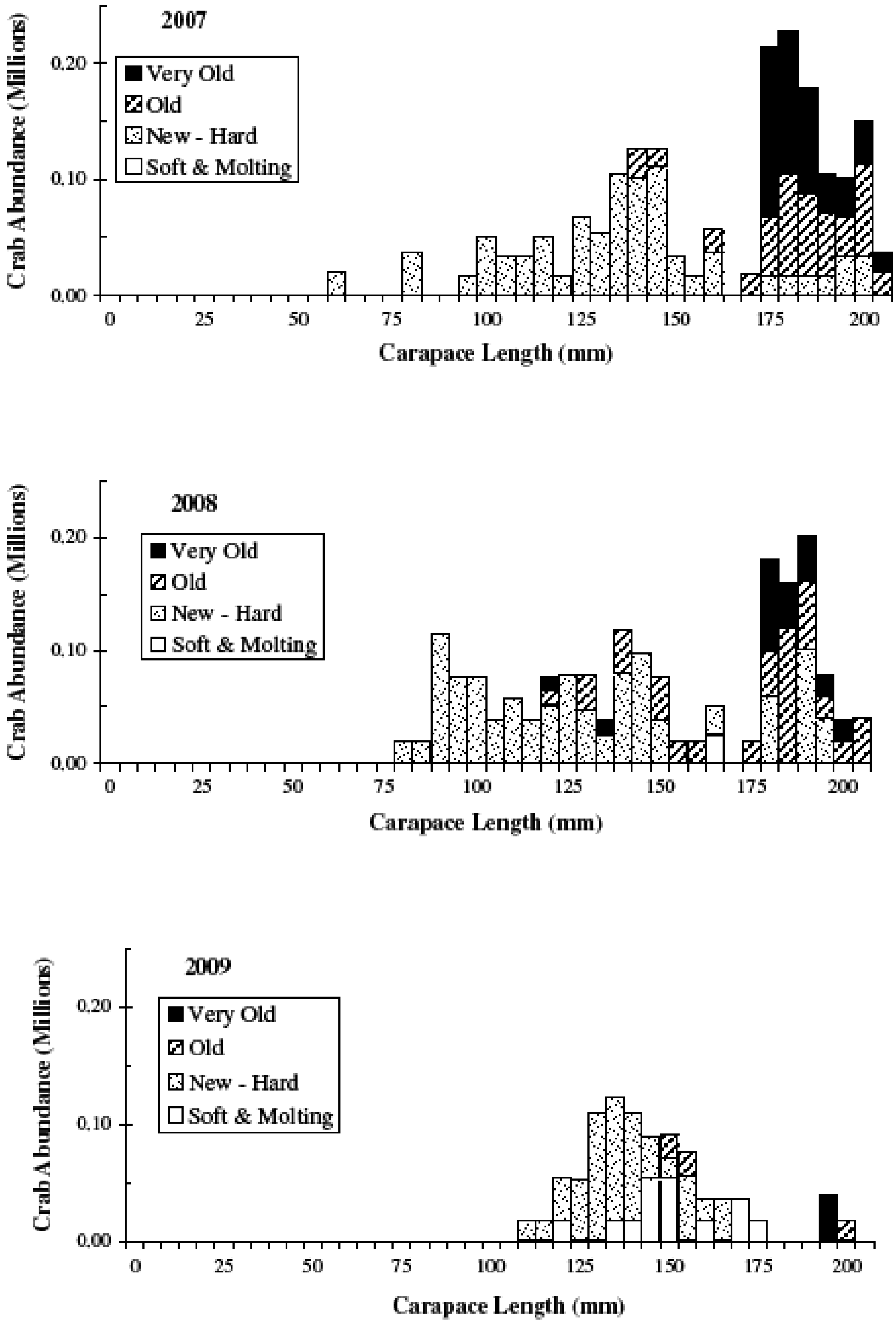

Figure 5. Distribution of Pribilof Island red king crab in 5 mm length bins by shell condition for the last 3 surveys.

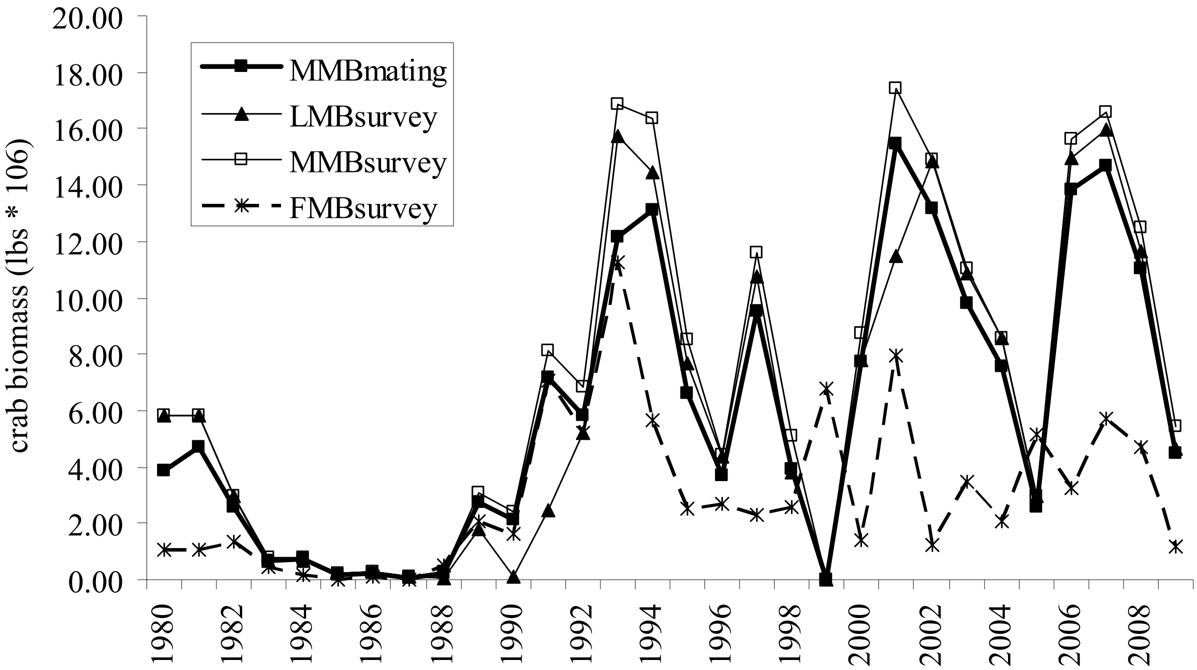

Figure 6. Historical trends of Pribilof Island red king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

Red king crab were caught at 7 of the 41 stations in the Pribilof District high-density sampling area in 2009 (Chilton et al. in press, Figure 7). The density of legal-sized males caught at a station ranged from 66 to 1,745 crab/nmi^2. Legal-sized male red king crab were caught at 6 stations in the Pribilof District and were estimated at 0.7 ± 0.9 million crab (Figure 8). Pre-recruit males were encountered at 2 of the 41 stations with an abundance estimate of 0.3 ± 0.4 million crab. Thirty percent of the legal-sized males were in molting or softshell condition while 53% were evaluated as new hardshell crabs and 17% as oldshell and very oldshell condition crabs. The 2009 size-frequency for red king crab males shows a decrease in the number of oldshell and very oldshell legal-sized males in comparison to the 2007 and 2008 shell conditions. The 2009 abundance estimate of large red king crab females was 0.3 ± 0.4 million crab. Thirteen percent of the total female red king crab caught were immature while 65% of the mature females were brooding uneyed embryos, 12% had eyed embryos, and 23% were barren or had empty egg cases.

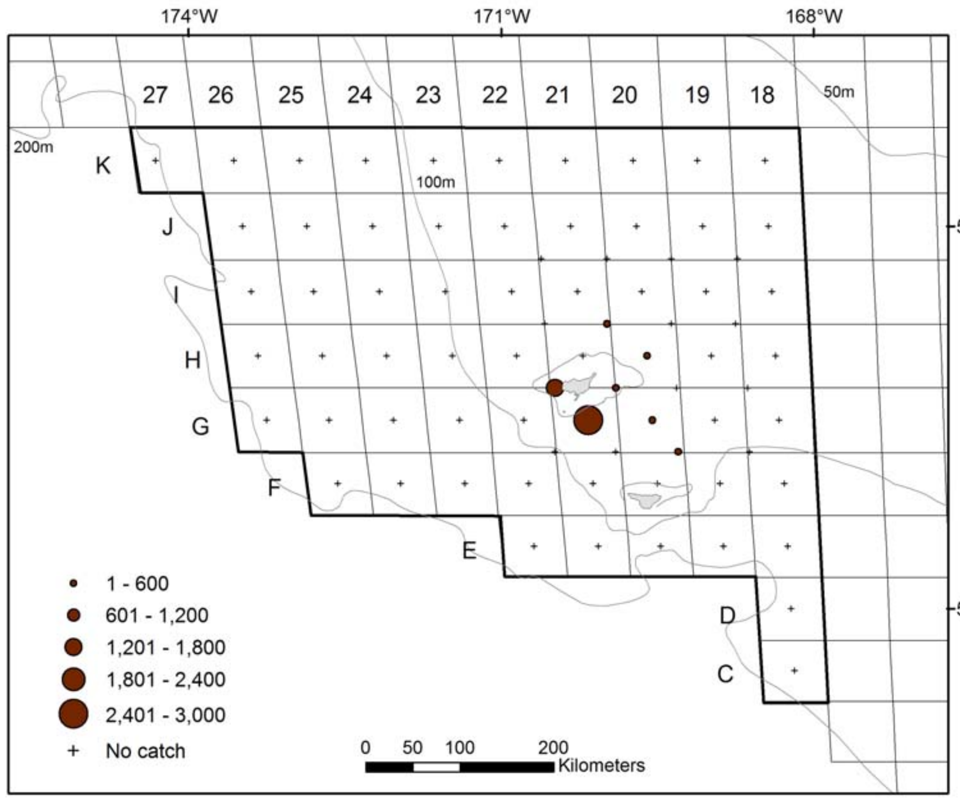

Figure 7. Total density (number/nm^2) of red king crab in the Pribilof District in the 2009 EBS bottom trawl survey.

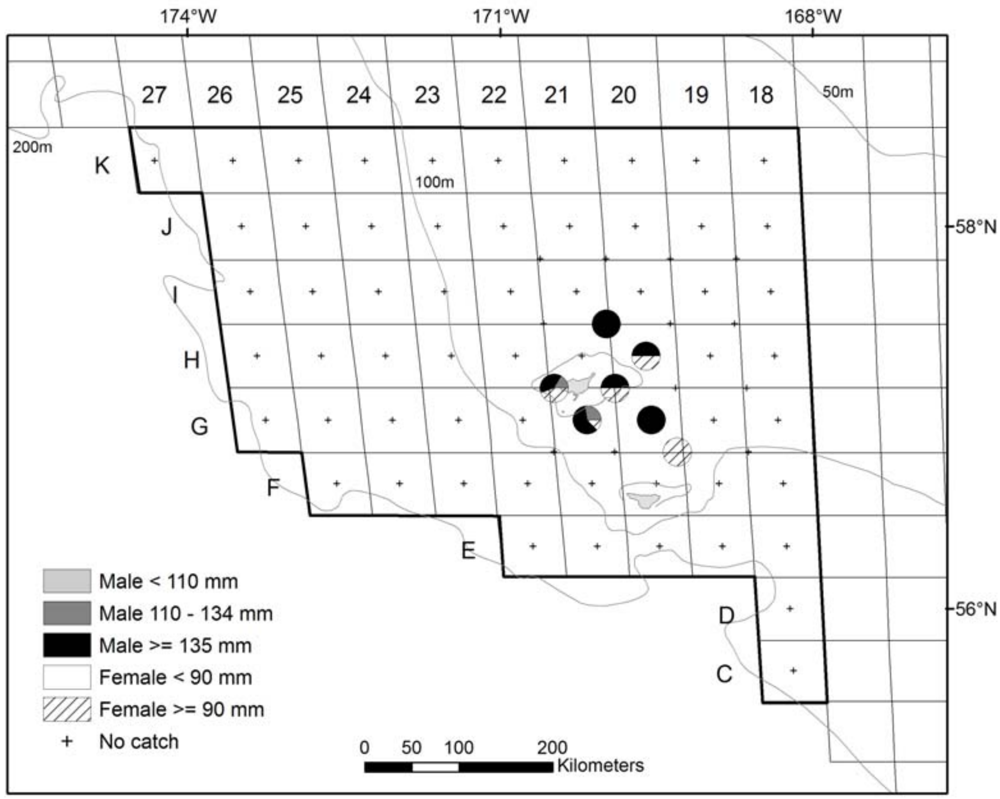

Figure 8. 2009 EBS bottom trawl survey size class distribution of red king crab in the Pribilof District.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and is proposed for future consideration (Appendix 1).

Calculation of the OFL

1. Based on available data, the authors, the Crab Plan Team, and the Science and Statistical Committee all recommend that this stock should be classified as a Tier 4 stock for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008).

2. In Tier 4, Maximum Sustainable Yield is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, and environmental conditions. In Tier 4, the fishing mortality that, if applied over the long-term, would result in MSY is approximated by F_{MSY}^{proxy}. The MSY stock size (B_{MSY}) is based on mature male biomass at mating (MMB_{mating}) which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of the complicated

female crab life history, unknown sex ratios, and male only fishery. The B_{MSY}^{proxy} represents the equilibrium stock biomass that provides maximum sustainable yield (MSY) to a fishery exploited at F_{MSY}^{proxy}. B_{MSY} can be estimated as the average biomass over a specified period that satisfies these conditions (i.e., equilibrium biomass yielding MSY by an applied F_{MSY}). This is also considered a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock. The current stock biomass reference point for status of stock determination is MMB_{mating}.

The mature stock biomass ratio β where B/B_{MSY}^{prox} = 0.25 represents the critical biomass threshold below which directed fishing mortality is set to zero (Figure 9). The parameter α determines the slope of the non-constant portion of the control rule line and was set to 0.1. Values for α and β where based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where B is greater than β includes the product of a scalar (**γ**) and M (equations 5 and 6) where the default **γ** value is 1 and M for Bering Sea red king crab is 0.18. The value of **γ** may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, the F_{OFL} control rule resulting in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as 0.5 B_{MSY}^{prox}; if current MMB at the time of mating drops below MSST, the stock is considered to be overfished.

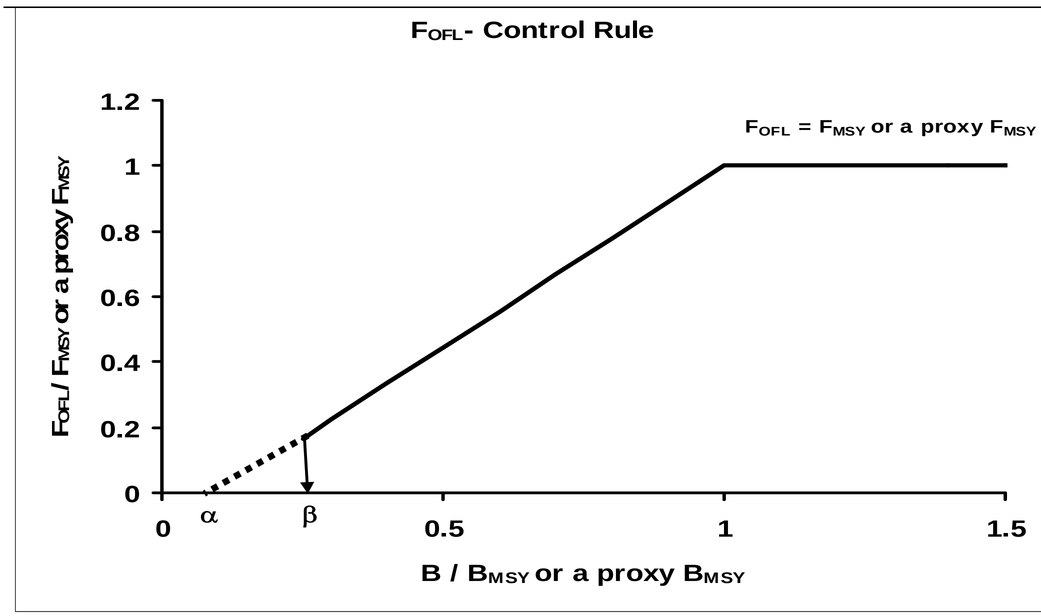

Figure 9. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

3. OFL specification:
   a. In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT)

or F_{OFL} Control Rule (Figure 8) where Stock Status Level (level a, b or c; equations 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. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$	(7)

B_{MSY}^{prox} for the 2009 assessment was calculated as 1) the average MMB_{mating} from 1991 to current based on the observation that red king crab were relatively uncommon in the area prior to 1991. 2) the average MMB_{mating} for the entire survey period 1980 to current.

b. The MMB_{Mating} projection is based on application of M from the 2009 NMFS trawl survey (July 15) to mating (February 15) and the removal of estimated retained, bycatch, and discarded catch mortality (equation 8). Catch mortalities are estimated from the proportion of catch mortalities in 2008/2009 to the 2009 survey biomass.

$$MMB_{Survey} \cdot e^{-PM(sm)} - \text{(projected legal male catch OFL)-(projected non-retained catch)} \quad (8)$$

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. PM(sm) is the partial M from the time of the survey to mating (8 months).

c. To project a total catch OFL for the upcoming crab fishing season, the F_{OFL} is estimated by an iterative solution that maximizes the projected F_{OFL} and projected catch based on the relationship of B to B_{MSY}^{prox}. B is approximated by MMB at mating (equation 8).

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.

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

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

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL
2006/07		13.84[A]	0	0	0.077	
2007/08		14.69[B]	0	0	0.015	
2008/09	4.33	11.06[C]	0	0	0.021	3.32
2009/10	4.39	4.46[D]				0.50

All units are millions of crabs and the OFL is a total catch OFL for all years. The stock was above MSST in 2008/09 and is hence not overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2006 and updated with 2006/2007 catches
B – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
C – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
D – Based on survey data available to the Crab Plan Team in September 2009

4. Recommendations:
For 2009/2010, two levels of B_{MSY}^{prox} were defined. $B_{MSY}^{prox}{}_{1}$=8.78 million lbs of MMB_{mating} derived as the mean of 1991/1992 to 2008/2009 and is recommended by the authors, CPT and SSC. $B_{MSY}^{prox}{}_{2}$=6.08 million lbs derived mean of 1980/1981 to 2008/2009 for comparison purposes. The stock demonstrated highly variable levels of MMB_{mating} during both of these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

Male mature biomass at the time of mating for 2009/2010 is estimated at 4.46 and 4.30 million lbs for $B_{MSY}^{prox}{}_{1}$ and $B_{MSY}^{prox}{}_{2}$ options, respectively. The B/B_{MSY}^{prox} ratios and F_{OFLs} corresponding to the two biomass reference options are, respectively, [$B/B_{MSY}^{prox}{}_{1}$=0.51, F_{OFL}=0.18] and [$B/B_{MSY}^{prox}{}_{2}$=0.71, F_{OFL}=0.18]. For both biomass reference options B/B_{MSY}^{prox} is < 1, therefore the stock status level is a (equation 5). For the 2009/2010 fishery, total catch OFLs were estimated at 0.50 and 0.73 million lbs of crab and legal male catch OFLs were estimated at 0.34 and 0.50 million lbs of crab for options 1 and 2 respectively. The projected exploitation rates based on full retained catches up to the OFL for LMB and $MMB_{fishery}$ are: 0.09 and 0.07 for B_{MSY}^{prox} option 1 and 0.12 and 0.11 for B_{MSY}^{prox} option 2.

Red king crabs in the Pribilof Islands have been historically harvested with blue king crabs and are currently the dominant of the two species in this area. There are concerns as to the low reliability of survey biomass estimates, and the high levels of blue king crab incidental catch mortality that would occur in a directed Pribilof Islands red king crab fishery.

Ecosystem Considerations

1. 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 is 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 1980s, with peaks in the mid 1980s and mid 1990s and a substantial decline by 1991. Stocks are currently facing another low point and are 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, generally increased from 1986 through 1990, and peaked in 1990. From 1991 through 1999 biomass tended to decrease, and from 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, and then 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, microsporidan, 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 have 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 in 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 systems; during low pressure the brood strength is reduced (Tyler and Kruse 1996; Zheng and Kruse 2000). Gish (2006) suggested that the lack of king crab recruitment in the Pribilof Islands area may be the result of a large-scale environmental event affecting abundance and distribution.

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).

2. 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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Appendix 1. Proposed Catch Survey Model for Pribilof Island king crab

The following model development is based on ADF&G CSA models currently employed to assess St. Matthew Island blue king crab and Pribilof Islands king crab for TAC setting. The methods to be used to analyze the model will be similar to those currently in review for St. Matthew blue king crab (Zheng, Pengilly, Foy, and Barnard. in review. Stock assessment model evaluation for St. Matthew blue king crab. 2009 Wakefield Symposium)

Input data will include NMFS EBS bottom trawl time series, ADF&G triennial pot survey time series, and commercial catches in number and weight and CPUE for the directed fishery.

Model development

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. 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 will be divided into four groups: prerecruit-2s ($P2$), prerecruit-1s ($P1$), recruits (R), and postrecruits (P).

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:

$$P2_t^b = P2_t\{1-[h\,H2^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},$$

$$P1_t^b = P1_t\{1-[h\,H1^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},$$

$$P2_{t+1} = P2_t^b[(1-m2_t)+m2_t\,G_{P2,P2}]e^{-M_t}+N_{t+1},$$

$$P1_{t+1} = \{P1_t^b[(1-m1_t)+m1_t\,G_{P1,P1}]+P2_t^b\,m2_t\,G_{P2,P1}\}e^{-M_t},$$

$$R_{t+1} = (P2_t^b\,m2_t\,G_{P2,R}+P1_t^b\,m1_t\,G_{P1,R})\,e^{-M_t},$$

$$P_{t+1} = (P_t+R_t+P2_t^b\,m2_t\,G_{P2,P}+P1_t^b\,m1_t\,G_{P1,P})\,e^{-M_t}-C_t\,e^{(y_t-1)M_t}, \quad (1)$$

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.

Molting probability for prerecruit-1s, $m1_t$, will be modeled 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.

Multiple scenarios will be developed for Pribilof Island king crab depending on parameters estimated independently and conditionally. These scenarios will consider combinations of fixing M and Q versus estimating each conditionally.

Parameter Estimation

Estimated parameters include natural mortality, molting probabilities, catchabilities, selectivities, crab entering the model for the first time each year except the first, and total abundance in the first year. Depending on the model scenario, *M* and *Q* may be estimated conditionally. When Q is not estimated, it is fixed to be 1. If *M* is not estimated, *M* is assumed to be 0.18 in this study, based on a maximum age of 25 and the 1% rule (Zheng 2005). Measurement errors of survey estimates of relative abundances will be assumed to follow a lognormal distribution. Parameters of the model will be estimated using a maximum likelihood approach:

$$
\begin{aligned}
Ln(L) = -\sum_t \{ & [\ln(P2_t QS2+1) - \ln(p2_t+1)]^2 / (2\ln(CV_{p2,t}^2+1)) \\
& + [\ln(P1_t QS1+1) - \ln(p1_t+1)]^2 / (2\ln(CV_{p1,t}^2+1)) \\
& + [\ln(R_t Q+1) - \ln(r_t+1)]^2 / (2\ln(CV_{r,t}^2+1)) \\
& + [\ln(P_t Q+1) - \ln(p_t+1)]^2 / (2\ln(CV_{p,t}^2+1)) \\
& + [\ln(P2_t s2/q+1) - \ln(ip2_t+1)]^2 / (2\ln(CV_{ip2,t}^2+1)) \\
& + [\ln(P1_t s1/q+1) - \ln(ip1_t+1)]^2 / (2\ln(CV_{ip1,t}^2+1)) \\
& + [\ln(R_t/q+1) - \ln(ir_t+1)]^2 / (2\ln(CV_{ir,t}^2+1)) \\
& + [\ln(P_t/q+1) - \ln(ip_t+1)]^2 / (2\ln(CV_{ip,t}^2+1)) + 10\eta_t^2 \},
\end{aligned} \tag{3}
$$

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*; *CV* is coefficient of variance for the survey abundance; *S*2 and *S*1 are trawl survey selectivities for prerecruit-2s and prerecruit-1s; *Q* is a trawl survey catchability, *s*2 and *s*1 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), parameters using the quasi-Newton method will be estimated to minimize –Ln(L).

Based on CPT input, further model development and testing will occur for review for the 2010-2011 assessment cycle. This will include investigating of multiple weighting factors for the trawl vs pot surveys due to the high CVs of the trawl survey.

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Appendix 2. Revised EBS trawl crab time series OFL calculations.

The EBS bottom trawl time series for crab has been revised from 1975 to 2008. Changes include error fixes and the inclusion of recalculated area swept estimates with net width estimated from net mensuration data instead of a fixed value. Thirty nine individual crab data points affecting abundance estimates at 19 stations were amended after transcription errors were found in the database. The error fixes resulted in minor survey catch count changes in 34 of the data points. Five fixes, however, resulted in increases or decreases in the survey catch count between 1000 and 2000 crabs. Using net width estimated from net mensuration data resulted in changes to all haul records from 1983 to 2008. The range of average net widths estimated in the revised time series was 14.9 to 17.4 m effectively increasing the area swept from a fixed net width of 15.3 m which was used previously. This revised time series was used for the 2008/2009 assessments for Pribilof Islands red king crab.

The revision of the Pribilof Islands red king crab time series of legal male abundance on the survey changed the original time series from 1 to 8% between 1998 and 2008 (Figure 1). Confidence intervals of survey mean abundance estimates were lower with the revised time series than with the original data (Figure 2). Confidence intervals were calculated by initially measuring variance within each size grouping (ie. legal males) as opposed to within each 5 mm length bin. The effects of the survey time series revision on the 2008 assessment results included a reduction of the B_{MSY}^{proxy} from 8.66 to 8.95 million lbs of MMB_{mating} and a reduction of 2009/2010 projected MMB_{mating} from 9.26 to 9.18 million lbs.

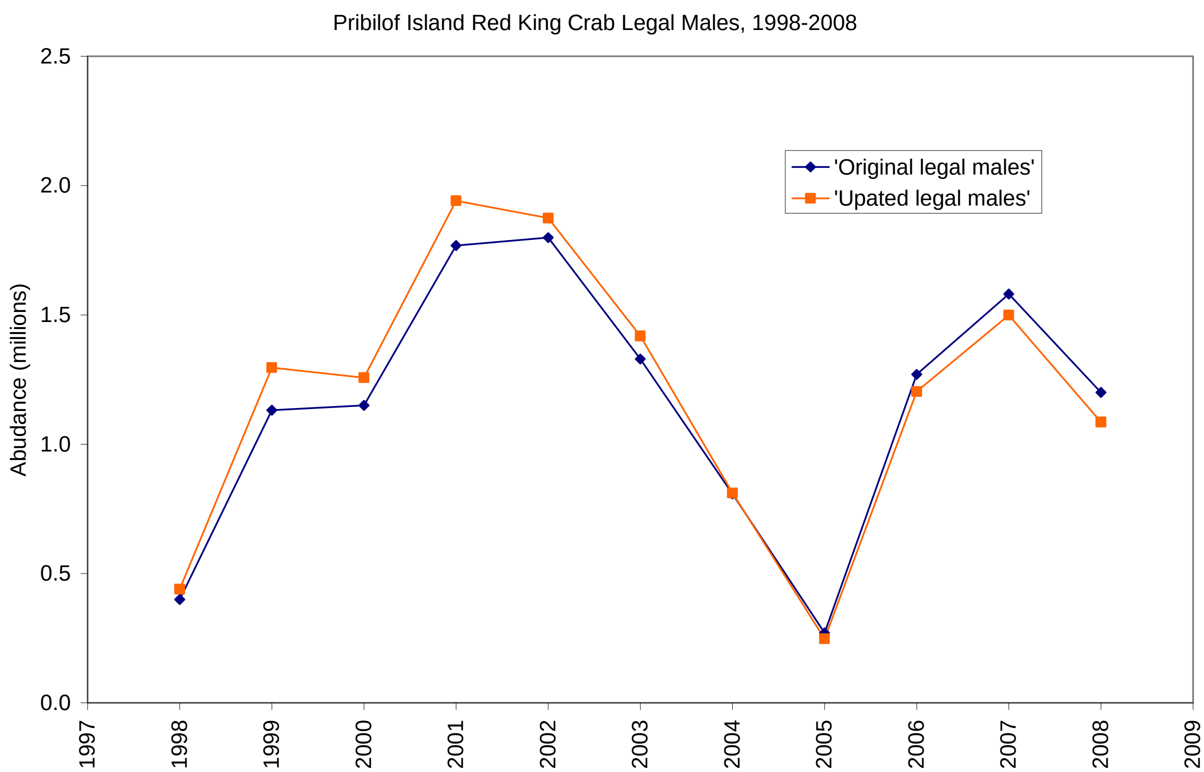

Figure 1. Comparison of entire time series of legal male red king crab in the Pribilof Islands.

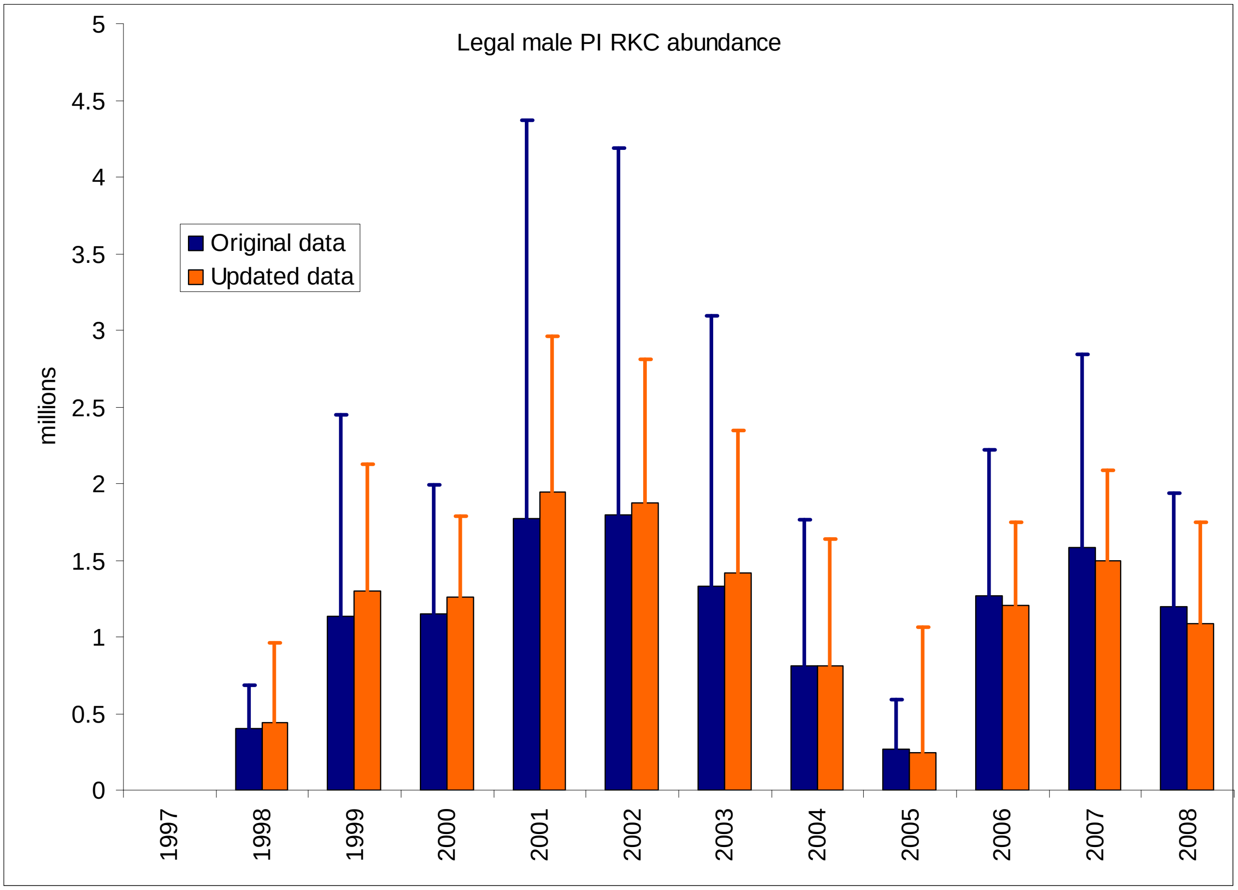

Figure 2. Original and revised abundance estimates and 95% confidence intervals for 1997 to 2008 time series of legal male red king crab in the Pribilof Islands.

2009 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Executive Summary

1. Stock: Pribilof Islands blue king crab, *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years to current levels near 0.001 million pounds.
3. Stock biomass: Stock biomass in recent years was decreasing between the 1995 and 2008 survey, however, there was an increase in most size classes in 2009.
4. Recruitment: Recruitment indices are not well understood for Pribilof blue king crab. Pre-recruit have remained relatively consistent in the past 10 years although may not be well assessed with the survey.
5. Management performance:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL
2006/07		0.34[A]	0	0	0.0004	
2007/08	4.64	0.67[B]	0	0	0.005	
2008/09	4.50	0.25[C]	0	0	0.001	0.004
2009/10		1.13[D]				0.004

All units are million pounds of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2008/09 and is hence overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2006 and updated with 2006/2007 catches
B – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
C – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
D – Based on survey data available to the Crab Plan Team in September 2009

6. Basis for 2009/2010 OFL projection:

Year	Tier	B_{MSY} 10^6 lbs	Current MMB_{mating} 10^6 lbs	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}
2009/10	4c	9.28	1.13	0.12	1.0	1980/1981-1984/1985 & 1990/1990-1997/1998	0.18

7. Rebuilding analyses results summary: The Pribilof Island blue king crab stock was declared overfished on September 23, 2002. The minimum required rebuilding time with 50% probability is 9 years (2011) and the maximum rebuilding time is 10 years (2012). As a result of not making adequate progress towards rebuilding a new rebuilding plan will be developed in 2009/2010.

Summary of Major Changes:

1. Management: There were no major changes to the 2008/2009 management of the fishery.
2. Input data: The new survey time series data incorporating data error fixes and variable net width calculations was used (Appendix 1). The new time series for groundfish discards incorporating new calculations for unmeasured crabs was used. The crab fishery retained and discard catch time series was updated with 2008/2009 data.
3. Assessment methodology: There were no changes to assessment methodology.
4. Assessment results: The projected MMB increased in this assessment but remained below the MSST. Therefore, the OFL remained low with no directed fishery. Total catch in 2008/2009 was 0.001 million pounds.

Responses to SSC and CPT Comments

SSC comments October 2008:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

none

Responses to CPT Comments: none

SSC comments June 2009:

General remarks pertinent to this assessment

- *As reiterated from our June 2008 report, "future stock assessments should provide analyses to support the choice of γ..." in Tier 4. Currently, analysts have used and the Crab Plan Team and the SSC have supported a value of 1 for γ in the calculation* $F_{OFL} = \gamma M$, *in which M is natural mortality, which results in a proxy for* F_{MSY}. *The SSC recommends that analysts provide rationale for the selection of γ=1. The value of 1 for γ is the default value used in Tier 5 for groundfish and should be conservative for crab stocks, since only the legal male component of the adult stock is harvested. However, analysis in the Environmental Assessment for Amendment 24 to revise overfishing definitions for crab showed that values of γ between 2 and 3 might be appropriate for* F_{msy} *estimation for some Bering Sea crab stocks. Therefore, it is desirable to investigate whether alternative approaches can be developed. Some suggestions for doing this will be forthcoming from the crab data weighting and stock assessment workshop held in Seattle during the May Crab Plan Team meeting. A report from that workshop will be available in time for the September Crab Plan Team meeting.*

- *The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number of years that are common across groups of species or areas.*

Specific remarks pertinent to this assessment

The SSC agrees with the Plan Team recommendation for management of Pribilof Islands Blue King Crab under Tier 4 with γ=1, M=0.18 using the 1980 -1984 and 1990-1997 *time periods to determine the average MMB as a proxy for B_{MSY}, estimated as 9.01 million pounds. The SSC appreciates seeing the written justification in the SAFE omission of the 1985-1989 period because it may not represent the productive potential of the current stock.*

This stock was declared overfished in 2002 and, even though there has not been any directed fishing since 1999, the stock has continued to decline and it is unlikely that it will be rebuilt by the end of the rebuilding plan 10 year horizon in 2012. Recognizing that a new rebuilding plan will be needed, and that additional protective measures could be taken, the SSC commends the Plan Team for considering 5 alternatives (listed in the September 2008 plan team minutes) to reduce bycatch of blue king crab, four of which pertained to closing areas to all targeted groundfish harvest or just to directed Pacific cod harvest, whereas the fifth was to modify pot gear for Pacific cod. If the Council initiates a review of these alternatives, the SSC requests that the analysts identify expected bycatch reductions that might be accrued. The SSC also encourages additional observer coverage as appropriate to improve monitoring of blue king crab bycatch. While the Plan Team suggested not considering item 5 above, the SSC suggests that use of a slick ramp for Pacific cod pots to make entry into a pot difficult for king crab could be considered.

In regards to a revised rebuilding plan, the SSC recommends that the time frame for estimation of B_{REFf} be reconsidered in terms of potential environmental changes that may have altered the potential productivity of the population. The SSC also requests that when a revised rebuilding plan is developed, it include an analysis examining information on stock separation from the St. Matthew Island blue king crab stock and the possibility of competitive or predation interactions with Pribilof Islands red king crab.

Responses to SSC Comments: The choice for gamma was discussed at the May 13-14, 2009 assessment workshop with guidance that will be used for the May 2010 assessment cycle. The discussion for specific shifts in recruitment has occurred briefly in previous meetings. This will be a focused topic in 2010. Options to include alternative for rebuilding plan bycatch reduction in the Pribilofs will be considered as additional rebuilding scenarios are developed. In addition the time period for B_{REF} will be reconsidered.

CPT comments September 2008:

General remarks pertinent to this assessment

- *The team agreed that assessment documents presented to September meetings should be the "track changes" version of the May assessment, to facilitate evaluating changes from that version.*
- *A checklist of the items which should be included in stock assessments on which OFL determinations are based should be developed. This checklist would include a table of survey estimates (and their associated CVs) by year. Having a standard approach to reporting assessment results will help the review process as well as how the work of the team is documented.*
- *Whenever possible survey estimates of abundance should be accompanied by measures of their precision because it is hard to assess model performance without this information.*

Specific remarks pertinent to this assessment

- *Analysis should cover changes in the Pacific cod pot fishery distribution in recent years.*

Responses to CPT Comments: Track changes were not used due to the volume of changes made to standardize this years assessments. Future assessments will use track changes. Standard format was used for this assessment. Confidence intervals were included for survey estimates. Bycatch was broken out by specific fishery information and pot fishery data was analyzed in more detail.

CPT comments May 2009:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The team agreed with the author's recommendation for the basis for the B_{msy} proxy as well as for the model parameters.

Responses to CPT Comments:

None

Introduction

1. **Blue king crabs,** *Paralithodes platypus*

2. **Distribution** - Blue king crab are anomurans in the family Lithodidae which also includes the red king crab (*Paralithodes camtschaticus*) and golden or brown king crab (*Lithodes aequispinus*) in Alaska. Blue king crabs occur off Hokkaido in Japan, with disjunct populations occurring in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are known from the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and the outer parts of Norton Sound. In the remainder of the Bering Sea, they are found in the waters off St. Matthew Island and the Pribilof Islands. In more southerly areas as far as southeastern Alaska in the Gulf of Alaska, blue king crabs are found in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). This disjunct, insular distribution of blue king crab relative to the similar but more broadly distributed red king crab is likely the result of post-glacial period increases in water temperature that have limited the distribution of this cold-water adapted species (Somerton 1985). Factors that may be directly responsible for limiting the distribution include the physiological requirements for reproduction, competition with the more warm-water adapted red king crab, exclusion by warm-water predators, or habitat requirements for settlement of larvae (Somerton 1985; Armstrong et al 1985, 1987).

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab were managed under the Bering Sea king crab Registration Area Q Pribilof District, which has as its southern boundary a line from 54° 36' N lat., 168° W long., to 54° 36' N lat., 171° W long., to 55° 30' N lat., 171° W. long., to 55° 30' N lat., 173° 30' E long., as its northern boundary the latitude of Cape Newenham (58° 39' N lat.), as its eastern boundary a line from 54° 36' N lat., 168° W long., to 58° 39' N lat., 168° W long., to Cape Newenham (58° 39' N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

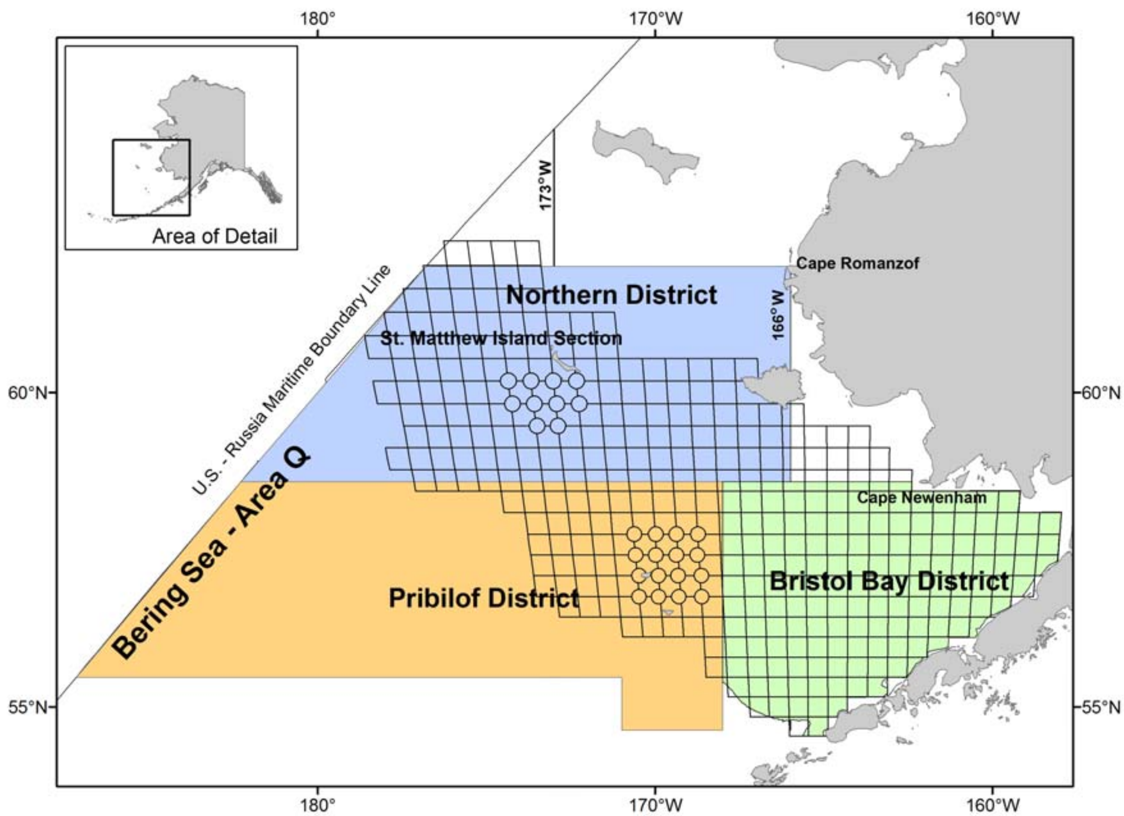

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

3. **Stock structure** - Stock structure of blue king crabs in the North Pacific is largely unknown.

4. **Life History** - Blue king crab are similar in size and appearance, except for color, to the more widespread red king crab, but are typically biennial spawners with lesser fecundity and somewhat larger sized (*ca.* 1.2 mm) eggs (Somerton and Macintosh 1983; 1985; Jensen et al. 1985; Jensen and Armstrong 1989; Selin and Fedotov 1996). Red king crab are annual spawners with relatively higher fecundity and smaller sized (*ca.* 1.0 mm) eggs. Blue king crab fecundity increases with size, from approximately 100,000 embryos for a 100-110 mm CL female to approximately 200,000 for a female >140-mm CL (Somerton and MacIntosh 1985). Blue king crab have a biennial ovarian cycle with embryos developing over a 12 or 13-month period depending on whether or not the female is primiparous or multiparous, respectively (Stevens 2006a). Armstrong et al. (1985, 1987), however, estimated the embryonic period for Pribilof blue king crab at 11-12 months, regardless of previous reproductive history and Somerton and MacIntosh (1985) placed development at 14-15 months. It may not be possible for large female blue king crabs to support the energy requirements for annual ovary development, growth, and egg extrusion due to limitations imposed by their habitat, such as poor quality or low abundance of food or reduced feeding activity due to cold water (Armstrong et al. 1987, Jensen and Armstrong 1989). Both the large size reached by Pribilof Islands blue king

crab and the generally high productivity of the Pribilof area, however, argue against such environmental constraints. Development of the fertilized embryos occurs in the egg cases attached to the pleopods beneath the abdomen of the female crab and hatching occurs February through April (Stevens 2006b). After larvae are released, large female Pribilof blue king crab will molt, mate, and extrude their clutches the following year in late March through mid April (Armstrong et al. 1987).

Female crabs require an average of 29 days to release larvae, and release an average of 110,033 larvae (Stevens 2006b). Larvae are pelagic and pass through four zoeal larval stages which last about 10 days each, with length of time being dependent on temperature; the colder the temperature the slower the development and vice versa (Stevens et al 2008). Stage I zoeae must find food within 60 hours as starvation reduces their ability to capture prey (Paul and Paul 1980) and successfully molt. Zoeae consume phytoplankton, the diatom *Thalassiosira* spp. in particular, and zooplankton. The fifth larval stage is the non-feeding (Stevens et al. 2008) and transitional glaucothoe stage in which the larvae take on the shape of a small crab but retain the ability to swim by using their extended abdomen as a tail. This is the stage at which the larvae searches for appropriate settling substrate, and once finding it, molts to the first juvenile stage and henceforth remains benthic. The larval stage is estimated to last for 2.5 to 4 months and larvae metamorphose and settle during July through early September (Armstrong et al. 1987, Stevens et al. 2008).

Blue king crab molt frequently as juveniles, growing a few mm in size with each molt. Unlike red king crab juveniles, blue king crab juveniles are not known to form pods. Female king crabs typically reach sexual maturity at approximately five years of age while males may reach maturity one year later, at six years of age (NPFMC 2003). Female size at 50% maturity for Pribilof blue king crab is estimated at 96-mm carapace length (CL) and size at maturity for males, as estimated from size of chela relative to CL, is estimated at 108-mm CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for those males larger than 100 mm CL (NOAA 2005).

Longevity is unknown for the species, due to the absence of hard parts retained through molts with which to age crabs. Estimates of 20 to 30 years in age have been suggested (Blau 1997). Natural mortality for male Pribilof blue king crabs has been estimated at 0.34-0.94 with a mean of 0.79 (Otto and Cummiskey 1990) and a range of 0.16 to 0.35 for Pribilof and St. Matthew Island stocks combined (Zheng et al. 1997). An annual natural mortality of 0.2 for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek at al 2002).

5. **Management history -** The king crab fishery in the Pribilof District began in 1973 with a reported catch of 1.3 million pounds by eight vessels (Figure 3). 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). Following 1995, declines in the stock resulted in a closure from 1999 to present. The Pribilof blue king crab stock was declared overfished in September of 2002 and the Alaska Department of Fish and Game developed a rebuilding harvest strategy as part of the North Pacific Fishery

Management Council's (NPFMC) comprehensive rebuilding plan for the stock. The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990, ADF&G 2008). The fishery was male only, and legal size was >16.5 cm carapace width (NOAA 1995). Guideline harvest level (GHL) was 10 percent of the abundance of mature male or 20 percent of the number of legal males (ADF&G 2006).

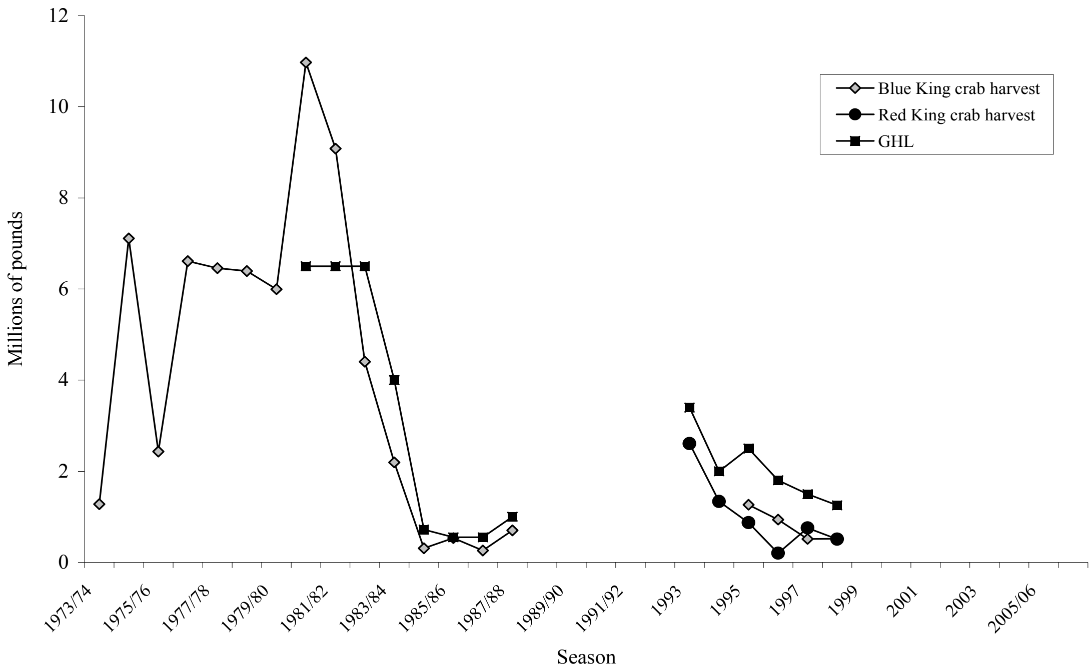

Figure 3. Historical harvests and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2007).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

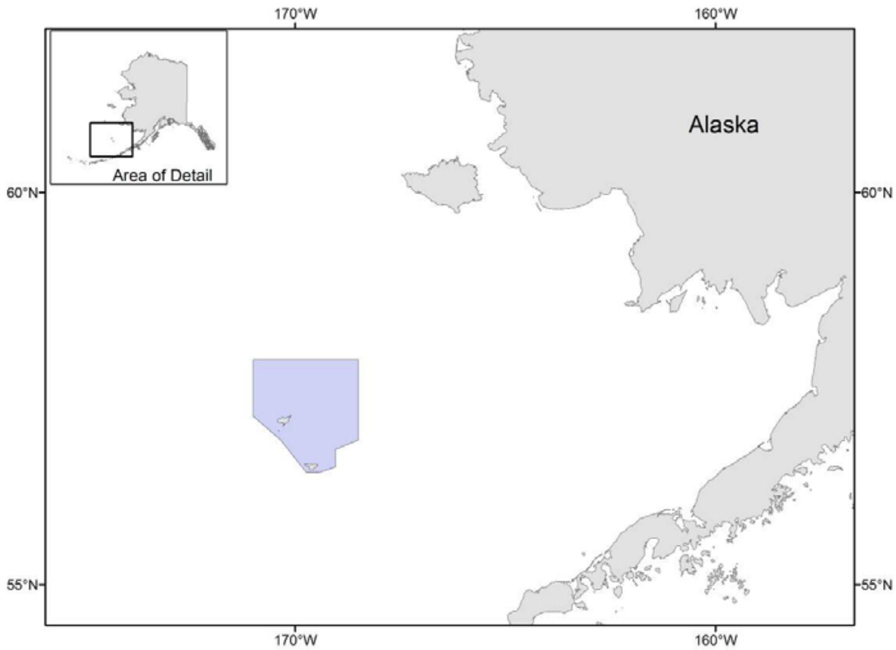

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area. Trawl fishing is prohibited year-round in this zone.

Blue king crab in the Pribilof District can occur as bycatch in the following crab fisheries: the eastern Bering Sea snow crab (*Chionocetes opilio*), the eastern Bering Sea Tanner crab (*chionocetes bairdi*), the Bering Sea hair crab (*Erimacrus isenbeckii*), and the Pribilof red and blue king crab. In addition blue king crab are bycatch in flatfish and Pacific cod fisheries.

Data

1. The new survey time series data incorporating data error fixes and variable net width calculations was used (Appendix 1). The new time series for groundfish discards incorporating new calculations for unmeasured crabs was used. The crab fishery retained and discard catch time series was updated with 2008/2009 data.

2. a. Total catch:
   <u>Crab pot fisheries</u>
   Retained pot fishery catches (live and deadloss landings data) are provided for 1973/1974 to 2008/2009 (Table 1), including the 1973/1974 to 1987/1988 and 1995/1996 to 1998/1999 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons blue king crab and red king crab were fished under the same GHL. There was no total allowable catch (TAC) and therefore zero retained catch in the 2008/2009 fishing season

Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2008; D. Pengilly, ADF&G, personal communications).

year	Total 10^6 lbs
1973/1974	1.28
1974/1975	7.11
1975/1976	2.43
1976/1977	6.61
1977/1978	6.46
1978/1979	6.40
1979/1980	6.00
1980/1981	10.97
1981/1982	9.08
1982/1983	4.41
1983/1984	2.19
1984/1985	0.31
1985/1986	0.53
1986/1987	0.26
1987/1988	0.70
1988/1989	0.00
1989/1990	0.00
1990/1991	0.00
1991/1992	0.00
1992/1993	0.00
1993/1994	0.00
1994/1995	0.00
1995/1996	1.38
1996/1997	0.94
1997/1998	0.51
1998/1999	0.52
1999/2000	0.00
2000/2001	0.00
2001/2002	0.00
2002/2003	0.00
2003/2004	0.00
2004/2005	0.00
2005/2006	0.00
2006/2007	0.00
2007/2008	0.00
2008/2009	0.00

b. Bycatch and discards:

Crab pot fisheries

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight (lbs) was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was calculated from length frequency tables where the CL (mm) was converted to g (see equation 3: males: A=0.000329, B=3.175; females: A=0.114389, B=1.9192), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 4).

$$\text{Weight (g)} = A * CL(mm)^B \qquad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \qquad (2)$$

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

Historical non-retained catch data are available from 1996/1997 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 3, Bowers et al. 2008) although data may be incomplete for some of these fisheries. Prior to 1998, limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here.

In 2008/2009, Pribilof blue king crab were not incidentally caught in any crab fishery (Table 2).

<u>Groundfish pot, trawl, and hook and line fisheries</u>
The 2008/2009 NMFS Alaska Region assessments of non-retained catch from all groundfish fisheries are included in this SAFE report (J. Mondragon, NMFS, personal communication). Groundfish catches of crab are reported for all males and females combined by federal reporting areas. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 2008 to June 2009. 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 2009 catches, sex ratios by size and sex from the 2009 EBS bottom trawl survey were applied. To assess crab mortalities in these groundfish fisheries a 50% handling mortality rate was applied to pot and hook and line estimates and an 80% handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been discriminated by each year's survey proportions (Table 2).

In 2008/2009, 0.001 million lbs of male and female blue king crab were caught in groundfish fisheries. The catch was mostly in non-pelagic trawls (77%) and longline (23%) fisheries. The targeted species in these fisheries were yellowfin sole (77%), and Pacific cod (23%).

Table 2. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District blue king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2008; D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Crab Pot Fisheries			Groundfish Fisheries	
	Legal non-retained 10^6 lbs	Sublegal male 10^6 lbs	All Female 10^6 lbs	All Pot 10^6 lbs	All Trawl 10^6 lbs
1991/1992	0	0	0	0.0001	0.0109
1992/1993	0	0	0	0.0010	0.1072
1993/1994	0	0	0	<0.0001	0.0604
1994/1995	0	0	0	<0.0001	0.0121
1995/1996	0	0	0	0.0001	0.0023
1996/1997	0	0.001	0	<0.0001	0.0001
1997/1998	0	0	0	0.0016	0.0002
1998/1999	0.003	0.001	0.004	0.0218	0.0001
1999/2000	0.004	0.005	0.002	0.0009	<0.0001
2000/2001	0	0	0	0.0001	<0.0001
2001/2002	0	0	0	0.0009	0.0001
2002/2003	0	0	0	0.0001	0.0005
2003/2004	0	0	0	0.0004	0.0004
2004/2005	0	0	0	0.0009	<0.0001
2005/2006	0	0	0.0001	0.0004	0.0024
2006/2007	0	0	0.0001	0.0002	0.0001
2007/2008	0	0	0.0001	0.0044	0.0002
2008/2009	0	0	0	0.0002	0.0008

c. Catch-at-length: NA

d. Survey biomass:
The 2009 NMFS EBS bottom trawl survey results (Chilton et al. in press) are included in this SAFE report (Table 3, Figure 5). Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock (Figure 6). Weight (equation 3) and maturity (equation 4) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass (million lbs).

$$\text{Weight (kg)} = 0.00047 * \text{CL(mm)}^{3.103}/1000 \quad (3)$$

$$\text{Proportion mature} = 1/(1 + (3.726 * 10^{15}) * e^{(\text{CL(mm)} * -0.332)} \quad (4)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 3).

Table 3. Pribilof Islands District blue king crab abundance, mature biomass, and legal male biomass (million lbs), and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature males @ survey 10^6 LB	Mature males @ mating 10^6 LB	Legal Males @ survey 10^6 LB	Total males @ survey 10^6 LB	Total females @ survey 10^6 LB	Total Crab @ survey 10^6 LB
1980/1981	32.63	17.97	28.00			
1981/1982	32.19	19.47	27.56			
1982/1983	16.95	10.63	14.57			
1983/1984	11.51	8.01	8.66			
1984/1985	4.92	4.05	3.97			
1985/1986	2.51	1.70	1.93			
1986/1987	2.84	2.26	2.80			
1987/1988	5.27	3.97	4.96			
1988/1989	1.40	1.24	1.39			
1989/1990	2.02	1.79	1.59			
1990/1991	6.17	5.47	2.29			
1991/1992	8.80	7.74	5.53			
1992/1993	9.17	8.05	5.51			
1993/1994	8.73	7.71	5.78			
1994/1995	6.24	5.53	4.63			
1995/1996	16.49	13.24	12.74			
1996/1997	9.94	7.88	7.63			
1997/1998	6.11	4.89	4.96			
1998/1999	6.75	5.46	5.45			
1999/2000	3.73	3.30	2.93			
2000/2001	4.14	3.67	3.37			
2001/2002	3.17	2.81	2.78			
2002/2003	1.36	1.20	1.29			
2003/2004	1.34	1.19	1.28			
2004/2005	0.29	0.26	0.11			
2005/2006	0.76	0.68	0.76			
2006/2007	0.39	0.34	0.28			
2007/2008	0.76	0.67	0.41	1.02	0.65	1.67
2008/2009	0.29	0.25	0.10	0.57	1.74	2.31
2009/2010	1.28	1.13	0.37	1.51	1.40	2.91

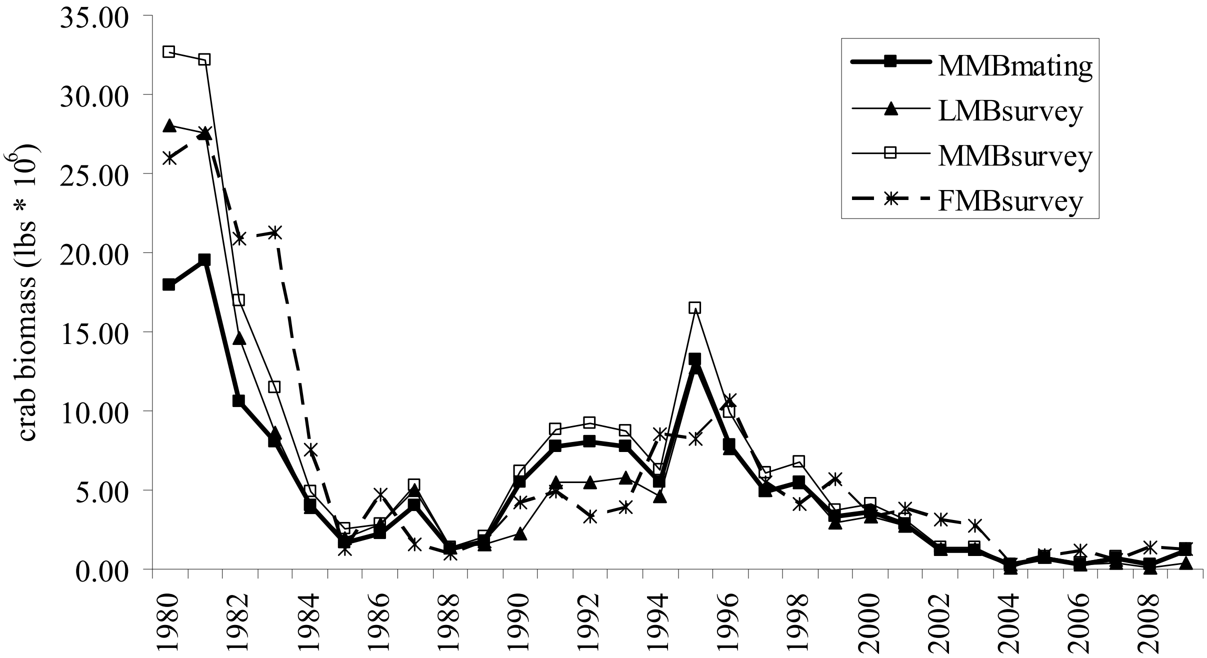

Figure 5. Historical trends of Pribilof Island blue king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

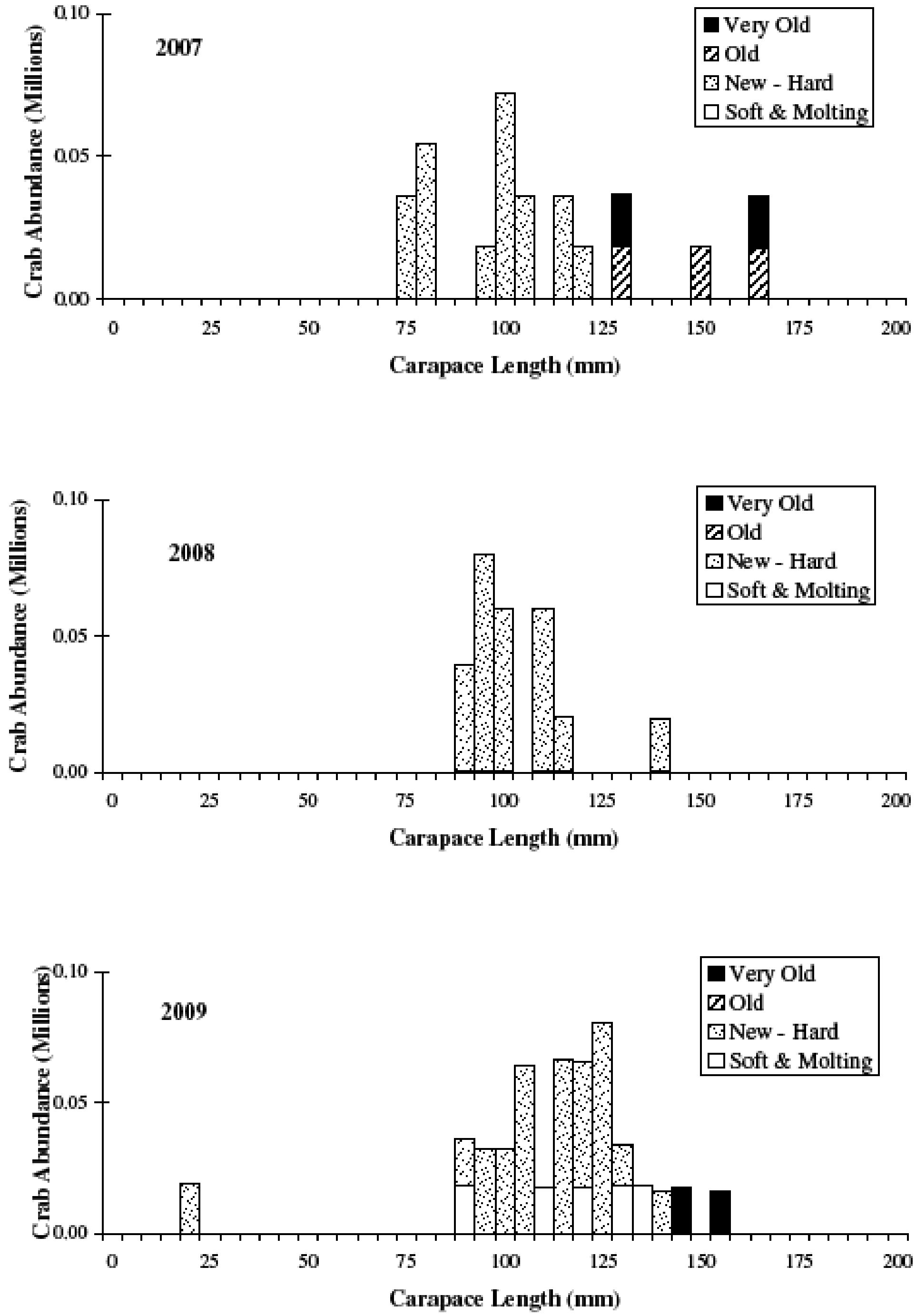

Figure 6. Distribution of Pribilof Island blue king crab in 5 mm length bins by shell condition for the last 3 surveys.

In 2009, Pribilof Island District blue king crab were observed in 6 of the 41 stations in the Pribilof District, all of which were in the high-density sampling area (Chilton et al. in press, Figure 7). Legal-sized males were caught at three stations east of St. Paul Island, with a density ranging from 73 to 131 crab/nmi^2. The 2009 abundance estimate of legal-sized males was 0.07 ± 0.08 million crab, representing 15% of the total male abundance and below the average of 0.56 million crab for the previous 20 years (Figure 8). Only 4 legal-sized male blue king crab were captured on the survey: one in molting or softshell condition and one in new hardshell condition, while two were in very oldshell condition. Large female blue king crab were caught at three stations in the Pribilof District with an abundance estimate of 0.6 ± 0.9 million crab representing 95% of the total female abundance. Fourteen of the 29 large female blue king crab sampled during the survey were brooding uneyed or eyed embryos. Among sampled mature females, 24% were new hardshell crab all with newly extruded embryos while 76% were oldshell females of which 24% were brooding eyed embryos and 52% had empty egg cases.

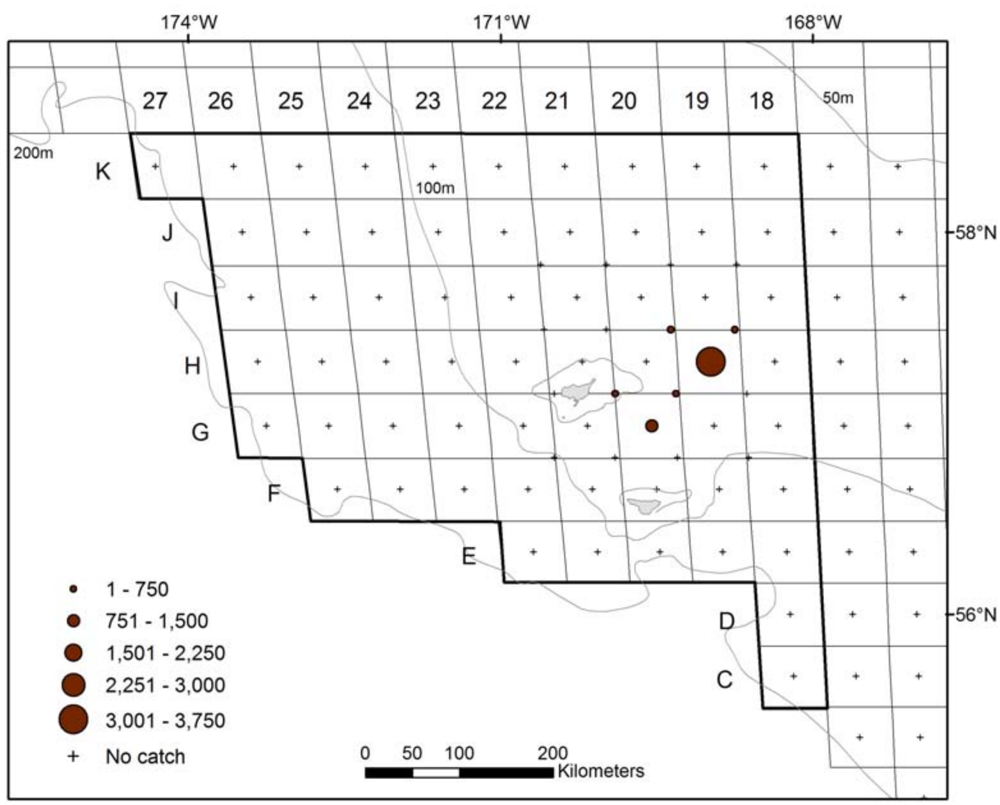

Figure 7. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2009 EBS bottom trawl survey.

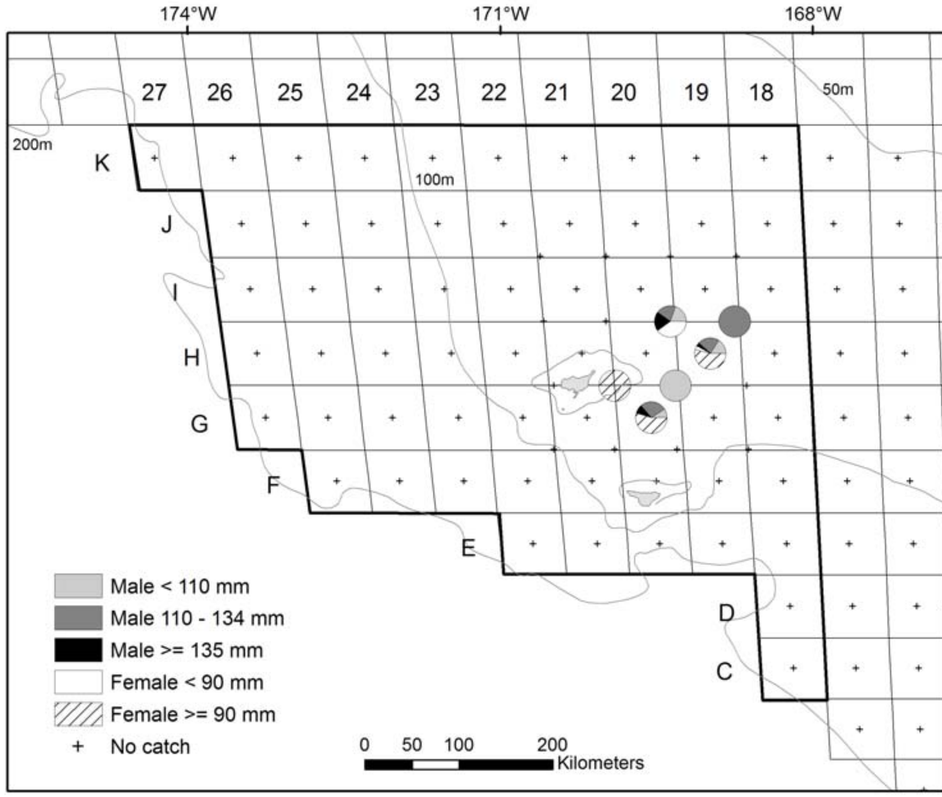

Figure 8. 2009 EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and is proposed for future consideration (Appendix 2).

Calculation of the OFL

1. Based on available data, the authors, the Crab Plan Team, and the Science and Statistical Committee all recommend that this stock should be classified as a Tier 4 stock for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008).

2. In Tier 4, MSY is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, and environmental conditions. In Tier 4, the fishing mortality that, if applied over the long-term, would result in MSY is approximated by F_{MSY}^{proxy}. The MSY stock size (B_{MSY}) is based on mature male biomass at mating (MMB_{mating}) which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of the complicated female crab life history, unknown

sex ratios, and male only fishery. The B_{MSY}^{proxy} represents the equilibrium stock biomass that provides maximum sustainable yield (MSY) to a fishery exploited at F_{MSY}^{proxy}. B_{MSY} can be estimated as the average biomass over a specified period that satisfies these conditions (i.e., equilibrium biomass yielding MSY by an applied F_{MSY}). This is also considered a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock. The current stock biomass reference point for status of stock determination is MMB_{mating}.

The mature stock biomass ratio β where $B/B_{MSY}^{prox} = 0.25$ represents the critical biomass threshold below which directed fishing mortality is set to zero (Figure 9). The parameter α determines the slope of the non-constant portion of the control rule line and was set to 0.1. Values for α and β where based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where B is greater than β includes the product of a scalar (**γ)** and M (equations 5 and 6) where the default **γ** value is 1 and M for Bering Sea blue king crab is 0.18. The value of **γ** may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, the F_{OFL} control rule resulting in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as 0.5 B_{MSY}^{prox}; if current MMB at the time of mating drops below MSST, the stock is considered to be overfished.

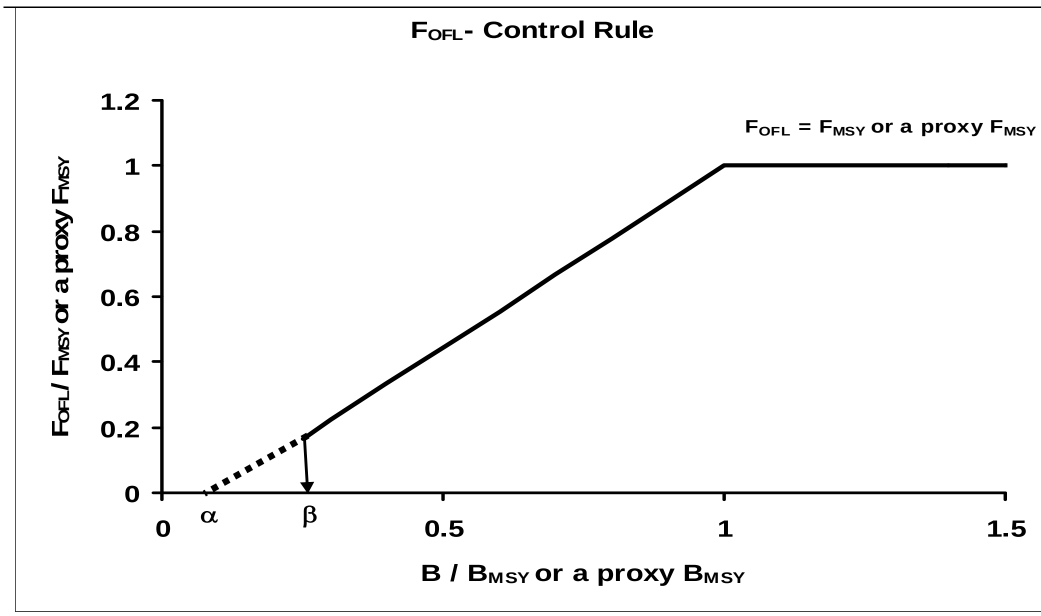

Figure 9. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

3. OFL specification:
a. In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT)

or F_{OFL} Control Rule (Figure 9) where Stock Status Level (level a, b or c; equations 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. $B/B_{MSY}^{prox} \leq \beta$	$F_{directed} = 0;\ F_{OFL} \leq F_{MSY}$	(7)

B_{MSY}^{prox} for the 2009 assessment was calculated as 1) the average MMB_{mating} from 1980 to 1984 and 1990 to 1997 to avoid time periods of low abundance possibly caused by high fishing pressure and 2) the average MMB_{mating} for the entire survey period 1980 to current.

b. The MMB_{Mating} projection is based on application of M from the 2009 NMFS trawl survey (July 15) to mating (February 15) and the removal of estimated retained, bycatch, and discarded catch mortality (equation 8). Catch mortalities are estimated from the proportion of catch mortalities in 2008/2009 to the 2009 survey biomass.

$$MMB_{Survey} \cdot e^{-PM(sm)} - \text{(projected legal male catch OFL)-(projected non-retained catch)} \quad (8)$$

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. PM(sm) is the partial M from the time of the survey to mating (8 months).

c. To project a total catch OFL for the upcoming crab fishing season, the F_{OFL} is estimated by an iterative solution that maximizes the projected F_{OFL} and projected catch based on the relationship of B to B_{MSY}^{prox}. B is approximated by MMB at mating (equation 8).

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.

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

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

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL
2006/07		0.34[A]	0	0	0.0004	
2007/08		0.67[B]	0	0	0.005	
2008/09	4.64	0.25[C]	0	0	0.001	0.004
2009/10		1.13[D]				0.004

All units are millions of crabs and the OFL is a total catch OFL for all years. The stock was below MSST in 2008/09 and is hence overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2006 and updated with 2006/2007 catches
B – Based on survey data available to the Crab Plan Team in September 2007 and updated with 2007/2008 catches
C – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
D – Based on survey data available to the Crab Plan Team in September 2009

4. Recommendations:
For 2009/2010, 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. $B_{MSY}{}^{prox}{}_2$=5.22 million lbs derived mean of 1980 to 2008 to assess the use of the entire time series. The stock demonstrated highly variable levels of MMB during both of these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

Male mature biomass at the time of mating for 2009/2010 is estimated at 1.13 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, [$B/B_{MSY}{}^{prox}{}_1$=0.12, F_{OFL}=0.00] and [$B/B_{MSY}{}^{prox}{}_2$=0.22, F_{OFL}=0.00]. For both biomass reference options $B/B_{MSY}{}^{prox}$ is < β, therefore the stock status level is c, $F_{directed} = 0$, and $F_{OFL} \leq F_{MSY}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008). The preferred alternative was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/2006 which was 0.004 million lbs. This period was after a targeted fishery and did not include the most recent 2006/2007 and 2007/2008 changes to the groundfish fishery that led to increased blue king crab bycatch. Appendix 3 is an alternative to calculate a total catch OFL using a surplus yield estimate for Pribilof Islands blue king crab revealing that losses to natural mortality (and any other losses not accounted for by the catch estimates) over the period considered in the analyses exceeded recruitment during this period.

Rebuilding Analyses

Under the current rebuilding plan, this stock has to recover to the B_{MSY} proxy in 2011/12 and 2012/13 to be defined as rebuilt. As the 2008/09 mature male biomass was smaller than B_{MSY} and has not shown signs of recovery in an adequate timeframe, the stock will likely fail to recover as planned. A new rebuilding plan will be needed for this stock. The development of a revised rebuilding plan should consider catches of blue crab in all other fisheries and the economic importance of these other fisheries to the Pribilof communities. Possible considerations in a new plan will be considered:

- Pribilof Islands Area Habitat Conservation Zone closed to all groundfish fishing.
- Pribilof Islands Area Habitat Conservation Zone closed to pot cod fishing.
- Analyze ADFG closure areas for all groundfish and just pot cod: 168°-170°W, south of 58° north to 57° latitude.
- Analyze new closure configurations which cover the entire distribution of the Pribilof Island blue king crab stock.
- Consider gear modifications to pot cod gear that could reduce bycatch of blue king crab. Specifically, the use of a slick ramp should be considered.

Ecosystem Considerations

1. Ecosystem effects on the stock

<u>Prey availability/abundance trends</u>

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).

<u>Predator population trends</u>

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).

<u>Changes in habitat quality</u>

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.

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).

2. Fishery Effects on the Ecosystem

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.

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.

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.

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.

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

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

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Appendix 1. Revised EBS trawl crab time series OFL calculations.

The EBS bottom trawl time series for crab has been revised from 1975 to 2008. Changes include error fixes and the inclusion of recalculated area swept estimates with net width estimated from net mensuration data instead of a fixed value. Thirty nine individual crab data points affecting abundance estimates at 19 stations were amended after transcription errors were found in the database. The error fixes resulted in minor survey catch count changes in 34 of the data points. Five fixes, however, resulted in increases or decreases in the survey catch count between 1000 and 2000 crabs. Using net width estimated from net mensuration data resulted in changes to all haul records from 1983 to 2008. The range of average net widths estimated in the revised time series was 14.9 to 17.4 m effectively increasing the area swept from a fixed net width of 15.3 m which was used previously. This revised time series was used for the 2008/2009 assessments for Pribilof Islands blue king crab.

The revision of the Pribilof Islands blue king crab time series of legal male abundance on the survey changed the original time series from 1 to 10% between 1975 and 2008 (Figure 1). Confidence intervals of survey mean abundance estimates were lower with the revised time series than with the original data (Figure 2). Confidence intervals were calculated by initially measuring variance within each size grouping (ie. legal males) as opposed to within each 5 mm length bin. The effects of the survey time series revision on the 2008 assessment results included a reduction of the B_{MSY}^{proxy} from 9.28 to 9.01 million lbs of MMB_{mating} and a reduction of 2009/2010 projected MMB_{mating} from 0.25 to 0.24 million lbs.

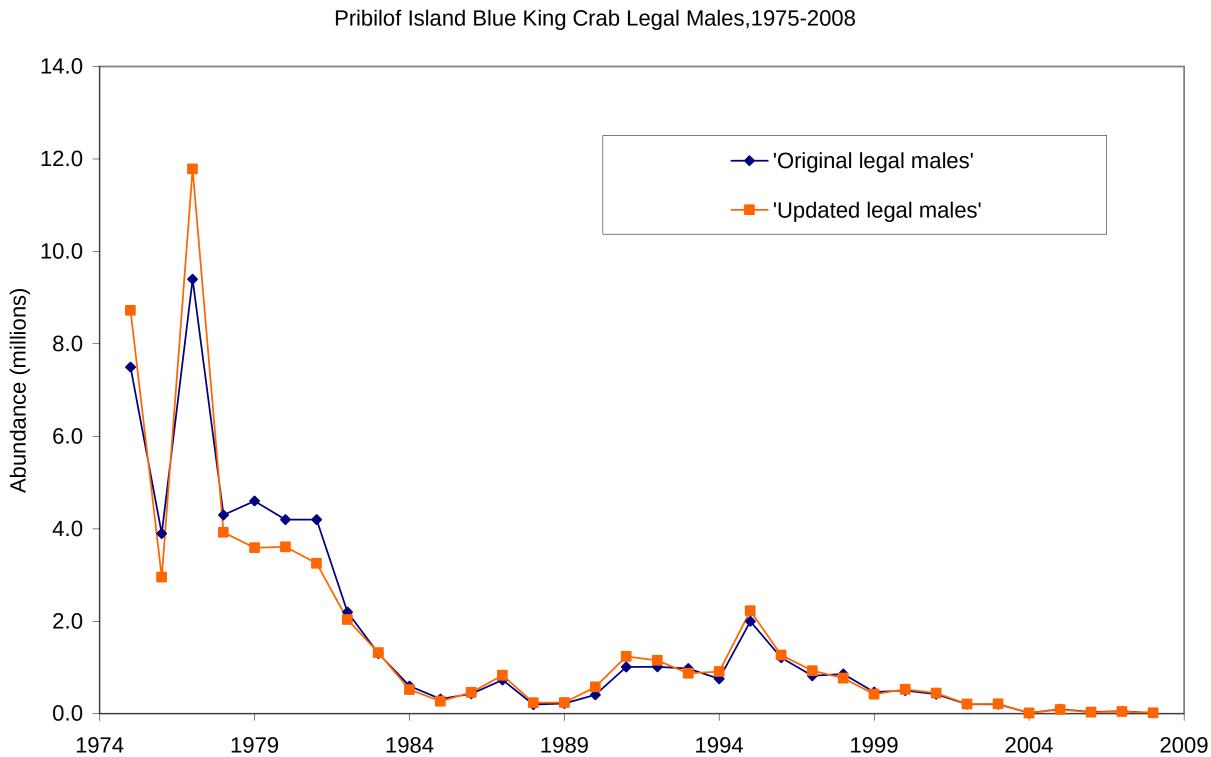

Figure 1. Comparison of entire time series of legal male blue king crab in the Pribilof Islands.

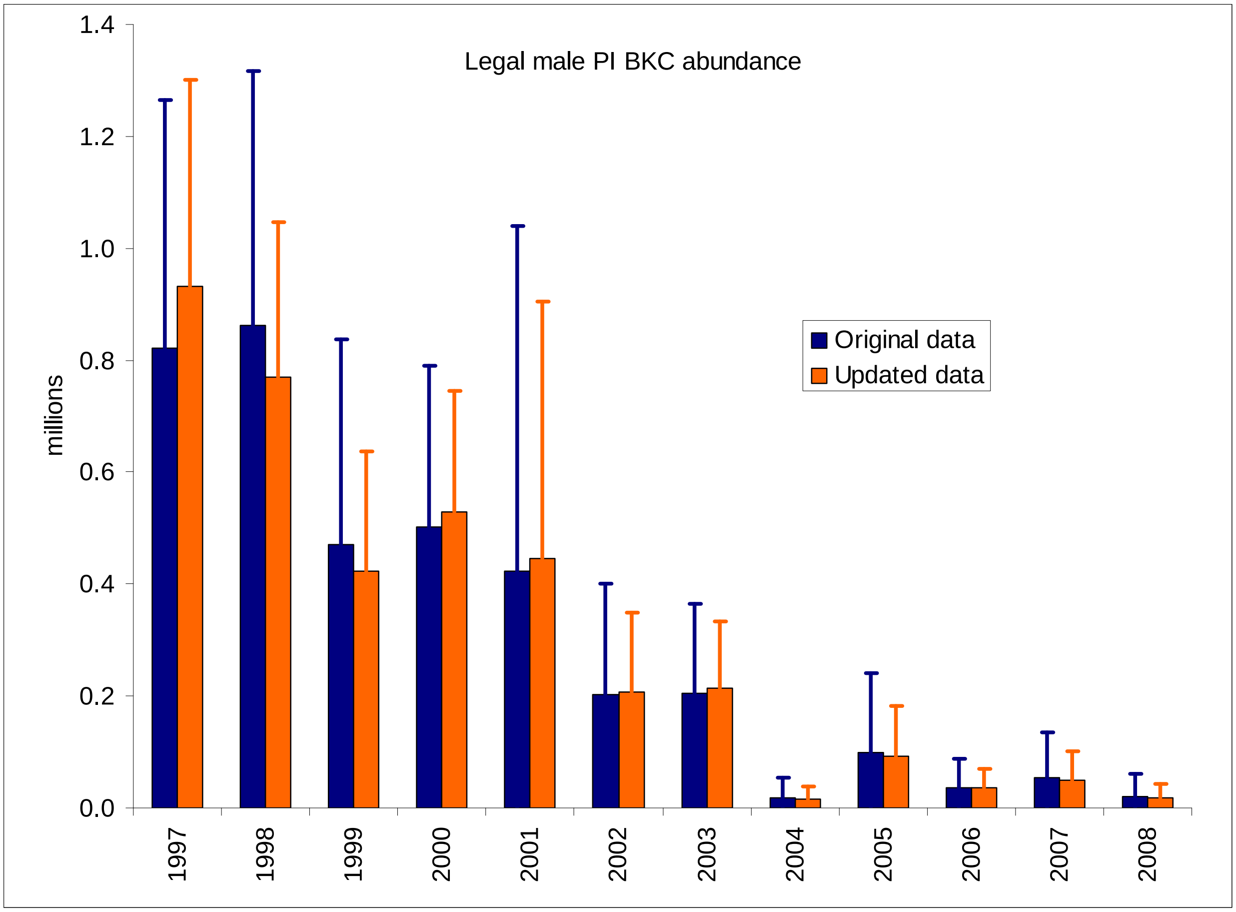

Figure 2. Original and revised abundance estimates and 95% confidence intervals for 1997 to 2008 time series of legal male blue king crab in the Pribilof Islands.

Appendix 2. Proposed Catch Survey Model for Pribilof Island king crab

The following model development is based on ADF&G CSA models currently employed to assess St. Matthew Island blue king crab and Pribilof Islands king crab for TAC setting. The methods to be used to analyze the model will be similar to those currently in review for St. Matthew blue king crab (Zheng, Pengilly, Foy, and Barnard. in review. Stock assessment model evaluation for St. Matthew blue king crab. 2009 Wakefield Symposium)

Input data will include NMFS EBS bottom trawl time series, ADF&G triennial pot survey time series, and commercial catches in number and weight and CPUE for the directed fishery.

Model development

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. 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 will be divided into four groups: prerecruit-2s (*P*2), prerecruit-1s (*P*1), recruits (*R*), and postrecruits (*P*).

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:

$$P2_t^b = P2_t\{1-[h\,H2^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},$$
$$P1_t^b = P1_t\{1-[h\,H1^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},$$
$$P2_{t+1} = P2_t^b[(1-m2_t)+m2_t\,G_{P2,P2}]e^{-M_t}+N_{t+1},$$
$$P1_{t+1} = \{P1_t^b[(1-m1_t)+m1_t\,G_{P1,P1}]+P2_t^b\,m2_t\,G_{P2,P1}\}e^{-M_t},$$
$$R_{t+1} = (P2_t^b\,m2_t\,G_{P2,R}+P1_t^b\,m1_t\,G_{P1,R})\,e^{-M_t},$$
$$P_{t+1} = (P_t+R_t+P2_t^b\,m2_t\,G_{P2,P}+P1_t^b\,m1_t\,G_{P1,P})\,e^{-M_t}-C_t\,e^{(y_t-1)M_t}, \quad (1)$$

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.

Molting probability for prerecruit-1s, $m1_t$, will be modeled 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.

Multiple scenarios will be developed for Pribilof Island king crab depending on parameters estimated independently and conditionally. These scenarios will consider combinations of fixing M and Q versus estimating each conditionally.

Parameter Estimation

Estimated parameters include natural mortality, molting probabilities, catchabilities, selectivities, crab entering the model for the first time each year except the first, and total abundance in the first year. Depending on the model scenario, *M* and *Q* may be estimated conditionally. When Q is not estimated, it is fixed to be 1. If *M* is not estimated, *M* is assumed to be 0.18 in this study, based on a maximum age of 25 and the 1% rule (Zheng 2005). Measurement errors of survey estimates of relative abundances will be assumed to follow a lognormal distribution. Parameters of the model will be estimated using a maximum likelihood approach:

$$\begin{aligned} Ln(L) = -\sum_t \{&[\ln(P2_t QS2+1) - \ln(p2_t+1)]^2 / (2\ln(CV^2_{p2,t}+1)) \\ &+ [\ln(P1_t QS1+1) - \ln(p1_t+1)]^2 / (2\ln(CV^2_{p1,t}+1)) \\ &+ [\ln(R_t Q+1) - \ln(r_t+1)]^2 / (2\ln(CV^2_{r,t}+1)) \\ &+ [\ln(P_t Q+1) - \ln(p_t+1)]^2 / (2\ln(CV^2_{p,t}+1)) \\ &+ [\ln(P2_t s2/q+1) - \ln(ip2_t+1)]^2 / (2\ln(CV^2_{ip2,t}+1)) \\ &+ [\ln(P1_t s1/q+1) - \ln(ip1_t+1)]^2 / (2\ln(CV^2_{ip1,t}+1)) \\ &+ [\ln(R_t/q+1) - \ln(ir_t+1)]^2 / (2\ln(CV^2_{ir,t}+1)) \\ &+ [\ln(P_t/q+1) - \ln(ip_t+1)]^2 / (2\ln(CV^2_{ip,t}+1)) + 10\eta_t^2\}, \end{aligned} \quad (3)$$

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*; *CV* is coefficient of variance for the survey abundance; *S*2 and *S*1 are trawl survey selectivities for prerecruit-2s and prerecruit-1s; *Q* is a trawl survey catchability, *s*2 and *s*1 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), parameters using the quasi-Newton method will be estimated to minimize –Ln(L).

Based on CPT input, further model development and testing will occur for review for the 2010-2011 assessment cycle. This will include investigating of multiple weighting factors for the trawl vs pot surveys due to the high CVs of the trawl survey.

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

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

Appendix 3. Surplus Yield Estimate for Pribilof Islands Blue King Crab (A. Punt, personal communication)

The dynamics of mature males can be modeled using the following equation, under the assumption of constant recruitment:

$$B_{t+1} = B_t + P_t - C_t \quad (1)$$

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

P_t is the production to the mature male biomass considering additions from recruitment and growth less losses to natural mortality.

Surplus production (SP) is $P_t - C_t$. 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) production can be estimated as:

$$\hat{P} = \overline{(B_{t+1} - B_t)} + \overline{C}_t \quad (2)$$

Application of Equation 2 results in an estimate of -0.43 million lbs, i.e. the average total stock losses from catch (retained plus non-retained) and natural mortality over the period considered in the analyses exceeded additions to the stock from growth and recruitment. Note that this estimate will be positively biased because the catches in Table 1 include, *inter alia* females. This indicates that total catches exceeded surplus production on average over this time period.

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 2009

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Executive Summary

A catch-survey analysis was updated with trawl survey data from 1978 to 2009, triennial pot survey data from 1995 to 2007, and commercial catch data from 1978 to 2008 to assess St. Matthew Island blue king crab abundance in 2009. A maximum likelihood approach was used to estimate abundance and recruitment. Five scenarios of the model were evaluated. Scenario (1) fixed natural mortality (*M*=0.18) for both 1978-1998 and 2000-2009 and fixed trawl survey catchability (*Q*=1) with estimating *M* in 1999; scenario (2) fixed *Q* = 1 and estimated two *M* values (one for 1978-1998, 2000-2009 and one for 1999); scenario (3) fixed *M*=0.18 for 1978-1998 and 2000-2009 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. Scenario (2) resulted in the lowest negative likelihood value, and scenario (4) had the highest negative likelihood (Table 6). The Chi-Square test was used to compare scenarios with different number of degrees of freedom. Overall, scenario (2) fit the data best, followed by scenario (3), (1), (5) and (4). All scenarios indicate an increasing recruitment, abundance and biomass since 1999, and estimated legal abundance and mature male biomass in 2009 were the highest values since 1999.

Estimated legal abundance and mature male biomass in 2009 are:

	Scenario (1)	Scenario (2)
Legal males:	2,606,310 crab or 9.584 million lbs,	2,426,980 crab or 8.450 million lbs

Mature male biomass (γ= 1): 12.470 million lbs 10.824 million lbs.

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
Based on average during 1978-2009:	8.273 million lbs	8.629 million lbs
Based on average during 1983-1998:	8.140 million lbs	8.690 million lbs
Based on average during 1983-2009:	7.187 million lbs	7.340 million lbs
Based on average during 1989-2009:	7.987 million lbs	8.041 million lbs

Estimated F_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
M	0.18	0.362
γ= 1:	0.180	0.362
Retained OFL:	1.532 million lbs	2.429 million lbs
Total male OFL (pot):	1.723 million lbs	2.954 million lbs

Estimated mature male biomass from either scenario in 2009 was above any of the suggested B_{MSY} proxies. The CPT suggested a period of 1989-2009, γ= 1 and scenario (1) for the 2009 OFL determination. The stock is estimated to have been above the *Bmsy* proxy for two years and is now a candidate for being considered rebuilt from overfishing status. The directed fishery has been closed since 1999.

Summary of Major Changes in 2009

1. Areas-swept for the NMFS surveys have been re-estimated and trawl survey abundances have been re-estimated, which are generally lower than previous assessments.
2. Survey CVs were used to compute likelihood values.
3. The Chi-Square test was used to compare five different scenarios.
4. Sensitivity study for weights on pot survey index was added.
5. Sensitivity study for weights on changes in molting probability was added.
6. Survey CVs were added to a table and the confidence intervals were plotted with the estimated abundances.
7. Pot bycatch was estimated and included in the OFL.
8. Total number of parameters for each scenario was added to a Table.

Response to CPT Comments (from September 2008)

"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)]."

First, five scenarios, including a constant *M*, were compared and tested. Second, CVs were used to compute likelihoods so no lambda is needed. Third, the lead assessment author had difficulty getting trawl bycatch observer data from Alaska Fishery Science Center, so no trawl bycatch was included in the model for this report. Once a complete bycatch dataset are obtained, the model can include it easily. Fourth, both trawl and pot survey data and fits are plotted. Finally, there are not enough data to fit the current model with pot survey data alone.

Response to CPT Comments (from May 2009)

"1) The model should continue to be refined for review at the May 2010 CPT meeting to allow this stock to be considered for Tier 3. 2) Bycatch data in all fisheries must be compiled to generate a total catch OFL. Note this MUST be done for the September 2009 assessment for a total catch OFL in the 2009/10 fishery. 3) Confidence intervals are needed on model output as well as CVs for survey data. The assessment needs to include figures showing data and fits to these data for both pot and trawl surveys including confidence intervals on data and model results. 4) The assessment should also examine the sensitivity of the weighting choices employed in the model to examine relative influence on results [e.g. conducting the assessment using each of the two indices of abundance in turn (pot and trawl survey)]. New recommendations include the following. 5) Include separate likelihood components for the total number of crab and the breakdown to size-class to address lack of independence in the residuals evident in the bubble

plots. 6) Report the number of parameters used in each of the model scenarios. 7) Justify how changes in molting probability affect model results. 8) Use the existing model and conduct a simulation to determine how the stock would, hypothetically, respond to fishing at the proxy for Fmsy as an exercise to inform Bmsy."

See the **Summary of Major Changes.** Most of the recommendations have been addressed in this report. The remaining items (2, 5 and 8) may be addressed in the May 2010 report.

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

"For the upcoming assessment cycle, and in concurrence with the CPT, the SSC would like the author to explore alternative models in which M is held constant and the anomaly in 1999 is handled differently. The 1999 data point may be the result of the combination of low temperatures and an early survey in that year. Some other stocks appear to show the same 1999 anomaly."

Five alternative scenarios (models) have been evaluated in this report. These scenarios include a constant *M* as well as treating the *M* in 1999 differently. The sharp drop in 1999 is not a sampling error caused by low temperatures or an early survey. If it were a sampling error, the survey abundance should have gone up during the following surveys during 2000-2008. The crabs disappearing in 1999 were not seen again during the following surveys. Low temperatures have not consistently been related to high *M* for crab stocks.

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

"In summary, these are: (1) towards possible future Tier 3 designation, continue model refinements for review at the May 2010 Crab Plan Team meeting; (2) include bycatch in the estimation model, so that a total male catch OFL can be estimated and, ultimately, total male and female catch OFL; (3) include confidence intervals on model output and CVs for surveys; (4) examine the sensitivity of weighting choices; (5) include separate likelihood components for total number of crab and breakdown to size classes; (6) report the number of parameters for each model scenario; (7) justify how changes in molting probability affect model results; and (8) run the model to determine how the stock might respond at a F_{MSY} *proxy to inform* B_{MSY}*."*

See the **Summary of Major Changes.** Most of recommendations have been addressed in this report. The remaining items (2, 5 and 8) may be addressed in the May 2010 report.

Introduction

Blue king crab, *Paralithodes platypus* (Brant 1850), are sporadically distributed throughout their range in the North Pacific Ocean from Hokkaido, Japan to southeastern Alaska. In the eastern Bering Sea, small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in cold water areas of the Gulf of Alaska at Olga Bay- Kodiak Island and at Port Wells- Prince William Sound, Russell Fjord, Glacier Bay, Lynn Canal, and Endicott Arm- Southeast Alaska (Figure 1) (Somerton 1985). Adult blue king crab are found at depths less than 180 meters and in average bottom water temperatures of 0.6° C (NPFMC 1998). The St. Matthew Island Section for blue king crab is within the Northern District of the Bering Sea king crab registration area (Area Q2) and includes the waters north of the latitude of Cape Newenham (58°39' N. lat.) and south of the latitude of Cape Romanzof (61°49' N. lat.) (Figure 2) (Bowers et al. 2008).

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof Islands based on a limited number of variable genetic markers using allozyme electrophoresis methods (1997, NOAA grant Bering Sea Crab Research II, NA16FN2621). Tag return data from studies by the National Marine Fisheries Service (NMFS) on blue king crab in the Pribilof Islands (n = 317) and St. Matthew Island (n = 253) support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). These two stocks are managed separately based on different life history characteristics and exploitation by the fishery.

Catch History

Fisheries

The St. Matthew Island fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (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 a harvest strategy established in regulation by the Alaska Board of Fisheries and area closures to control bycatch as well as gear modifications and an area closure for habitat protection. Since 1999, the abundance estimates calculated from the National Marine Fisheries Service (NMFS) annual eastern Bering Sea shelf survey data have not met the rebuilding plan's harvest strategy threshold or minimum TAC, although 2006 and 2007 abundance estimates, 11.2 and 15.6 million pounds respectively, were above MSST and the stock is considered rebuilding (Bowers et al. 2008). 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 were scheduled in the fall and early winter to reduce the potential for bycatch from handling mortalities due to molting and mating crabs. Some bycatch has been observed of non-retained St. Matthew blue king crab in both the St. Matthew blue king crab fishery and the eastern Bering Sea snow crab fishery. The St. Matthew Island golden king crab fishery, the third commercial crab fishery in that area, is executed in areas with depths deeper than blue king crab distribution. Discard mortality rates have been established by the NPFMC (1999) as either species or fishery specific. Bycatch mortality rates for all crab species were set at 80% in trawl fisheries, 40% in dredge fisheries, 20% in fixed gear fisheries, and 8% in king crab pot fisheries (NPFMC 2006). A higher bycatch mortality rate for the directed pot fishery was used for development of the current ADF&G harvest strategy, and we assumed the directed crab fishery mortality rate to be 20% for blue king crab in this report.

Harvest Strategy

Subject to the federal overfishing limits, the current TAC is determined based on the state harvest strategy (**5 AAC 34.917**), which was adopted by the BOF in March 2000 as part of a rebuilding plan developed for the stock (NPFMC 2000). 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 guideline 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 (including deadloss) were used in the catch-survey analysis.

Trawl Survey Data

NMFS has conducted annual summer trawl surveys of St. Matthew Island blue king crab since 1978. The survey stations used to assess the St. Matthew Island blue king crab stock are located within the St. Matthew Island Section of the ADF&G Northern District. From 1978 to 1982 40 stations centered in 20 X 20 nm (37.04 X 37.04 km) cells were sampled in a total area of 16,040 nm^2. From 1983 to 2009, 2 strata were identified with low and high density of stations. The low-density strata consisted of 28 stations within a 11,228 nm^2 area and the high density strata consisted of 29 stations in a 7,619 nm^2 area. Total area calculations for each stock management unit uses an area of 401 nm^2 for each 20 X 20 nm cell due to a spherical projection of the grid surface in an area as large as the EBS.

The fishing gear used from 1978 to 1980 was a 400-mesh Eastern otter trawl with an effective path width of 12.19 m, and in 1981 was an 83-112 trawl towed by the R/V *Chapman* with an effective path width of 18 m. From 1982 to 2009 a standardized 83-112 Eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope (Acuna and Lauth 2008) was used and net width was measured from net mensuration equipment during each tow. Each tow was approximately 0.5 h in duration and 1.5 nm (2.8 km) in length at a speed of 3 knots (1.54 m/sec) (Stauffer 2004). Fishing power was assumed to be equal between vessels if more than one vessel was used.

Crab density (number/nm^2) was estimated at each station for pre-recruit 1 (105-119 mm CL), pre-recruit 2 (90-104 mm CL), recruit (newshell 120-133 mm CL), and post recruit (oldshell ≥120 mm CL and newshell ≥134 mm CL) males. The area swept by the trawl was calculated as the product of the distance traveled while the net had bottom contact by the effective width. Distance traveled by the trawl was determined from ship positions recorded at the beginning and end of each tow using LORAN or GPS equipment. Total crab population abundance within the St. Matthew Island Section management unit was estimated by averaging crab densities among all stations, multiplying by the total area of the strata, and then adding strata within the management unit. Variance was estimated by summing the estimated variances for individual strata weighted by squared area of each stratum in each year. Stage-specific area-swept survey abundance estimates that were entered into the catch-survey model are summarized in Table 3 and Figure 4.

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 5, 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 6, 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 7). 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 8). 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 9). 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 (1)-(3). For scenarios with a fixed natural mortality value, it was estimated with a maximum age of 25 and the 1% rule (Zheng 2005).

(2) Survey selectivities are a function of stage and are constant over time.

(3) Growth is a function of stage and does not change over time.

(4) Molting probability is a function of stage and changes over time with a random walk process.

(5) A fishing season for the directed fishery is short.

(6) Handling mortality was assumed to be 0.2 and bycatch selectivities were assumed to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s, which are similar to bycatch selectivities estimated for Bristol Bay red king crab (Zheng and Siddeek 2008).

(7) 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) Area-swept estimates of 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 the CSA because the analysis requires commercial catch data and only males may be retained by the fishery. Male crab abundance was divided into four groups: prerecruit-2s (*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 in the same stage or become postrecruits. The model links the crab abundances in four stages in year $t+1$ to the abundances and catch in the previous year through natural mortality, molting probability, and the growth matrix:

$$
\begin{aligned}
&P2_t^b = P2_t\{1-[h\,H2^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
&P1_t^b = P1_t\{1-[h\,H1^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
&P2_{t+1} = P2_t^b[(1-m2_t)+m2_t\,G_{P2,P2}]e^{-M_t}+N_{t+1},\\
&P1_{t+1} = \{P1_t^b[(1-m1_t)+m1_t\,G_{P1,P1}]+P2_t^b\,m2_t\,G_{P2,P1}\}e^{-M_t},\\
&R_{t+1} = (P2_t^b\,m2_t\,G_{P2,R}+P1_t^b\,m1_t\,G_{P1,R})\,e^{-M_t},\\
&P_{t+1} = (P_t+R_t+P2_t^b\,m2_t\,G_{P2,P}+P1_t^b\,m1_t\,G_{P1,P})\,e^{-M_t}-C_t\,e^{(y_t-1)M_t},
\end{aligned}
\qquad (1)
$$

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:

$$m1_{t+1} = m1_t e^{\eta_t}, \qquad (2)$$

where η_t are independent, normally distributed random variables with a mean of zero. This allows us to model the changes in molting probability under a constraint condition.

Parameters Estimated Independently

Five scenarios of the model were developed for St. Matthew Island blue king crab, depending on parameters estimated independently and conditionally. In scenarios (1) and (4), both *M* for 1978-1998 and 2000-2009 and *Q* were fixed (estimated independently) and *M* for 1999 was independently estimated for scenario (1) and fixed for scenario (4); in model scenarios (2) and (5), *M* was estimated conditionally whereas *Q* was fixed and *M* was constant for the whole time series for scenario (5) and a different *M* value was independently estimated for 1999 for scenario (2); and in model scenario (3), *Q* was estimated conditionally and *M* was fixed for 1978-1998 and 2000-2009 and estimated for 1999:

	Scenario				
	(1)	(2)	(3)	(4)	(5)
M for 1978-1998, 2000-2009	0.18	Estimate	0.18	0.18	Estimate
M for 1999	Estimate	Estimate	Estimate	0.18	Same as above
Q	1.0	1.0	Estimate	1.0	1.0

The independently-estimated *Q* is 1. To reduce the number of parameters estimated, we used the ratio (1.44) of *m*1 to *m*2 from tagging data to estimate *m*2 from *m*1. The growth matrix was estimated from tagging data (Table 5; Otto and Cummiskey 1990). We assumed that the relative frequencies of length groups from the first-year trawl survey data approximate the true relative frequencies. Thus, we did not need to conditionally estimate length-specific abundance for the first year. Handling mortality rate was assumed to be 0.2, and to be 0.0 and 0.5 in a sensitivity study. Observer coverage was very limited for the directed fishery, and only 1-3 out of 90-131 vessels were covered from 1995 to 1998 (Moore et al. 2000). Due to limited observer data, fishery selectivities of pre-recruits 2 and 1 in the directed pot fishery were assumed to be 0.4 and 0.6 relative to legal crab, respectively, based on the results of the Bristol Bay red king crab stock assessment (Zheng and Siddeek 2008).

Natural Mortality

The estimate of natural mortality for all species of king crab in the eastern Bering Sea is 0.2 as defined by the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). Siddeek et al. (2002) reexamined tagging experiments conducted around St. Matthew Island in 1995 and 1998 to estimate natural mortality (*M*). Based on a multinomial likelihood *M* estimator using returned tag data, values of *Z* (annual instantaneous total mortality) for both male and female blue king crab ranged from 0.65 to 0.74 assuming that *M* and SR (initial tagging survival/recapture ratio) did not vary by sex. Using the combined sexes returned tag data (80-157 mm CL) from the 1995 tagging experiment, the mean estimate of *M* = 0.19. One other natural mortality estimate has been reported for St. Matthew Island blue king crab based on tagging data. Values ranged from 0.19 to 2.04 with a mean estimate of 0.81 for adult male blue king crab (105-139 mm CL) (Otto and Cummiskey 1990).

The independently-estimated *M* is 0.18 in this report, based on a maximum age of 25 and the 1% rule (Zheng 2005).

Length-weight Relationships

Based on 136 samples collected in 1978 to 1981 from St. Matthew Island (Somerton and MacIntosh 1983b), the carapace length (mm)-weight (g) relationship for blue king crab males (range = 59-147 mm) is described by the equation:

$$W = 0.000329 * CL^{3.175}, \quad (3)$$

Somerton and MacIntosh (1983b) compared the carapace size-weight relationship of blue king crab males collected in the Bering Sea and found no statistical difference between St. Matthew Island and the Pribilof Islands stocks. Recent samples collected from both the Pribilof Islands and St. Matthew Island area in 2006 and 2007 on the annual AFSC eastern Bering Sea shelf trawl survey provide an updated carapace length-weight relationship for male blue king crab (n = 172, range = 57-172 mm) described by the equation: $W = 0.0005257 * CL^{3.1040800}$. The carapace size-weight relationship for blue king crab ovigerous females is: $W = 0.114389 * CL^{1.919200}$ and non-ovigerous females is: $W = 0.035988 * CL^{2.155575}$.

Sizes at Maturity

Blue king crab males do not have a specific morphometric indication of maturity. Earlier studies exploring the relationship of the major chela height measurement to the carapace length (CL) of an individual crab as a measurement of male maturity did not produce statistically sound results, although one study reports males from St. Matthew Island were considered mature at 77 mm CL based on this relationship (Somerton and MacIntosh 1983a). St. Matthew Island blue king crab males were found to produce spermatophores at the 50-59 mm CL size range, which indicates these crab are reaching sexual maturity at a smaller size than estimated using chela height morphology (Paul et al. 1991). ADF&G considers males mature at carapace length of ≥ 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 6-8). Depending on the model scenario, *M* and *Q* may be estimated conditionally (Table 6).

Measurement errors of survey area-swept estimates of relative abundances were assumed to follow a lognormal distribution. Parameters of the model were estimated using a maximum likelihood approach:

$$
\begin{aligned}
Ln(L) = -\sum_t \{ & [\ln(P2_t QS2+1) - \ln(p2_t+1)]^2 / (2\ln(CV^2_{p2,t}+1)) \\
& + [\ln(P1_t QS1+1) - \ln(p1_t+1)]^2 / (2\ln(CV^2_{p1,t}+1)) \\
& + [\ln(R_t Q+1) - \ln(r_t+1)]^2 / (2\ln(CV^2_{r,t}+1)) \\
& + [\ln(P_t Q+1) - \ln(p_t+1)]^2 / (2\ln(CV^2_{p,t}+1)) \\
& + [\ln(P2_t s2/q+1) - \ln(ip2_t+1)]^2 / (2\ln(CV^2_{ip2,t}+1)) \\
& + [\ln(P1_t s1/q+1) - \ln(ip1_t+1)]^2 / (2\ln(CV^2_{ip1,t}+1)) \\
& + [\ln(R_t/q+1) - \ln(ir_t+1)]^2 / (2\ln(CV^2_{ir,t}+1)) \\
& + [\ln(P_t/q+1) - \ln(ip_t+1)]^2 / (2\ln(CV^2_{ip,t}+1)) + 10\eta_t^2 \},
\end{aligned}
\qquad (4)
$$

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*; *CV* is coefficient of variation for the survey abundance; *S*2 and *S*1 are trawl survey selectivities for prerecruit-2s and prerecruit-1s; *Q* is a trawl survey catchability, *s*2 and *s*1 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 parameters and likelihood values for different scenarios are compared in Table 6 and estimated abundance, recruitment to the model and mature male biomass are summarized in Tables 7-8 for scenarios (1) and (2). Scenarios (1) and (4) with fixed *Q* and *M* resulted in relatively high abundance and biomass estimates during the recent 10 years (Figure 10). Scenario (2) resulted in the lowest negative log likelihood value, and scenario (4) had the highest negative log likelihood (Table 6). The Chi-Square test was used to compare scenarios with different numbers of degrees of freedom. Scenario (2) outperformed scenarios (1), (4) and (5) with p-values of all less than 0.001. Scenario (3) performed better than scenario (1) (p-value of 0.032), scenario (4) (p-value < 0.001), and scenario (5) (p-value < 0.001). Scenario (1) performed better than scenario (4) (p-value < 0.001), and scenario (5) outperformed scenario (4) (p-value < 0.001). Overall, scenario (2) fit the data best, followed by scenario (3), (1), (5) and (4). All scenarios indicate an increasing abundance and biomass since 1999, and estimated legal abundance and mature male biomass in 2008 were the highest values since 1999 (Figure 10; Tables 7-8). Scenarios (2) and (5) fitted the pot survey index better than the other three scenarios (Table 6, Figure 11).

The model fitted the pre-recruit 1, pre-recruit 2, and recruits pretty well (Figures 12 and 13). The fit of post-recruits is a slightly biased high for scenario (1) since 2002, which is not performing as well as scenario (2) (Figures 12 and 13). Scenario (1) with $M = 0.18$ generally has higher estimates of post-recruits than the trawl survey after the stock collapse in 1999 (Figure 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 (scenarios 2 and 5), its values were 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 legal harvest rates were very high during 1982-1985, above 50% (Figure 14). The fishery has been closed since 1999.

Natural mortality estimates are strongly correlated with estimated trawl survey catchability: with high assumed natural mortality leading to lower estimated catchability (Figure 15). A relatively high natural mortality fits the data better than a low natural mortality. With a fixed catchability = 1, estimated natural mortality was 0.362, much higher than the value (0.18) we assumed for this stock. The likelihood value was very low for an assumed natural mortality of 0.18 (Figure 15). When fixing natural mortality = 0.18, estimated trawl survey catchability was greater than 1, an unlikely value (Figure 15).

Handling mortality may also affect abundance estimates. Handling mortality reduces future recruitment to fisheries by reducing both prerecruit abundance and spawning biomass. Besides mortality, handling may also produce sublethal effects on crab, such as reduced growth (Kruse 1993). Based on limited observer data, bycatch of sublegal male and female crabs from the directed blue king crab fishery off St. Matthew Island was relatively high, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs (Moore et al. 2000). But observer data were extremely limited for the St. Matthew Island blue king crab directed pot fishery. We assumed fishery selectivities to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s and handling mortality rate to be 0.2, based on the results for Bristol Bay red king crab (Zheng and Siddeek 2008). Although estimated recruitment to the model is affected by handling mortality, handling mortality rates ranging from 0 to 50% do not affect legal male abundance and mature male biomass estimates much (Zheng et al. 2008).

A likelihood profile for estimated legal male abundance in 2009 is illustrated in Figure 16. The 95% confidence intervals for legal male abundance are 1.598 million to 2.616 million of crabs. The 95% confidence intervals for mature male biomass in 2009 with the assumed fishing mortality of 0.18 are 8.892 million lbs to 16.253 million lbs.

Retrospective Analyses

Two kinds of retrospective analyses are presented in this report: (1) historical results and (2) the 2009 model results. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Assuming the estimates in 2009 as the baseline values, we can also evaluate how well the model had done in the past. The 2009 model results are based on leaving one year's data out at a time to evaluate how well the current model performs with less data.

Before 2008, the baseline scenario was scenario (2), which has been used to set the catch quota for more than 10 years. In 2008 and 2009, scenario (1) was used to set the federal OFL. Therefore, the historical results consisted of the model results from scenario (2) before 2008 and scenario (1) for 2008 and 2009, and the assessments made before 2009 came from slightly different area-swept estimates of trawl survey data because areas-swept were re-estimated for all trawl surveys in 2009. Legal male abundance and mature male biomass were slightly overestimated historically during the last 10 years (Figure 17).

The 2009 model results are compared in Figures 18-19 for scenarios (1) and (4). Scenarios with estimating natural mortality in 1999 performed very well with only a small bias in abundance estimates. Because of relatively low legal abundance from the trawl survey data during the early and mid 2000s, the estimated legal males and mature male biomass during the terminal years tended to be higher during this period than those estimated with the terminal year of 2009 for scenario (1) (Figure 18). This bias is less for scenarios (2) and (3) than for scenario (1). 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). Scenario (3) performed close to or slightly worse than scenario (2). Because trawl survey catchability was estimated to be greater than 1 for scenario (3), estimated legal male abundance was generally less than survey area-swept estimates. Scenario (4) with fixed *M* and *Q* for the whole period performed poorly. The estimated legal abundance and mature male biomass during the terminal years were systematically higher during 1999-2008 than those estimated with the terminal year of 2009 for scenario (4) (Figure 19). This systematic bias also occurred for scenario (5) but was smaller than for scenario (4).

Sensitivities of Weighting Factors on Pot Survey Index and Changes in Molting Probability

The baseline model uses survey CV to weight the survey data annually. To examine the relative influence of the trawl and pot survey data, we added a weighting factor to the pot survey index in additional to the survey CV. These factors range from 0.5 to 100 with 1 being the baseline model. Estimated legal male abundance and mature male biomass over time are generally similar except for the weighting factor of 100, which results in a 20% to 30% difference for some years (Figure 20). Overall, the trawl and pot index were similar except for 2001 and 2004. In 2001, the pot survey had higher abundance than that from the trawl survey, whereas in 2004, the pot survey was the opposite.

The model uses a random walk approach to estimate changes in molting probability of pre-recruit crabs. Some annual change is allowed but is penalized. We varied the weighting factor for the penalized function from 2 to 2000, with the baseline factor = 20. There is little penalty with the weighting factor of 2, and a factor of 2000 results in a nearly constant molting probability over time. Estimated legal male abundances over time were similar with different weighting factors (Figure 21). However, some difference occurred for estimated mature male biomass over time with different weights (Figure 21). This is due to confounded effects between molting probability and survey selectivity of pre-recruit crabs. Changes in molting probability resulted in changes to selectivity, which affects mature male biomass estimates. Overall, the difference in mature male biomass estimates is small (Figure 21).

Overfishing Limits for 2009

The St. Matthew Island blue king crab stock has been recommended for placement in Tier 4 (NPFMC 2007). For Tier 4 stocks, abundance estimates are available, but complete population parameters are not available for computer simulation studies and spawning biomass per recruit analyses needed for Tier 3 stocks. Average of estimated biomasses for a certain period is used to develop B_{MSY} proxy for Tier 4 stocks. We evaluated averages of mature male biomasses from four periods for a B_{MSY} proxy: 1978-2009, 1983-1998, 1983-2009, and 1989-2009 (Figures 22 and 23).

Besides B_{MSY} proxy, a γ value also needs to be determined. The CPT selected $\gamma = 1$ for determining overfishing limits for 2008. The fishery was closed for 2008 because the OFL catch was below the minimum TAC in regulation for a fishery opening.

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
Based on average during 1978-2009:	8.273 million lbs	8.629 million lbs
Based on average during 1983-1998:	8.140 million lbs	8.690 million lbs
Based on average during 1983-2009:	7.187 million lbs	7.340 million lbs
Based on average during 1989-2009:	7.987 million lbs	8.041 million lbs

Estimated F_{MSY} proxy:

Model scenario (1)	Model scenario (2)

$\gamma = 1$:	0.180	0.362
Retained OFL:	1.532 million lbs	2.429 million lbs
Total male OFL (pot):	1.723 million lbs	2.954 million lbs

Estimated mature male biomass in 2009 was 12.470 and 10.824 million lbs, respectively for model scenarios (1) and (2) under the target level of $\gamma = 1$. The estimated mature male biomass in 2009 would exceed all six B_{MSY} proxies even after adjusting the catch should directed fishing be allowed in 2009. Year classes after the 1976/77 regime shift (Overland et al. 1999) were about to reach the mature population after 1982, so two of the three periods used to estimate B_{MSY} proxy started in 1983. The stock collapsed and was at a low level during the early and mid 2000s, so this period might reasonably be excluded from estimating the B_{MSY} proxy, resulting in use of the period of 1983-1998. The CPT suggested a period of 1989-2009. The period of 1978-2009 includes all data. For a given model scenario, the averages from the three periods were not greatly different.

Overfishing limits for 2009 depend on the choice of years used to average mature biomass as the B_{MSY} proxy and the choice of γ value or $F_{\%}$. In 2008, $\gamma = 1$ and years of 1989-2008 were used for overfishing limits.

The high abundance estimate for 2009 was primarily caused by the relatively good trawl survey abundance of prerecruit-2s in 2006 and 2008, very high trawl survey abundance of prerecuti-1s and prerecruit-2s in 2007 and 2009, and high trawl survey abundance of postrecruits in 2008, and high pot survey abundance in 2007. The stock is estimated to have been above the B_{MSY} proxy for two years, which is the criteria for it to be considered rebuilt from overfishing status. The estimated retained OFL in 2009 is below the harvest strategy minimum TAC threshold. Once the stock has rebuilt, the harvest strategy minimum TAC may need to be adjusted based on the current fishing fleet.

Ecosystem Considerations

Ecosystem Effects on Stock

Prey Availability/Abundance Trends

Early juvenile and larval *Paralithodes* spp. are planktotrophic, actively feeding on diatoms, nauplii and copepods (Paul et al. 1979, Abrunhosa and Kittaka 1997). Blue king crab larvae are described as obligate plankton feeders (Otto 2006). Zheng and Kruse (2000) found a relationship between periods of weak year class strength in blue king crab stocks in the eastern Bering Sea and decadal climate shifts, which exhibit strong winter Aleutian lows with periods with an unstable water columns due to vertical mixing. These winter Aleutian lows may prevent diatom growth, such as *Thalassiosira* spp., that are rich in nutrients and are important prey for early stages of larval blue king crab.

Recently settled blue king crab juveniles switch from a planktivorous diet to benthic prey such as echinoderms (including sea stars, sea urchins and sand dollars), mollusks (bivalves and snails), and polychaetes, as well as other crustaceans including crab. Invertebrates accounted for 23% of the total demersal animal biomass of 15.4 million tons estimated for the eastern Bering Sea shelf. The 2007 biomass of invertebrates was composed primarily of crustaceans minus commercially important crab and shrimp species (1.4 million t), echinoderms (1.3 million t), and crab (1.3 million t) (Acuna and Lauth 2008).

Predator Population Trends

Since it is difficult to distinguish between red and blue king crab as prey items without the whole carapace, there is no predator information specific to blue king crab in data published by the AFSC food habitats laboratory. Pacific cod, Pacific halibut and skate stomachs contained small amounts of unidentified king crab collected from the eastern Bering Sea annual summer shelf survey (Lang et al. 2005).

The 2007 abundance estimate for Pacific cod in the eastern Bering Sea shelf was 423,703 metric tons, with the highest catch rate of Pacific cod occurring in the northwestern part of the eastern Bering Sea shelf. Biomass estimates of Pacific cod have been declining, although there has been an increase in population size indicating an increase in a number of smaller sized fish and suggesting the emergence of a strong year class (Acuna and Lauth 2008).

The International Pacific Halibut Commission predicts low levels of recruitment and even lower estimates of productivity for Pacific halibut in the St. Matthew Island area, resulting in a 2008 harvest level below the optimal rate of 20% (IPHC 2008). Low commercial and survey catch rates support a general decline in abundance estimates of Pacific halibut in the eastern Bering Sea (Clarke 2008).

Paralithodid species are especially vulnerable as adults when in the soft shell state just after the molting process (Loher et al. 1998) and as recently settled juveniles. Numerous planktivorous fishes prey on *Paralithodid* larvae (Livingston et al. 1993, Wespestad et al. 1994).

Changes in Habitat Quality

Table 9 lists the potential ecosystem effects by changes in habitat quality. According to Somerton (1985), blue king crab (BKC) have a restricted distribution in Alaska waters, occurring in isolated populations that are thought to be relicts from a former, broader distribution (Figure 1). The general rise in water temperature that has occurred during the present inter-glacial period is thought to be the primary factor in shaping their distribution into these isolated refuges. Somerton (1985) hypothesized that the isolated distribution of BKC could be due to three mechanisms that might come into play, either singly or in combination, following an increase in temperature: reproductive interference, competitive displacement and predatory exclusion. Due to these restricted and discrete isolated populations of BKC, they are particularly susceptible to any perturbations during critical life history stages and to their critical habitats. An increase in temperature, ocean acidification, and oil mishaps could affect their survival, reproductive success, distribution, habitat quality, recruitment success, year class strength, and predator or prey distribution.

Early life history studies of blue king crab around the Pribilof Islands during the spring of 1983 and 1984 by Armstrong et al. (1985) have demonstrated that larvae hatch in mid to late April. Although the average current patterns in the southeastern Bering Sea show a general northwest direction and slow speeds along the shelf breaks near the islands, for the local scale of the Pribilof and presumably St. Matthew Island there must be current patterns and eddies that will retain the larvae nearshore to enhance settlement to the preferred but limited refuge in the area. Armstrong et al. (1985) also pointed out that in certain years it would be probable that anomalous events could occur that would transport larvae well beyond the Pribilof Islands, resulting in settlement into unfavorable habitats and very low survival.

Juvenile blue king crab (<30 mm carapace length) are known to occur predominately along nearshore rocky and shell hash (a mixture of broken bivalve and gastropod shells) habitats near the Pribilof Islands, and these habitats are considered vital refuge from predation and for successful recruitment (Palacios et al. 1985). Shell hash is a key material for refuge and thus the survival of blue king crab is ultimately linked to certain mollusk species that are abundant within the species assemblage that characterize the BKC juvenile habitat along the Pribilof Islands (Armstrong et al. 1985). The preferred shelltype epibenthic substrate for juvenile BKC was composed primarily of four species of bivalves (*Serripies groenlandicus*, *Spisula polynyma*, *Chlamys sp*., *Modiolus modiolus*), and large neptunid gastropods. Shells of this type were usually intact or in large pieces and usually covered with dense epiphytic growth including feathery bryozoans, barnacles, anemones, and ascidians.

Male and female adult blue king crab along the Pribilof Islands had a high occurrence offshore on deeper, mud-sand substrates. In August of 1998, ovigerous females occurred in high abundance and dominated all catches (99% females, almost all ovigerous) along mostly rocky habitats in nearshore waters sampled during St Matthew Island pot surveys (Blau and Watson 1999). A high percentage of mature blue king crabs also occurred in the vicinity of St. Matthew Island during a trawl survey in 1983 (NMFS 1984) and have not been located anywhere else in the Bering Sea (Armstrong et al. 1985, Palacios et al. 1985, Moore et al. 1998). The high incidence of ovigerous females during the 1998 pot survey occurred at depths from 7 to 20 fathoms in mostly rocky habitats and CPUE (number of crab per pot) ranged from 10 at 7 fm to 146 at 8 fm, whereas CPUE of all males at those depths was <2. The nearshore rocky habitats of St Matthew Island are very important habitat for ovigerous females during the summer and fall months. Nearshore dive surveys along St. Matthew Island by the Alaska Department of Fish & Game (ADF&G) have not revealed juvenile blue king crab nor have their habitat associations been described (Blau 2000).

Recently several studies have investigated the effects of temperature on embryonic development, hatch timing, respiration, and larval survival of BKC (Stevens 2006a, Stevens 2006b, Stevens et al. 2008). This research will aid in understanding the impacts of climate change, especially seawater warming, on BKC production.

Due to their restricted distribution along the Pribilof and St Mathews Islands, blue king crab are considered highly vulnerable to oil mishaps (Armstrong et al. 1987). There have been numerous studies that have investigated the potential impacts of oil on blue king crab along the Pribilof Islands (Armstrong et al. 1983, Armstrong et al. 1987, Laevastu et al. 1985). The life history stages considered most vulnerable are the larval stages since they are in the water column and would follow the same currents as the oil. The restricted distribution of early juveniles on and in substrates such as shellhash and gravel/cobble that are limited to the Pribilof Islands (compared to hundreds of km in all directions) underscores the unique habitat required by this species. The high concentrations and dominance by ovigerous females that occur in nearshore waters during the summer and fall would be at great risk during an oil mishap for St. Matthew and the Pribilof Islands. If oil reaches these islands the impact on BKC could be great depending on a variety of biological and physical factors (Laevastu et al. 1985).

Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects (M. Sigler, AFSC NOAA Fisheries, pers. comm.). These effects have been measured as decreased pH of the water, as well as measurable increases in dissolved inorganic carbon over a large section of the northeastern Pacific suspected to be a problem in surface water affecting calcifying planktonic organisms in the northeast Pacific Ocean (R. Feely, NOAA PMEL, pers. comm.). Some investigators believe that the effects of decreased calcification in microscopic algae and animals could impact food webs and, combined with other climatic changes in salinity, temperature and upwelled nutrients, could substantially alter the biodiversity and productivity of the ocean (Orr et al. 2005). A recent trial laboratory study has shown a 15% reduction in growth and 67% reduction in survival when pH was reduced 0.5 units (Litzow et al., trial data, AFSC NOAA Fisheries). Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival. Current studies underway will investigate the effect pH has on survival, growth, and morphology of larval and juvenile blue and red king crab (K. Swiney, NMFS/AFSC/Kodiak Lab, pers. comm.).

Disease

Diseases that may infect *Paralithodid* species include a herpes-type viral disease of the bladder, a pansporoblastic microsporidian (*Thelohania* sp.), and a parasitic rhizocephalan (*Briarosaccus* sp.) which feeds on female egg clutches (Sparks and Morado 1997).

Fishery Effects on the Ecosystem

The St. Matthew blue king crab commercial fishery has been closed since 1999. Non-retained blue king crab such as females and sub-legal males may have been caught in previous directed fishing for St. Matthew blue king crab and eastern Bering Sea snow crab commercial fisheries (see bycatch in directed fishery section).

Seapens or seawhips, corals, anemones, and sponges are species groups in the eastern Bering Sea considered as Habitat Areas of Particular Concern (HAPC), which are defined as living substrates in shallow or deep waters, although not many corals (gorgonians, soft corals and stony corals) are encountered on the EBS shelf. Relative CPUE from EBS shelf survey data 1982-2007 is available for these species groups but the survey gear is not appropriate for effective sampling of these types of organisms and survey results provide imprecise abundance information. Since most of the eastern Bering Sea survey stations are repeated from survey to survey, apparent decreases in abundance for many of the slow growing HAPC organisms could result from repeated trawling of these areas by the survey (Lauth 2007).

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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. NMFS EBS summer trawl survey area-swept estimates of abundance (million of crab) and associated CV for 4 length groups. In this and subsequent tables, P2 is an abbreviation for the prerecruit 2 length group; P1 = prerecruit 1, R – recruits, and P = postrecruits.

Year	P2	CV	P1	CV	R	CV	P	CV	Matures	Legals
1978	2.221	0.441	2.147	0.477	1.138	0.371	0.563	0.311	3.849	1.701
1979	2.791	0.498	2.107	0.452	1.719	0.440	0.394	0.423	4.221	2.113
1980	1.755	0.702	1.905	0.582	1.275	0.351	1.065	0.444	4.245	2.340
1981	0.468	0.436	1.218	0.275	0.959	0.429	1.365	0.477	3.542	2.324
1982	1.712	0.786	2.496	0.511	3.123	0.311	2.863	0.289	8.482	5.986
1983	1.078	0.529	1.663	0.449	1.390	0.267	1.967	0.293	5.020	3.357
1984	0.410	0.306	0.500	0.277	0.769	0.248	0.709	0.242	1.978	1.478
1985	0.381	0.305	0.377	0.332	0.489	0.287	0.634	0.233	1.500	1.123
1986	0.206	0.418	0.456	0.663	0.179	0.478	0.198	0.428	0.833	0.377
1987	0.325	0.409	0.631	0.332	0.477	0.329	0.238	0.302	1.346	0.715
1988	0.410	0.475	0.815	0.333	0.504	0.323	0.452	0.220	1.772	0.957
1989	2.145	0.445	1.154	0.299	0.884	0.290	0.903	0.269	2.940	1.786
1990	1.053	0.544	1.032	0.393	1.075	0.300	1.262	0.267	3.369	2.337
1991	1.084	0.407	1.665	0.293	1.305	0.226	0.930	0.320	3.900	2.235
1992	1.073	0.319	1.382	0.292	1.183	0.206	1.107	0.246	3.672	2.290
1993	1.522	0.320	1.828	0.209	1.460	0.182	1.818	0.198	5.105	3.277
1994	0.883	0.240	1.299	0.278	1.183	0.209	1.074	0.199	3.556	2.257
1995	1.025	0.302	1.189	0.253	0.909	0.187	0.831	0.264	2.929	1.741
1996	1.238	0.372	1.891	0.352	1.467	0.294	1.599	0.221	4.957	3.066
1997	1.165	0.444	2.229	0.489	2.056	0.373	1.733	0.268	6.018	3.789
1998	0.660	0.349	1.660	0.450	1.249	0.397	1.600	0.330	4.509	2.849
1999	0.223	0.411	0.222	0.292	0.164	0.328	0.393	0.222	0.779	0.557
2000	0.282	0.420	0.285	0.355	0.291	0.332	0.449	0.395	1.025	0.740
2001	0.419	0.334	0.502	0.338	0.325	0.312	0.614	0.311	1.441	0.939
2002	0.111	0.722	0.230	0.417	0.161	0.403	0.479	0.417	0.870	0.640
2003	0.449	0.525	0.280	0.566	0.156	0.395	0.308	0.303	0.745	0.464
2004	0.247	0.568	0.183	0.702	0.252	0.328	0.310	0.309	0.746	0.562
2005	0.320	0.459	0.310	0.479	0.258	0.603	0.243	0.348	0.811	0.501
2006	0.917	0.389	0.642	0.570	0.682	0.380	0.558	0.278	1.882	1.240
2007	2.517	0.498	2.020	0.422	0.681	0.388	0.512	0.266	3.212	1.193
2008	1.351	0.382	0.801	0.333	0.529	0.465	0.928	0.244	2.258	1.457
2009	1.573	0.238	2.161	0.347	0.597	0.256	0.813	0.266	3.571	1.410

Table 4. Crabs per pot lift and associated CV for the pot surveys from the common 96 stations performed during the 1995-2007 ADF&G triennial St. Matthew Island blue king crab pot survey.

Year	P2	CV	P1	CV	R	CV	P	CV
1995	1.919	1.409	3.198	1.294	3.214	1.276	3.708	1.304
1998	0.964	1.100	2.763	0.797	3.906	0.615	4.898	0.771
2001	1.266	1.426	1.737	1.071	2.378	0.820	3.109	0.838
2004	1.719	1.903	0.453	1.943	0.299	2.151	0.826	1.607
2007	0.500	1.063	2.721	0.953	2.773	0.993	2.063	1.234

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 log likelihood values for a catch-survey analysis of St. Matthew Island blue king crab with data from 1978 to 2009. Five scenarios of the model are (1)

fixed M = 0.18 and Q=1 with 2 *Ms*, (2) fixed Q = 1 and estimating M with 2 *Ms*, (3) fixed M = 0.18 and estimating Q with 2 *Ms*, (4) fixed M = 0.18 for the whole time series and Q=1, (5) fixed Q = 1 and estimating M for the whole time series. An M value is estimated for 1999 with the "2 *Ms*" scenario. A value of "fix" indicates that it is fixed in the model.

	Model Scenario				
Parameter	(1)	(2)	(3)	(4)	(5)
Natural mortality for years other than 1999	fix	0.362	fix	fix	0.411
Natural mortality in 1999	1.846	1.756	1.780	fix	0.411
Trawl survey catchability (Q)	fix	fix	1.240	fix	fix
Trawl survey selectivity: prerecruit-2s ($S2$)	0.421	0.232	0.356	0.490	0.202
Trawl survey selectivity: prerecruit-1s ($S1$)	0.615	0.440	0.531	0.608	0.384
Pot survey selectivity: prerecruit-2s ($s2$)	0.100	0.059	0.086	0.097	0.043
Pot selectivity: prerecruit-1s ($s1$)	0.341	0.260	0.304	0.293	0.208
Pot scaling parameter (q)	0.223	0.234	0.182	0.160	0.183
Molting probability in 1978: prerecruit-1s	0.750	0.762	0.726	0.788	0.755
Population abundance in 1978 (million)	6.3001	8.359	5.563	6.163	8.982
Negative log likelihood components					
Trawl survey: prerecruit-2s	16.808	19.435	17.160	18.878	20.668
Trawl survey: prerecruit-1s	12.434	13.509	13.614	23.000	21.866
Trawl survey: recruits	25.783	14.907	20.379	38.240	18.540
Trawl survey: postrecruits	30.332	22.063	29.608	34.290	24.584
Pot survey: total	4.871	3.925	4.835	5.150	3.590
Molting probability variation penalty	3.425	3.664	4.310	5.082	6.230
Total	93.653	77.502	89.905	124.639	95.457
Total number of parameters	69	70	70	68	70

Table 7. Estimated recruits to the model (Model R), abundance (P2, P1, R, P, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-

recruit-1s (Molt1) for model scenario (1) fixing *M* and *Q*. Recruits and abundance are in million of crab and biomass is in million lbs. *F* = *M* (0.18) for 2009.

Year	Model R	P2	P1	R	P	Legals	Matures	Bio215	Molt1
1978	NA	2.306	2.229	1.181	0.585	1.766	3.995	9.250	0.750
1979	4.087	4.715	2.146	0.863	1.163	2.025	4.172	12.222	0.786
1980	2.835	4.016	3.486	0.992	1.705	2.698	6.183	17.969	0.817
1981	0.599	1.513	3.716	1.530	2.324	3.854	7.570	18.626	0.858
1982	1.251	1.542	2.295	1.545	2.444	3.989	6.284	12.605	0.871
1983	0.492	0.770	1.731	0.968	1.760	2.728	4.458	6.336	0.869
1984	0.556	0.693	1.050	0.690	0.677	1.367	2.418	3.979	0.854
1985	0.945	1.077	0.774	0.427	0.456	0.883	1.657	2.990	0.861
1986	0.832	1.032	0.897	0.343	0.344	0.686	1.583	3.562	0.888
1987	1.489	1.665	0.945	0.412	0.412	0.824	1.768	4.133	0.900
1988	1.329	1.600	1.354	0.467	0.516	0.983	2.336	5.315	0.893
1989	2.874	3.141	1.455	0.628	0.603	1.231	2.686	6.683	0.870
1990	1.968	2.551	2.413	0.727	0.859	1.586	3.999	9.483	0.846
1991	2.105	2.620	2.402	1.056	1.058	2.114	4.516	10.015	0.826
1992	2.133	2.696	2.401	1.017	1.205	2.223	4.624	11.325	0.814
1993	2.175	2.784	2.460	1.017	1.455	2.472	4.932	12.177	0.791
1994	1.582	2.255	2.515	1.013	1.587	2.600	5.115	12.001	0.794
1995	2.846	3.384	2.239	1.008	1.525	2.533	4.772	11.851	0.822
1996	2.473	3.214	2.780	0.991	1.602	2.593	5.373	13.254	0.809
1997	1.730	2.466	2.893	1.173	1.671	2.844	5.737	13.195	0.764
1998	1.156	1.796	2.497	1.109	1.639	2.748	5.245	3.947	0.713
1999	0.574	0.675	0.376	0.167	0.311	0.478	0.855	2.720	0.699
2000	0.418	0.631	0.506	0.150	0.408	0.558	1.065	3.383	0.621
2001	0.529	0.764	0.533	0.171	0.477	0.648	1.181	3.817	0.462
2002	0.000	0.376	0.563	0.136	0.550	0.686	1.249	4.102	0.450
2003	0.663	0.852	0.457	0.130	0.581	0.711	1.169	4.007	0.542
2004	0.383	0.751	0.574	0.142	0.603	0.745	1.319	4.386	0.606
2005	0.938	1.227	0.616	0.190	0.634	0.824	1.440	4.765	0.694
2006	1.980	2.371	0.885	0.248	0.703	0.951	1.836	5.818	0.689
2007	1.575	2.341	1.558	0.375	0.816	1.190	2.748	8.127	0.639
2008	2.900	3.743	1.826	0.553	1.029	1.581	3.407	10.208	0.679
2009	2.497	3.736	2.648	0.722	1.364	2.086	4.734	12.470	0.750

Table 8. Estimated recruits to the model (Model R), abundance (P2, P1, R, P, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-

recruit-1s (Molt1) for model scenario (2) fixing *Q* and estimating *M*. Recruits and abundance are in million of crab and biomass is in million lbs. $F = M$ (0.362) for 2009.

Year	Model R	P2	P1	R	P	Legals	Matures	Bio215	Molt1
1978	NA	3.059	2.957	1.567	0.776	2.343	5.300	11.290	0.762
1979	9.667	10.341	2.393	0.977	1.383	2.360	4.753	12.419	0.807
1980	5.623	7.644	5.650	1.119	1.661	2.780	8.429	19.964	0.841
1981	1.737	3.073	5.603	2.166	2.048	4.214	9.817	20.540	0.873
1982	2.565	3.033	3.266	2.006	2.329	4.335	7.601	13.709	0.876
1983	0.970	1.418	2.467	1.188	1.714	2.902	5.369	7.236	0.868
1984	1.036	1.248	1.404	0.833	0.672	1.505	2.909	4.495	0.858
1985	1.710	1.906	1.018	0.491	0.474	0.965	1.983	3.283	0.871
1986	1.662	1.947	1.226	0.399	0.341	0.740	1.966	3.859	0.898
1987	2.805	3.071	1.352	0.495	0.385	0.880	2.232	4.486	0.909
1988	2.614	3.013	1.977	0.589	0.475	1.065	3.042	5.969	0.905
1989	5.224	5.623	2.124	0.801	0.570	1.371	3.495	7.439	0.885
1990	3.898	4.717	3.488	0.939	0.826	1.766	5.253	10.735	0.865
1991	3.841	4.583	3.415	1.340	1.027	2.367	5.782	11.259	0.846
1992	4.179	4.945	3.275	1.268	1.188	2.457	5.732	12.158	0.831
1993	4.022	4.901	3.411	1.227	1.387	2.614	6.025	12.698	0.812
1994	3.293	4.221	3.401	1.236	1.429	2.665	6.066	12.094	0.819
1995	5.757	6.533	3.070	1.210	1.318	2.528	5.598	11.625	0.845
1996	4.694	5.797	4.106	1.227	1.337	2.564	6.670	13.612	0.829
1997	2.956	3.992	4.067	1.512	1.389	2.901	6.968	13.510	0.779
1998	2.174	3.002	3.158	1.341	1.409	2.750	5.908	4.588	0.723
1999	1.050	1.231	0.595	0.240	0.346	0.586	1.181	3.138	0.710
2000	0.918	1.233	0.738	0.205	0.420	0.626	1.363	3.603	0.638
2001	1.087	1.458	0.766	0.221	0.449	0.670	1.436	3.814	0.488
2002	0.000	0.574	0.784	0.179	0.477	0.656	1.440	3.845	0.496
2003	1.455	1.678	0.543	0.167	0.468	0.635	1.179	3.335	0.596
2004	0.896	1.445	0.817	0.171	0.451	0.623	1.440	3.781	0.671
2005	1.875	2.280	0.893	0.260	0.449	0.709	1.602	4.154	0.727
2006	3.672	4.232	1.301	0.329	0.512	0.841	2.142	5.344	0.705
2007	2.716	3.815	2.235	0.491	0.612	1.103	3.338	7.902	0.640
2008	5.503	6.647	2.352	0.674	0.809	1.483	3.835	9.408	0.673
2009	4.928	6.783	3.543	0.820	1.078	1.898	5.441	10.824	0.762

Table 9. Ecosystem effects on the St. Matthew Island blue king crab stock. Changes in habitat quality.

Ecosystem effects on St. Matthew Island blue king crab stocks			
Indicator	Observation	Interpretation	Evaluation
Changes in Habitat Quality			
EFH-HAPC	Rocky/shellhash nearshore habitats are critical habitat/vital refuge for juveniles in the Pribilof Islands. Ovigerous females dominate nearshore rocky habitats during the warmer months.	Effects on population dynamics of mollusk species that compose the shellhash and associated epiphytes, such as oil mishaps, coastal development, and dredging.	Concern
Temperature regime	Experimental studies.- temperature effects on hatch timing, embryonic development, larval growth and survival.	Lower temperatures delay development, hatch timing, and growth. Higher temperatures may increase all of the above and decrease survival.	Concern
Ocean Acidification	Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects.	Lab studies have shown a ~15% reduction in growth and ~67% reduction in survival when pH was reduced 0.5 units. Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival.	Concern
Oil exploration	Restricted distribution makes them vulnerable to oil mishaps.	Oil mishap would impact planktonic larvae the most. Juveniles in shallow water nearshore habitats would be impacted. As well as ovigerous females that occur in shallower warmer water during the summer and fall.	Concern
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability. Concern.
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability and recruitment in year class strength	Possible concern

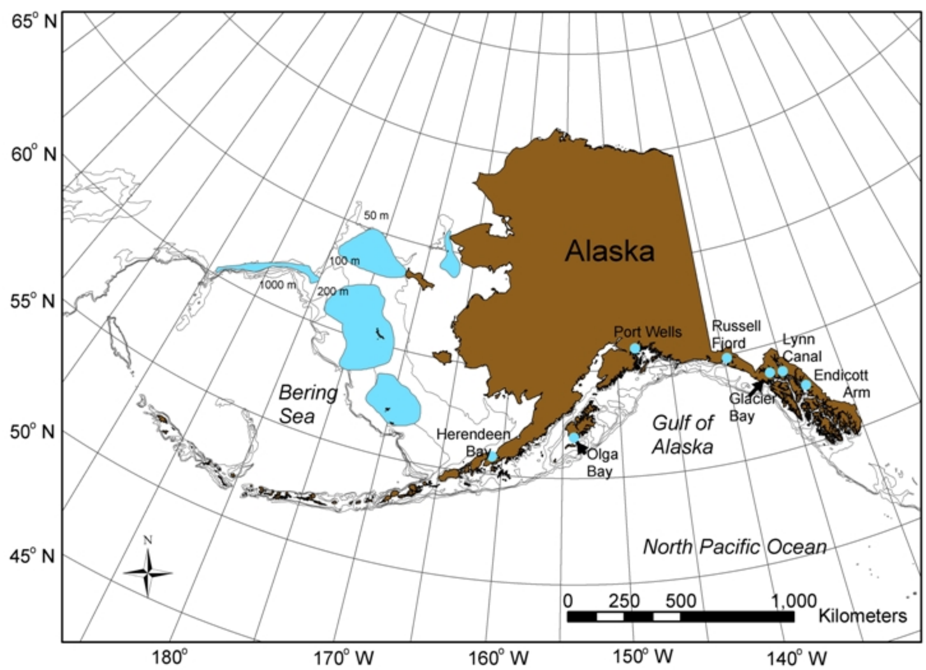


Figure 1. Distribution map of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters.

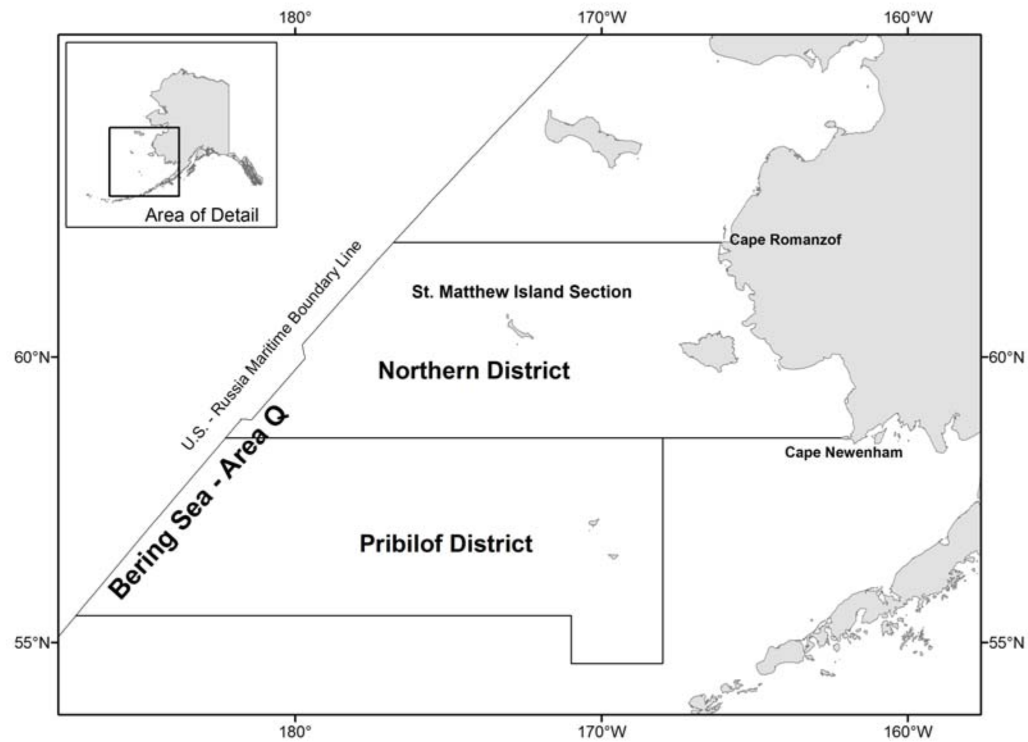


Figure 2. King crab Registration Area Q (Bering Sea).

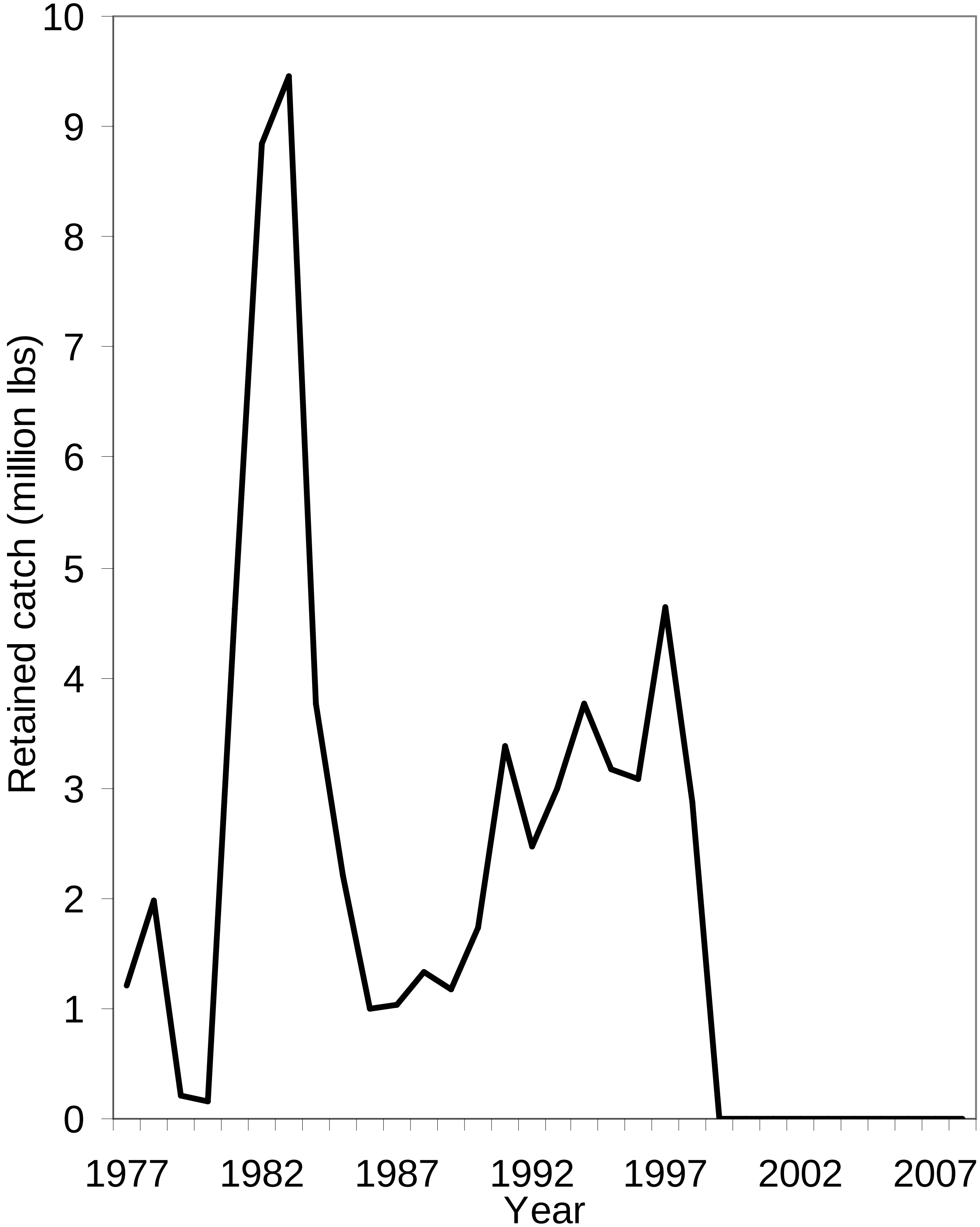


Figure 3. Retained catch over time for St. Matthew Island blue king crab.

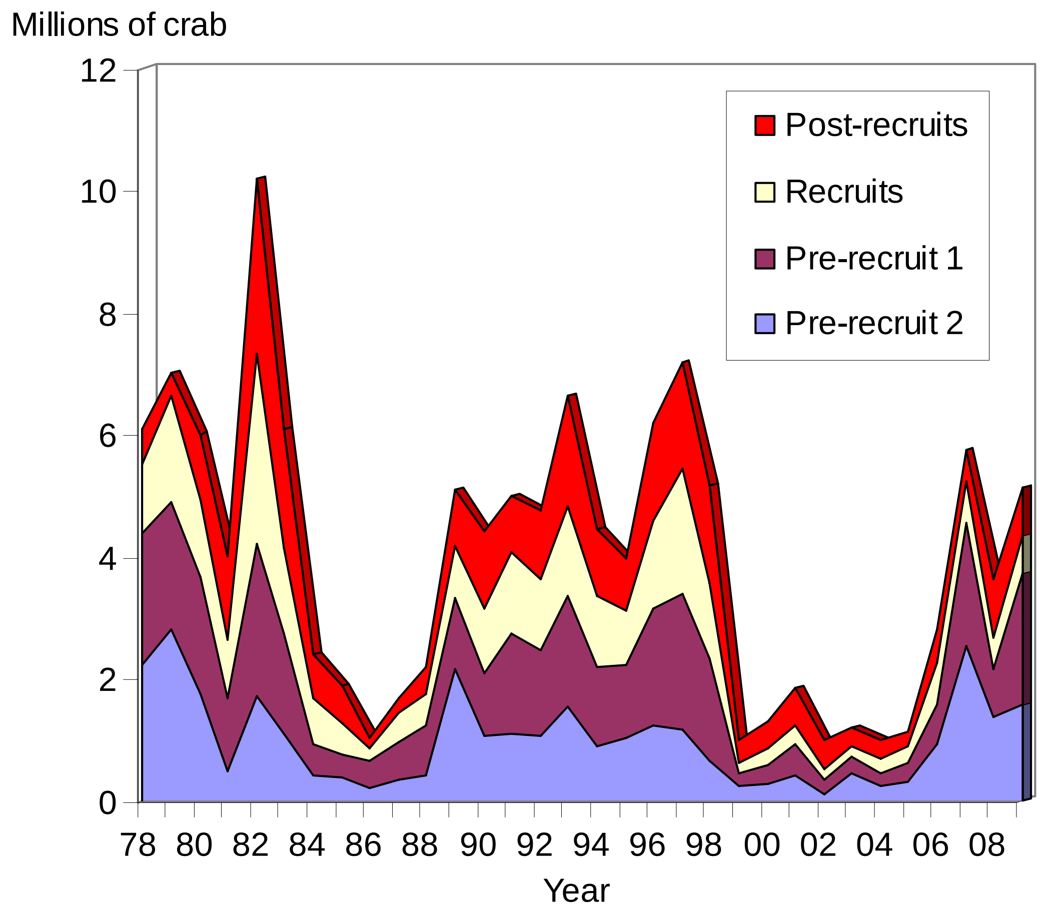


Figure 4. Area-swept abundance estimates from trawl surveys from 1978 to 2009 for St. Matthew Island blue king crab.

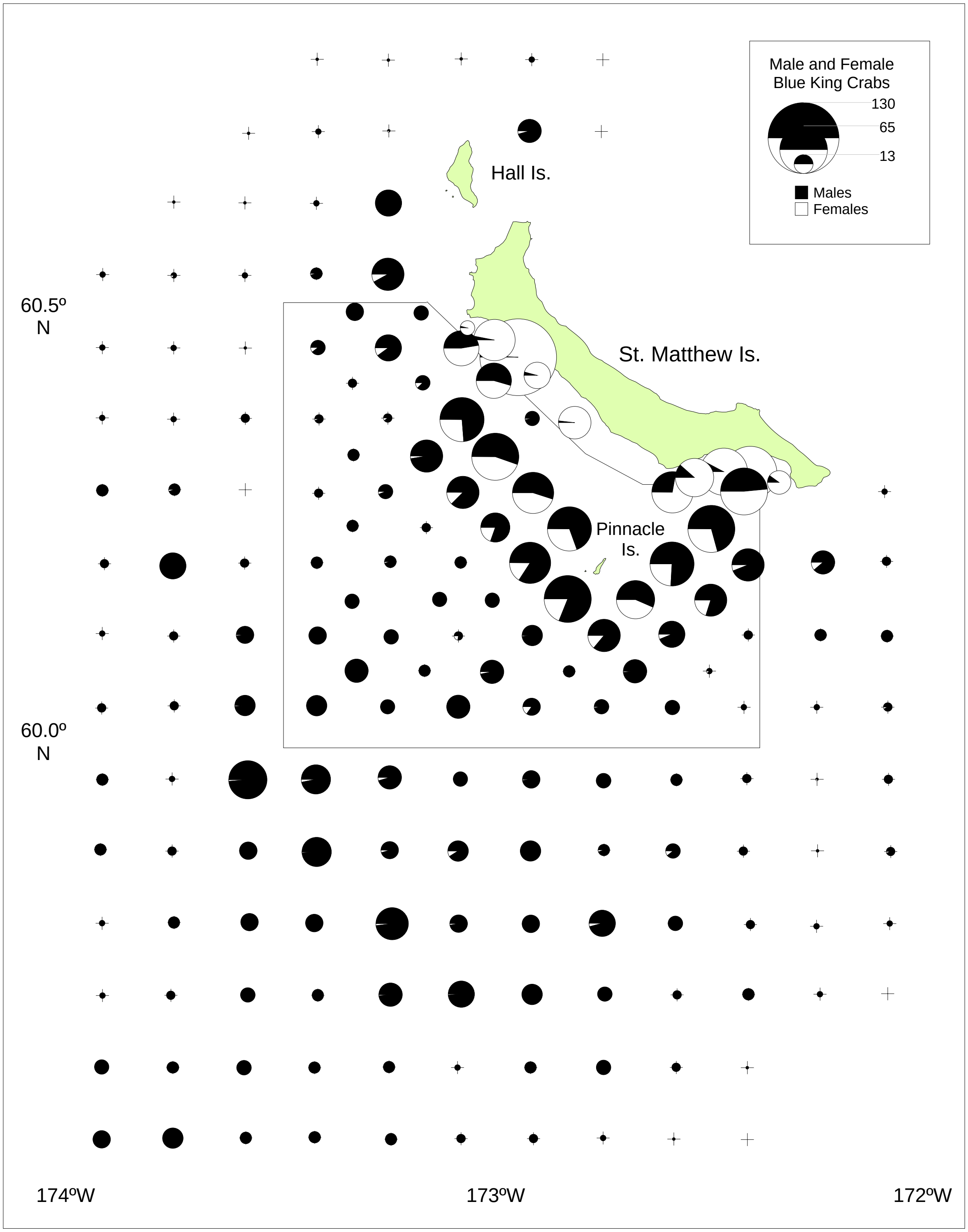


Figure 5. Male and female blue king crab catch per unit effort (CPUE) by station in the 2007 St. Matthew Island survey. (Source: Watson 2008).

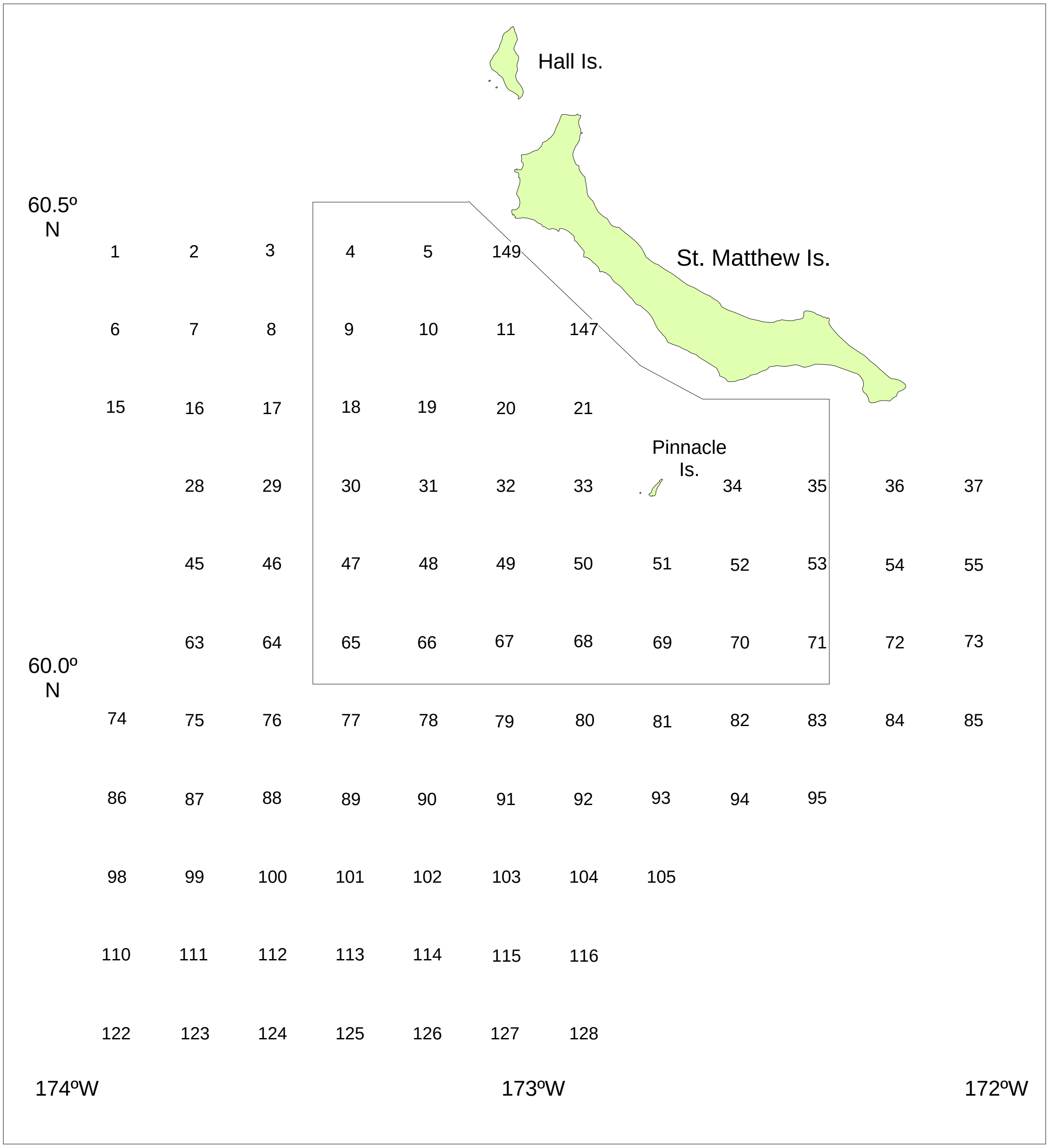


Figure 6. Location of the 96 stations fished in common during the five triennial St. Matthew Island blue king crab surveys, 1995 - 2007. (Source: Watson 2008).

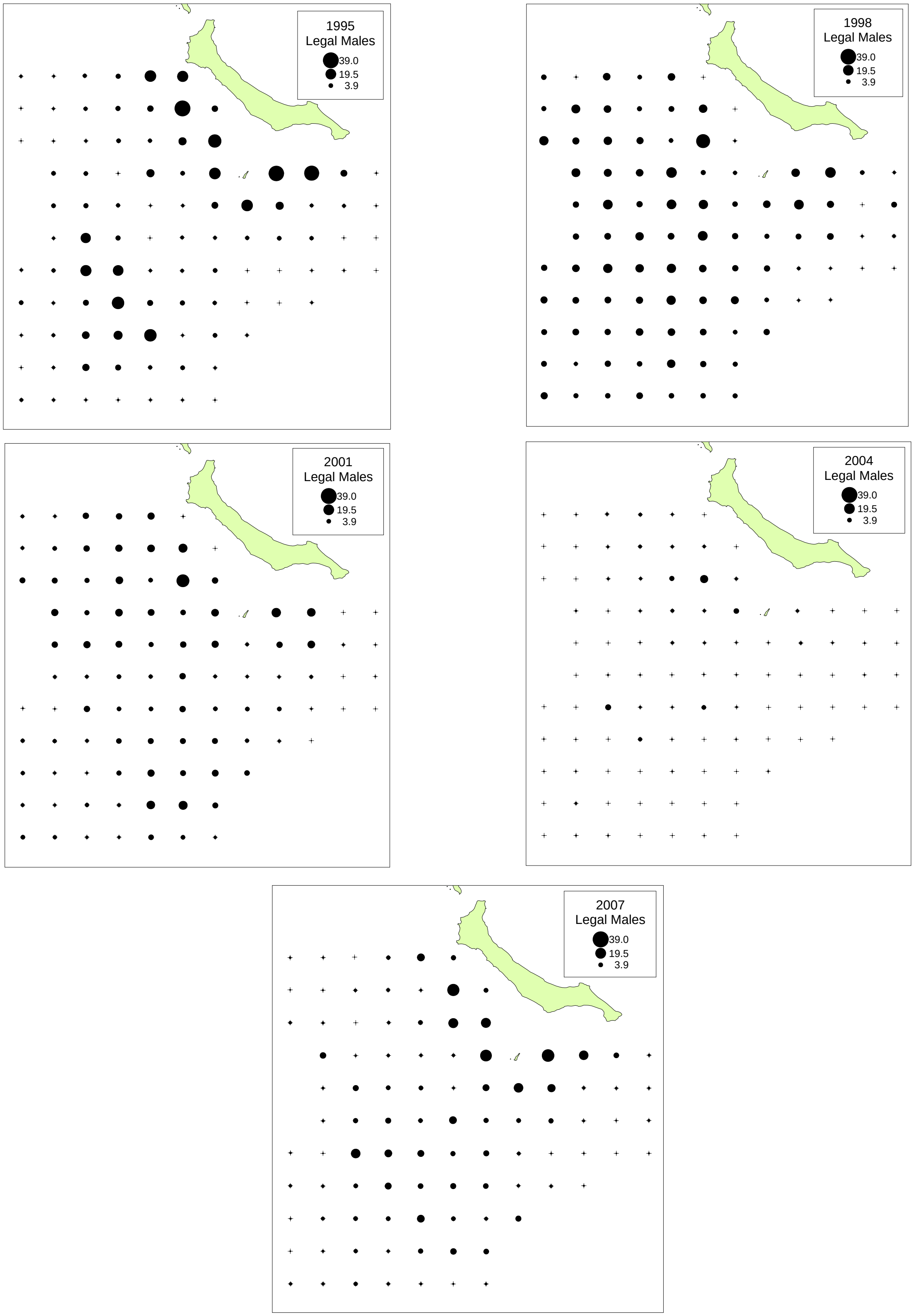


Figure 7. Legal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

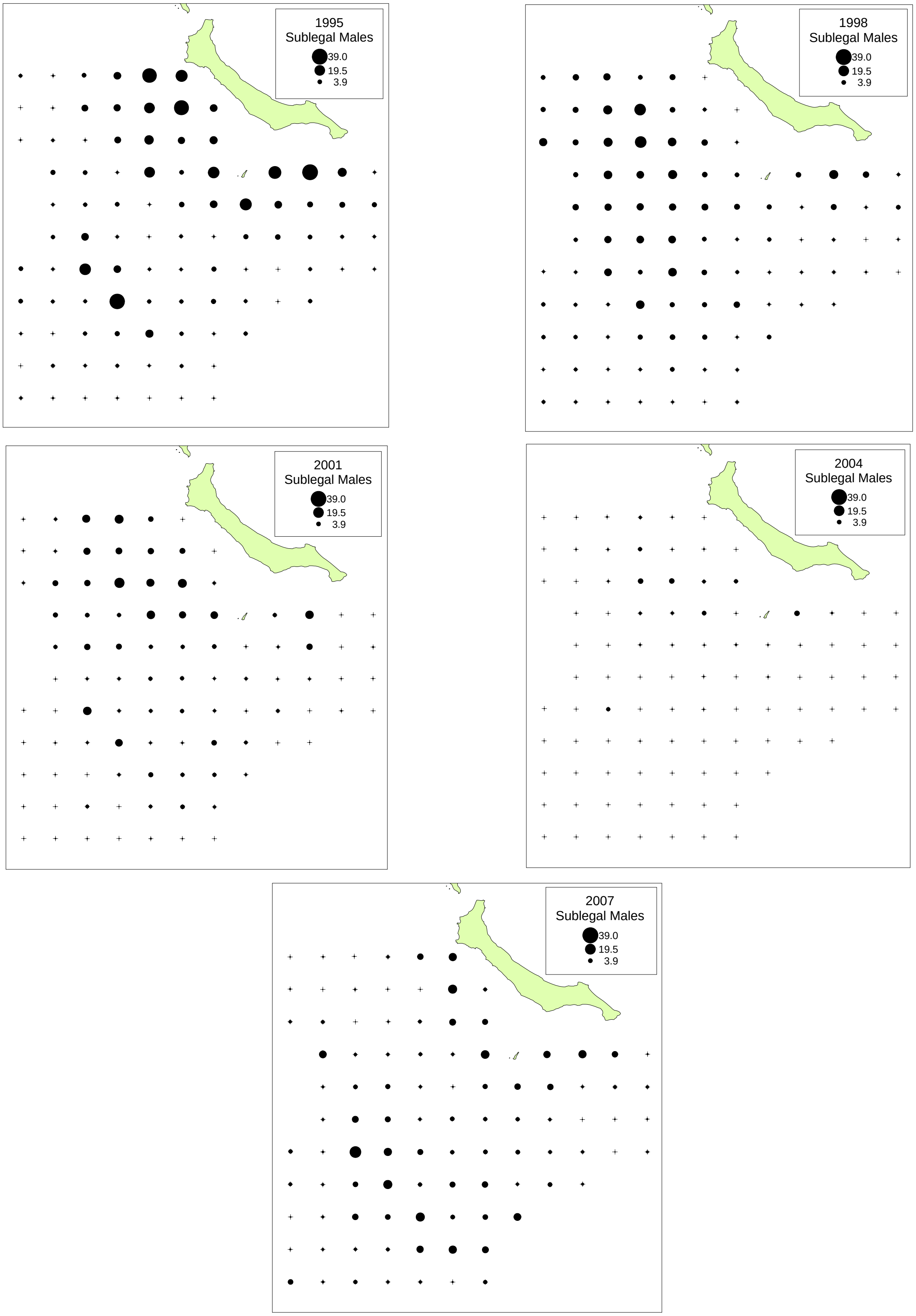


Figure 8. Sublegal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

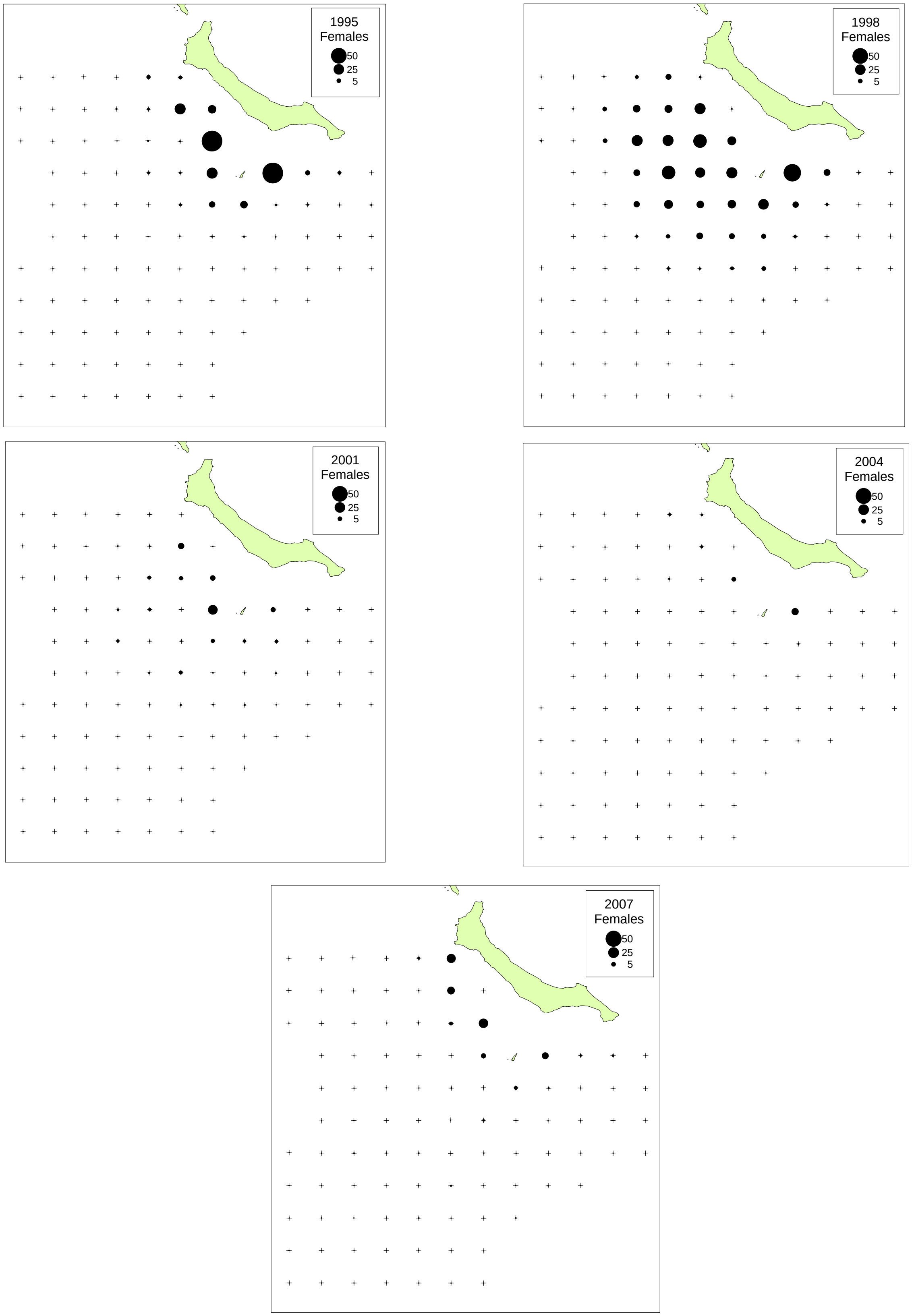
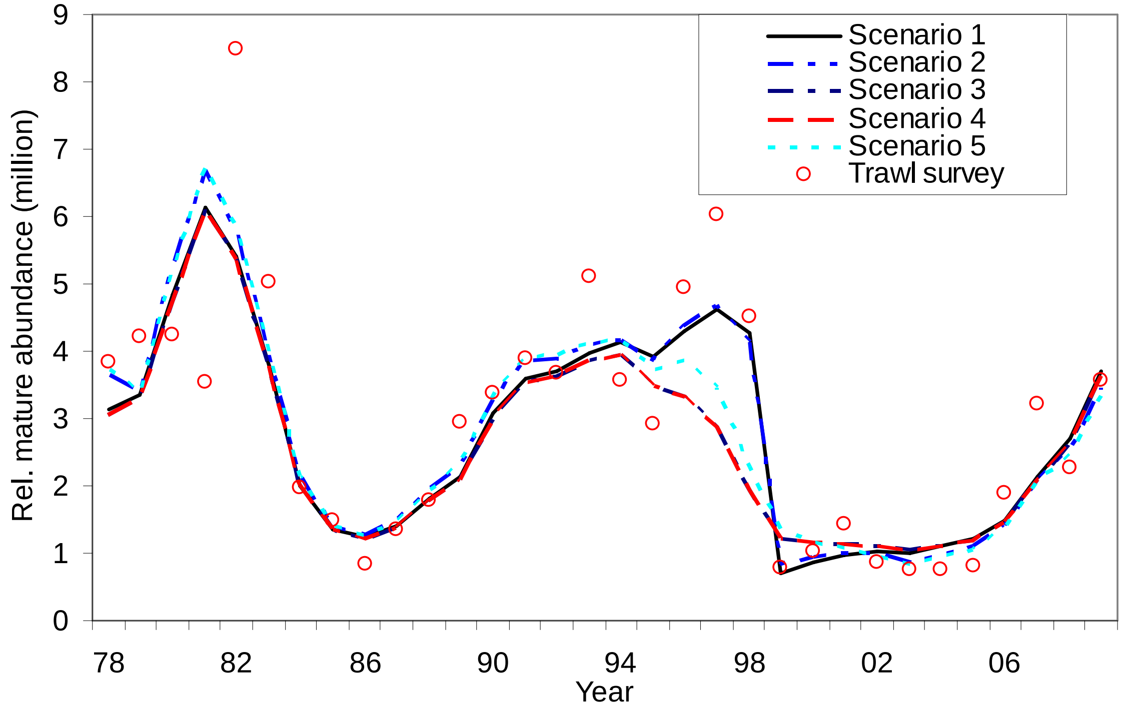


Figure 9. Female blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).



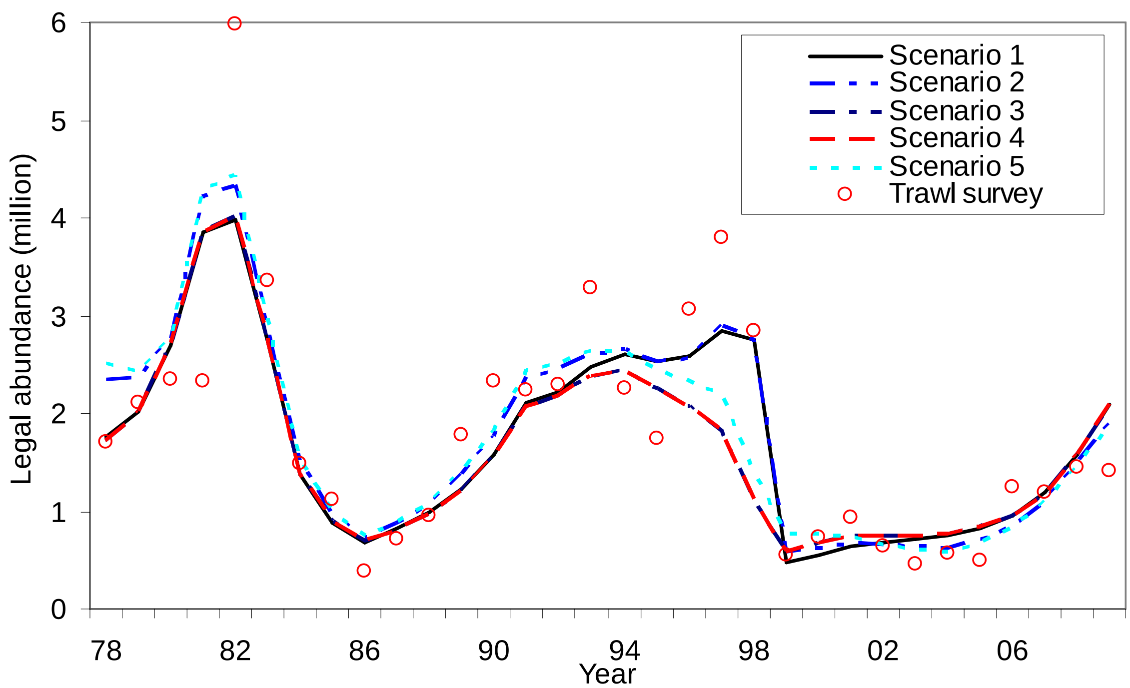


Figure 10. Comparison of relative mature male (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with five scenarios of the catch-survey analysis and trawl survey abundance.

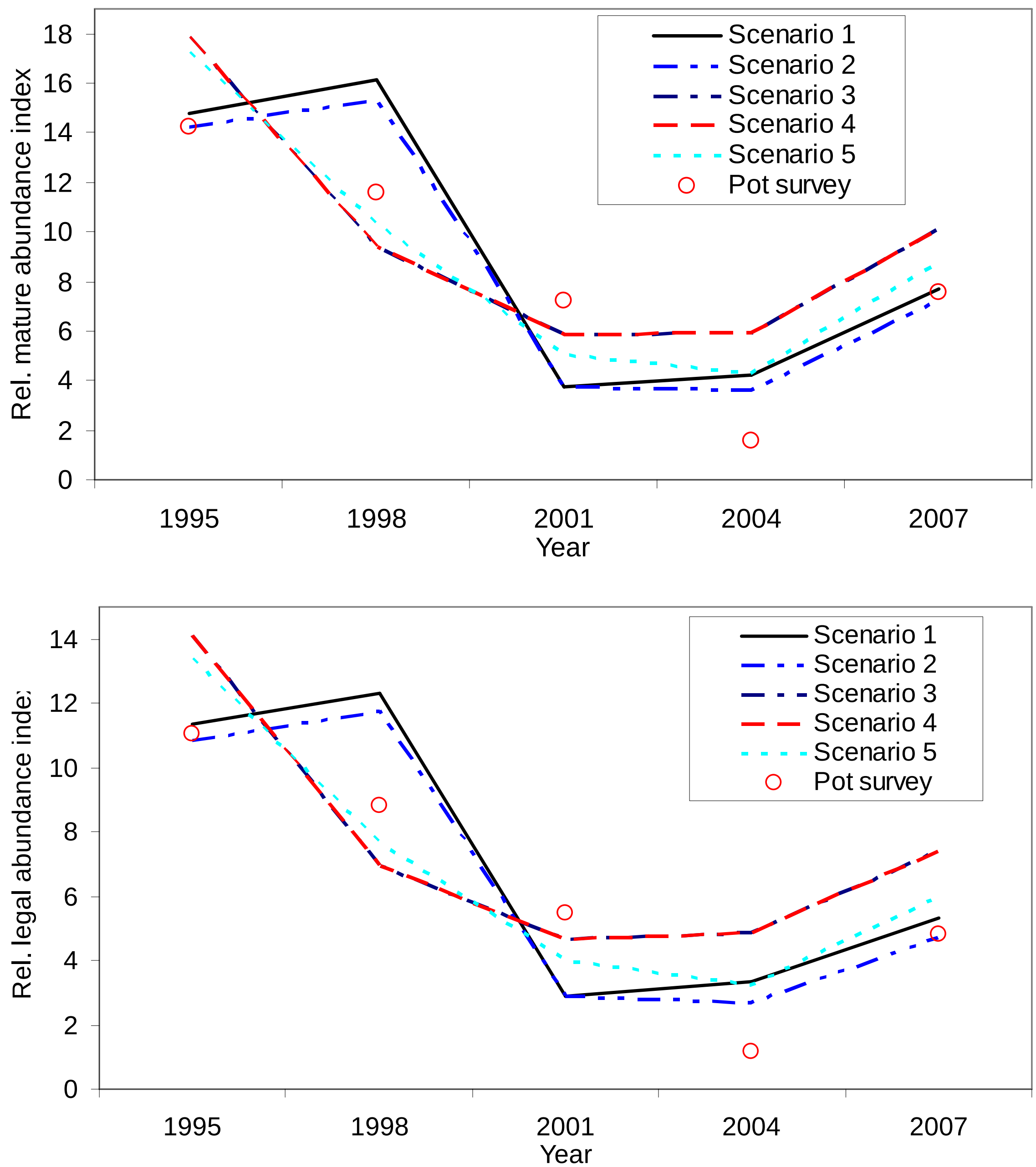
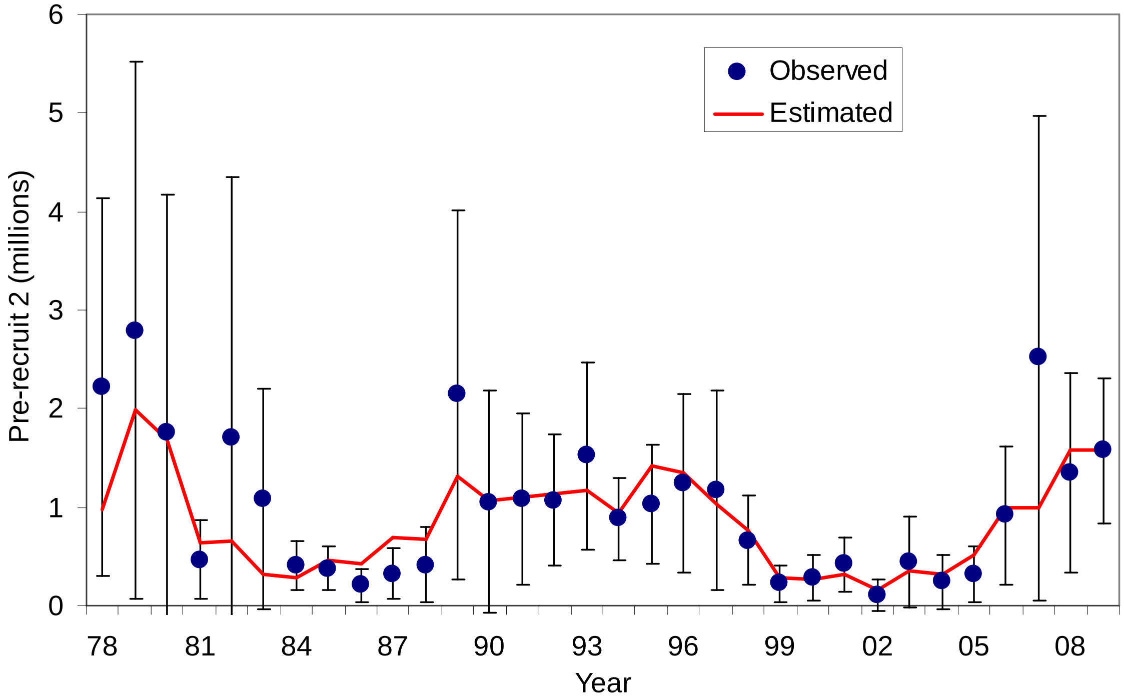


Figure 11. Comparison of relative mature male (upper plot) and legal male abundance (lower plot) estimates of St. Matthew Island male blue king crab for five scenarios of the catch-survey analysis and the pot survey CPUE abundance index.



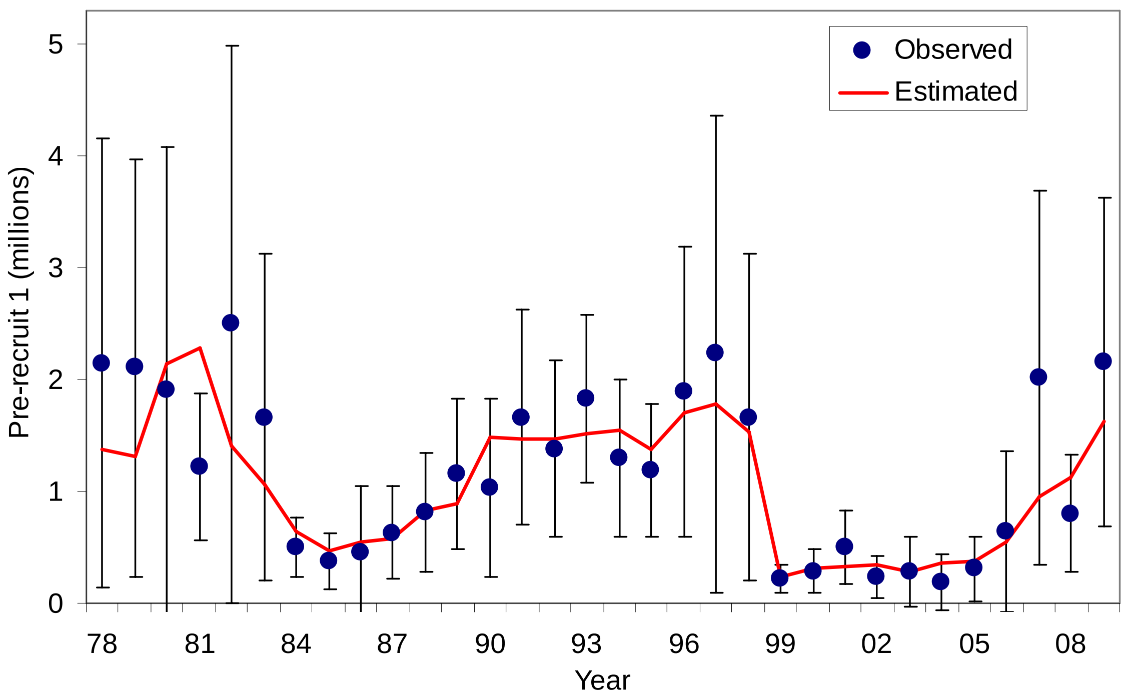


Figure 12a. Comparison of pre-recruit 1 and pre-recruit 2 (millions of crab) of trawl surveys with 95% confidence intervals to model estimates with scenario (1) of fixed both *M*=0.18 and *Q*=1.

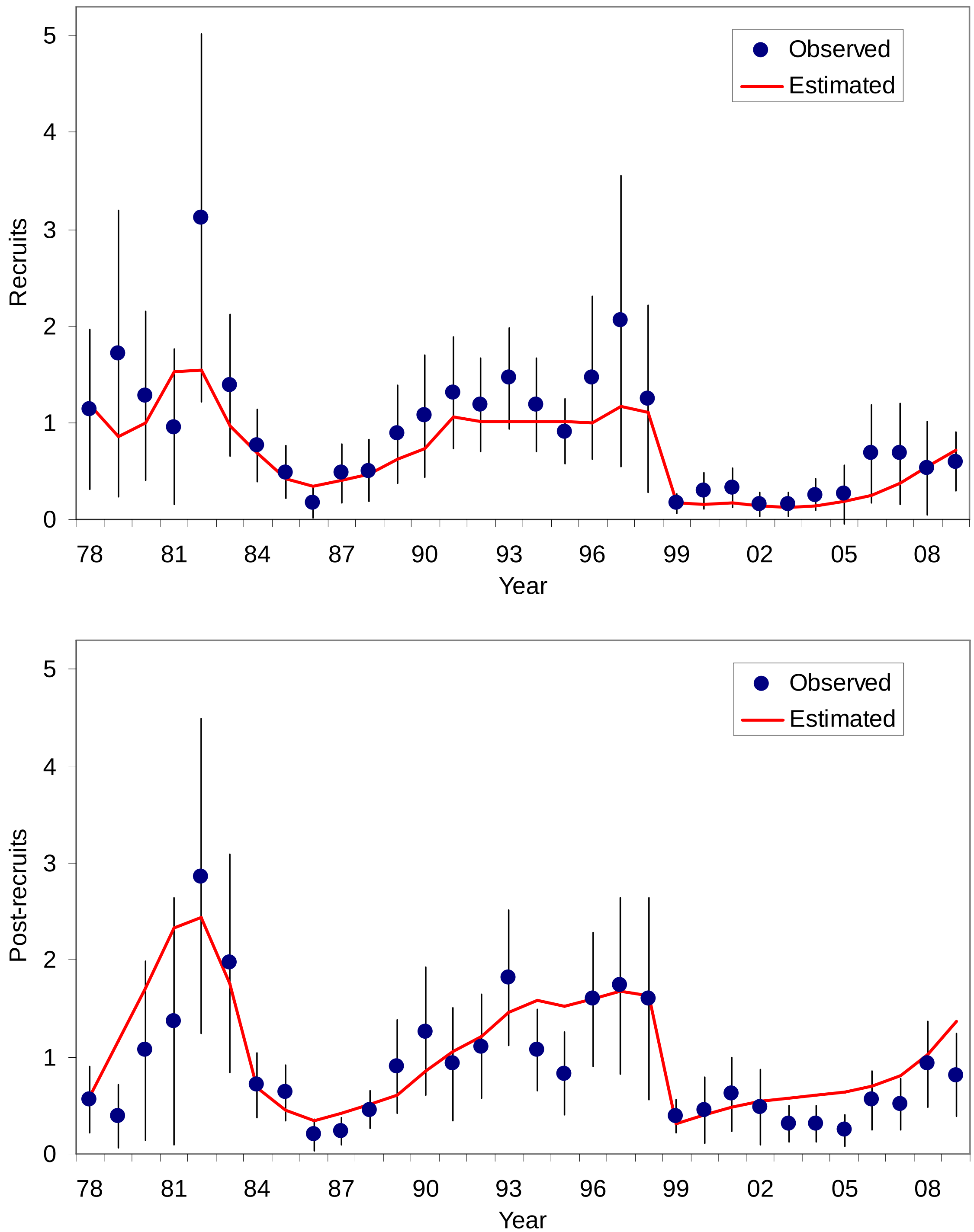
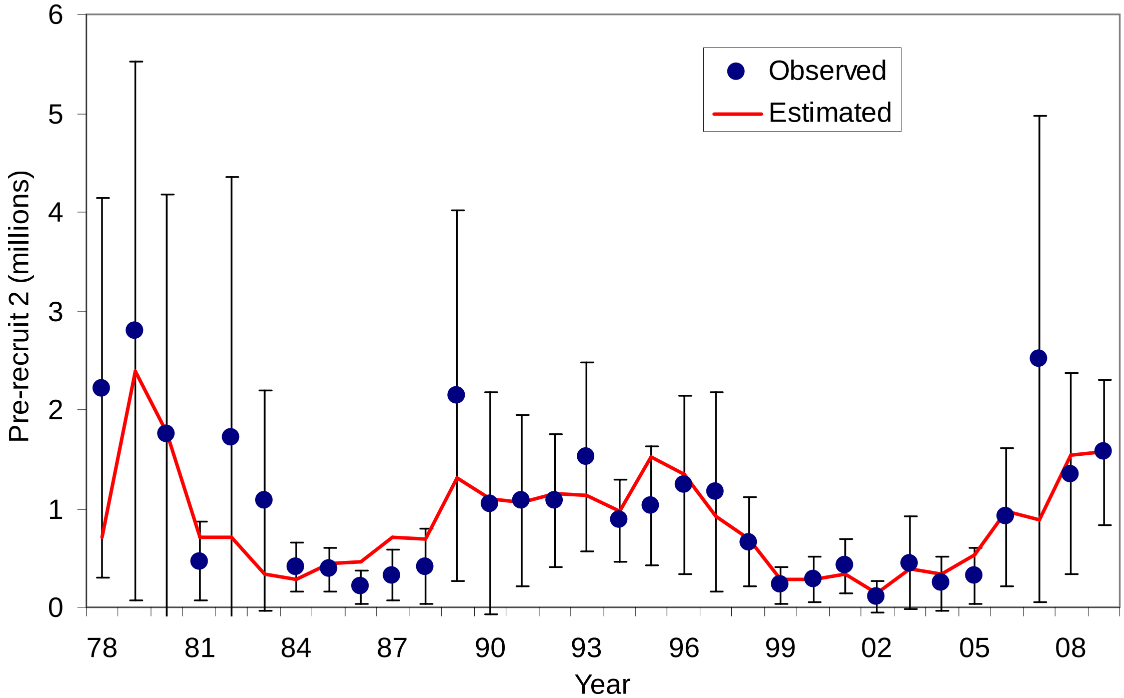


Figure 12b. Comparison of recruits and post-recruits (millions of crab) of trawl surveys with 95% confidence intervals to model estimates with scenario (1) of fixed both M=0.18 and Q=1.



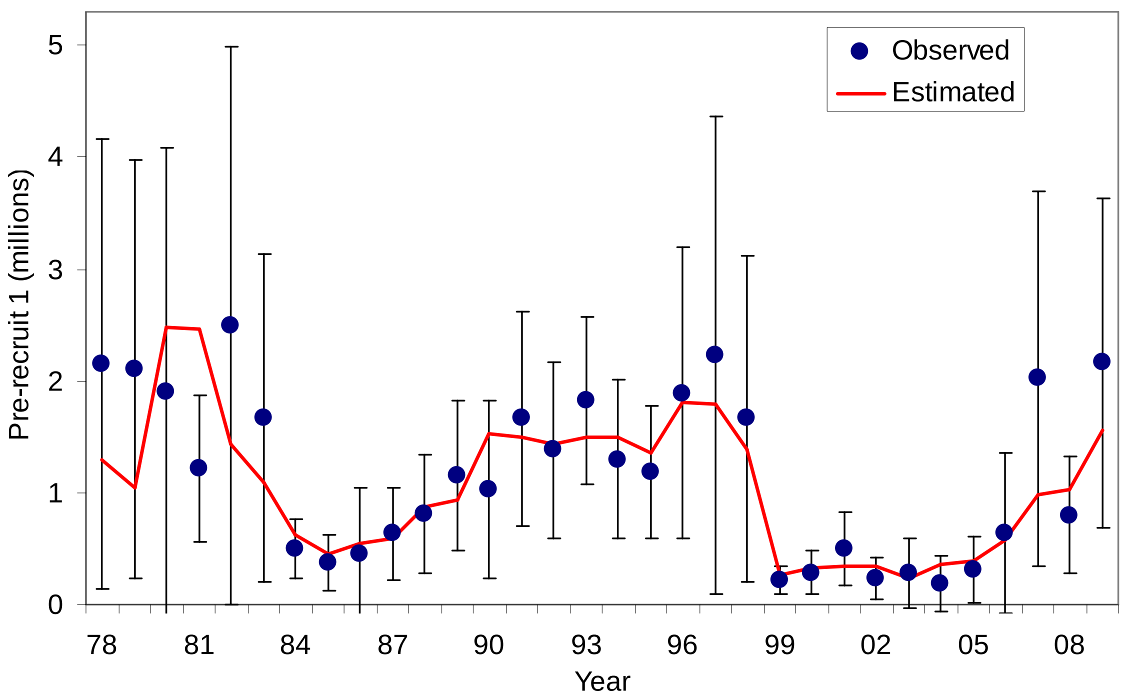


Figure 13a. Comparison of pre-recruit 1 and pre-recruit 2 (millions of crab) of trawl surveys with 95% confidence intervals to model estimates with scenario (2) of fixed *Q*=1 and estimating *M*.

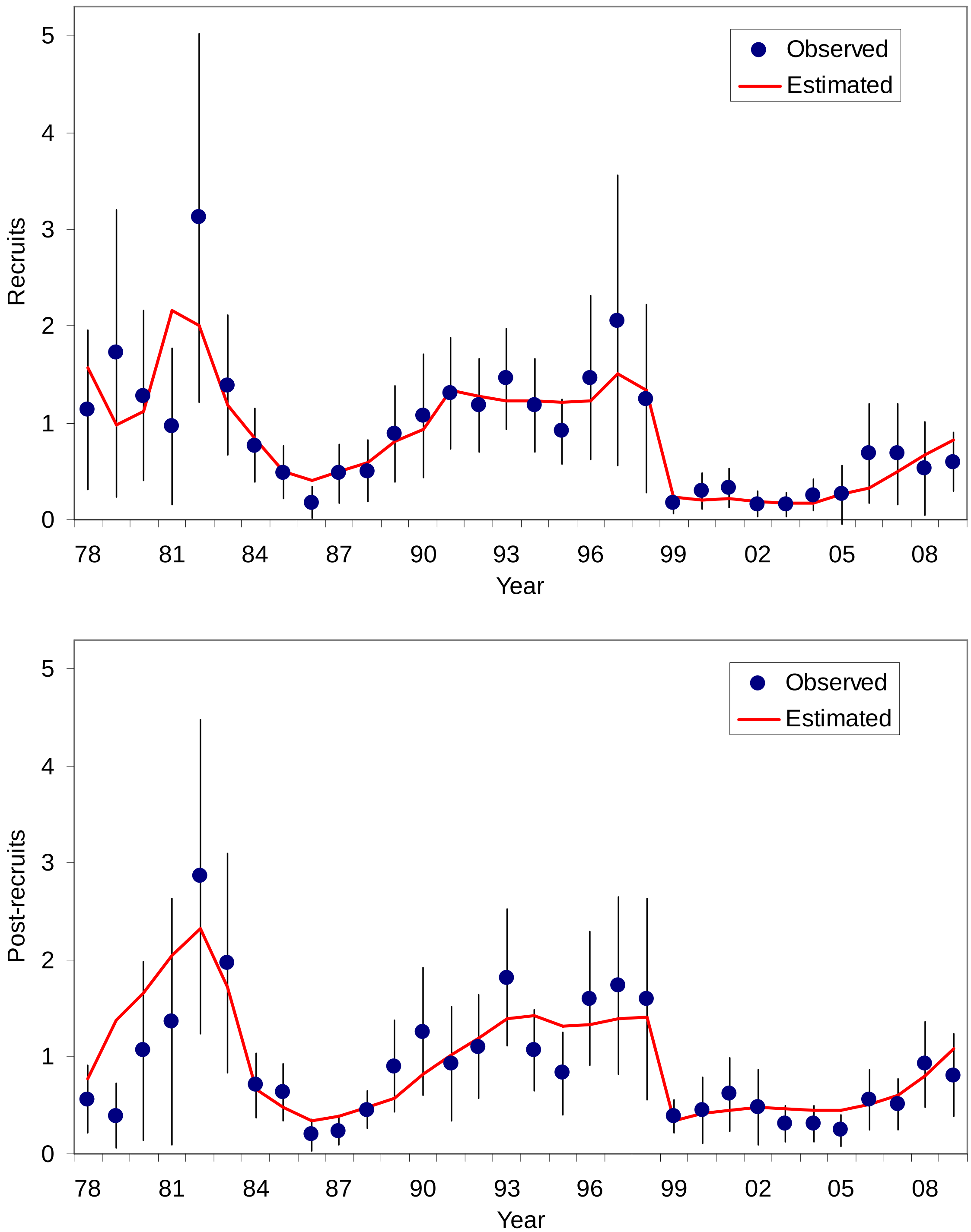


Figure 13b. Comparison of recruits and post-recruits (millions of crab) of trawl surveys with 95% confidence intervals to model estimates with scenario (2) of fixed *Q*=1 and estimating *M*.

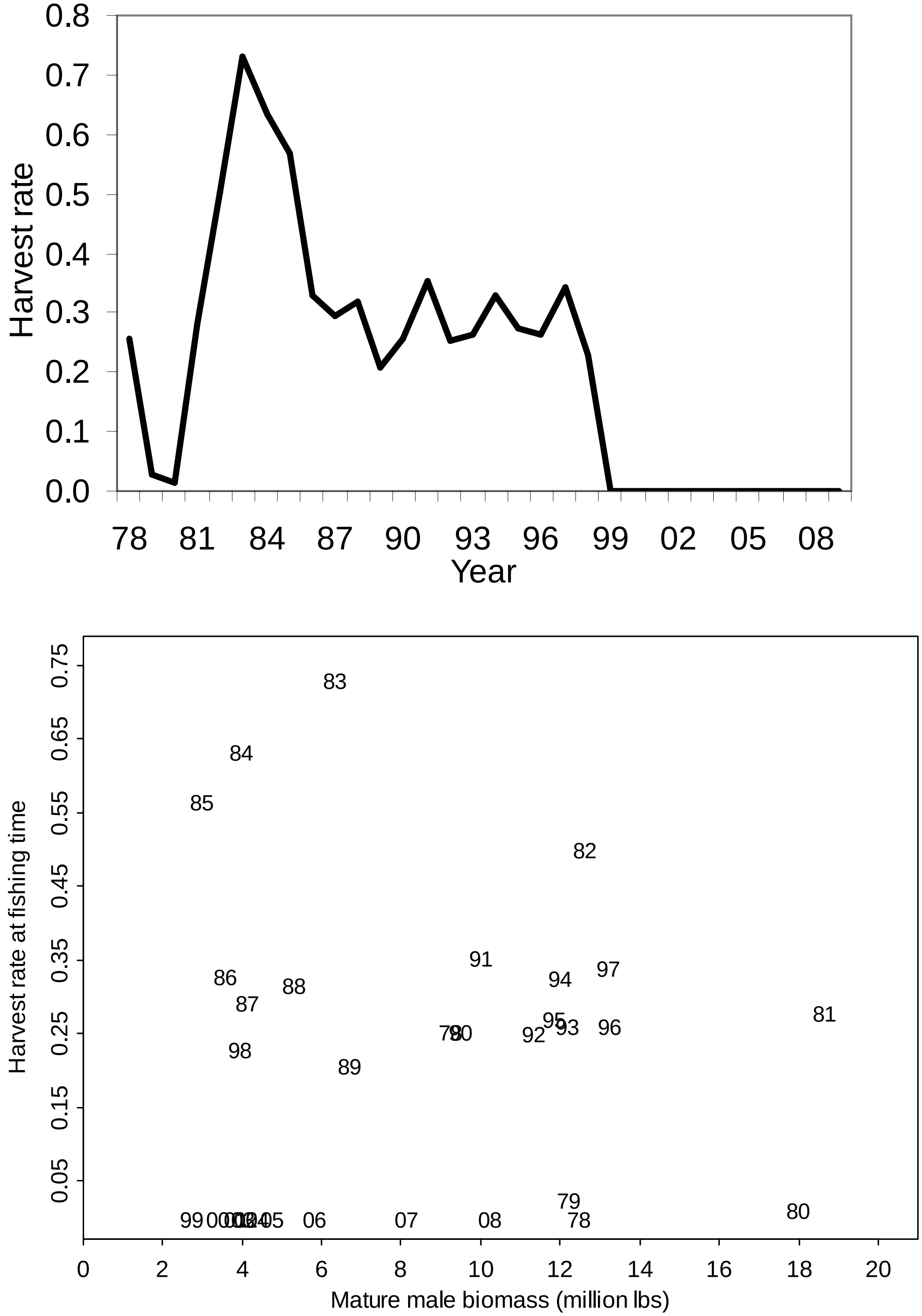


Figure 14. Estimated harvest rates (upper plot) and relationship between harvest rate and mature male biomass (lower plot) of St. Matthew Island blue king crab with scenario (1) of fixed *M*=0.18 and *Q*=1.0.

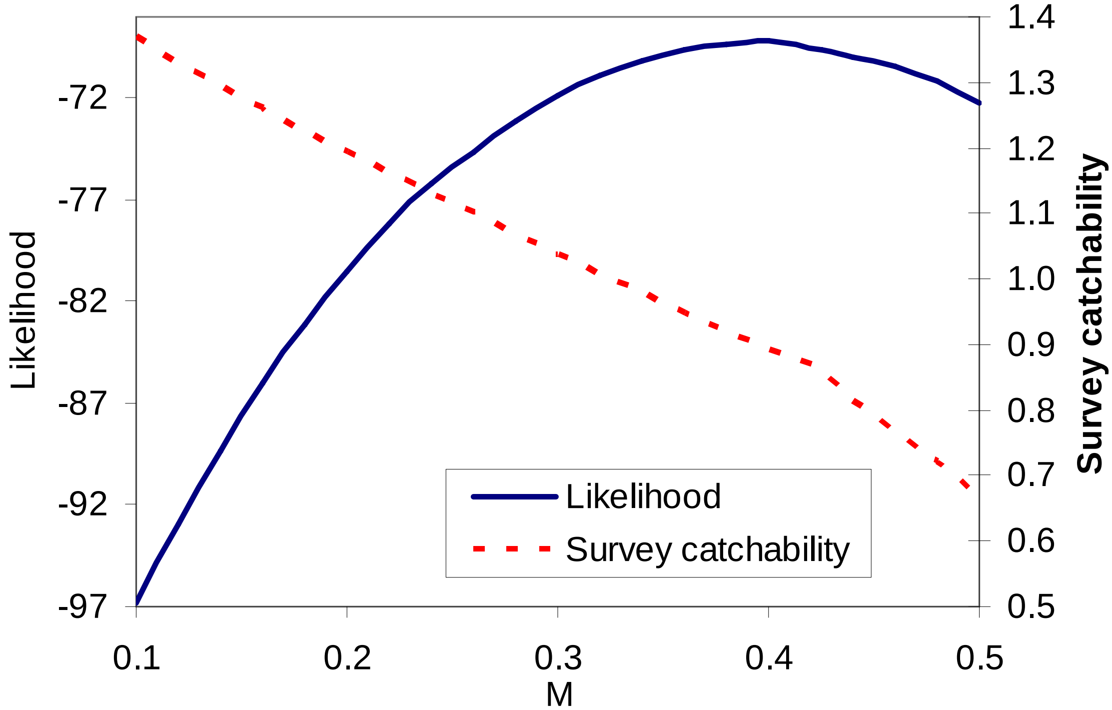


Figure 15. Relationships among natural mortality, trawl survey catchability and likelihood with a scenario of estimating natural mortality in 1999 and trawl survey catchability (similar to scenario 3). This figure has not been updated with the data in 2009.

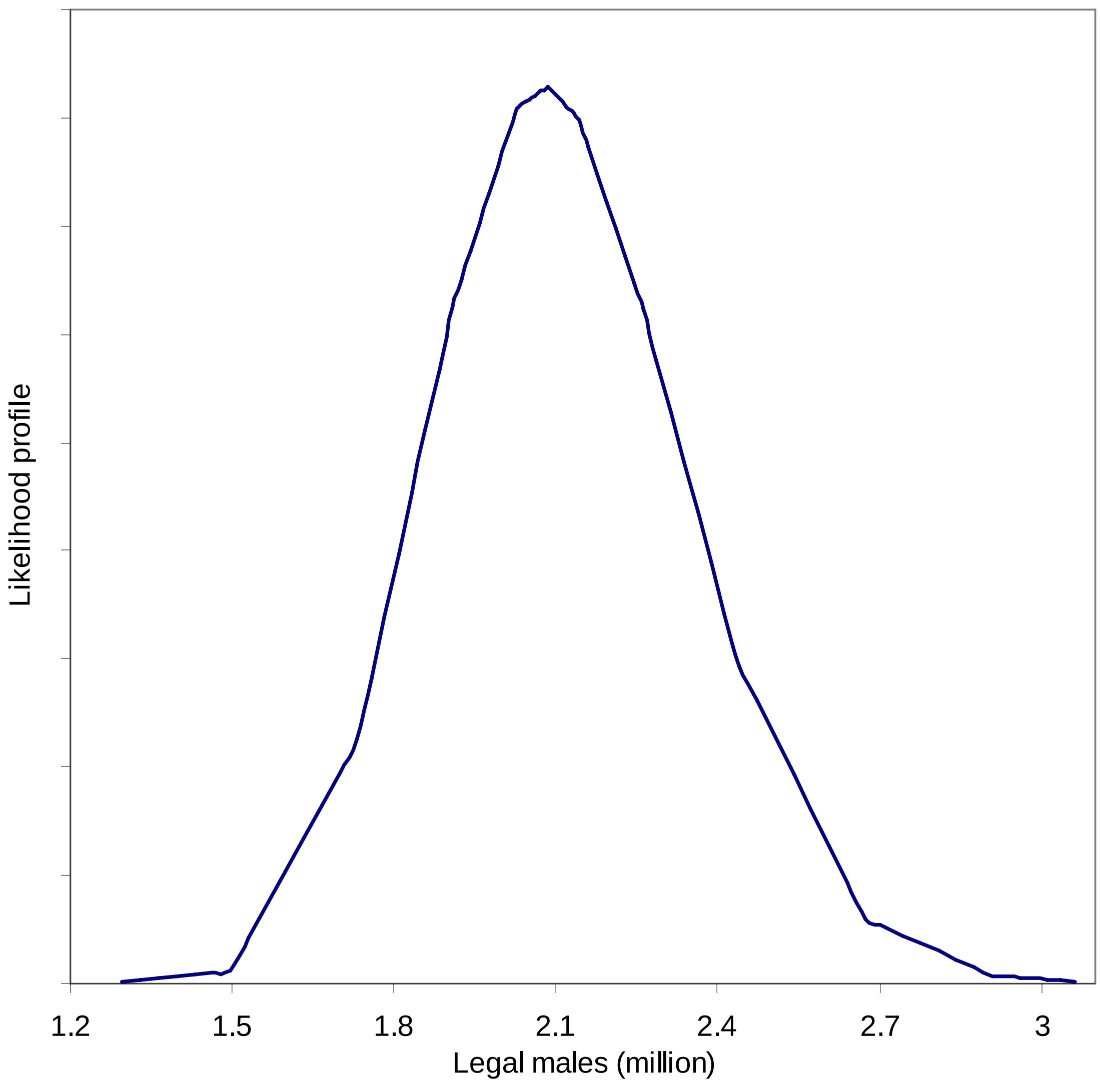
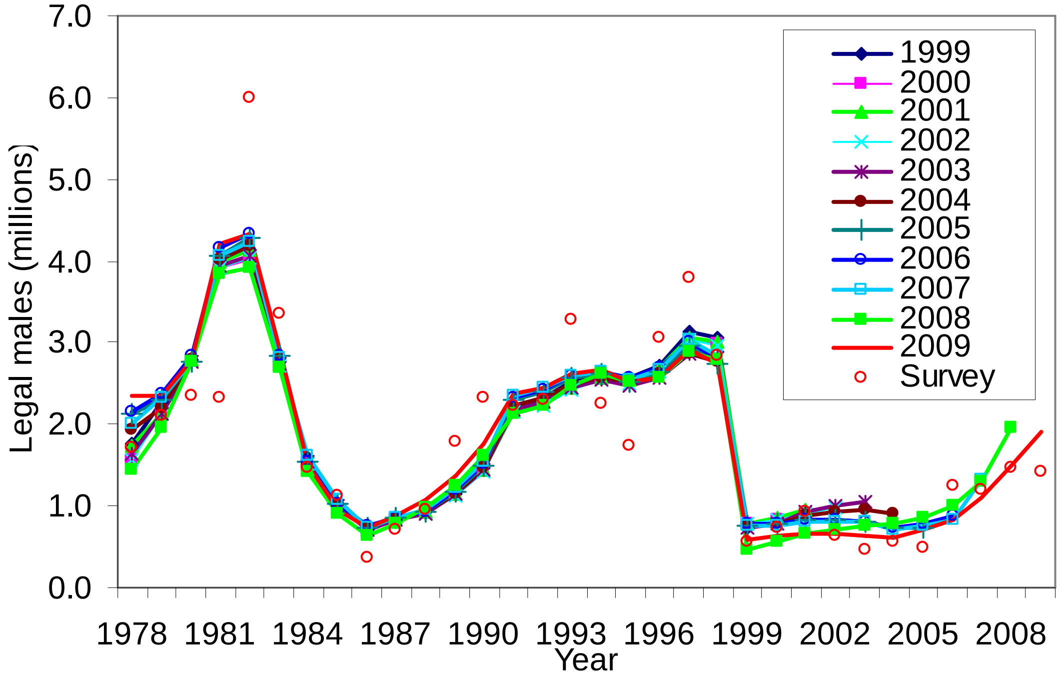


Figure 16. Likelihood profile for estimated legal male abundance in 2009 with scenario 1.



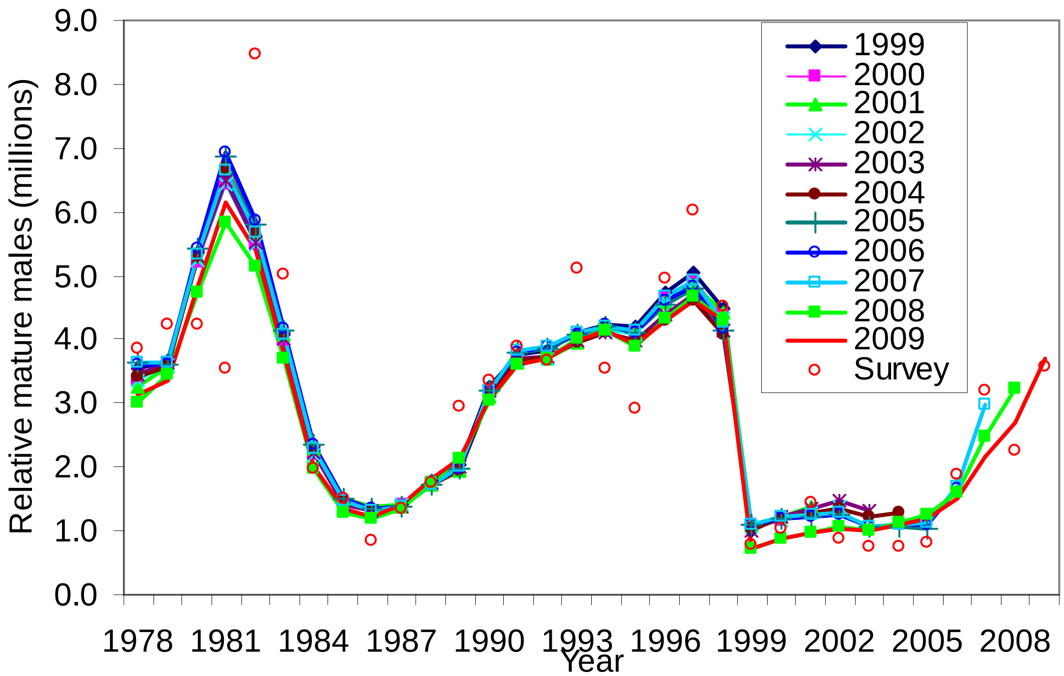


Figure 17. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2009 made with terminal years 1999-2009. These are historical results. Legend shows the year in which the assessment was conducted.

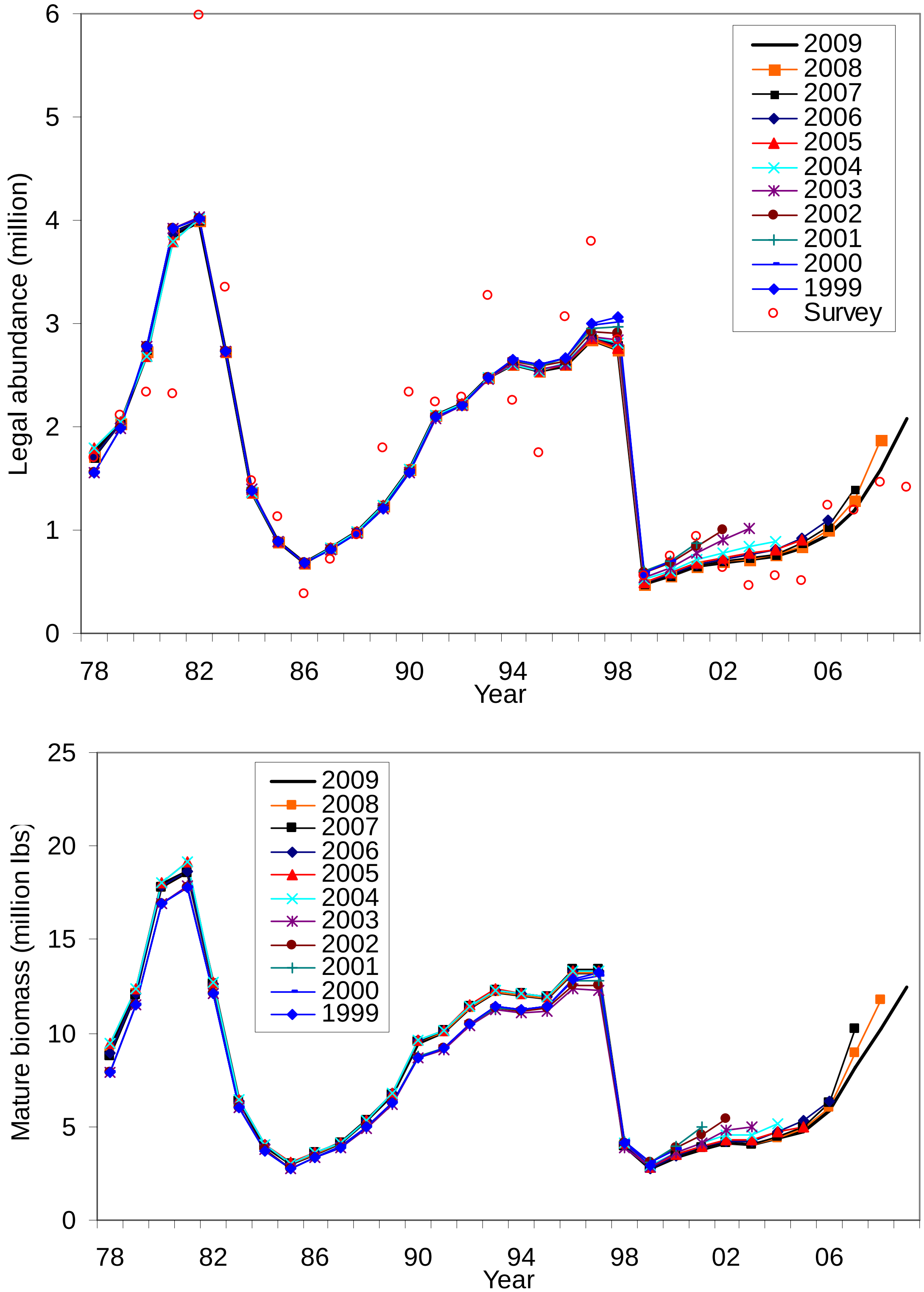


Figure 18. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2009 made with terminal years 1999-2009. These are results of the 2009 model with a fixed *M*=0.18 and *Q*=1.0 (scenario 1). Legend shows the year in which the assessment was conducted.

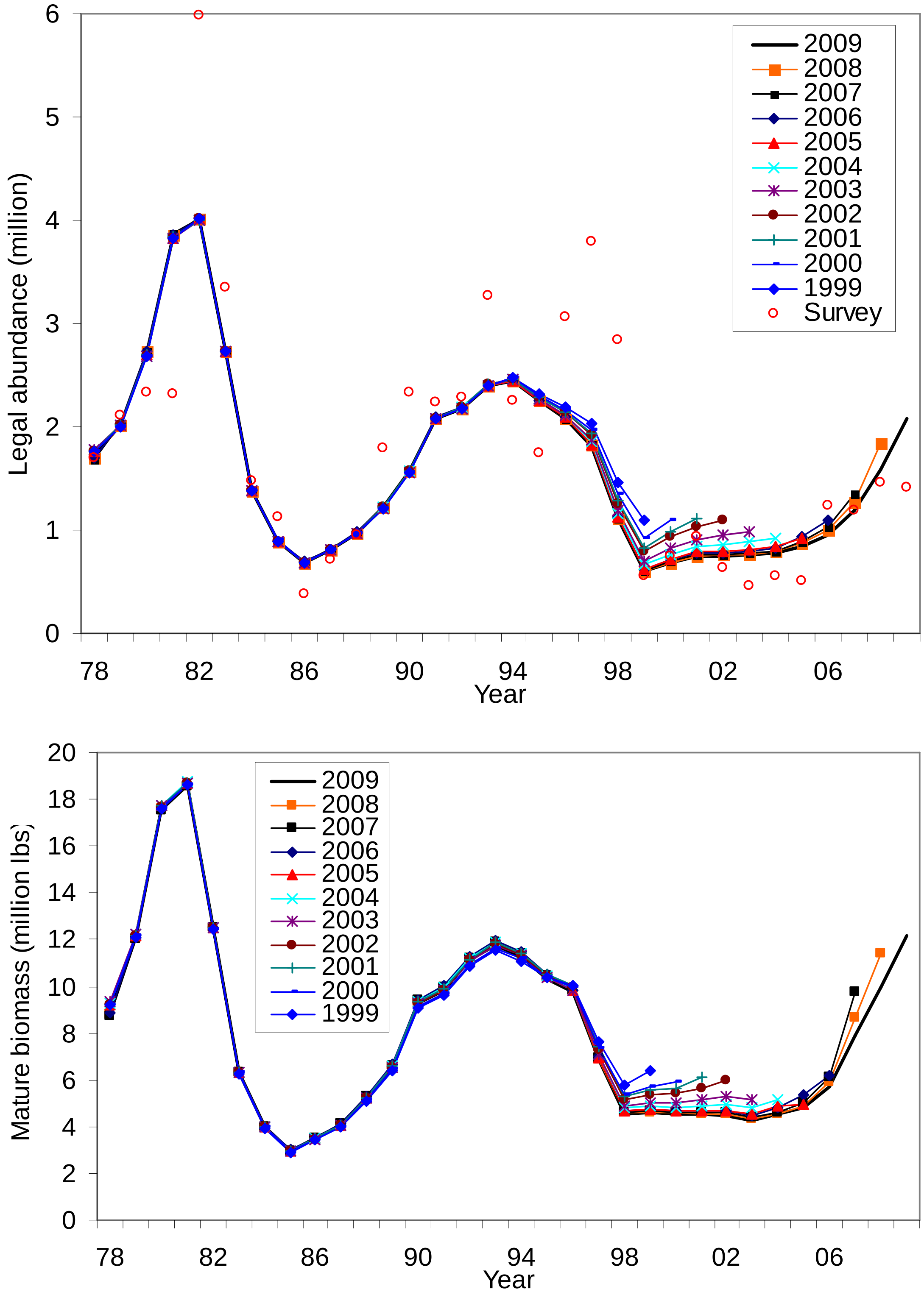


Figure 19. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2009 made with terminal years 1999-2009. These are results of the 2009 model with a fixed *M*=0.18 and *Q*=1.0 (scenario 4). Legend shows the year in which the assessment was conducted.

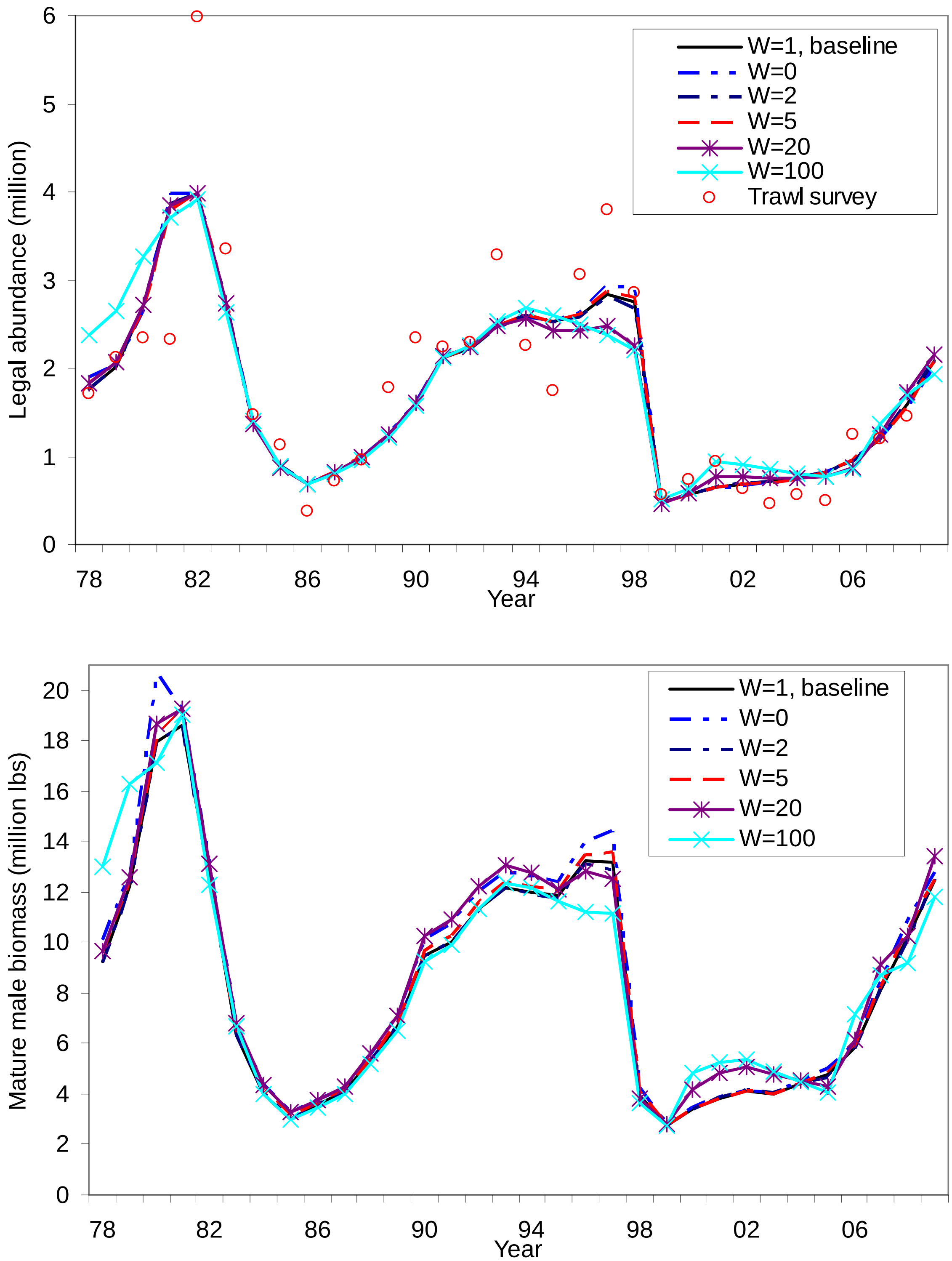
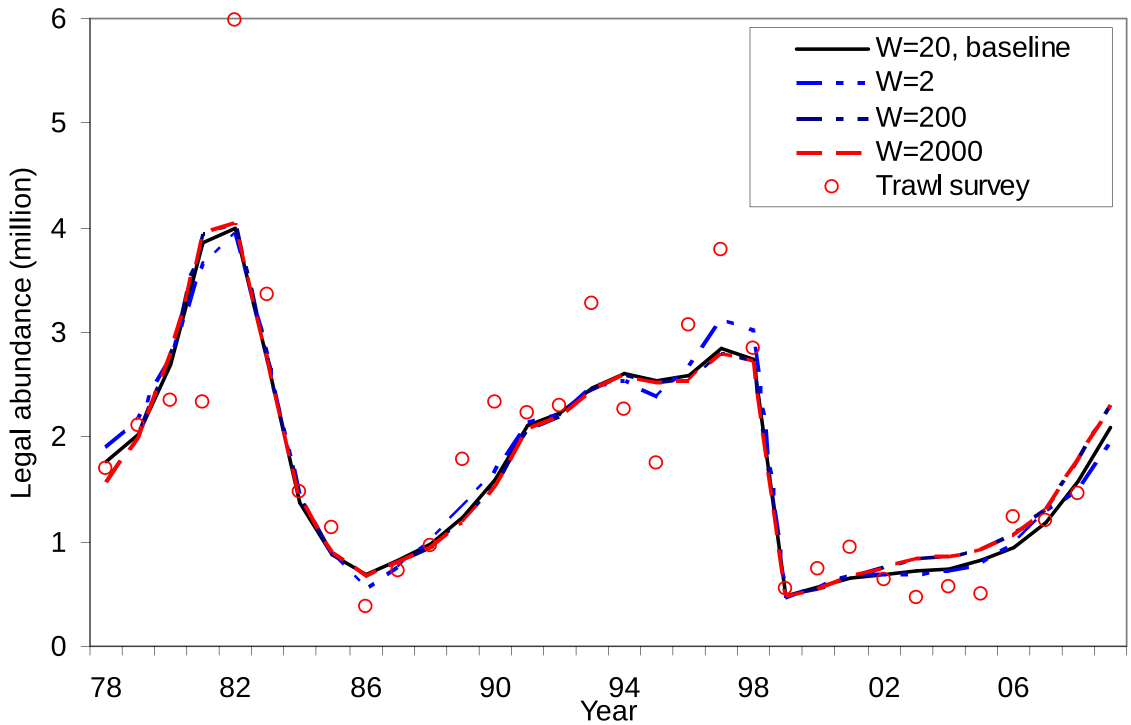


Figure 20. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2009 with different weights on pot survey index for model scenario 1. W=1 is equal weight, the base scenario.



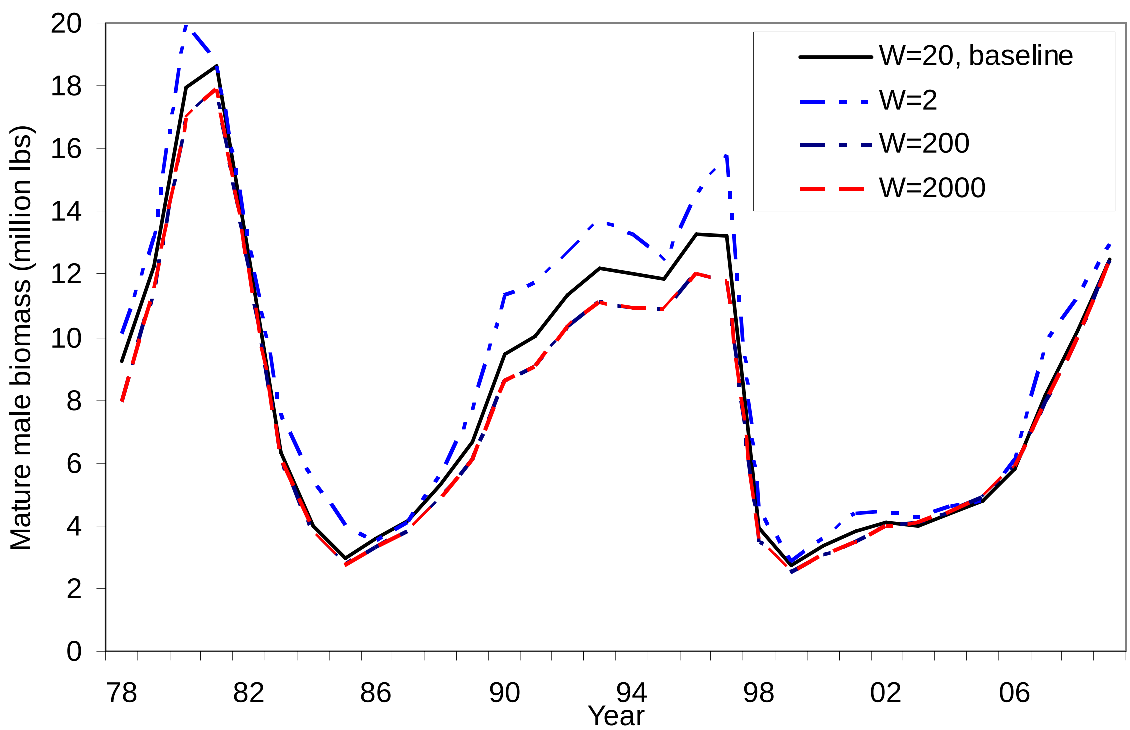


Figure 21. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2009 with different weights on molting probability changes for model scenario 1. W=20 is the base scenario.

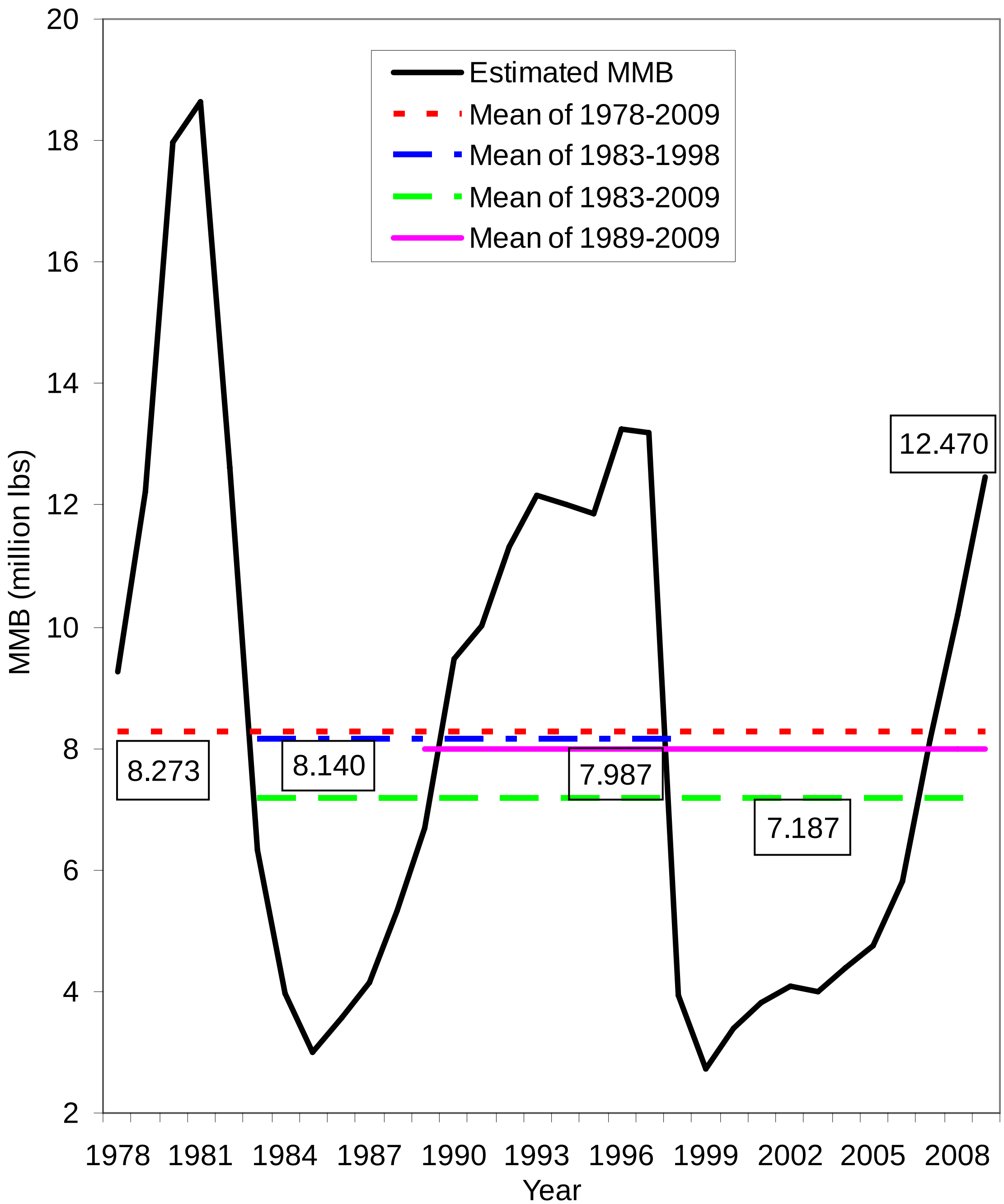


Figure 22. Comparison of estimated mean mature male biomasses during different periods for St. Matthew Island blue king crab. The model was with a fixed *M*=0.18 and *Q*=1.0 (scenario 1). $\gamma = 1$ was used for the 2009 fishery to project mature male biomass in 2009.

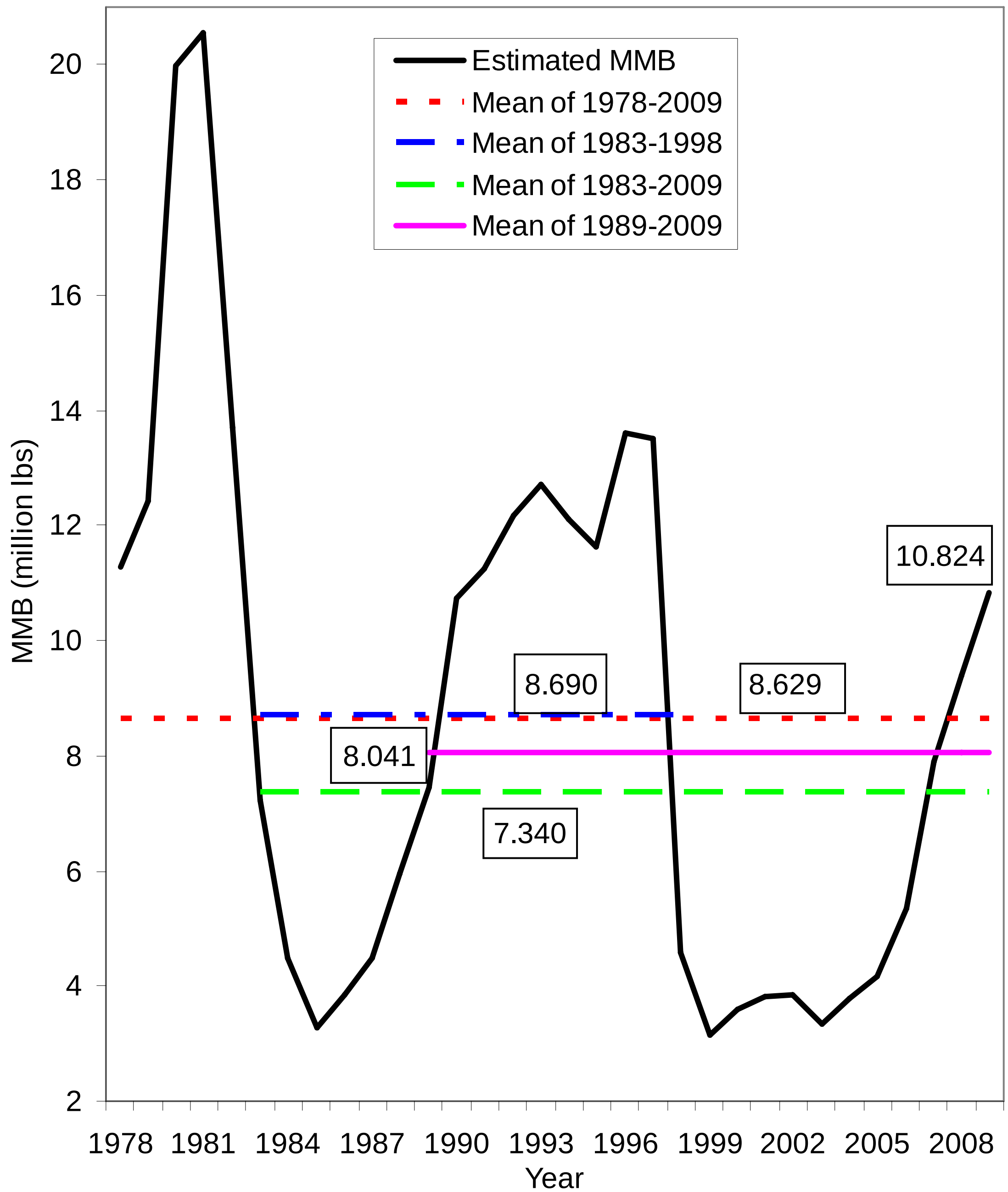


Figure 23. Comparison of estimated mean mature male biomasses during different periods for St. Matthew Island blue king crab. The model was with a fixed Q=1.0 and estimating M (scenario 2). $\gamma = 1$ was used for the 2009 fishery to project mature male biomass in 2009.

Norton Sound Red King Crab Stock Assessment in 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.

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 southeast side of the Sound, off shore 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 of 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:

$$\begin{aligned} N_{s,l,t+1} &= (N_{w,l,t} - C_{w,t}\,P_{w,n,l,t} - C_{p,t}\,P_{p,n,l,t})\,e^{-0.417 M_l}, \\ O_{s,l,t+1} &= (O_{w,l,t} - C_{w,t}\,P_{w,o,l,t} - C_{p,t}\,P_{p,o,l,t})\,e^{-0.417 M_l}, \end{aligned} \qquad (1)$$

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:

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} [G_{l',l}((N_{s,l',t} + O_{s,l',t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l',t} + P_{s,o,l',t}))m_{l'} e^{-(0.583-y_t)M_l}] + R_{l,t}, \qquad (2)$$

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:

$$O_{w,l,t} = [(N_{s,l,t} + O_{s,l,t})e^{-y_t M_l} - C_{s,t}(P_{s,n,l,t} + P_{s,o,l,t})](1 - m_l)e^{-(0.583-y_t)M_l}. \qquad (3)$$

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:

$$m_l = 1 - \frac{1}{1 + e^{-\alpha(\iota-\beta)}}, \qquad (4)$$

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:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2). \qquad (5)$$

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:

$$R_{1,t} = r\,R_t\,,\; R_{2,t} = (1-r)\,R_t\,, \tag{6}$$

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:

$$P_{w,n,l,t} = N_{w,l,t} S_{w,l} L_l \,/ \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l\,],$$
$$P_{w,o,l,t} = O_{w,l,t} S_{w,l} L_l \,/ \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l\,], \tag{7}$$

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 $l > 2$:

$$P_{p,n,l,t} = N_{w,l,t} S_{w,l} \,/ \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}\,],$$
$$P_{p,o,l,t} = O_{w,l,t} S_{w,l} \,/ \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}\,]. \tag{8}$$

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:

$$P_{s,n,l,t} = N_{s,l,t} S_{s,l} L_l \,/\, A_t\,,$$
$$P_{s,o,l,t} = O_{s,l,t} S_{s,l} L_l \,/\, A_t\,, \tag{9}$$

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:

$$S_{s,l} = \frac{1}{1 + e^{-\phi(l-\omega)}}. \tag{10}$$

$S_{s,l}$ 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:

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t})S_{s,l} L_l]. \tag{11}$$

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:

$$f_t = C_t \,/\, [q(A_t - 0.5C_t)]. \tag{12}$$

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:

$$\begin{aligned} P_{b,n,l,t} &= N_{s,l,t} S_{s,l}(1-L_l) \,/\, \sum_l [(N_{s,l,t} + O_{s,l,t})S_{s,l}(1-L_l)], \\ P_{b,o,l,t} &= O_{s,l,t} S_{s,l}(1-L_l) \,/\, \sum_l [(N_{s,l,t} + O_{s,l,t})S_{s,l}(1-L_l)]. \end{aligned} \tag{13}$$

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:

$$\begin{aligned} P_{sf,n,l,t} &= N_{s,l,t} S_{s,l} \,/\, \sum_l [(N_{s,l,t} + O_{s,l,t})S_{s,l}], \\ P_{sf,o,l,t} &= O_{s,l,t} S_{s,l} \,/\, \sum_l [(N_{s,l,t} + O_{s,l,t})S_{s,l}]. \end{aligned} \tag{14}$$

Estimated length/shell condition compositions of summer pot survey abundance were:

$$\begin{aligned} P_{sp,n,l,t} &= N_{s,l,t} S_{sp,l} \,/\, \sum_l [(N_{s,l,t} + O_{s,l,t})S_{sp,l}], \\ P_{sp,o,l,t} &= O_{s,l,t} S_{sp,l} \,/\, \sum_l [(N_{s,l,t} + O_{s,l,t})S_{sp,l}] \end{aligned} \tag{15}$$

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:

$$\sum_{i=1}^{i=6}\sum_{t=1}^{t=n_i}\{K_{i,t}\sum_{l=1}^{l=6}[\hat{P}_{i,l,t}\, ln(P_{i,l,t}+\kappa)]\} - \sum_{i=1}^{i=2}\{W_i\sum_{k=1}^{k=2}\sum_{t=1}^{t=n_i}[ln(\hat{B}_{i,k,t}+\kappa) - ln(B_{i,k,t}+\kappa)]^2\}$$
$$-W_f\sum_{t=1}^{t=32}[ln(\hat{f}_t+\kappa) - ln(f_t+\kappa)]^2 - W_R\sum_{t=1}^{t=32}\tau_t^2, \qquad (16)$$

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.

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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)	Legal Male Population Est. lbs[b]	Commercial Harvest (lbs)[a] Open Access	Commercial Harvest (lbs)[a] CDQ	Total Number (incl. CDQ) Vessels	Total Number (incl. CDQ) Permits	Total Number (incl. CDQ) Landings	Total Number of Registered	Total Number of Pulls	Total Exvessel Price/lb	Total Fishery Value (millions $)	Season Length Days	Season Length 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.

Parameter	Value		Parameter	Value
N_{76}	5.5809		q_1	1.6031E-05
R_{76}	NA		q_2	1.5464E-05
R_{77}	0.0002		r	0.6098
R_{78}	0.0002		α	0.0891
R_{79}	0.2302		β	103.6272
R_{80}	1.0515		$S_{st,1}$	0.9000
R_{81}	0.4078		$S_{st,2}$	1.0000
R_{82}	0.7891		$S_{sp,1}$	0.8000
R_{83}	0.9727		$S_{sp,2}$	0.8000
R_{84}	0.5390		$S_{w,1}$	0.8000
R_{85}	0.2422		$S_{w,2}$	1.0000
R_{86}	0.5243		$S_{w,6}$	0.3078
R_{87}	0.5319		ϕ_1	0.0670
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

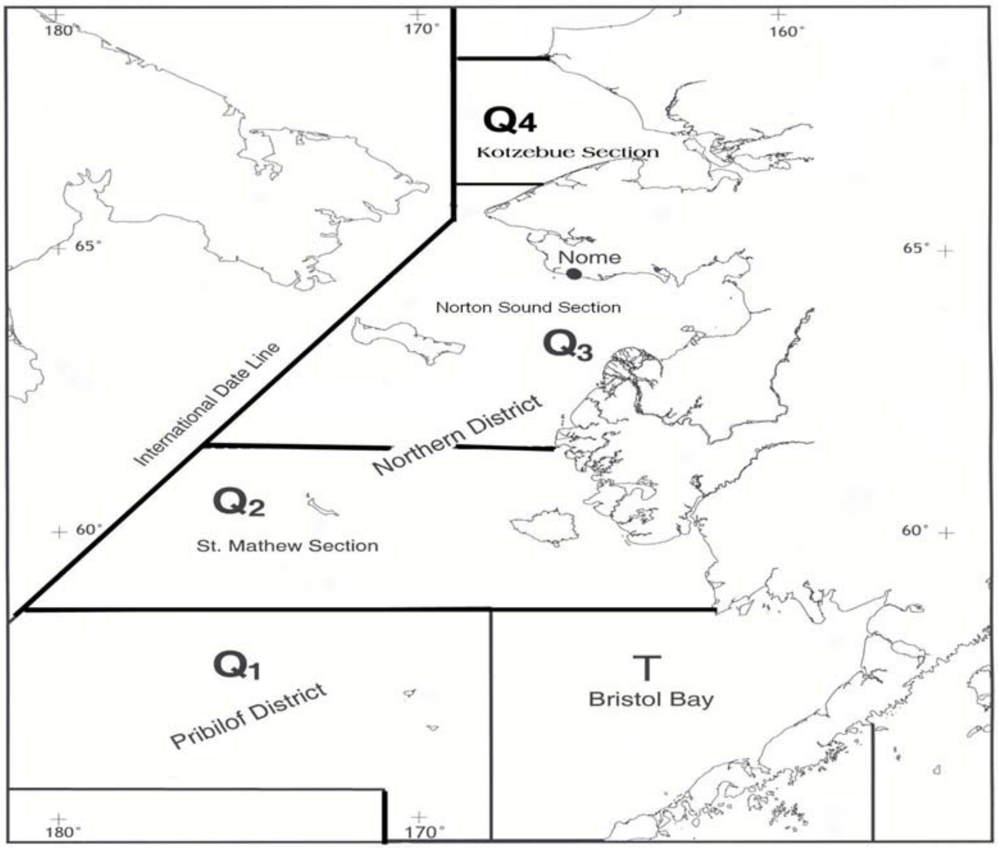


Figure 1. King crab fishing districts and sections of Statistical Area Q.

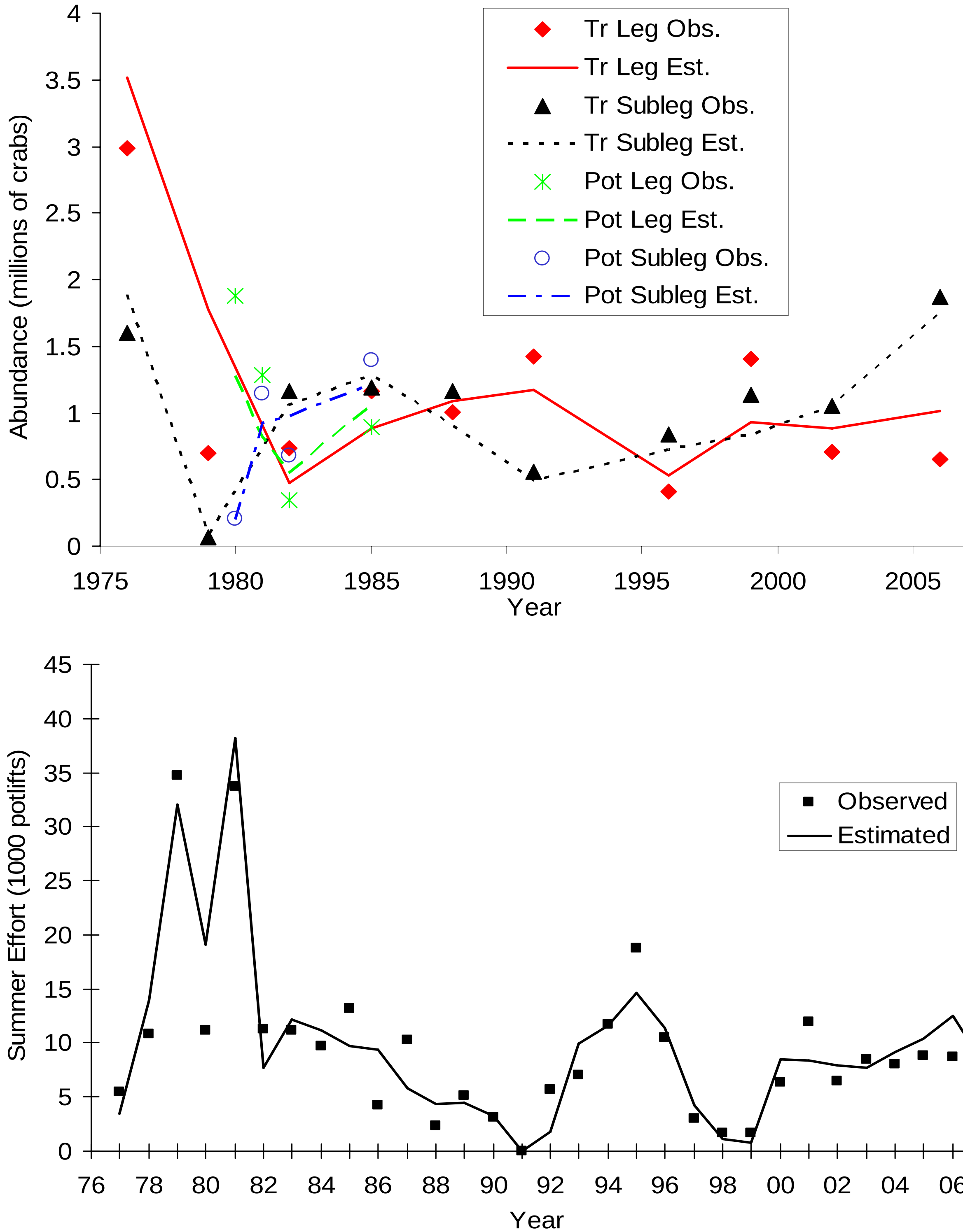


Figure 2. Comparison of observed and estimated Norton Sound red king crab abundances (legal and sublegal males) by summer trawl and pot surveys (upper plot) and observed and estimated summer fishing efforts (lower plot). "Tr" is trawl, "Leg" is legal, "Obs." is observed or survey catchable abundance, and "Est." is estimated catchable abundance. Catchable abundance is equal to population abundance times survey selectivities.

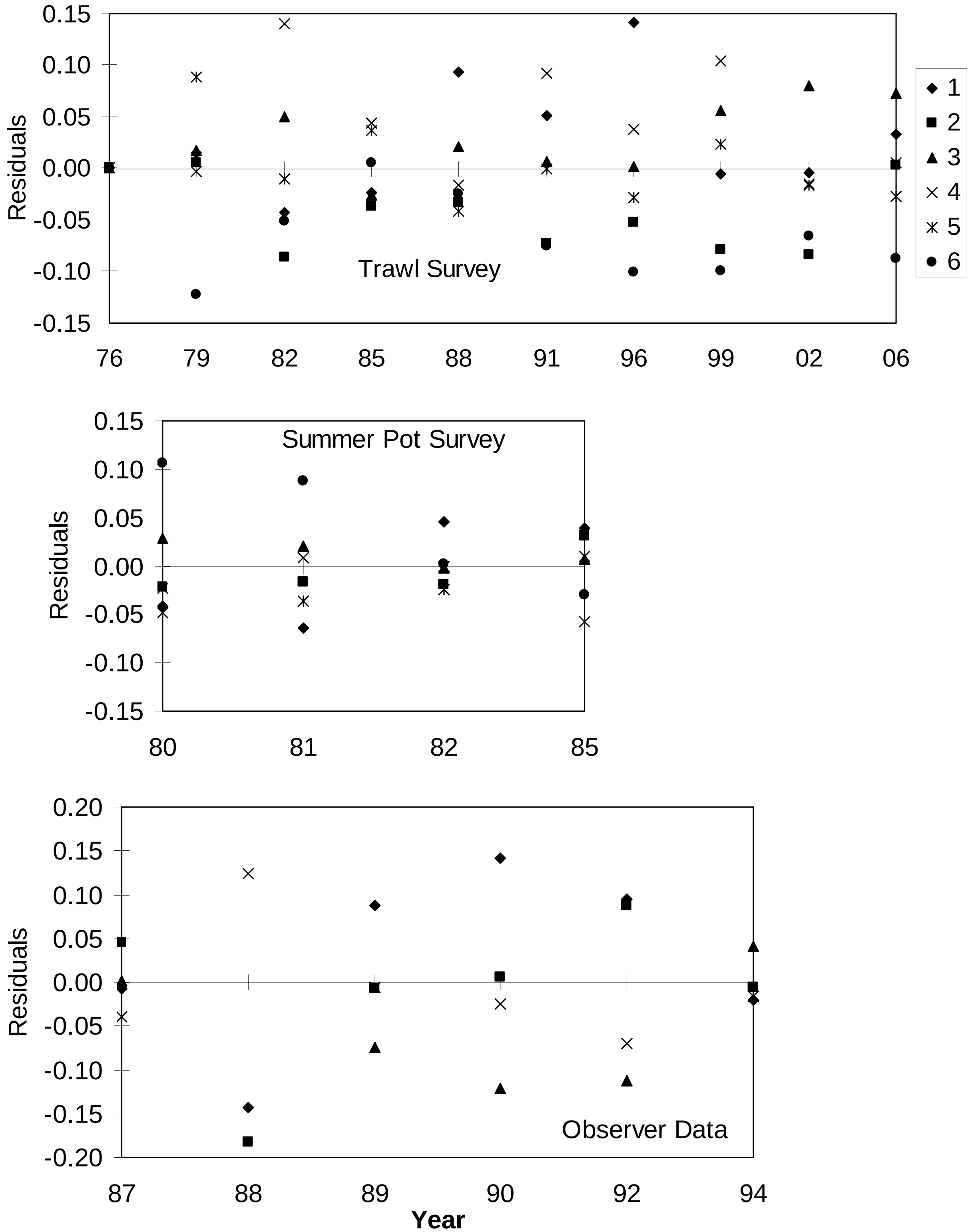


Figure 3. Residuals of length compositions by year for summer trawl and pot surveys and observer data for Norton Sound red king crab. Numbers in the legend represent length classes. All plots have the same legend.

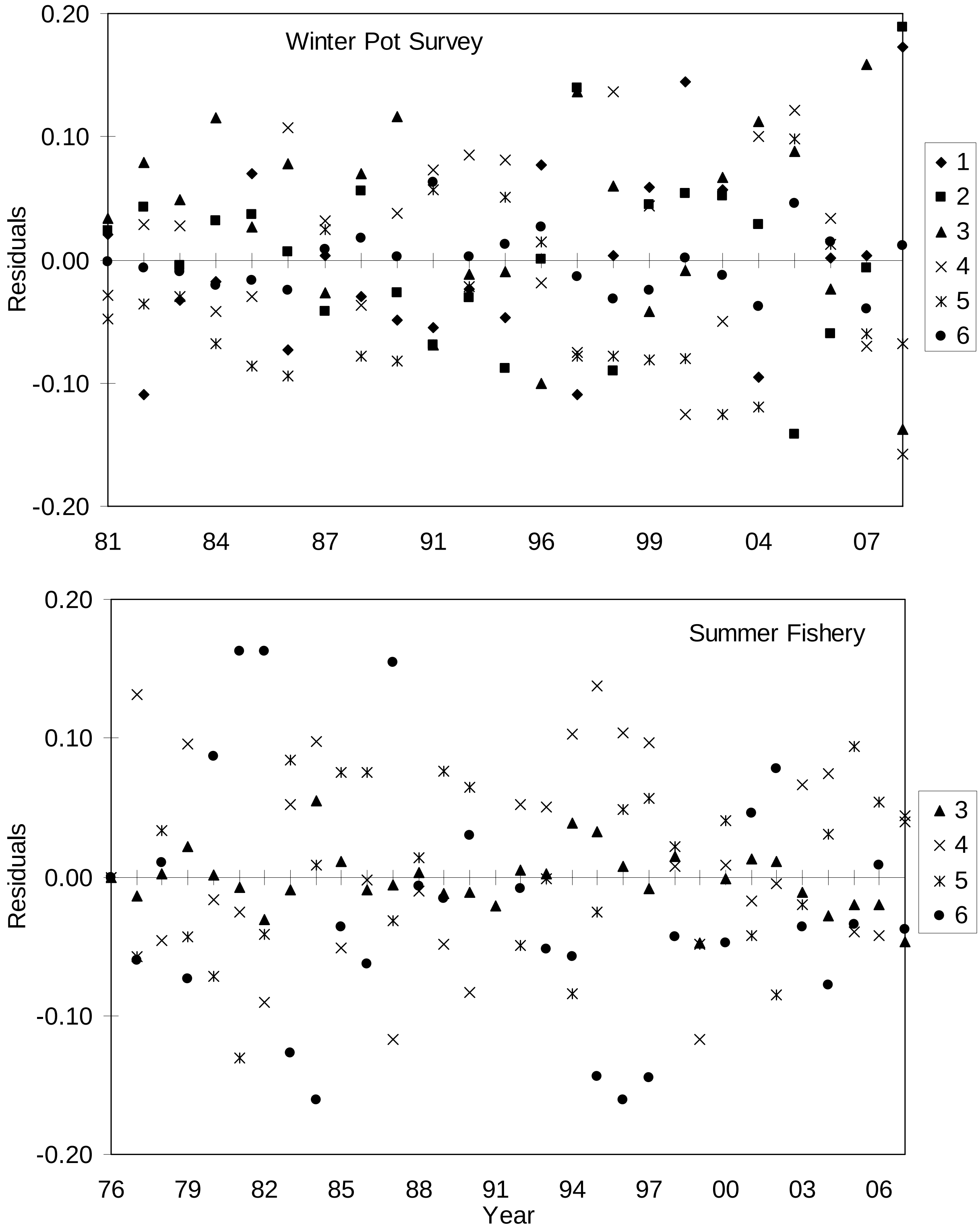


Figure 4. Residuals of length compositions by year for winter pot surveys and summer fishery for Norton Sound red king crab. Numbers in the legend represent length classes. All plots have the same legend.

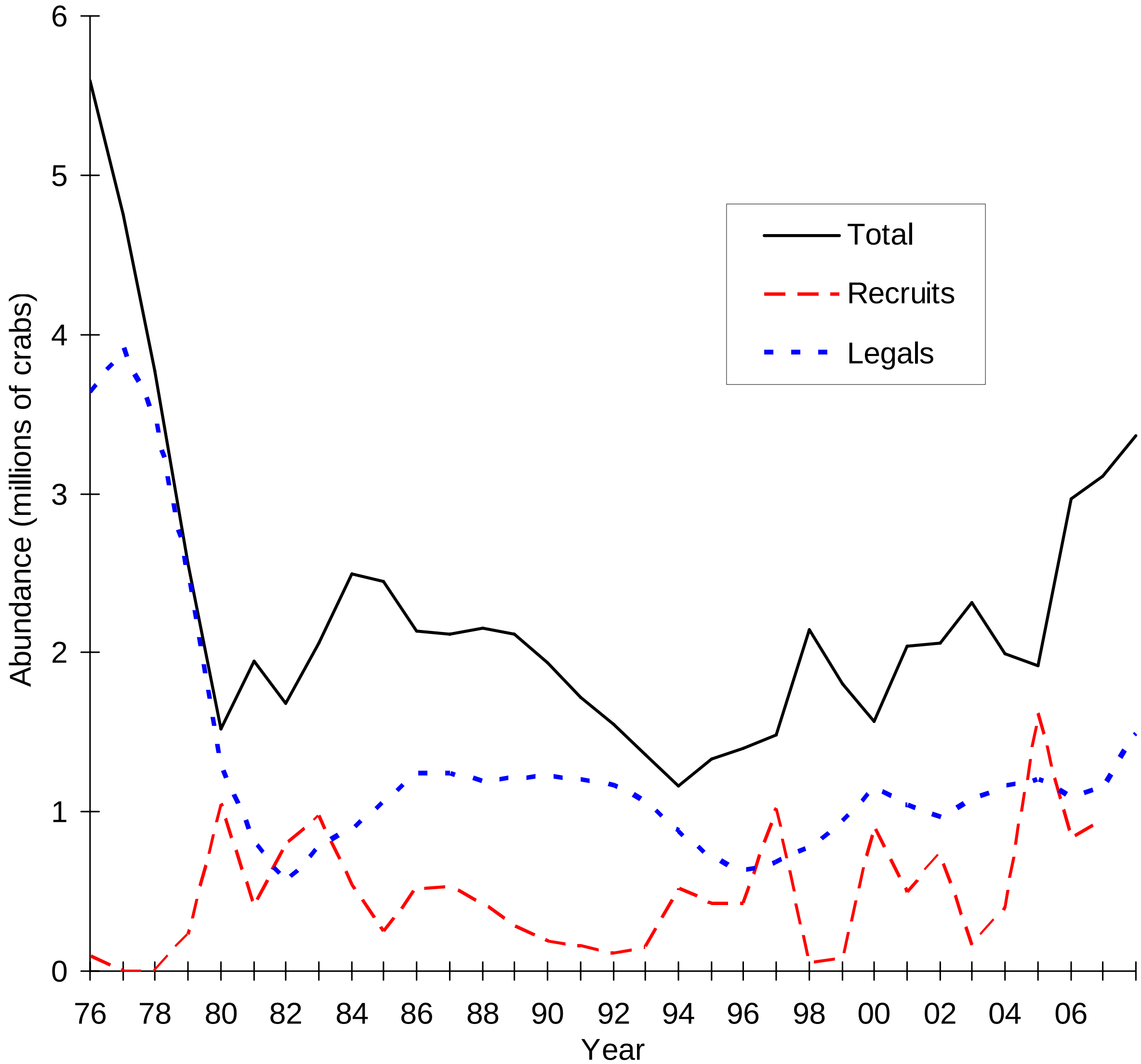
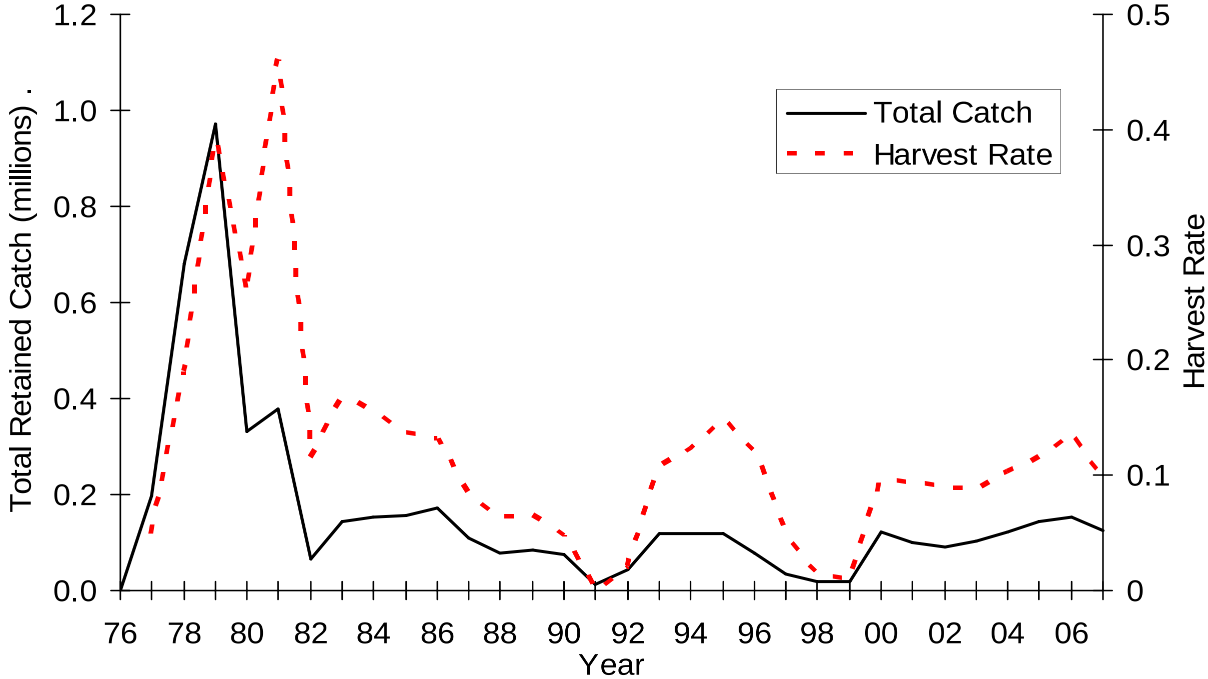


Figure 5. Estimated total (crabs>73 mm CL) and legal male abundances and recruits from 1976 to 2008.



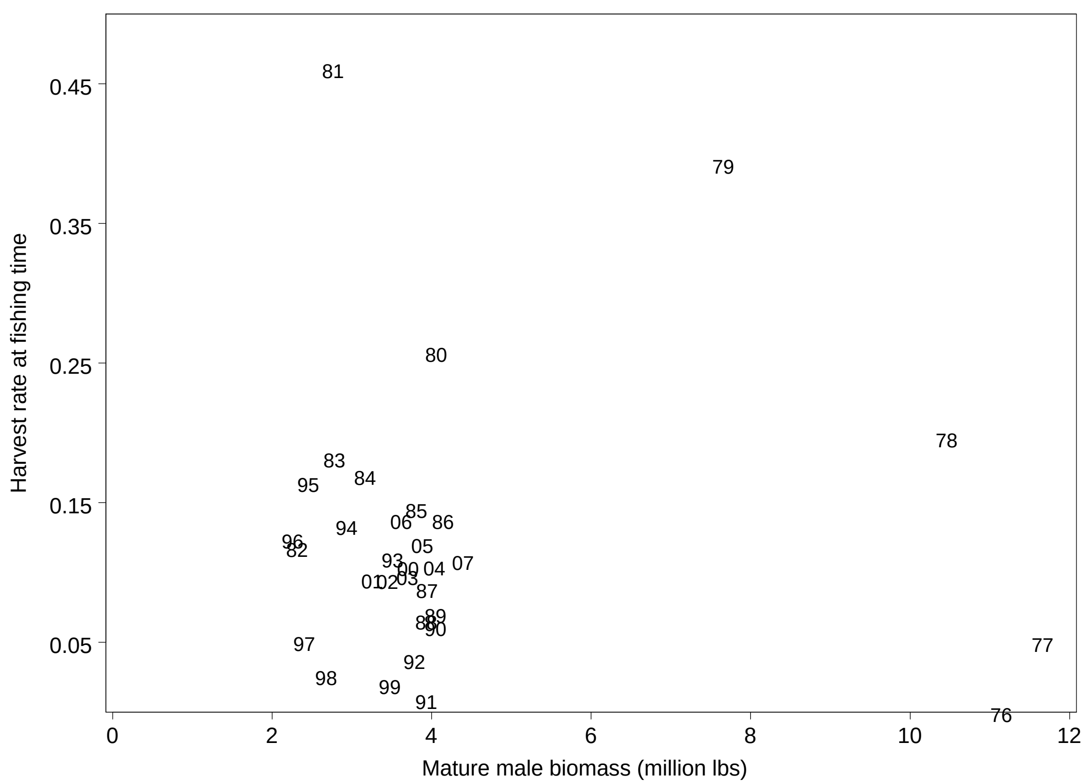


Figure 6. Total retained catches and harvest rates (upper plot) and relationship between harvest rates and mature male biomass (lower plot) of Norton Sound red king crab from July 1, 1976 to June 30, 2008.

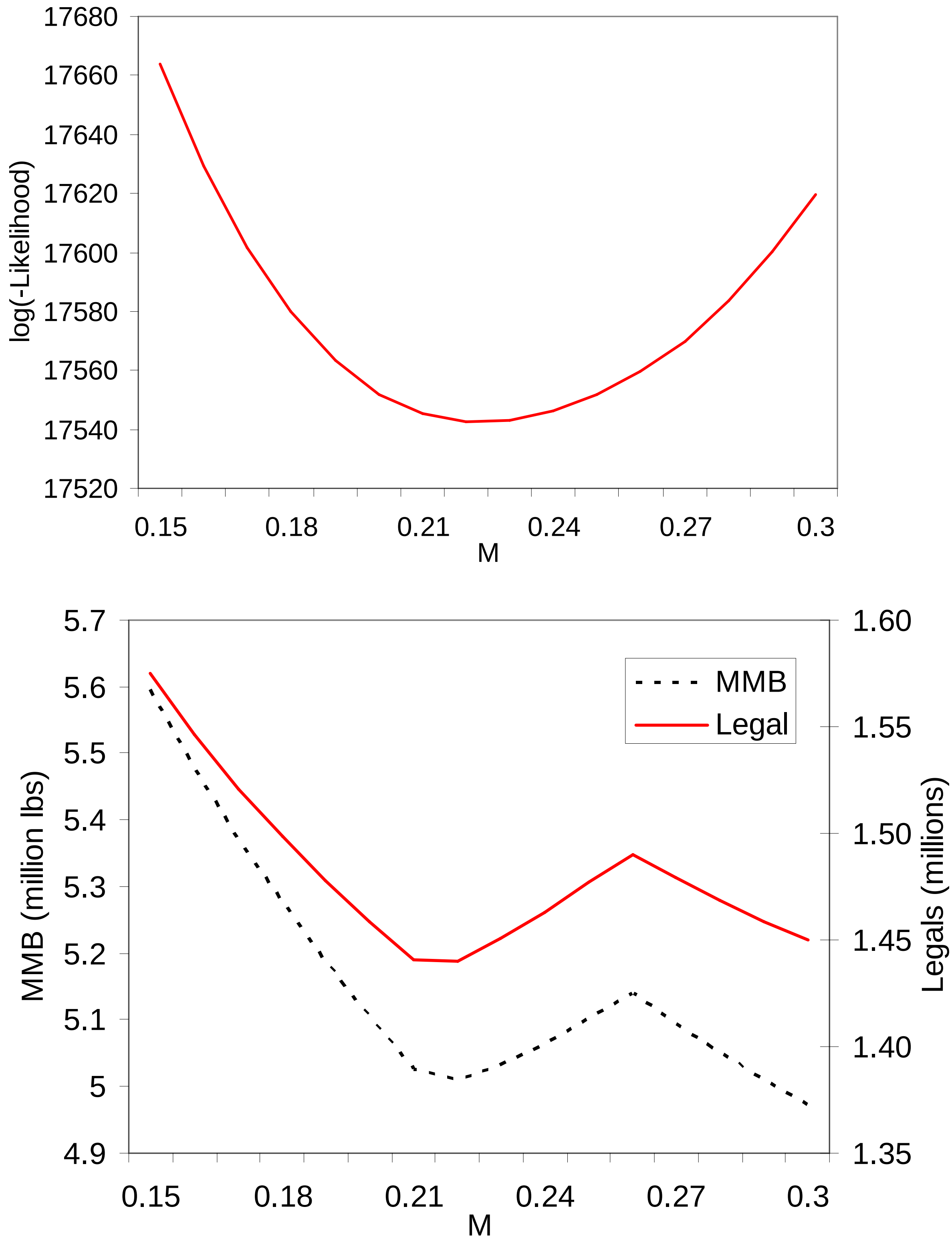


Figure 7. Likelihood profile for natural mortality and estimated legal abundance and mature male biomass in 2008 under different natural mortality values.

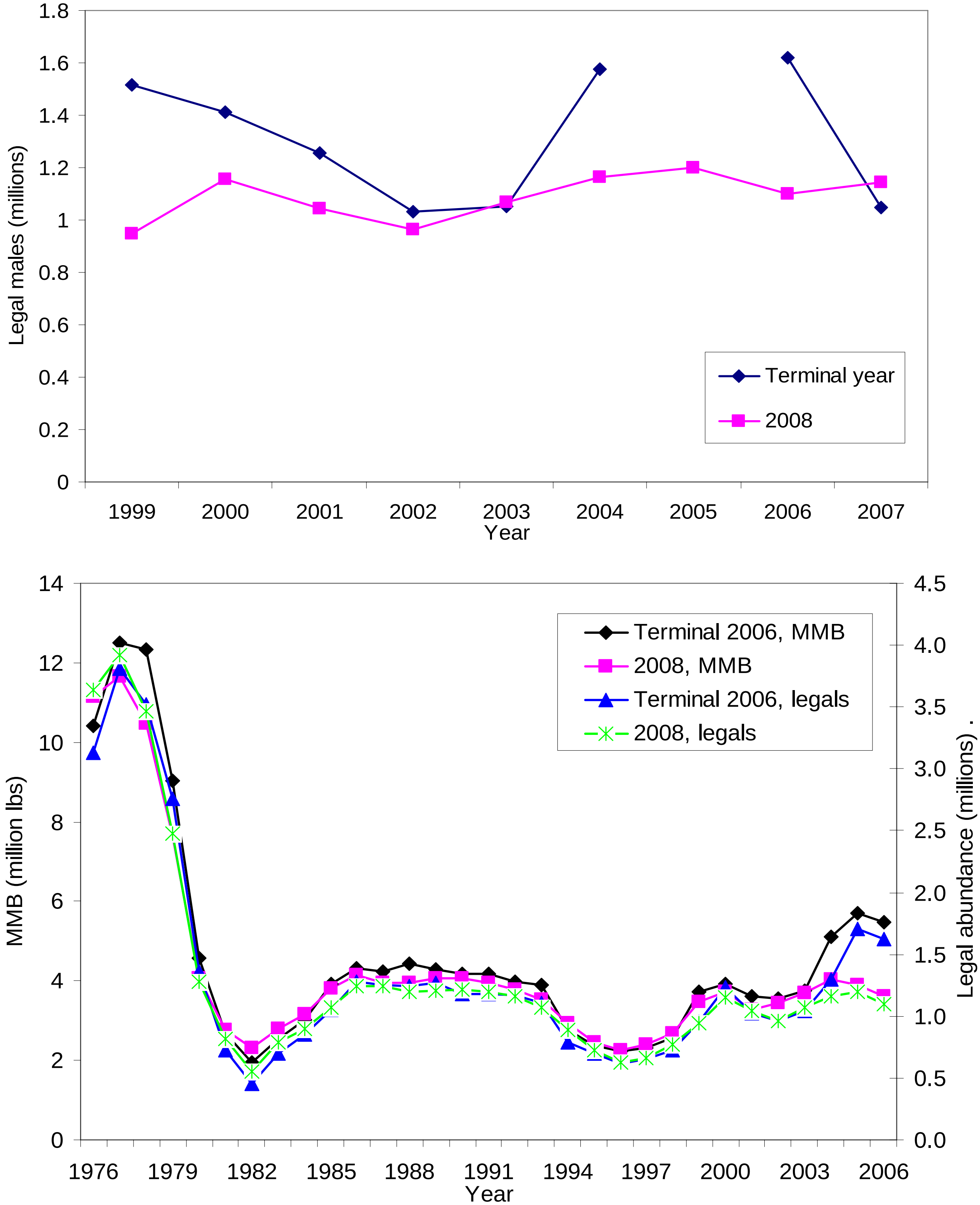


Figure 8. Comparison of estimates of legal male abundance (upper plot) of Norton Sound red king crab with terminal years 1999-2008 and legal abundance and mature male biomass (lower plot) with terminal years of 2006 and 2008. These are results of historical assessments. Legend shows the year in which the assessment was conducted.

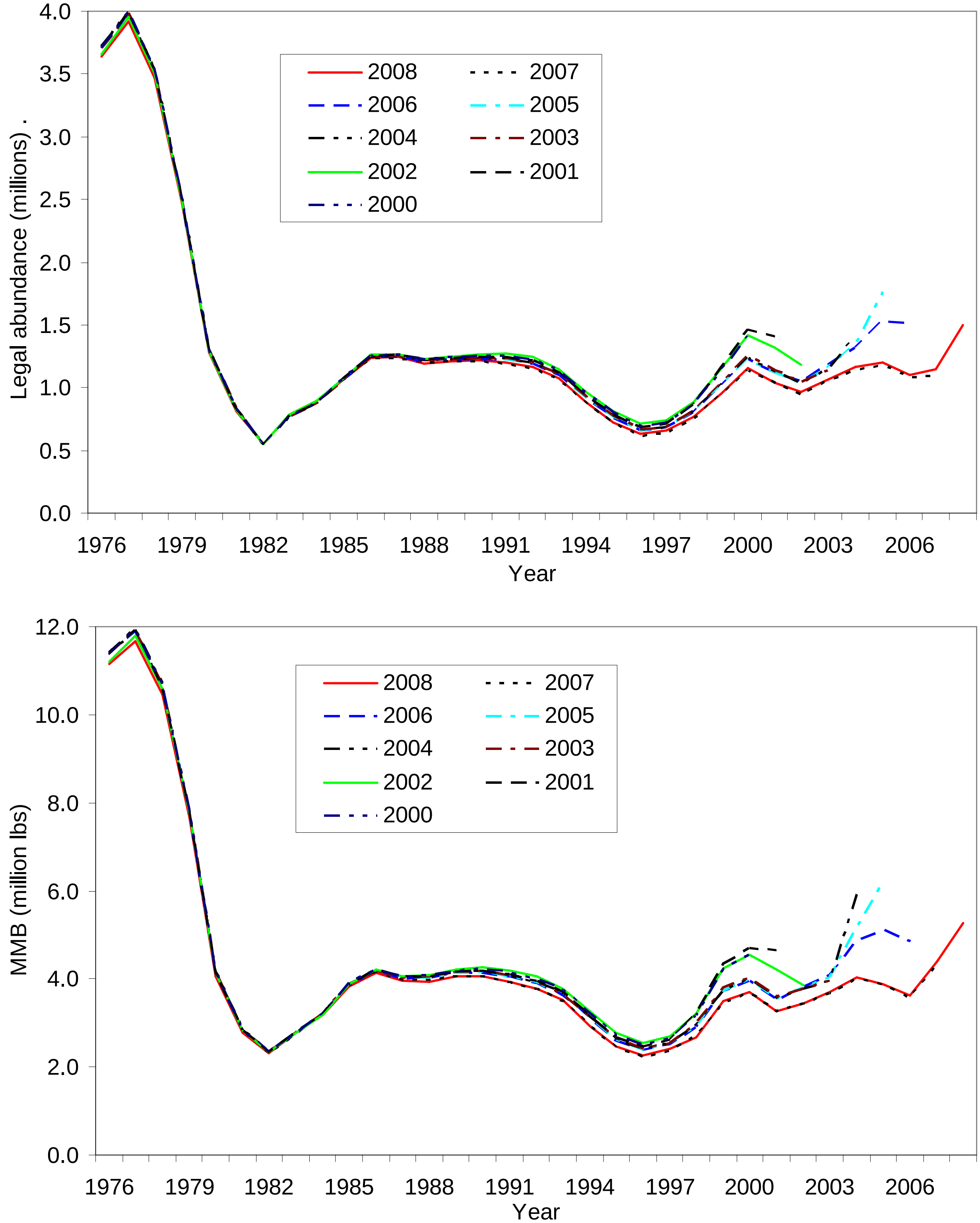


Figure 9. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of Norton Sound red king crab from 1976 to 2008 made with terminal years 2000-2008. These are results of the 2008 model. Legend shows the year in which the assessment was conducted.

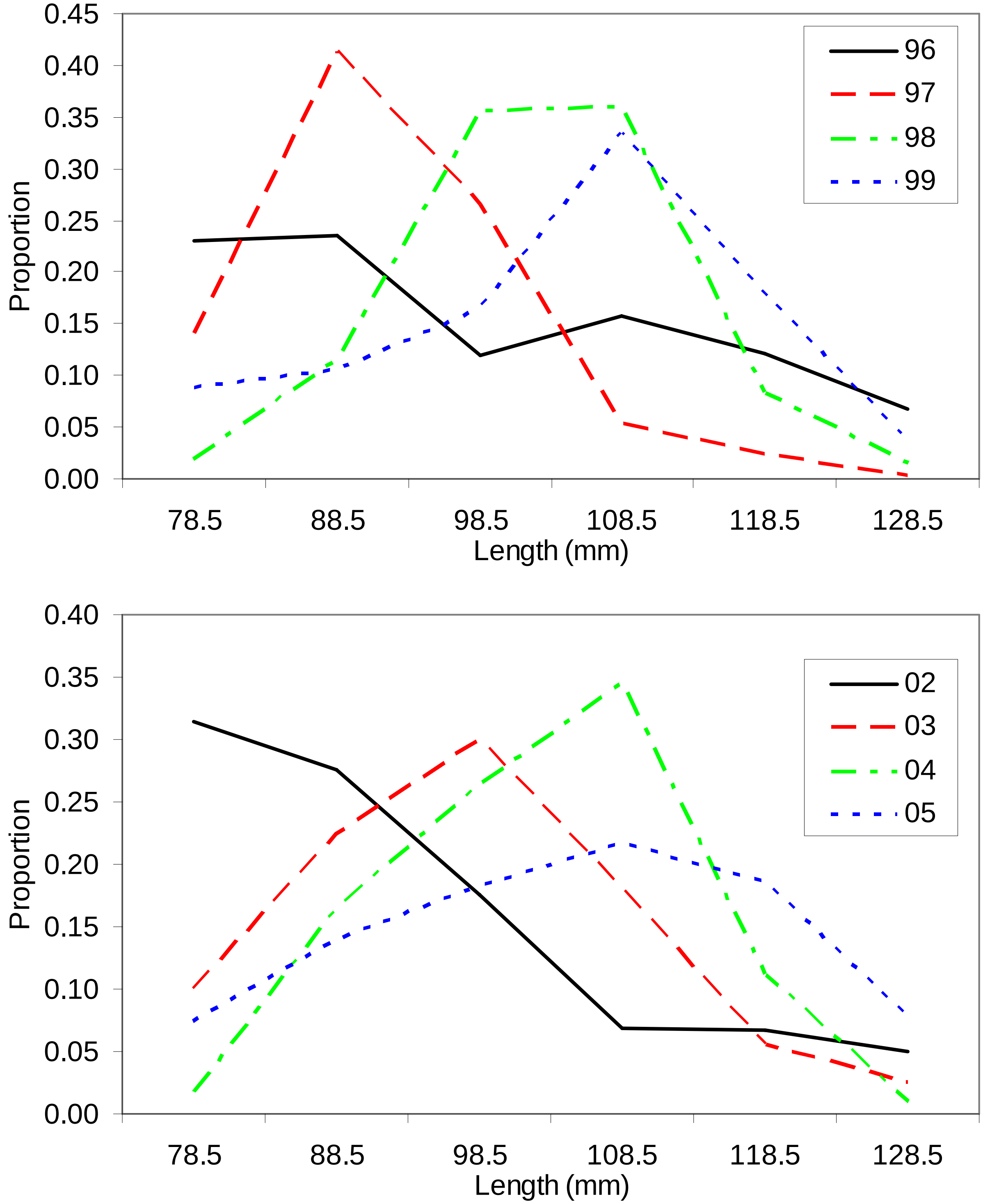


Figure 10. Length frequency of newshell crabs from the winter survey during two periods: 1996-1999 and 2002-2005.

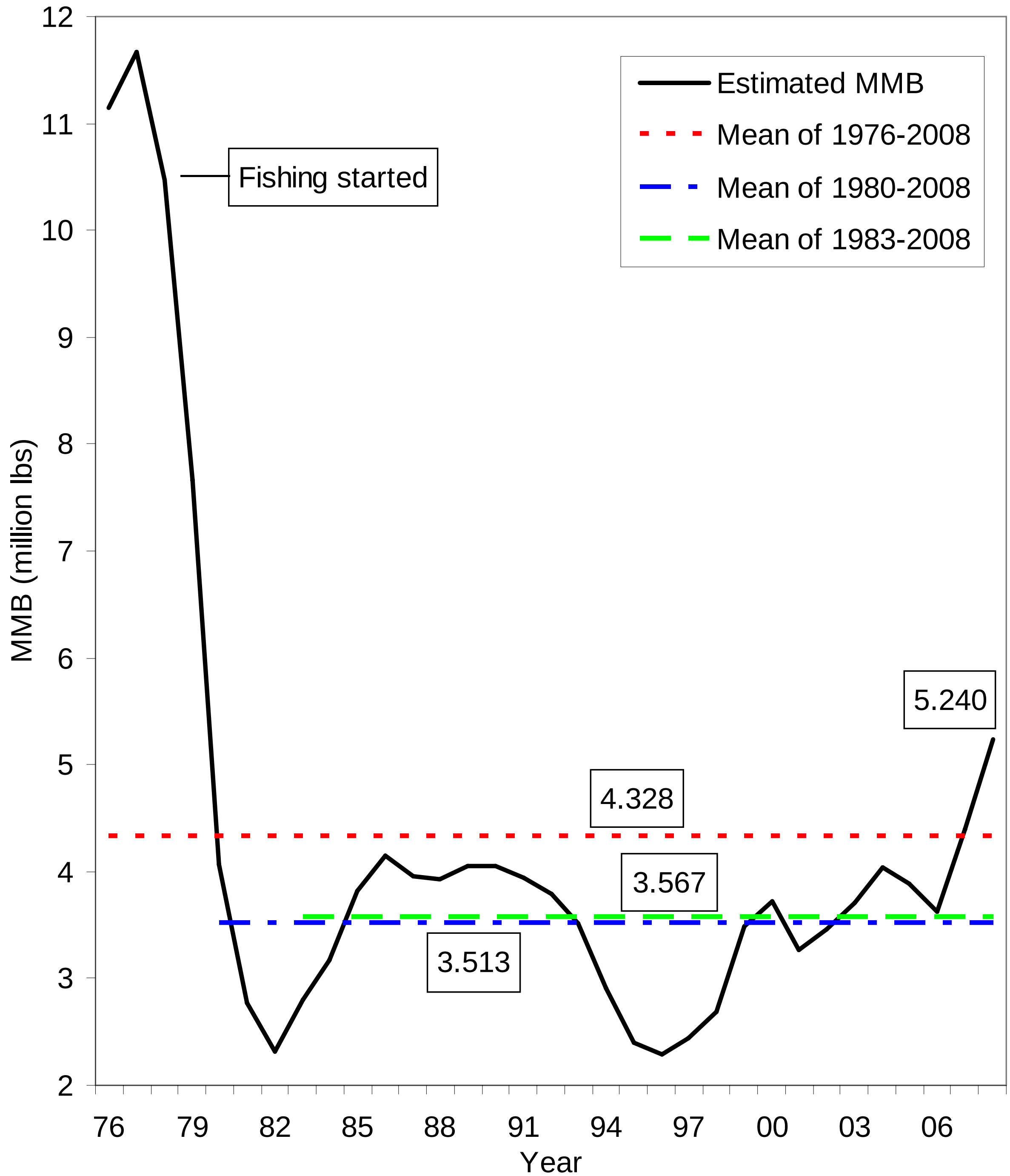


Figure 11. Comparison of estimated mean mature male biomasses during different periods of Norton Sound red king crab.

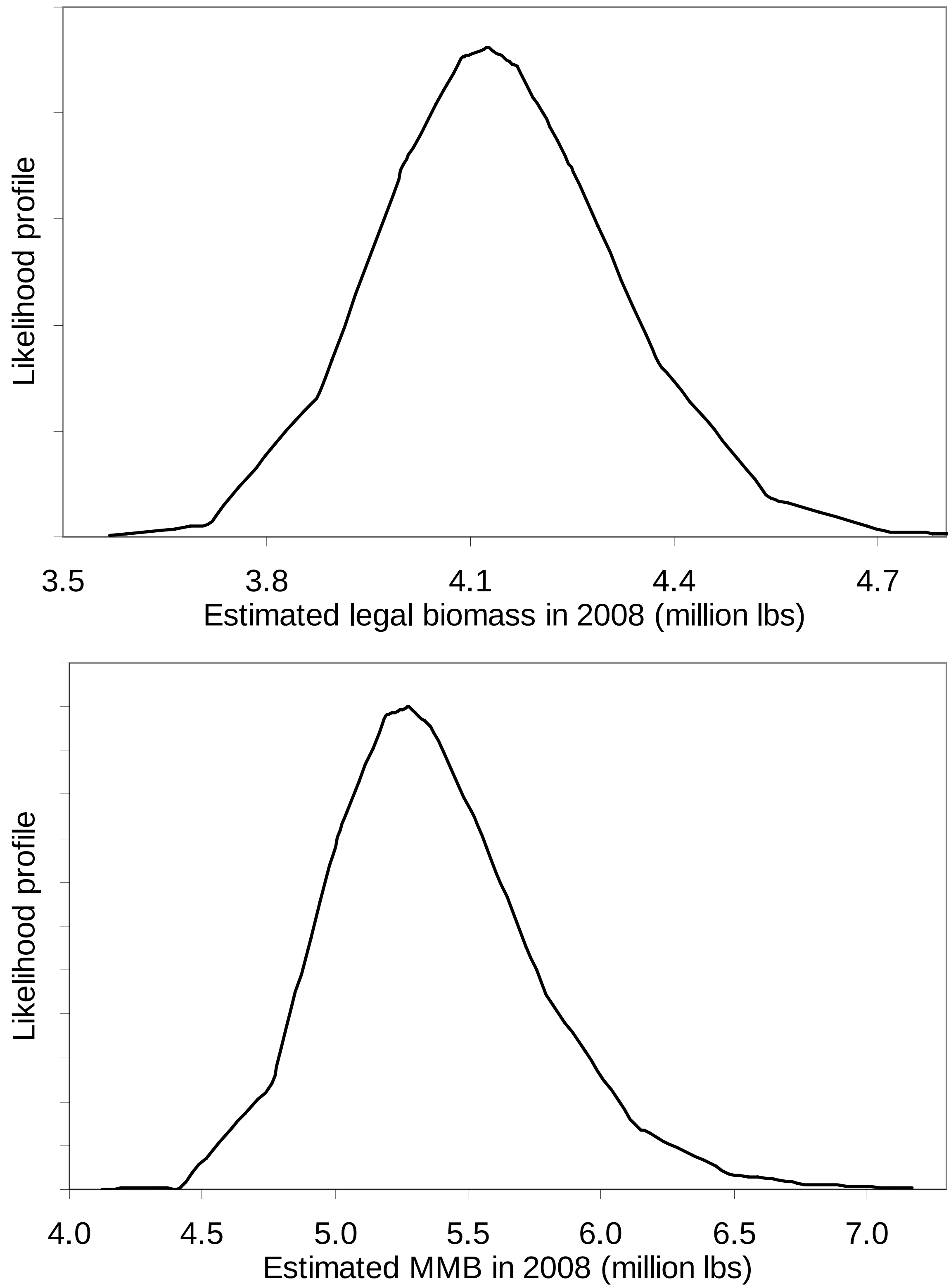


Figure 12. Likelihood profiles for estimated legal male biomass and mature male biomass in 2008.

Aleutian Islands Golden King Crab

Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak

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

Changes (if any) in the input data — N/A (= "not applicable" or "not available" or both)

Changes (if any) in the assessment methodology — N/A

Changes (if any) in the assessment results, including projected biomass, TAC, total catch (including discard mortality and retained catch), and FOFL (the full selection fishing mortality rate (F) that results in overfishing) — N/A

Responses to SSC Comments

Responses to SSC comments specific to this assessment (for each comment that is addressed in the main text, list comment and give name of section where it is discussed; if the SSC did not make any comments specific to this assessment, say so) — N/A

Responses to SSC comments on assessments in general (for each comment that is addressed in the main text, list comment and give name of section where it is discussed; if the SSC did not make any comments on assessments in general, say so) — N/A

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).

<u>Description of management unit(s) (be sure to include any spatial and/or seasonal management measures)</u>:

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.

<u>Evidence of stock structure, if any</u>

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 (e.g., special features of reproductive biology)

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 (Items in this section should be presented in tabular form.)

Data which should be presented as time series:

- Total catch, partitioned by strata used in the assessment model, if any

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 age or catch at length, as appropriate

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 biomass estimates and variances, and/or confidence intervals — N/A

- Survey numbers at age or numbers at length, as appropriate

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.

- Other time series data (e.g., predator abundance, fishing effort)

The time series of fishing effort (pot lifts) are provided in Tables 7–9.

- Sample sizes (e.g., numbers of age or length samples by year, gear, and area)

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.

Data which may be aggregated over time:

- 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.

Analytic Approach

Model Structure — N/A

Description of overall modeling approach (e.g., age/size structured versus biomass dynamic, maximum likelihood versus Bayesian) — N/A

Reference for software used (e.g., Synthesis, AD Model Builder) — N/A

Description of, or reference for, population dynamic representations used in the model (e.g., Baranov catch equation, Brody length-at-age equation) — N/A

List and description of all likelihood components in the model — N/A

Discussion of changes in any of the above since the previous assessment — N/A

Parameters Estimated Independently

List of parameters that are estimated independently of others (e.g., the natural mortality rate, parameters governing the maturity schedule)

- 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)

Parameters Estimated Conditionally — N/A

List of parameters that are estimated conditionally on those described above (e.g., full-selection fishing mortality rates, parameters governing the survey and fishery selectivity schedules, recruitments) — N/A

Description of how these parameters are estimated (e.g., error structures assumed, list of likelihood components, constraints on parameters) — N/A

Critical assumptions and consequences of assumption failures — N/A

Model Evaluation — N/A

Description of alternative models, if any (e.g., alternative M values or likelihood weights) — N/A

Evidence of search for balance between realistic (but possible over-parameterized) and simpler (but not realistic) models — N/A

Use hierarchical approach where possible (e.g. asymptotic vs domed selectivities, constant vs time varying selectivities) — N/A

Do parameter estimates make sense, are they credible? — N/A

Description of criteria used to evaluate the model or to choose between alternative models, including the role (if any) of uncertainty — N/A

Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach) — N/A

Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented — N/A

List of final parameter estimates, with confidence intervals or other statistical measures of uncertainty if possible (if the set of parameters includes quantities listed in the "Results" section below, the values of these quantities should be presented in the "Results" section rather than here) — N/A

Schedules, if any, defined by final parameter estimates — N/A

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.

Time periods for averaging the retained catch. 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.

<u>The GHL and pre-rationalization period, 1996/97–2004/05</u>. 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 longitude during 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° W longitude (Pengilly 2005). Legal males tagged and released in 2003 at locations east of 171° 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° 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 that reduction 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.

Results

Definition of biomass measures used (e.g., biomass at length 50 and above):

- weight of retained catch during the commercial fishery for estimation of OFL

Definition of recruitment measures used (e.g., numbers at length 40-70) – N/A

Definition of fishing mortality measures used (e.g., full-recruitment F multiplied by selectivity for lengths 80 and above):

- weight of retained catch during the commercial fishery

Table of estimated abundance and biomass time series, including spawning biomass as one measure, with confidence bounds or other statistical measure of uncertainty if possible. Include estimates from previous SAFE for retrospective comparisons:

- Tables 4–6 and Tables 7–9 provide the annual weight of retained catch in a variety of formats and contexts.

Table of estimated recruitment time series, including average, with confidence bounds or other statistical measure of uncertainty if possible. Include estimates from previous SAFE for retrospective comparisons — N/A

Table of estimated catch/biomass time series, with confidence bounds or other statistical measure of uncertainty if possible:

- Tables 4–6 and Tables 7–9 provide the annual weight of retained catch in a variety of formats and contexts.

Graphs of fishery and survey selectivities, molting probabilities, and other schedules depending on parameter estimates

- See Figure 5 for graph of molting probability in 12–15 months at size for males
- Otherwise — N/A

Graph of estimated male, female, total and effective mature biomass time series, with confidence bounds if possible — N/A

Include a graph of the estimated fishing morality versus estimated spawning stock biomass, including applicable OFL and maximum F_{target} definitions for the stock. The rationale is that graphs of this type are useful to evaluate management performance:

- 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% the GHL/TAC (1998/99 season) and as much as 6% above the GHL/TAC.

Graph of estimated full selection F over time. — N/A

Graphs of model fits to survey numbers or proportions by age or length. — N/A

Graphs of model fits to catch numbers or proportions by age or length. — N/A

Uncertainty and sensitivity analyses. — N/A

1. The best approach for describing uncertainty and range of probable biomass estimates in stock assessments may depend on the situation. Approaches used previously are:
   a) Sensitivity analyses (tables or figures) that show ending biomass levels or likelihood component values obtained while systematically varying emphasis factors for each type of data in the model. — N/A
   b) Likelihood profiles for parameters or biomass levels may also be used. — N/A
   c) CVs for biomass estimated by bootstrap, implicit autodifferentiation, or the delta method; — N/A
   d) Subjective appraisal of magnitude and sources of uncertainty; — N/A
   e) Comparison of alternate models; — N/A
   f) Comparison of alternate assumptions about recent recruitment. — N/A

2. If a range of model runs (e.g.; based on CV's or alternate assumptions about model structure or recruitment) is used to depict uncertainty, then it is important that some qualitative or quantitative information about relative probability be included. If no statements about relative probability can be made, then it is important to state that all scenarios (or all scenarios between the bounds depicted by the runs) are equally likely. — N/A

3. if possible, ranges depicting uncertainty should include at least three runs: (a) one judged most probable; (b) at least one that depicts the range of uncertainty in the direction of lower current biomass levels; and (c) one that depicts the range of uncertainty in the direction of higher current biomass levels. The entire range of uncertainty should be carried through stock projections and decision table analyses. — N/A

4. retrospective analysis (retrospective bias in base model or models for each area). — N/A

5. historic analysis (plot of actual estimates from current and previous assessments for each area). — N/A

6. Simulation results (if available). — N/A

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

Table of 12-year projected catches corresponding to the alternative harvest scenarios, using stochastic methods if possible (mean values or other statistics may be shown in the case of stochastic recruitment scenarios) — N/A

Table of 12-year 5-year (or 10-year, if the stock is overfished) projected spawning biomass corresponding to the alternative harvest scenarios, using stochastic methods if possible (mean values or other statistics may be shown in the case of stochastic recruitment scenarios) — N/A

Table of 12-year projected fishing mortality rates corresponding to the alternative harvest scenarios, using stochastic methods if possible (mean values or other statistics may be shown in the case of stochastic recruitment scenarios) — N/A

Discussion of information, if any, that might warrant setting the GHL or total catch below the upper bound:

- ?

Recommendation of F_{OFL} , OFL total catch, OFL retained catch for coming year: TBA

Include a subsection titled "Area Allocation of Harvests" and provide results and details of any apportionment schemes that are used. — N/A

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

Table showing M, Tier (previous year or recommended), projected total biomass (give age or length range), female spawning biomass, male spawning biomass and total spawning biomass for current year and for next year. Male spawning biomass values at the time of mating for B0 and Bmsy and Fmsy (if available from stock-recruit relationship) or proxy values, FOFL , the maximum allowable value for Ftarget , the recommended value of OFL, the maximum allowable total catch.

Parameter	Value
M	Default = 0.18
Tier	5
Projected total biomass	N/A
Female spawning biomass, current year (2007/08)	N/A
Male spawning biomass, current year (2007/08)	N/A
Total spawning biomass, current year (2007/08)	N/A
Female spawning biomass, next year (2008/09)	N/A
Male spawning biomass, next year (2008/09)	N/A
Total spawning biomass, next year (2008/09)	N/A
Male spawning biomass values at the time of mating for B0 and Bmsy and Fmsy, or proxy values	N/A
Maximum allowable value for Ftarget	N/A
Recommended value of OFL	6,930,627 pounds (retained catch)
Maximum allowable total catch	N/A

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Perhaps in the future, dependent on the availability of time and information, a section on "ecosystem considerations" pertaining to Aleutian Islands golden king crabs will be included in this chapter. If and when that does happen, the section will follow an outline something like this:

Ecosystem Considerations

Discussion of any ecosystem considerations (e.g., relationships with species listed under the ESA, prohibited species concerns, bycatch issues, refuge areas, and gear considerations).

The following subsections should provide information on how various ecosystem factors might be influencing their stock or how the specific stock fishery might be affecting the ecosystem and what data gaps might exist that prevent assessing certain effects.

Stock assessment authors would be encouraged to rely on information in the Ecosystem Considerations chapter to assist them in developing stock-specific analysis and recommending new information to the Ecosystem Considerations chapter that might be required in future years to improve the analysis. Time-series that are in the Ecosystem Chapter would be referred to by the author and not duplicated in their chapter. In cases where the authors have time series or relationships that are specific to their stock, that information should be in their assessment chapter and not in the Ecosystem chapter.

Ecosystem Effects on Stock

There are several factors that should be considered for each stock in this subsection. These include:

1) Prey availability/abundance trends (historically and in the present and foreseeable future). These prey trends could affect growth or survival of a target stock.

2) Predator population trends (historically and in the present and foreseeable future). These trends could affect stock mortality rates over time.

3) Changes in habitat quality (historically and in the present and foreseeable future). These would primarily be changes in the physical environment such as temperature, currents, or ice distribution that could affect stock migration and distribution patterns, recruitment success, or direct effects of temperature on growth.

Fishery Effects on the Ecosystem

In this section the following factors should be considered:

1) Fishery-specific contribution to bycatch of prohibited species, forage (including herring and juvenile pollock), HAPC biota (in particular, species common to *YourFishery*), marine mammals and birds, and other sensitive non-target species (including top predators such as sharks, expressed as a percentage of the total bycatch of that category of bycatch.

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.

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

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

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

6) Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance).

Authors should consider summarizing the results of these analyses into a table as shown below (for example):

Analysis of ecosystem considerations for *YourStock* and the *YourFishery*. The observation column should summarize the past, present, and foreseeable future trends. The interpretation column should provide details on how the trend affects the stock (ecosystem effects on the stock) or how the fishery trend affects the ecosystem (fishery effects on the ecosystem). The evaluation column should indicate whether the trend is of: *no concern, probably no concern, possible concern, definite concern,* or*unknown.*

Ecosystem effects on Aleutian Islands golden king crab			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	Stable, data limited	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on Pollock	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Probably no concern
Fish (Pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to pollock mortality	
Changes in habitat quality			
Temperature regime	Cold years pollock distribution towards NW on average	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability low	No concern

Aleutian Islands golden king crab fishery effects on ecosystem			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	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	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Generally more diffuse	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Decreasing	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	New study initiated in 2002	NA	Possible concern

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.

			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	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.

				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	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)

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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)

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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)

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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

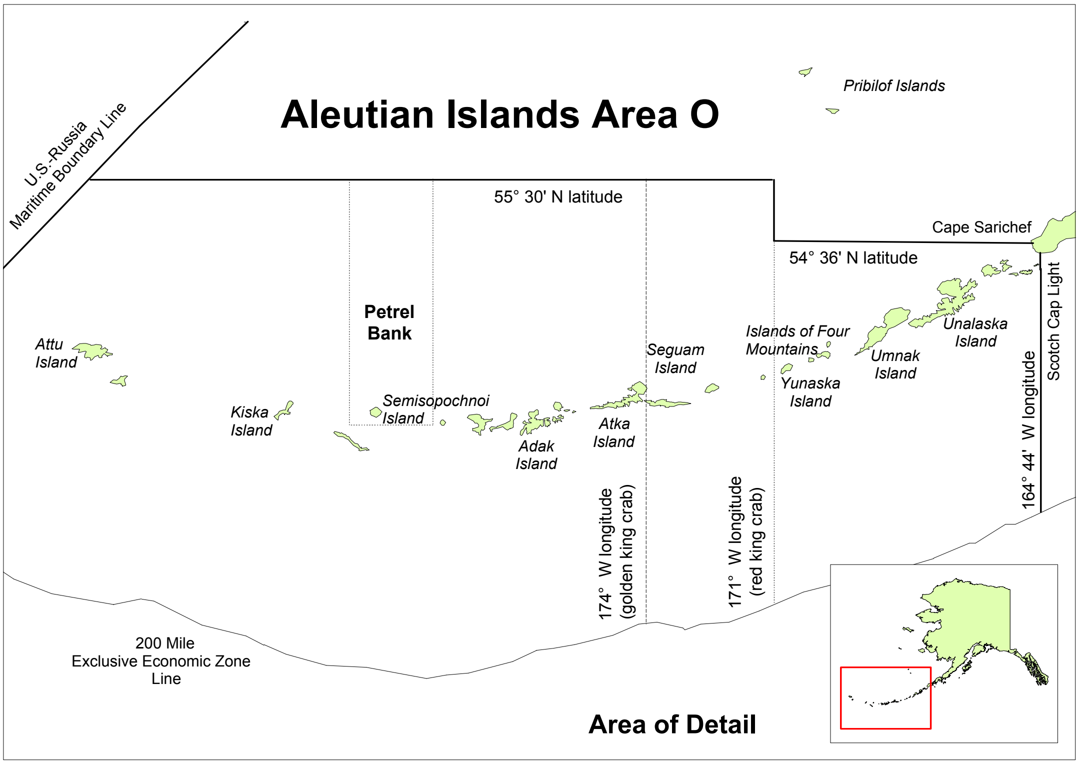


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Failor-Rounds 2008).

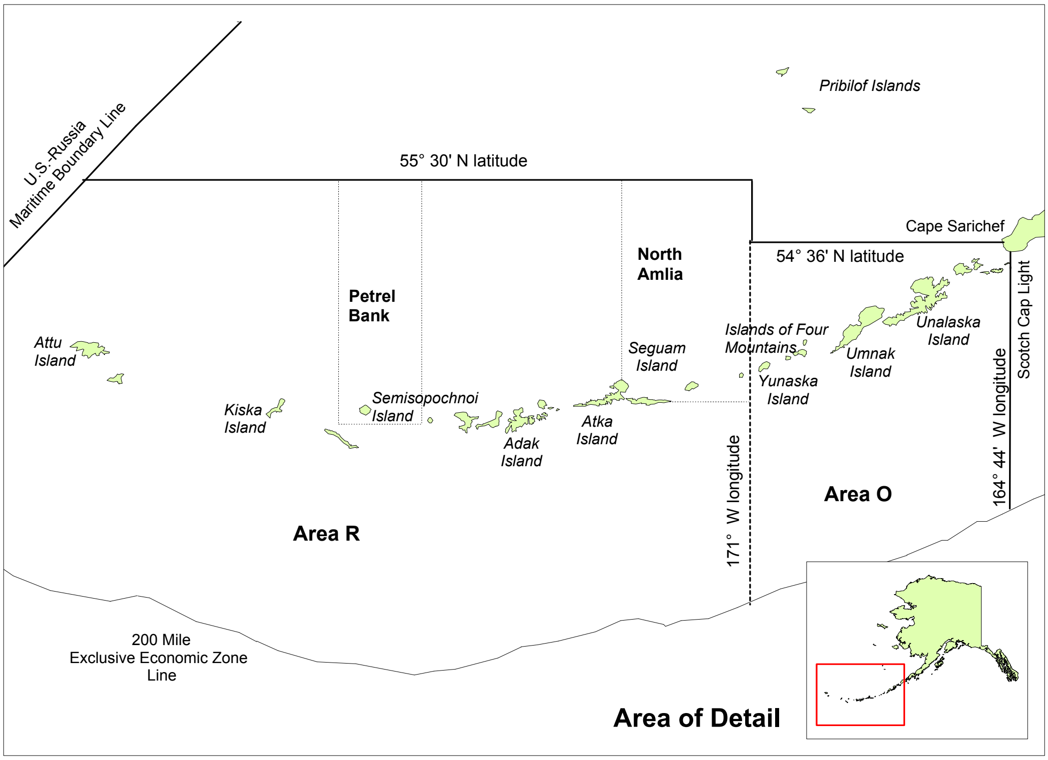


Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85 – 1995/96 seasons (from Failor-Rounds 2008).

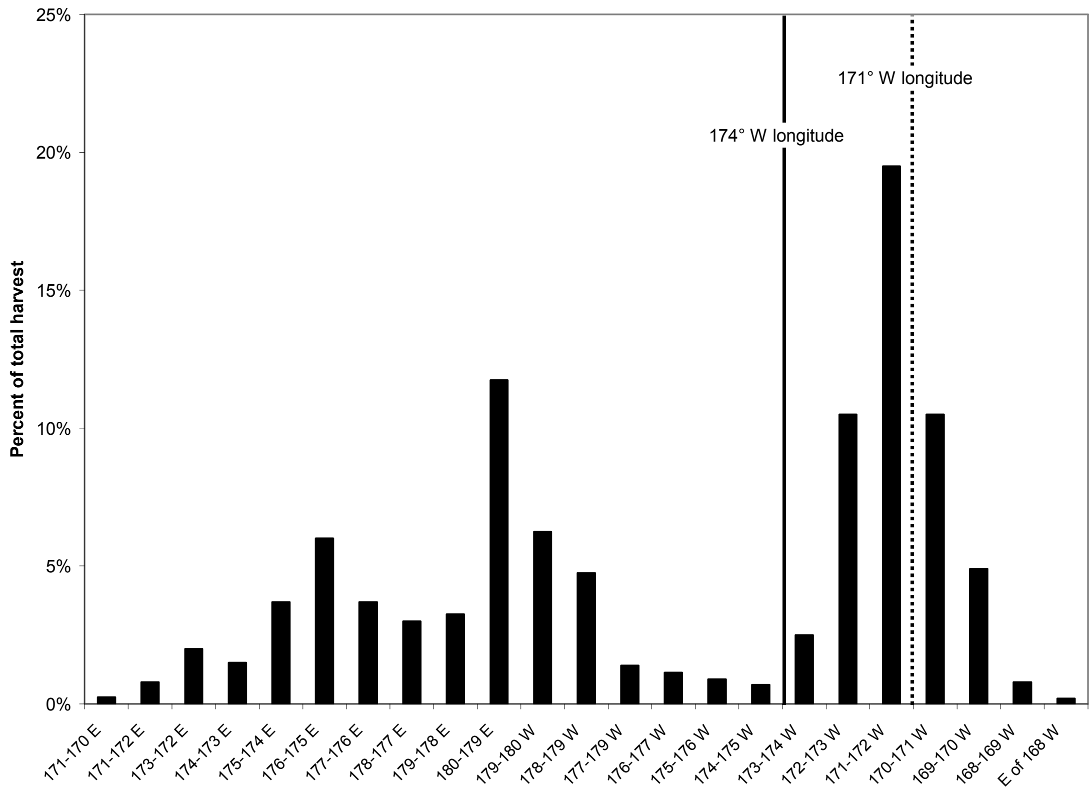


Figure 3. Percent of total 1982–1996 golden king crab harvest by one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude that was used until the end of the 1995/96 season to divide fishery management between the Dutch Harbor Area (east of 171° 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).

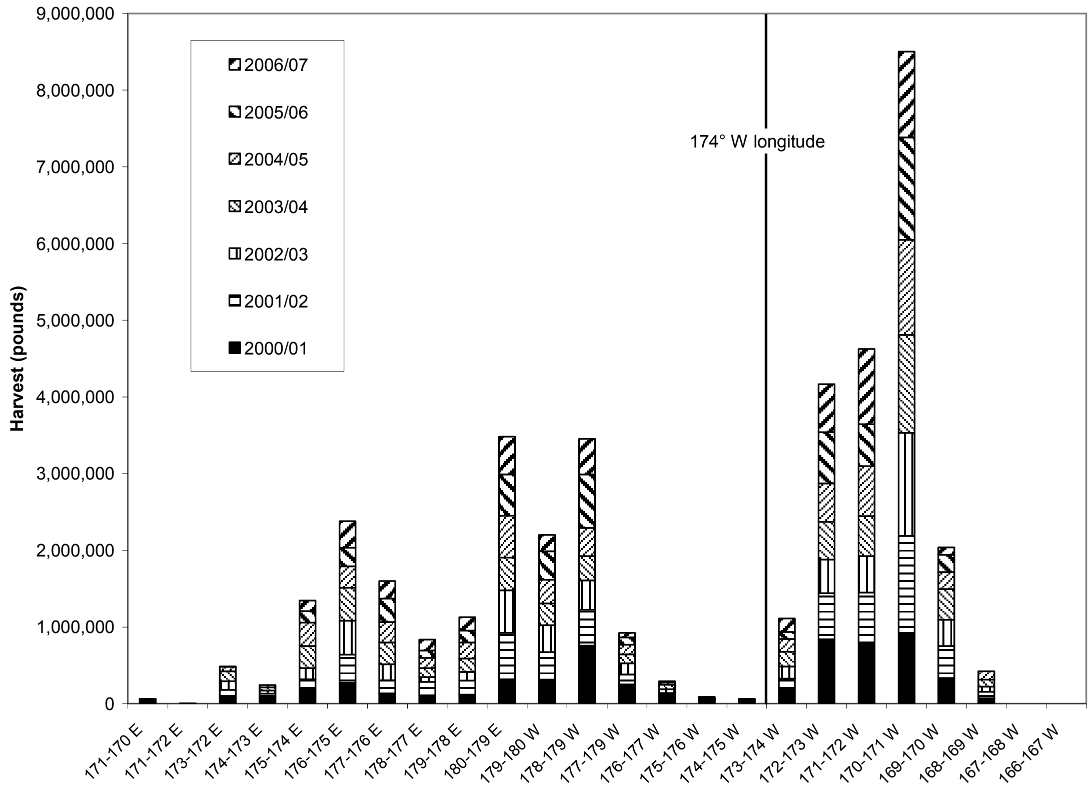


Figure 4. Harvest (pounds) of golden king crabs by one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2006/07 commercial fishery seasons, with solid line denoting the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden 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).

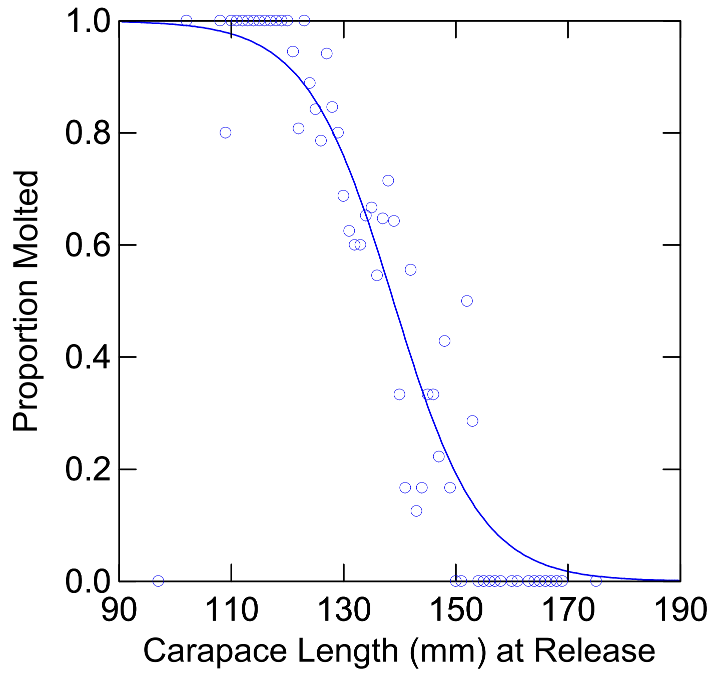


Figure 5. Proportion molting prior to recovery as related to carapace length at release of 487 new-shell male golden king crab tagged and released in the Yunaska Island area of the Aleutian Islands, Alaska, July-August 1997 and recovered 12-15 months later during the 1998/99 commercial golden king crab fishery, with curve showing a logistic regression fit to the data (from Watson et al. 2002).

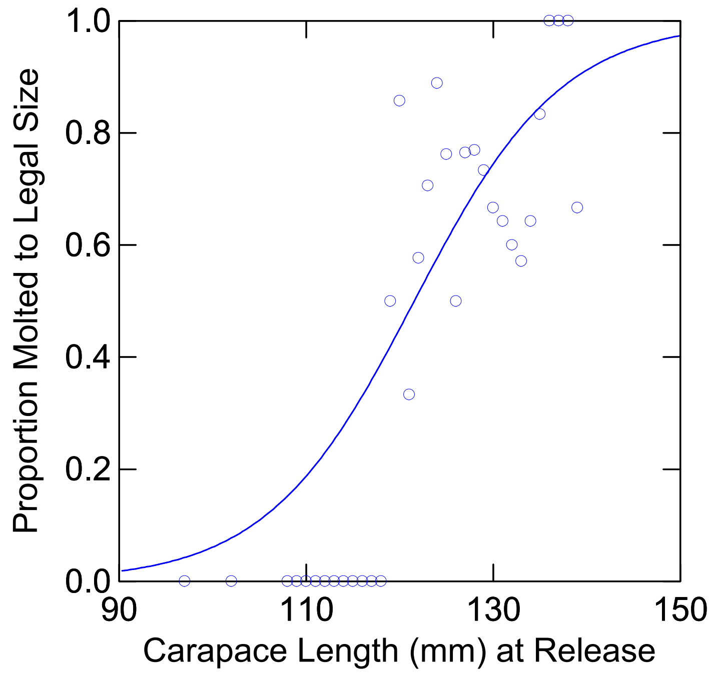


Figure 6. Proportion by carapace length at release of 281 male golden king crabs tagged and released as sublegal new-shell males in Yunaska Island area of Aleutian Islands, Alaska, July-August 1997, that molted to legal size prior to their recovery 12-15 months later during the commercial golden king crab fishery, with curve showing a logistic regression fit to the data (from Watson et al. 2002).

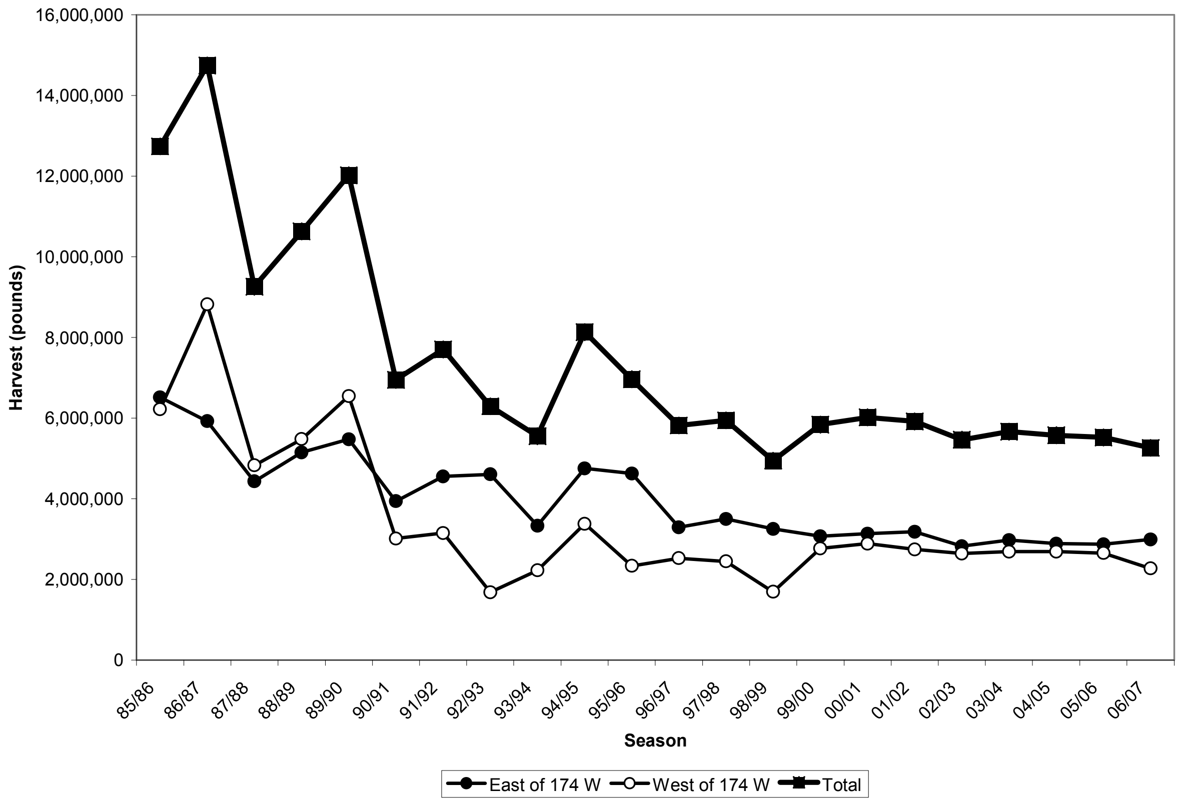


Figure 7. Retained catch (harvest in pounds) in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons for the entire Aleutian Islands Area and for each of the areas east and west of 174° W longitude.

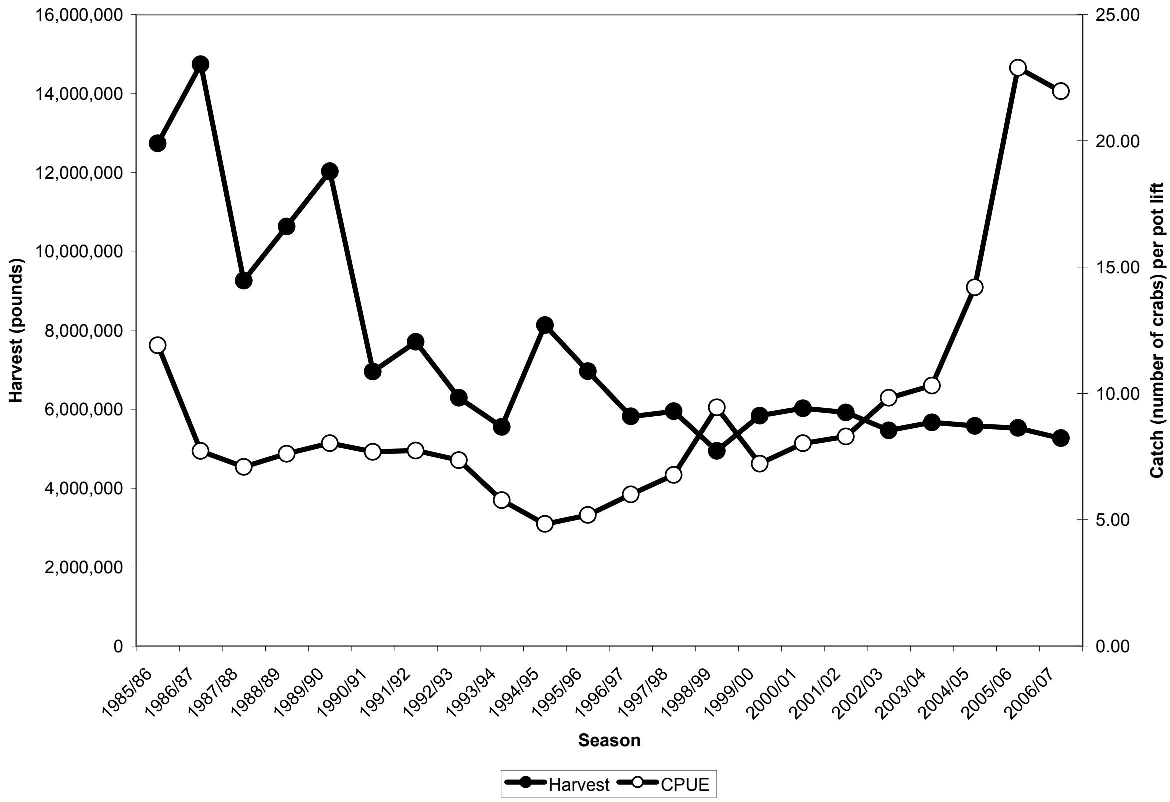


Figure 8. Retained catch (harvest in pounds) and catch (number of retained legal crabs) per pot lift (CPUE) in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons.

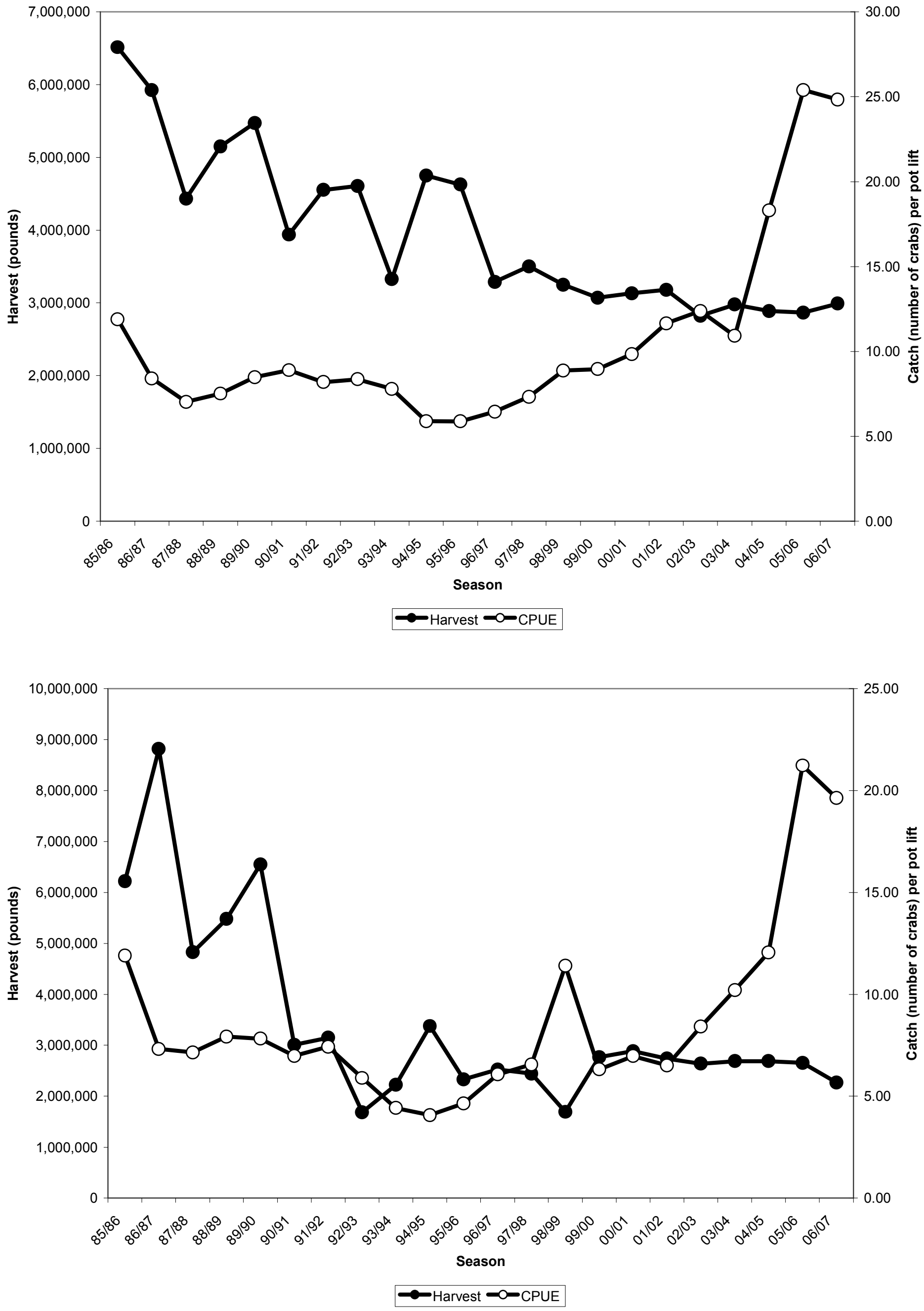


Figure 9. Retained catch (harvest in pounds) and catch (number of retained legal crabs) per pot lift (CPUE) in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons, for the area east of 174° W longitude (top panel) and the area west of 174° W longitude (bottom panel).

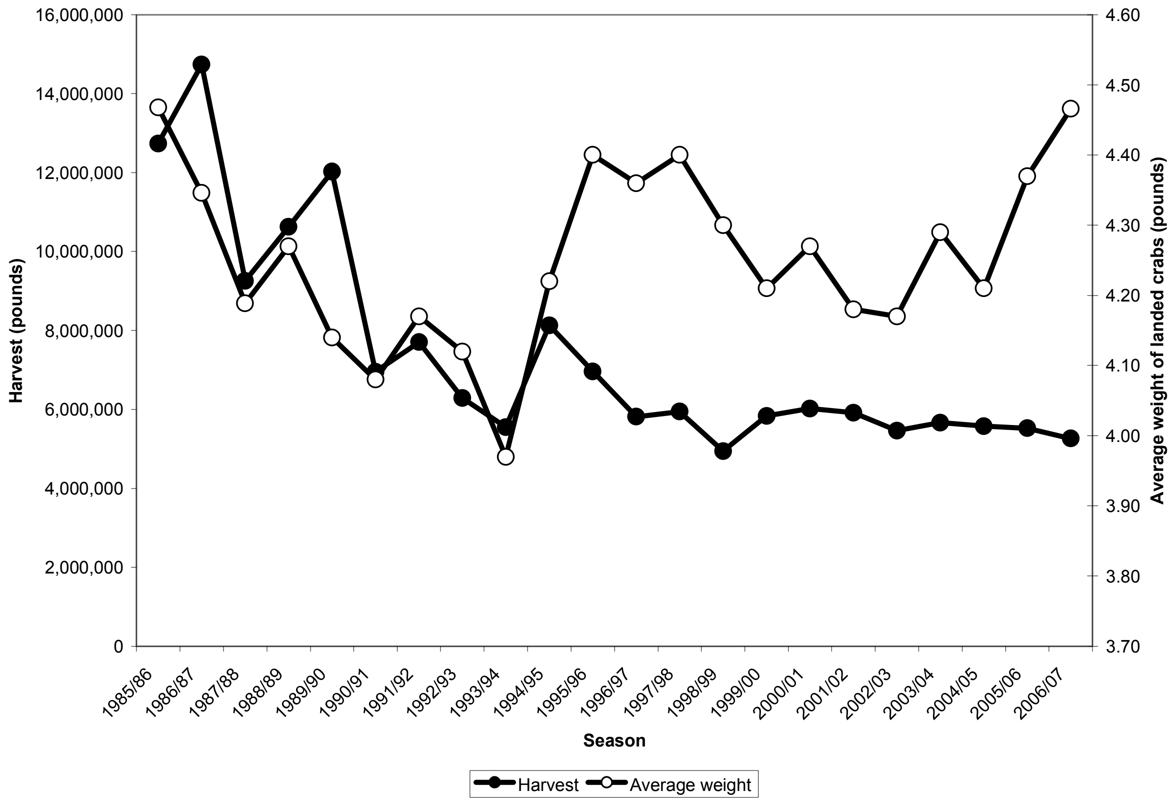
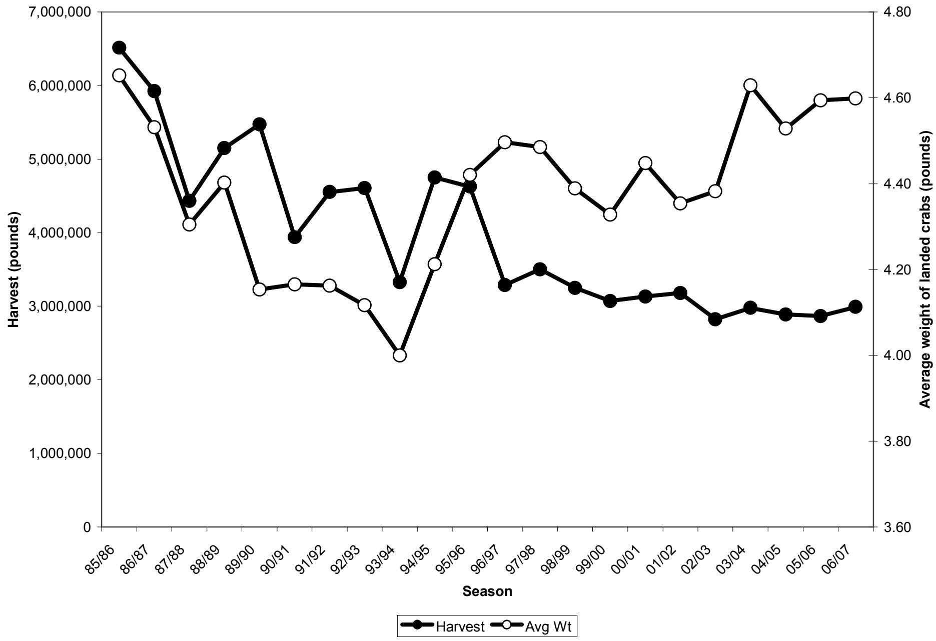


Figure 10. Retained catch (harvest in pounds) and average weight (pounds) of landed crabs in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons.



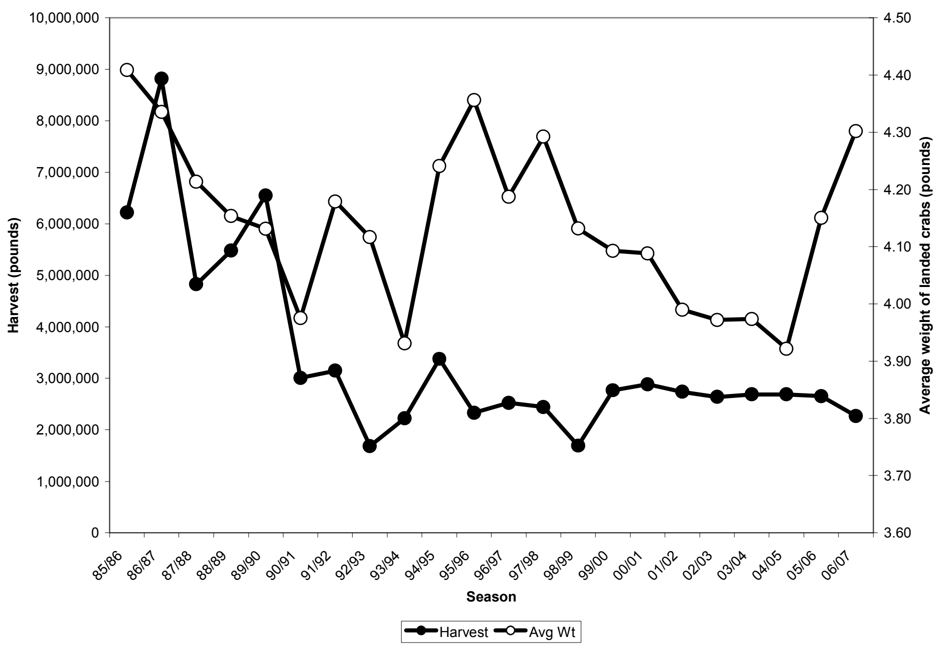


Figure 11. Retained catch (harvest in pounds) and average weight (pounds) of landed crabs in the Aleutian Islands golden king crab fishery, 1985/86–2006/07 seasons, for the area east of 174° W longitude (top panel) and the area west of 174° W longitude (bottom panel).

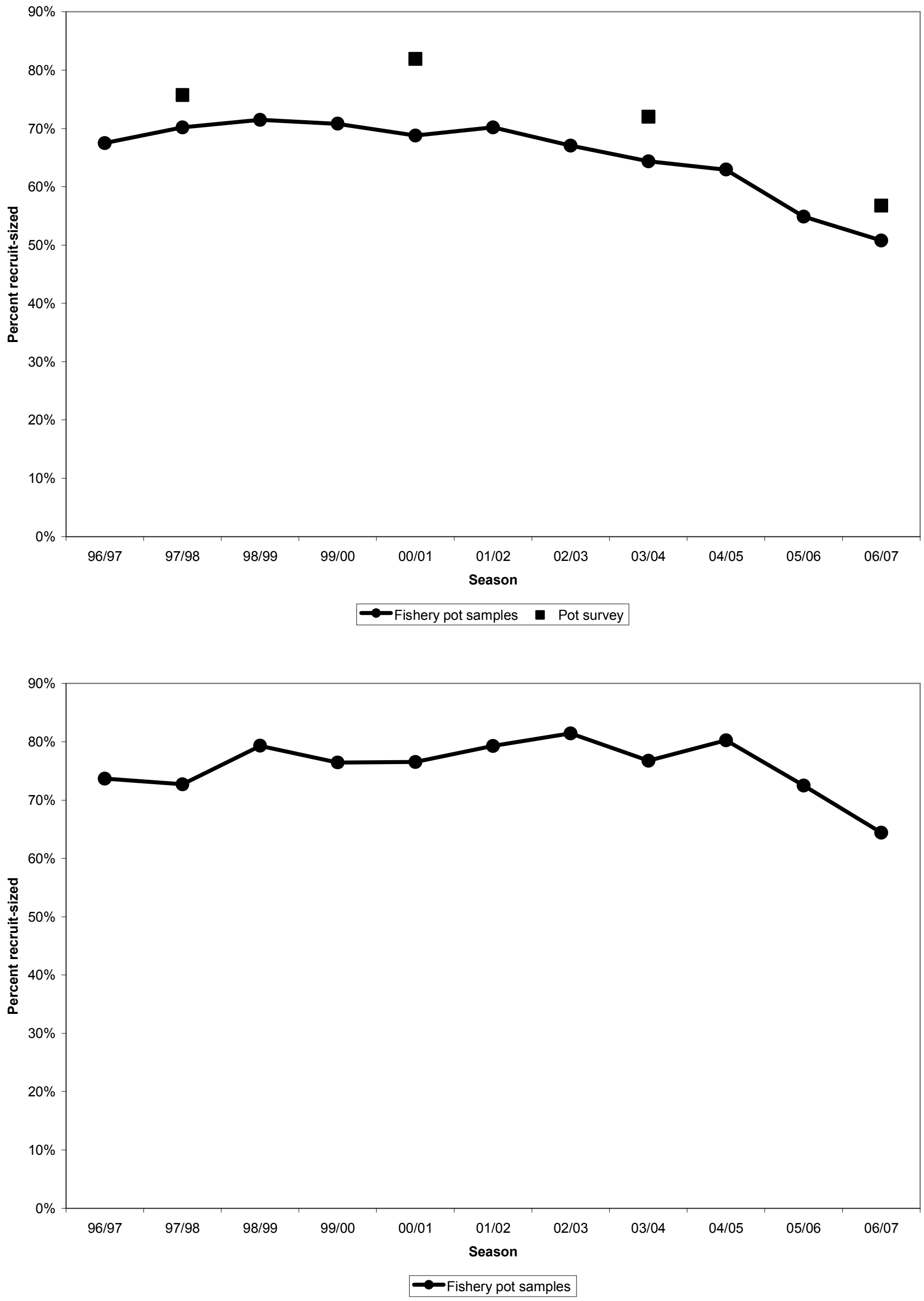


Figure 12. Percent of legal males that were recruit-sized (<151 mm CL) in pots randomly sampled by observers during the Aleutian Islands golden king crab fishery east of 174º W longitude, 1996/97–2006/07, and in pots fished during the triennial ADF&G Aleutian Islands golden king crab pot survey, 1997–2006 (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).

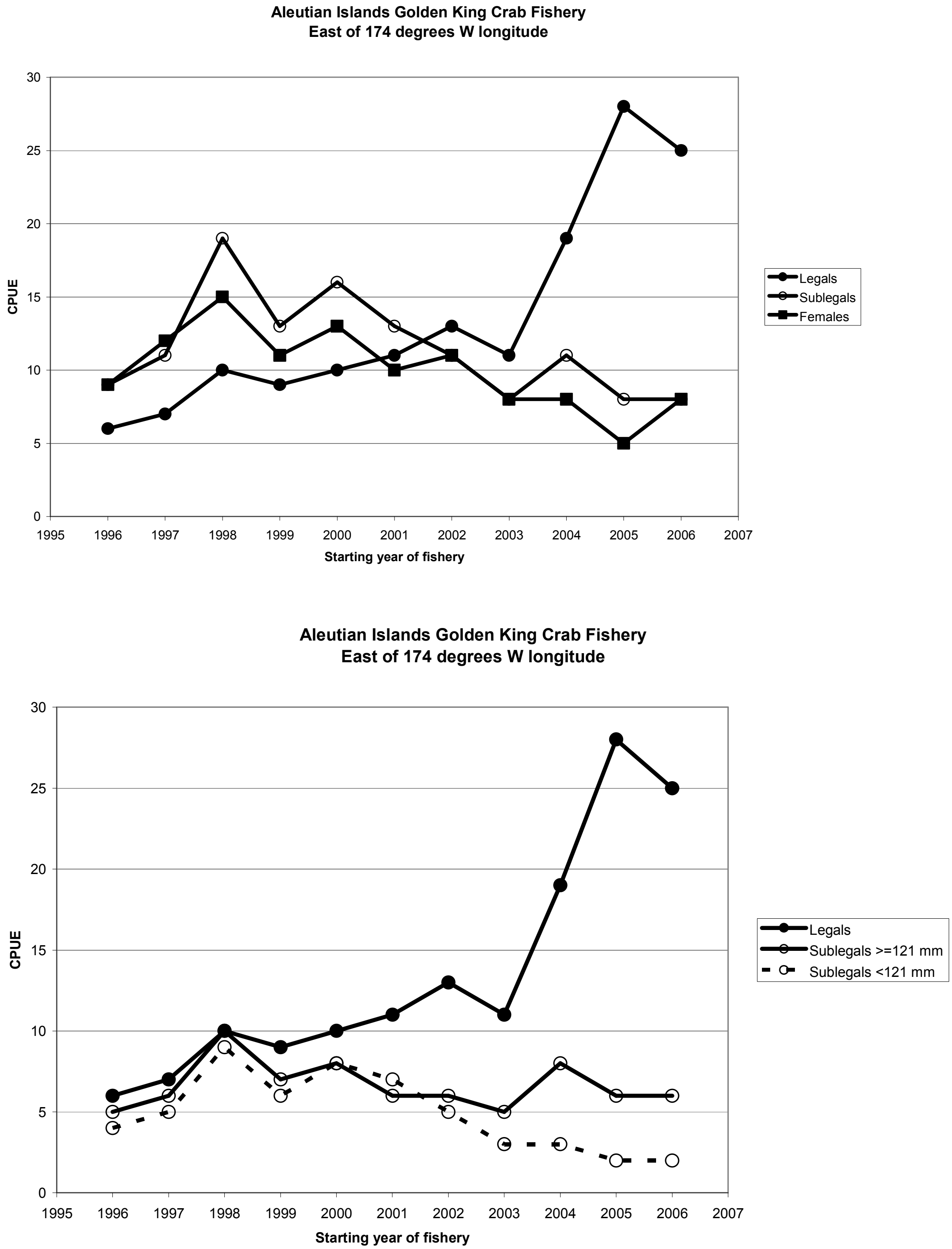
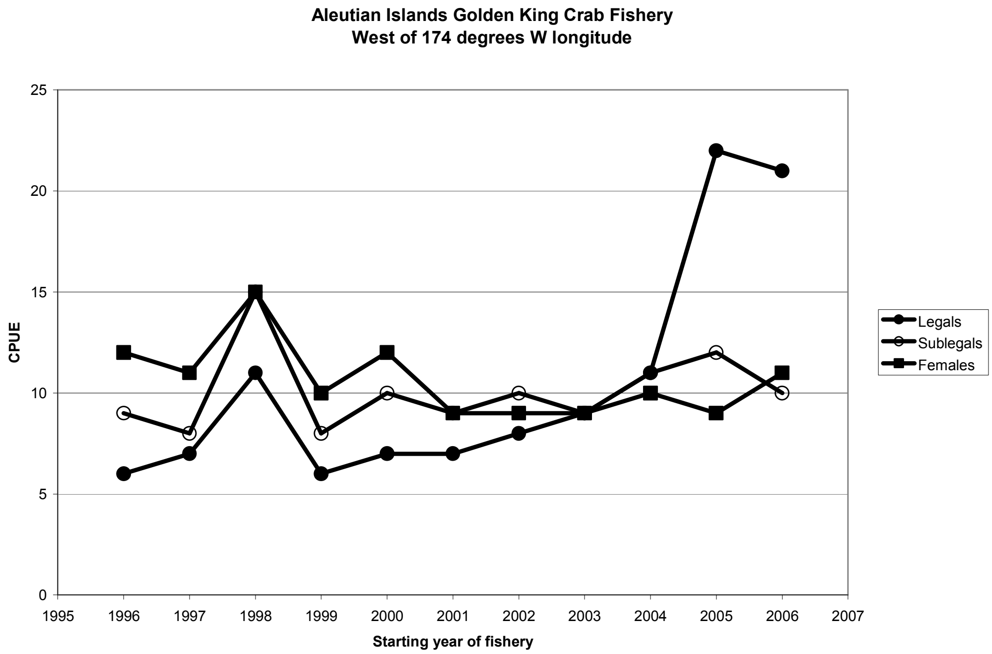


Figure 13. Catch per unit effort of legal males, sublegal males, and females (top panel) and of legal males, sublegal males ≥121 mm CL, and sublegal males <121 mm CL (bottom panel) in the Aleutian Islands golden king crab fishery east of 174º W longitude, 1996/97–2006/07 seasons, as estimated from contents of pots randomly sampled by observers.



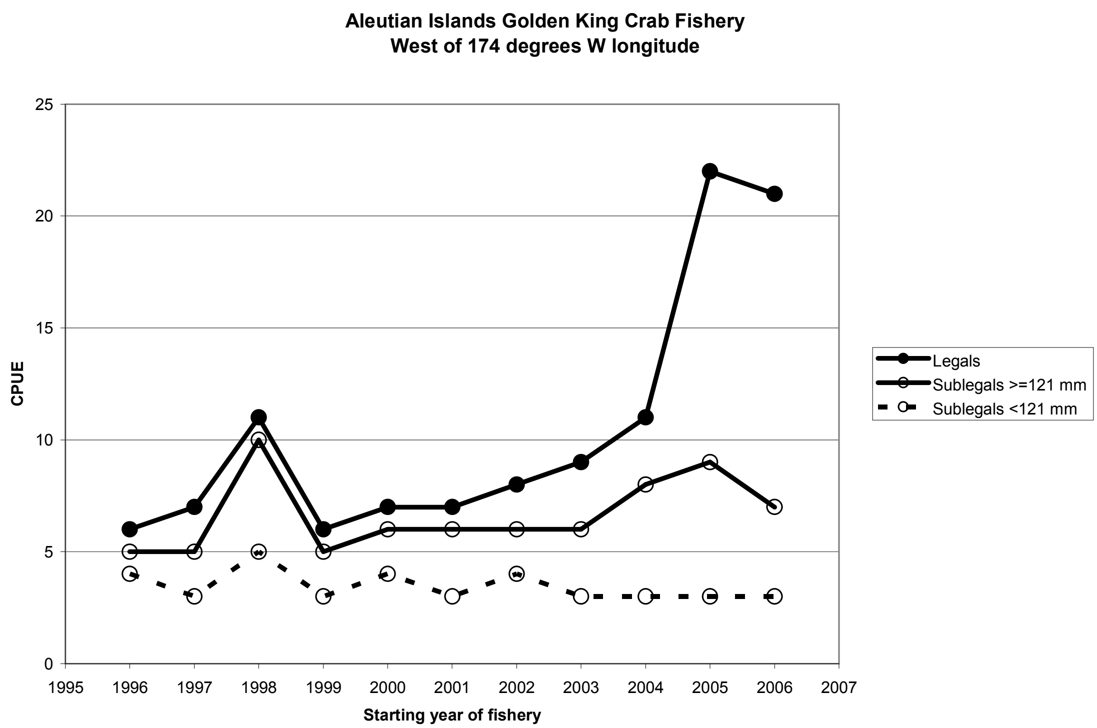


Figure 14. Catch per unit effort of legal males, sublegal males and females (top panel) and of legal males, sublegal males ≥121 mm CL, and sublegal males <121 mm CL (bottom panel) in the Aleutian Islands golden king crab fishery west of 174º W longitude, 1996/97–2006/07 seasons, as estimated from contents of pots randomly sampled by observers.

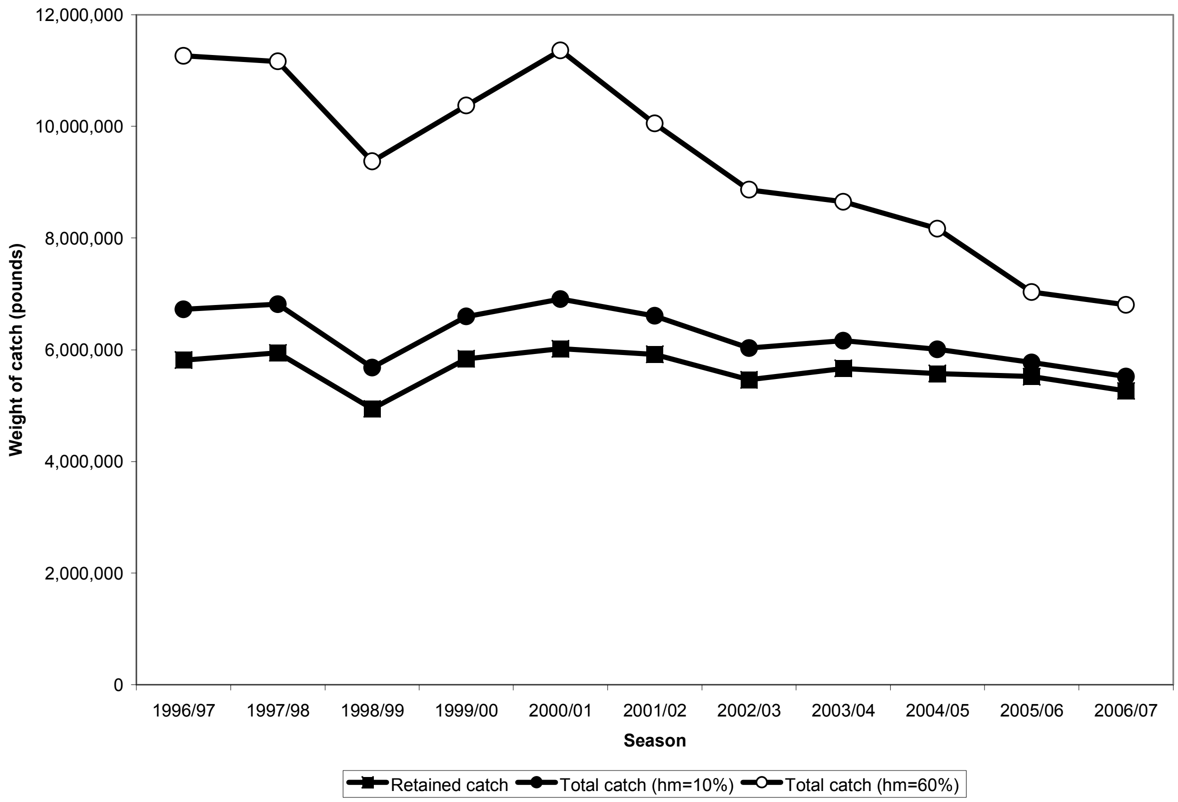


Figure 15. Annual retained catch (pounds) for the 1996/97–2006/07 Aleutian Islands golden king crab fishery compared to total catch (retained catch plus handling mortality of discarded bycatch, pounds) estimated by assuming handling mortality (*hm*) rates of *hm*=10% and *hm*=60%.

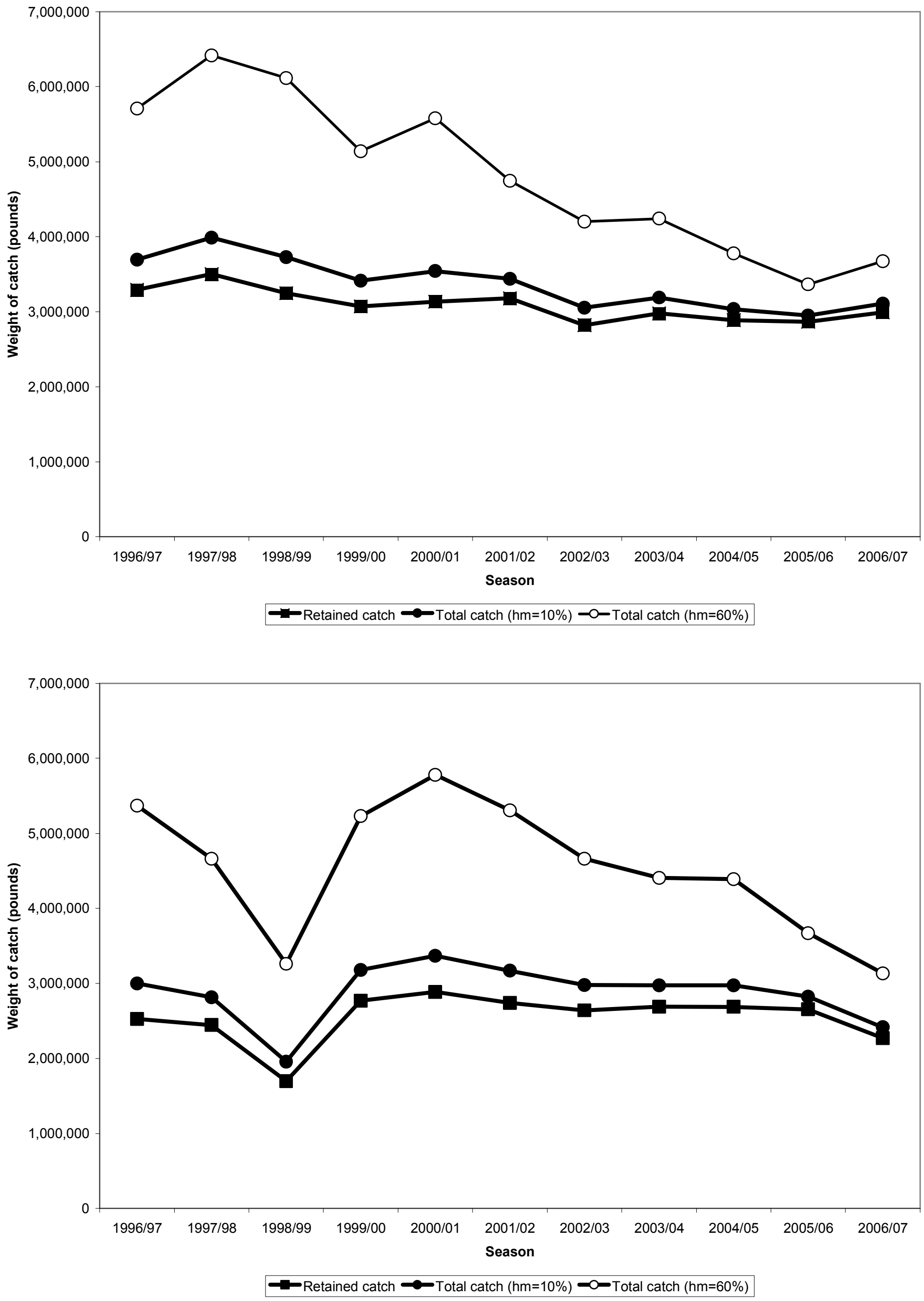


Figure 16. Annual retained catch (pounds) for the 1996/97–2006/07 Aleutian Islands golden king crab fishery in the area east of 174° W longitude (top panel) and in the area west of 174° W longitude (bottom panel) compared to total catch (retained catch plus handling mortality of discarded bycatch, pounds) estimated by assuming handling mortality (*hm*) rates of *hm*=10% and *hm*=60%.

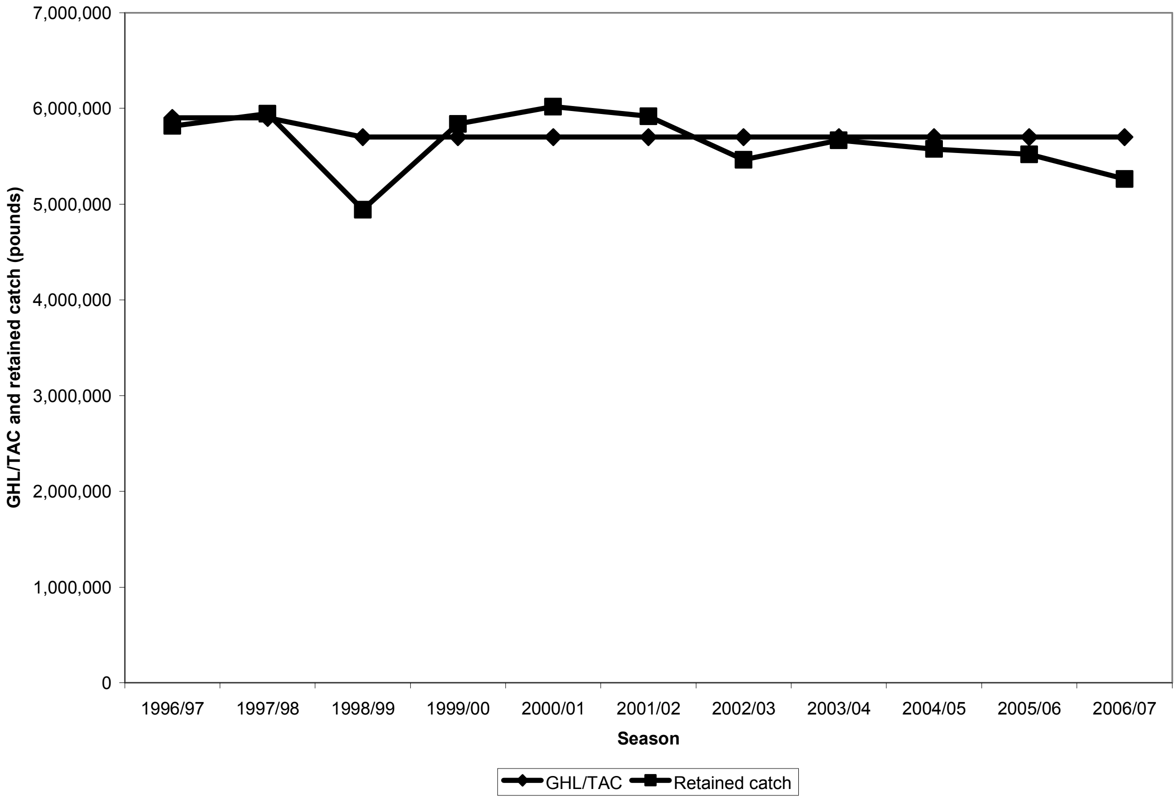
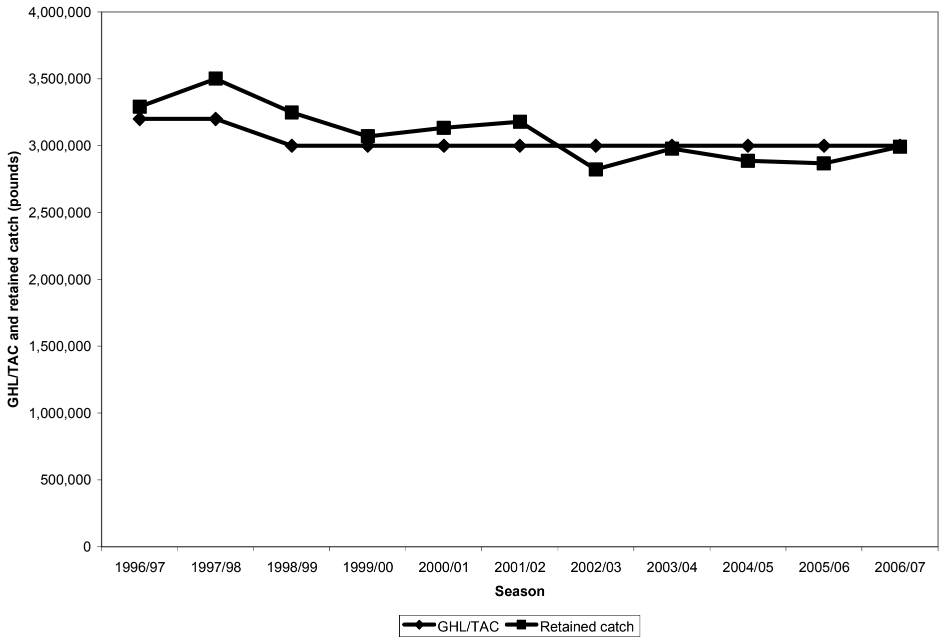


Figure 17. Pre-season GHL (in pounds for the 1996/97–2004/05 seasons) and TAC (in pounds for the 2005/06–2006/07 seasons) compared to the retained catch (pounds) during the 1996/97–2006/07 Aleutian Islands golden king crab fishery.



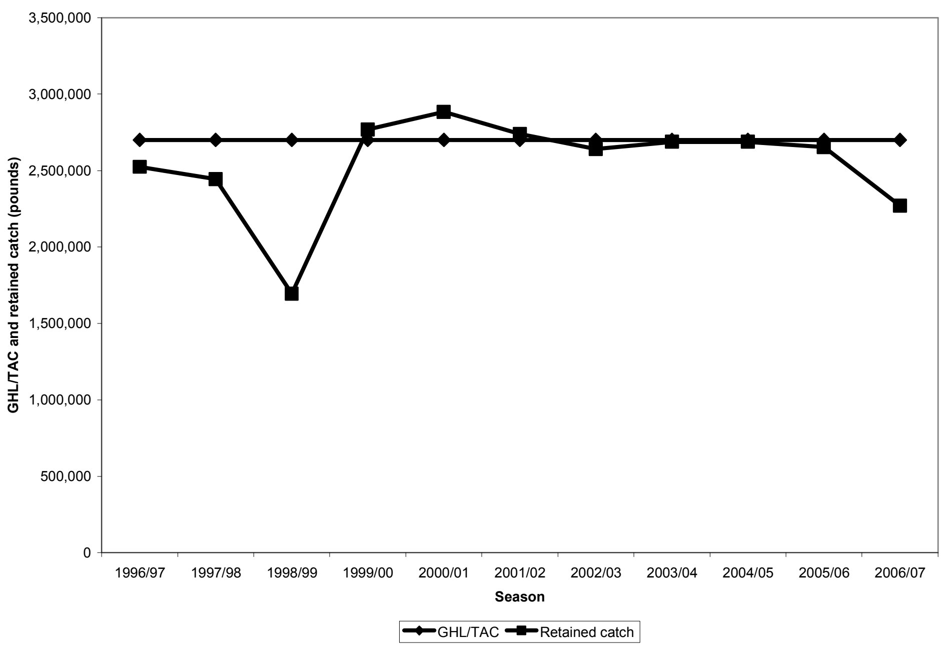


Figure 18. Pre-season GHL (in pounds for the 1996/97–2004/05 seasons) and TAC (in pounds for the 2005/06–2006/07 seasons) compared to the retained catch (pounds) during the 1996/97–2006/07 Aleutian Islands golden king crab fishery in the area east of 174° W longitude (top panel) and in the area west of 174° W longitude (bottom panel).

Pribilof Islands Golden King Crab

September 2009 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak

Executive Summary

1. **Stock:** Golden king crab/Pribilof Islands (Pribilof District)

2. Catches:
Commercial fishing for golden king crab in the Pribilof District has been concentrated in the Pribilof Canyon. The fishing season for this stock has defined as a calendar year since 1984. The domestic fishery developed in 1982. Peak harvest occurred in the 1983/84 season with a retained catch of 856-thousand pounds by 50 vessels. Since then, participation in the fishery has been sporadic and annually retained catch has been variable, from 0 pounds in the eight years that no vessels participated (1984, 1986, 1990–1992, 2006–2008) up to a maximum of 342-thousand pounds in 1995, when seven vessels made landings. The fishery is not rationalized and has been managed towards a GHL of 150-thousand pounds since 2000. Non-retained bycatch can occur in the directed fishery, as well as in the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and Bering Sea groundfish fisheries. Estimated weight of non-retained bycatch during crab fisheries ranges from 0 pounds to 49-thousand pounds annually during calendar years 2001–2008; estimates of fishery mortality (in terms of catch) during 2002–2008 crab fisheries range from 0 pounds to 160-thousand pounds (average = 76-thousand pounds). Estimates of discarded bycatch during Bering Sea groundfish fisheries ranges from 0.1-thousand to 12-thousand pounds annually during the 1991/92–2008/09 "crab fishery years"; estimates of fishery mortality during 1991/92–2008/09 groundfish fisheries range from 0.1-thousand pounds to 9-thousand pounds (average = 3-thousand pounds). There was no participation in the fishery and no landings for the fishery in 2008. The current 2009 season will end on 31 December 2009.

3. Stock biomass:
Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained during eastern Bering Sea upper continental slope trawl surveys performed by NMFS-AFSC in 2002, 2004, and 2008. The estimate for the Pribilof Canyon area in 2008 was 919 metric tons (2.03-million pounds).

4. Recruitment:
From data collected during the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea upper continental slope surveys biomass of golden king crabs (all sizes and both sexes) are estimated to have increased in the eastern Bering Sea. In the Pribilof Canyon area biomass has been estimated to have increased from 682 metric tons (1.50-million pounds) in 2002 to 919 metric tons (2.03-million pounds) in 2008.

5. Management performance:
No overfished determination (i.e., MSST) is possible for this stock given the limited information and analysis on stock biomass that has been presented; there are presently no estimates of mature male biomass or mature female biomass for this stock. The Pribilof Island golden king crab season is based on a calendar year and the 2009 season is currently open. Hence an overfishing determination cannot be made until the end of 2009. There was no participation in the fishery and no landings for the fishery in 2008. See table, below.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c,e]
2006	N/A	N/A	0.150	0	0.000	N/A
2007	N/A	N/A	0.150	0	0.000	N/A
2008	N/A	N/A	0.150	0	0.001	N/A
2009	N/A	N/A	0.150	TBD	TBD	0.17
2010	N/A	N/A	TBD	TBD	TBD	TBD

a. The Pribilof Island golden king crab season is based on a calendar year.
b. Guideline harvest level, millions of pounds. The Pribilof Islands golden king crab fishery is not rationalized and a TAC is not established for the fishery.
c. Millions of pounds.
d. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data is summarized by "crab fishery year" rather than calendar year; estimates of bycatch mortality during 2004/05–2008/09 groundfish fisheries range from <0.001-million pounds to 0.004-million pounds.
e. Retained-catch OFL.

6. **Basis for the OFL:** See table, below.

Year[a]	Tier	Years to define Average catch (OFL)	Natural Mortality
2009	5	1993–1999[b]	0.18[c]
2010	5	TBD	0.18[c]

a. The Pribilof Island golden king crab season is based on a calendar year.
b. OFL was for retained catch and was determined by the average of the retained catch for these years.
c. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.

7. **A summary of the results of any rebuilding analyses:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **Changes to the management of the fishery:** None. Fishery continues to be managed under authority of an ADF&G commissioner's permit and with a guideline harvest level (GHL) of 150,000 pounds. There was no participation in the fishery during 2008. The 2009 season ends on 31 December 2009.

2. **Changes to the input data:**
   - Retained catch data has been updated with the results for 2008, during which there was no fishery participation (note: the Pribilof Island golden king crab season is based on a calendar year).

3. **Changes to the assessment methodology:** None.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:**
   - The OFL for 2009 was 0.17-million pounds of retained catch and was estimated by the average annual retained catch (including deadloss) for the period 1993–1999. The recommended

retained-catch OFL for 2010 is 0.17-million pounds and was estimated as the average retained catch (including deadloss) for the period 1993–1998.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general</u>:**
   - <u>CPT, September 2008</u>: Only two general comments by the CPT pertain to a Tier 5 assessment,
     - i. *"The team agreed that assessment documents presented to September meetings should be the "track changes" version of the May assessments, to facilitate evaluating changes from the version."*

       <u>Response</u>: There was no May 2009 version of this assessment. A "track changes" version applied to the September 2008 assessment would be a real mess due to the substantial change in standard outline for assessments (see below).
     - ii. *"A checklist of the items which should be included in stock assessments on which the OFL determinations are based should be developed. This checklist would include a table of survey estimates (and their associated CVs) by year. Having a standard approach to reporting assessment results will help the review process as well as how the work of the team is documented."*

       <u>Response</u>: This assessment was prepared according to "Appendix C: A Guide to the Preparation of Bering Sea and Aleutian Islands Crab SAFE Report Chapters" developed during the CPT's Alaska Crab Stock Assessment Workshop of May 2009.
   - <u>SSC, October 2008</u>: "*The SSC commends the CPT for the detailed review of the revised stock assessments conducted at its September meeting. In particular, the SSC supports the CPT's intention to compile the checklist of items to be included in stock assessment documents as a template for authors. The SSC especially appreciates the CPT's identification of the need to include tables of annual survey estimates of abundance, including a standardized measure of precision."*
     - <u>Response</u>: This report follows the template for assessment documents that has been developed since October 2008.
   - <u>CPT, May 2009</u>: Only one general comment by the CPT pertained to a Tier 5 assessment: *"The timing for final assessments for Tier 5 stocks should be done annually in May and only brought back to the CPT as an agenda item in September should there be new information over the summer and/or modification to the CPT recommendation from the SSC. This year the other two Tier 5 assessments (Adak RKC and PIGKC) will be finalized in September; next year they will be on the May schedule."*
     - <u>Response</u>: This is the last final assessment for Pribilof Islands golden king crab that will occur in September.
   - <u>SSC, June 2009</u>: The SSC made two general comments on BSAI crab assessments, one of which did not pertain to Tier 5 stocks. The other general comment was: "*The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number of years that are common across groups of species or areas."*
     - <u>Response</u>: Discussion on this issue has yet to occur.

2. **<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:**
   - <u>CPT, September 2008</u>: *"There may be some additional information available from the recent EBS trawl survey on the AIGKC stock. These data will be processed over the winter and available information will be provided to the stock assessment author for the following year."*
     - <u>Response</u>: Information from published results of the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea continental slope trawl survey are presented in this assessment (see Executive Summary item 4, and sections C.2, D.2.d , and D.2.e).

- SSC, October 2008: The SSC made no comments on the Pribilof Islands golden king crab stock assessment at the October 2008 meeting.
- CPT, May 2009: *"The team supported the author's recommendation to use the same years for calculating the retained catch OFL for this stock. Bycatch data will be compiled and included in the September assessment."*
    - Response: A retained-catch OFL is calculated as recommended (see section E). Bycatch estimates from crab fisheries prosecuted during calendar years 2001–2008 have been compiled (see section D.2.a). Bycatch estimates from the federal groundfish fisheries 1991/92–2008/09 have been compiled and summarized (see section D.2.a).
- SSC, June 2009: Not applicable. A Pribilof Islands golden king crab stock assessment report was not reviewed by SSC at the June 2009 meeting.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crabs is summarized by NMFS (2004):

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI, golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (page 3-34).
>
> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of 300-1,000 m on extremely rough bottom. They are frequently found on coral bottom (page 3-43).

The Pribilof Islands king crab stock boundary is defined by the boundaries of the Pribilof District of Registration Area Q (Figure 1). Bowers et al. (2008, page 84) define those boundaries:

> The Bering Sea king crab Registration Area Q has as its southern boundary a line from 54° 36' N lat., 168° W long., to 54° 36' N lat., 171° W long., to 55° 30' N lat., 171° W. long., to 55° 30' N lat., 173° 30' E long., as its northern boundary the latitude of Point Hope (68° 21' N lat.), as its eastern boundary a line from 54° 36' N lat., 168° W long., to 58° 39' N lat., 168° W long., to Cape Newenham (58° 39' N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991. Area Q is divided into the Pribilof District, which includes waters south of Cape Newenham, and the Northern District, which incorporates all waters north of Cape Newenham.

Results of the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea continental slope trawl surveys presented by Haaga et al. (2009) and of the 2004 survey presented by Hoff and Britt (2005) show that the biomass, number, and density (kg/ha and number/ha) of golden king crabs on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas. Highest densities, biomass, and abundance of golden king crabs in the Bering Sea occur in the Pribilof Canyon (Hoff and Britt 2005, Haaga et al. 2009; Figure 2), as does most of the commercial catch of golden king crabs (Bowers et al. 2008, Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006).

Results of the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea continental slope trawl surveys presented by Haaga et al. (2009) and of the 2004 survey presented by Hoff and Britt (2005) show that majority of golden king crabs on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (see section D.2.d). Commercial fishing for golden king crabs in the Bering Sea typically occurs at depths of 100–300 fathoms (183–549 m; Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006); average depth of pots fished in the Pribilof golden king crab fishery during the 2002 fishery (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 m).

3. **Evidence of stock structure:** We are aware of no data for evaluating stock structure within this stock.

4. **Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):**

The following review of molt timing and reproductive cycle of golden king crabs is adapted from Watson et al. (2002):

> Unlike red king crabs, golden king crabs may have an asynchronous molting cycle (McBride et al. 1982, Otto and Cummiskey 1985, Sloan 1985, Blau and Pengilly 1994). In a sample of male golden king crabs 95–155-mm CL and female golden king crabs 104–157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crabs in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.
>
> Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From their observations on embryo development in golden king crabs, Otto and Cummiskey's (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crabs. Data from tagging studies on female golden king crabs in the Aleutian Islands are generally consistent with a molt period for mature females of 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al 2002). From laboratory studies of golden king crabs collected from Prince William Sound, Paul and Paul (2001c) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.
>
> Numerous observations on clutch and embryo condition of mature female golden king crabs captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985, Hiramoto 1985, Sloan 1985, Somerton and Otto 1986, Blau and Pengilly 1994, Blau et al. 1998, Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crabs may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crabs without eating; Shirley and Zhou 1997).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crabs likely makes scoring shell conditions very difficult and especially difficult to relate to "time post-molt," posing problems for inclusion of shell condition data into assessment models.

5. Brief summary of management history:

A complete summary of the management history is provided in the ADF&G Area Management Report appended to this SAFE and in Bowers et al. (2008, pages 88–90). The first domestic harvest of golden king crabs in the Pribilof District was in 1982 when two vessels fished (Bowers et al. 2008). Peak harvest and participation occurred in the 1983/84 season with a retained catch of 0.86-million pounds (Table 1, Figure 3) and from landings by 50 vessels. Since 1984 the fishery has been managed with a calendar-year season under authority of a commissioner's permit and landings and participation has been low and sporadic. Retained catch during 1984–2008 has ranged from 0 pounds to 0.34-million pounds and the number of vessels participating annually has ranged from 0 to 8; no vessels registered for the fishery and there was no retained catch in 2006–2008. The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was 0.20-million pounds, whereas for the 2000-2009 the GHL has been 0.15-million pounds.

A summary of relevant fishery regulations and management actions pertaining to the Pribilof District golden king crab fishery is provided below.

Only males of a minimum legal size may be retained by the Pribilof Islands golden king crab fishery. By State of Alaska regulation (5 AAC 34.920 (a)), the minimum legal size limit is 5.5-inches (140 mm) carapace width (CW), including spines. A carapace length (CL) ≥124 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007).

Golden king crabs may be commercially fished only with king crab pots (as defined in 5 AAC 34.050). Pots used to fish for golden king crabs in the Pribilof Islands must have at least four escape rings of no less than five and one-half inches inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crabs (5 AAC 34.925 (c)). There is a pot limit of 40 pots for vessels ≤125-feet LOA and of 50 pots for vessels >125-feet LOA (AAC 34.925 (e)(1)(B)).

Golden king crab can be harvested from 1 January through 31 December only under conditions of a permit issued by the commissioner of ADF&G (5 AAC 34.910 (b)(3)). Since 2001 those conditions have included the carrying of a fisheries observer.

D. Data

1. Summary of new information:

- Retained catch (0 pounds) during 2008 has been added to the retained catch time series.
- Estimated bycatch (weight) and total fishery mortality of golden king crabs in crab fisheries prosecuted during calendar years 2001–2008. This information is presented in response to a request of the CPT in May 2009.
- Estimated bycatch and total fishery mortality of golden king crabs during federal groundfish fisheries in reporting areas 513, 517, and 521 for 1991/92–2008/09 is presented (summarized by "crab-fishing years" – i.e., July 1 to 30 June – as opposed to calendar year – which is unfortunate in this case as the directed fishery is managed by calendar year). This information is presented in response to a request of the CPT in May 2009.
- Stock distribution data and stock biomass estimates from the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea upper continental slope trawl surveys is presented. This information is presented in response to a request of the CPT in May 2008.

2. Data presented as time series:

a. Total catch** and b. **Information on bycatch and discards:

- The 1981/82–1983/84, 1984–2000 time series of retained catch (number and pounds of crabs harvested, including deadloss), effort (vessels, landings, and pot lifts), average weight of landed crabs, average carapace length of landed crabs, and CPUE (number of landed crabs captured per pot lift) is presented in Table 1.
  - The 1981/82–1983/84, 1984–2000 time series of retained catch (pounds of landed crabs) is presented graphically in Figure 3.
- The 2001–2008 times series of weight of retained catch, estimated bycatch and estimated weight of fishery mortality of Pribilof Islands golden king crabs during commercial crab fisheries is given in Table 2. Bycatch of Pribilof Islands golden king crabs occurs mainly in the directed golden king crab fishery, when prosecuted, and to a lesser extent in the Bering Sea snow crab fishery and the Bering Sea grooved Tanner crab fishery. Because the Bering Sea snow crab fishery is prosecuted mainly or entirely between January and May and the Bering Sea grooved Tanner crab fishery is prosecuted with a calendar-year season, the bycatch estimates for the crab fisheries can be estimated on a calendar-year basis to align with the season for Pribilof District golden king crab. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of golden king crabs by applying a weight-at-length estimator (see below). 2001 is the first year that observers were deployed to collect data on bycatch during the Pribilof District golden king crab fishery. Due to the limited number of observed vessels, retained catch or observer data from at least one of the fisheries is confidential for 2001 and for 2003–2005. Estimates of the weight of fishery mortality can be made for 2002–2008 without revealing confidential data by pooling of data; the estimate of total fishery mortality during crab fisheries for 2001 cannot be presented without revealing confidential data. Following Siddeek et al. (2009), the handling mortality rate of king crabs captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2. Following Foy and Rugolo (2009), handling mortality rate during the snow crab fishery was assumed to be 0.5. The handling mortality rate during the grooved Tanner crab fishery was also assumed to be 0.5. Average annual total fishery mortality in crab fisheries during 2002–2008 is estimated at 78-thousand pounds.
- The 1991/92–2008/09 time series of estimated weight of bycatch and total fishery mortality of golden king crabs in reporting areas 513, 517, and 521 during federal groundfish fisheries by gear type (fixed or trawl) is provided in Table 3. Following Foy and Rugolo (2009), the handling mortality of king crabs captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crabs captured by trawls during groundfish fisheries was assumed to be 0.8. Due to the mismatch in definition of years for the crab fishery and groundfish fishery data, the estimates of total fishery mortality during groundfish fisheries cannot be directed to the estimates of total fishery mortality during crab fisheries. Average annual total fishery mortality in groundfish fisheries during 1991/92–2008/09 is estimated at 3-thousand pounds

c. Catch-at-length:

The size (carapace length, CL, mm) distribution of retained legal male golden king crabs from the Pribilof Islands golden king crab fishery sampled prior to processing at-sea and dockside by observers and ADF&G catch samplers during 2002 is provided in Figure 4. 2002 is the only year for which these data are not confidential and which can be separated from catch samples from the St. Matthew golden king crab fishery.

d. Survey biomass estimates:

Biomass estimates of golden king crabs (all sizes and sexes) by area and depth zone from the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey are presented in Table 4. Details on the survey sampling effort during the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey and the biomass estimates of golden king crabs (all sizes and sexes) by area and depth zone with estimated variances and CVs are presented in Table 5.

e. Survey catch at length:
Size composition, by sex and depth zone, of the estimated golden king crab population from the 2004 eastern Bering Sea upper continental slope trawl survey in presented in Figure 5.

f. ***Other data time series:*** See section D.4 on other time-series data that is available, but not presented here.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):
We are not aware of data on growth per molt of Pribilof Islands golden king crabs. Growth per molt of juvenile golden king crabs, 2–35-mm CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here.

See section C.4 for discussion of evidence that mature female and the larger male golden king crabs exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):
Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crabs according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.0002988 and B = 3.135 for males and A = 0.001424 and B = 2.781; note that although the estimated parameters, A and B, are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to pounds by dividing by 453.6.

c. Natural mortality rate:
The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18. Note, however, natural mortality was not used for OFL estimation because this stock belongs to Tier 5.

4. Information on any data sources that were available, but were excluded from the assessment:
Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea upper continental slope have been performed in 2002, 2004, and 2008 (Hoff and Britt 2005, Haaga et al. 2009). The raw data from those surveys have not been accessed for this assessment; only summary of results and stock biomass estimates that have been published for the 2004 survey (Hoff and Britt 2005) and reported for the 2002, 2004, and 2008 surveys (Hagga et al. 2009) are presented in this assessment. Access to the raw data from those standardized surveys could allow for estimation of abundance and biomass of golden king crab in the Pribilof District by relevant size, sex, and reproductive-status classes (e.g., mature male biomass, mature female biomass, legal-sized male biomass, etc). Additionally, a pilot slope survey was also performed in 2000 and triennial surveys using a variety of nets, methods, vessels, and sampling locations were performed during 1979–1991 (Hoff and Britt 2005) and no data from those surveys were accessed and no results from those surveys were reported on in this assessment. Note, however, that the "degree of comparability between the post-2000 surveys and those conducted from 1979 to 1991 has yet to be determined due to the differences in sampling gear, survey design, sampling methodology, and species identification" (Hoff and Britt 2005).

E. Analytic Approach

1. History of modeling approaches for this stock: This is a Tier 5 stock; there is no assessment model and no history of assessment modelling approaches for this stock.

2. Model Description: *Subsections a–i are not applicable to a Tier 5 sock.*
No assessment model for the Pribilof Islands golden king crab stock exists and none is in development. Accordingly, it has been recommended by NPFMC (2007) and by the CPT and SSC in 2008 that the Pribilof Islands golden king crab stock be managed as a Tier 5 stock. For Tier 5 stocks only an OFL is

estimated, because it is not possible to estimate MSST without an estimate of biomass, and "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). 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."

Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which nontarget fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). Hence, alternative configurations for the Tier 5 model are limited to: 1) a retained-catch versus total-catch OFL, and 2) alternative time periods for computing the average catch (whether retained or total). The important questions to resolve when choosing from among alternative time periods for computing average catch (whether retained or total) as an estimate of OFL are:

1. Over what time period in the history of the fishery was the retained catch "representative of the production potential of the stock?"
2. In choosing the time period, what available information should be used when considering "the required risk aversion for stock conservation?"
3. In choosing the time period, what available information should be used when considering "utilization goals?"

NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof Islands golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching during the 1976/77 "regime shift" and growth to legal size. With regard to excluding data from years 1985 to 1992 and years after 1999, NPFMC (2007) states, "The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than 10% of the average or the GHL was set below the previous average catch." In 2008 the CPT and SSC endorsed the approach of estimating OFL as the average retained catch during 1993–1999 for setting a retained-catch OFL for 2009 and in May 2009 the CPT again recommended that approach for setting a retained-catch OFL for 2010.

3. <u>Model Selection and Evaluation</u>:

a. <u>Description of alternative model configurations</u>

The recommended OFL is set as a retained-catch OFL due to lack of data on bycatch of golden king crabs during the Pribilof District golden king crab fishery prior to the establishment of GHLs (GHLs were first established in 1999 and observers were not deployed to the fishery until 2001.

Three alternative configurations for computing average retained catch to estimate a retained-catch OFL for 2010 were considered and described below (the "Base" and Alternatives 1 and 2). In 10 of the 12 seasons prior to the 1993 season, there was either no fishery effort (five seasons) or the fishery data are confidential (five seasons). Hence the author recommends that years prior to the 1993 fishery season not be included in any computation of average retained-catch weight as a measure of OFL. Likewise, in the six completed seasons after 2002 (i.e., 2003–2008), fishery data for 2003–2005 are confidential and there was no fishery effort in 2006–2008. Hence the author recommends that years after the 2002 fishery season not be included in any computation of average retained catch weight as an estimate of OFL.

For choice of a time period within 1993–2002, the following should be considered. No GHL was established for the fishery prior to the 1999 season. The 1999 season was managed with a GHL of 200,000 pounds, which was established inseason in response to higher-than-expected catch rates, and the fishery was closed by emergency order to avoid exceeding the GHL (Morrison et al. 2000). The actual fishery harvest for 1999 was 177,427 pounds, which was nearly equal to that for 1997 (184,803 pounds) and to the average for 1993–1998 (175,563 pounds), but far above that for 1998 (36,196 pounds; Table 1, Figure 3). The 2000–2002 seasons were each constrained by a GHL of 150,000 pounds that was established pre-season and which was below the average catch for 1993–1999 (175,829 pounds). Whereas the fishery remained open through the entirety of 2000 without achieving the GHL, the fishery was closed by emergency order in both 2001 and 2002 to avoid exceeding the GHL. The average retained catch during the 2000–2002 seasons was 148,446 pounds.

Model	**Retained- vs. Total-catch**	**Time Period (n of years)**	**Description/Comments**
Base	Retained	1993–1999 (7)	• Used to determined the 2009 OFL • Catch was not constrained by GHL during 1993–1998 • Catch for 1999 was constrained by GHL
Alt. 1	Retained	1993–2002 (10)	• Longer time period than the Base • Includes more recent years of data than the Base • The catch in the additional, more-recent years were constrained by the GHL in 2000–2002
Alt. 2	Retained	1993–1998 (6)	• Shortest, least recent time period considered • Catch was not constrained by GHL in any year

b. ***<u>Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed</u>:*** See the table, below.

Model	**Retained- vs. Total-catch**	**Time Period (n of years)**	**Resulting OFL (millions of pounds)**
Base	Retained	1993–1999 (7)	0.17
Alt. 1	Retained	1993–2002 (10)	0.16
Alt. 2	Retained	1993–1998 (6)	0.17

c. ***<u>Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models</u>:***

All alternatives assume that catch is indicative of stock productivity without any regard to harvest restraints (GHLs, TACs, fishery closures, etc) that were imposed by management during the history of the fishery. The reality of that assumption was discussed for the time periods considered in section E.3.a. Alternative 2 is the most realistic in this regard.

d. ***<u>Convergence status and convergence criteria for the base-case model (or proposed base-case model)</u>:*** Not applicable.

e. ***<u>Table (or plot) of the sample sizes assumed for the compositional data</u>:*** Not applicable.

f. ***<u>Do parameter estimates for all models make sense, are they credible?</u>:***

- Estimates of total retained catch (pounds) during a season are from fish tickets landings recorded at landings and are assumed here to be correct.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** See section E.3.c, above.

4. **Results (best model(s)):**

a. ***List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties:*** Not applicable.

b. ***Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):*** Not applicable.

c. ***Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible):*** Information requested for this subsection is not applicable to a Tier 5 stock. Alternative retained-catch OFLs are graphed relative to actual retained catch during history of fishery in Figure 6.

d. ***Evaluation of the fit to the data:*** Not applicable for Tier 5 stock.

e. ***Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments):*** Not applicable for Tier 5 stock.

f. ***Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):*** Not applicable for Tier 5 stock.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5: Retained-catch OFL estimated by average retained catch over a specified period (as recommended by CPT in May 2009; see section B.2).
   - Recommended time period for computing retained-catch OFL: 1993–1998.
     - The recommended time period departs slightly from the May 2009 recommendation of the CPT in that it excludes 1999 from the time period that was used to compute the OFL for 2009 (see section B.2). The time period 1993–1998 provides the longest continuous time period through 2008 during which vessels participated in the fishery, retained-catch data can be retrieved that is not confidential, and the retained catch was not constrained by a GHL. There is no difference between the retained-catch OFL computed from 1993–1999 data and that computed from 1993–1998 data at the level of precision that the OFL is specified in this assessment.

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable for Tier 5 stock.

3. **Specification of the OFL:**

a. ***Provide the equations (from Amendment 24) on which the OFL is to be based:***

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. Basis for projecting MMB to the time of mating: Not applicable for Tier 5 stock.

c. Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring: See table below.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]
2006	N/A	N/A	0.150	0	0.000	N/A
2007	N/A	N/A	0.150	0	0.000	N/A
2008	N/A	N/A	0.150	0	0.001	N/A
2009	N/A	N/A	0.150	TBD	TBD	0.17[e]
2010	N/A	N/A	TBD	TBD	TBD	0.17[f]

a. The Pribilof Island golden king crab season is based on a calendar year.
b. Guideline harvest level, millions of pounds; a TAC is not established for the fishery.
c. Millions of pounds.
d. Total retained catch plus bycatch mortality of discarded bycatch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data is summarized by "crab fishery year" rather than calendar year; estimates of bycatch mortality during 2004/05–2008/09 groundfish fisheries range from <0.001-million pounds to 0.004-million pounds.
e. Retained-catch OFL established for 2009.
f. Retained-catch OFL recommended by author for 2010.

4. Recommendation for *F_{OFL}*, OFL total catch (or OFL retained catch) for the coming year:

Recommended OLF = 0.17-million pounds, retained-catch.

G. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

H. Data Gaps and Research Priorities

The available data from the NMFS-AFSC eastern Bering Sea upper continental shelf trawl surveys that have been performed (see Hoff and Britt 2005 for review through the 2004 survey) should be examined for their utility in providing reliable estimates of biomass and abundance of golden king crabs by size, sex, and reproductive status within the Pribilof District. As well as the need to determine the comparability of results from the standardized survey that has been performed since 2002 with the results of the surveys performed during 1979–1991 (see section D.4 and Hoff and Britt 2005), there is also a need to estimate the catchability of golden king crabs, by sex and size, by the currently-used survey gear.

I. Ecosystem Considerations

1. Ecosystem Effects on Stock:

a. Prey availability/abundance trends (historically and in the present and foreseeable future): Existence and availability of such information is not known to the author.

b. Predator population trends (historically and in the present and foreseeable future): Existence and availability of such information is not known to the author.

c. Changes in habitat quality (historically and in the present and foreseeable future): Existence and availability of such information is not known to the author.

2. Fishery Effects on the Ecosystem

a. Fishery-specific bycatch of HAPC biota marine mammals and birds, and other sensitive non-target species:

A summary of bycatch during the 2001 and 2002 Pribilof District golden king crab fisheries, the two most recent years for which data is not confidential, are provided in Tables 6 and 7. Note that, due to no participation in the fishery, there was no bycatch due to the fishery during 2006–2008.

b. Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components:

Existence and availability of such information is not known to the author. Note that, the fishery is concentrated in the Pribilof Canyon, typically at depths of 100–300 fathoms (183–549 m; see section C.2). Note that, due to no participation in the fishery, there has been no effect during 2006–2008.

c. Fishery-specific effects on amount of large size target crab:

The fishery can only retain males ≥ 5.5-inches carapace width. Bycatch of sublegal males has been low relative to catch of legal males in seasons for which observer data is available and not confidential; estimated catch of sublegal males was roughly 1/3 that of legal males in 2001 (Neufeld and Barnard 2003) and approximately half that of legal males in 2002 (Barnard and Burt 2004). Hence the fishery, when prosecuted, would be expected to decrease the amount of large size males. However, without background information on the available biomass of large size males, the magnitude of the effect cannot be estimated. Due to lack of fishery effort there has been no effect during 2006–2008.

d. Fishery-specific contribution to discards:

Estimated contribution of discards of Pribilof Islands golden king crabs in the Pribilof District golden king crab fishery relative to the retained catch and to the bycatch in other Bering Sea crab fisheries during 2001–2002 is provided in Table 2. See Table 3 for comparison with the estimated bycatch of Pribilof Islands golden king crabs in federal groundfish fisheries during 1991/92–2008/09. Note that, due to lack of participation in the fishery, there has been no contribution from the fishery during 2006–2008.

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

Existence and availability of such information is not known to the author. Note that, due to no participation in the fishery, there has been no effect during 2006–2008.

f. Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance):

Number of pot lifts performed in the Pribilof District golden king crab fishery, 1981/82–1983/84 and 1984–2008 is plotted in Figure 7 (see also Table 1). Note that most of the fishery effort has been concentrated in the Pribilof Canyon (see section C.2).

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Table 1. Harvest history for the Pribilof Islands golden king crab fishery from the 1981/82 season through 2007 (from Bowers et al. 2008); though not included in this table, there was no effort or landings in 2008.

	Number of					Average			
Season	Vessels	Landings	Crabs[a]	Pots lifted	Harvest[a,b]	Weight[b]	CPUE[c]	Length[d]	Deadloss[b]
1981/82	2				CONFIDENTIAL				
1982/83	10	19	15,330	5,252	69,970	4.6	3	151	570
1983/84	50	115	253,162	26,035	856,475	3.4	10	127	20,041
1984	0				NO LANDINGS				
1985	1				CONFIDENTIAL				
1986	0				NO LANDINGS				
1987	1				CONFIDENTIAL				
1988	2				CONFIDENTIAL				
1989	2				CONFIDENTIAL				
1990	0				NO LANDINGS				
1991	0				NO LANDINGS				
1992	0				NO LANDINGS				
1993	5	15	17,643	15,395	67,458	3.8	1	NA	0
1994	3	5	21,477	1,845	88,985	4.1	12	NA	730
1995	7	22	82,489	9,551	341,908	4.1	9	NA	716
1996	6	32	91,947	9,952	329,009	3.6	9	NA	3,570
1997	7	23	43,305	4,673	179,249	4.1	9	NA	5,554
1998	3	9	9,205	1,530	35,722	3.9	6	NA	474
1999	3	9	44,098	2,995	177,108	4.0	15	NA	319
2000	7	19	29,145	5,450	127,217	4.4	5	NA	4,599
2001	6	14	33,723	4,262	145,876	4.3	8	143	8,227
2002	8	20	34,860	5,279	150,434	4.3	6	144	8,984
2003	3				CONFIDENTIAL				
2004	5				CONFIDENTIAL				
2005	4				CONFIDENTIAL				
2006-2007	0				NO LANDINGS				

Notes: "Confidential" = Less than three vessels or processors participated in the fishery, and "NA" = Not available.

[a] Deadloss included.

[b] In pounds.

[c] Number of legal crabs per pot lift.

[d] Carapace length in millimeters.

Table 2. Weight (in pounds) of retained catch, estimated non-retained bycatch, and estimated total fishery mortality of Pribilof Islands golden king crabs during crab fisheries, 2001–2008 (bycatch estimates for 2001–2007 provided by D. Barnard, ADF&G, 25 July 2008; bycatch estimates for 2008 by D. Pengilly 27 August 2009; retained catch for 2001–2002 from Table 1; retained catch for 2003–2005 from F. Bowers, ADF&G, 27 August 2009).

		Bycatch			
Year	Retained Catch	Pribilof Islands golden king crab	Bering Sea snow crab	Bering Sea grooved Tanner crab	Total Fishery Mortality
2001	145,876	39,278	0	confidential	confidential
2002	150,434	41,894	2,335	no fishing	159,980
2003	confidential	confidential	329	confidential	159,184
2004	confidential	confidential	0	confidential	147,552
2005	confidential	confidential	0	confidential	65,817
2006	no fishing	no fishing	0	0	0
2007	no fishing	no fishing	0	0	0
2008	no fishing	no fishing	2,122[a]	no fishing	1,061[a]

a. Value is likely an over-estimate. Only 5 golden king crabs (1 sublegal male and 4 legal males) were counted in 1,657 pot lifts sampled out of the 163,536 pot lifts performed during the 2008/09 Bering Sea snow crab fishery, but none of those were measured to provide an estimate of weight. An average weight of 4.3 pounds per crab was used to estimate the total bycatch weight; 4.3 pounds is average weight of landed golden king crabs during the 2002 Pribilof District golden king crab fishery.

Table 3. Estimated annual weight (pounds) of discarded bycatch and total fishery mortality of golden king crabs (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 513, 517, and 521, 1991/92–2008/09 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office through R. Foy AFSC, Kodiak Laboratory, 7 August 2009).

Season	Fixed	Trawl	Total Bycatch	Total Bycatch Mortality
1991/92	50	6,107	6,157	4,911
1992/93	3,488	8,865	12,353	8,836
1993/94	506	9,638	10,144	7,963
1994/95	253	3,222	3,475	2,704
1995/96	406	1,899	2,305	1,722
1996/97	24	870	894	708
1997/98	1,339	487	1,826	1,059
1998/99	6,772	179	6,951	3,529
1999/00	4,788	647	5,435	2,912
2000/01	1,628	1,875	3,503	2,314
2001/02	1,497	355	1,852	1,033
2002/03	553	214	767	448
2003/04	228	182	410	260
2004/05	155	390	545	390
2005/06	90	57	147	91
2006/07	1,322	115	1,437	753
2007/08	8,472	159	8,631	4,363
2008/09	3,991	1,557	5,548	3,241
Average	1,976	2,045	4,021	2,624

Table 4. Biomass estimates (metric tons) of golden king crabs (all sizes, both sexes) from results of the 2002, 2004, and 2008 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey, by survey subarea and depth zone (from Haaga et al. 2009 and J. Haaga, NMFS-AFSC, Kodiak, 26 August 2009).

Year	Depth (m)	Bering Canyon[a]	Pribilof Canyon[b]	Inter-canyon Pribilof-Zhemchug[b]	Zhemchug Canyon[b]	Inter-canyon Zhemchug-Navarin[a]	Perenets /Zhemchug Canyons[c]
2002	200-400	53	289	49	52	16	29
	400-600	78	253	32	1	3	14
	600-800	0	121	1	0	0	0
	800-1000	1	0	0	0	0	0
	1000-1200	0	19	0	0	0	0
	Total	131	682	81	53	19	44
2004	200-400	4	526	25	121	13	2
	400-600	45	220	13	0	13	22
	600-800	14	67	10	0	0	0
	800-1000	1	4	3	0	0	0
	1000-1200	0	0	0	0	0	0
	Total	65	817	51	121	25	24
2008	200-400	67	258	65	173	0	38
	400-600	78	584	19	0	2	29
	600-800	2	76	8	32	0	0
	800-1000	0	0	0	0	0	0
	1000-1200	0	2	0	0	0	0
	Total	146	919	91	206	2	66

a. Partially in Pribilof District.
b. Entirely in Pribilof District.
c. Not in Pribilof District.

Table 5. Survey effort (hauls), surveyed area, biomass estimates (metric tons) of golden king crabs (all sizes, both sexes), estimated variances of biomass estimates, and estimated CVs of biomass estimates from results of the 2004NMFS-AFSC eastern Bering Sea upper continental slope trawl survey, by survey subarea and depth zone (from Tables 1 and 47 *in* Hoff and Britt 2005).

Area	Depth (m)	Hauls	Area (km^2)	Biomass	Variance of Biomass	CV
Bering Canyon[a]	200-400	33	4,012.41	4.21E+00	1.77E+01	100%
	400-600	37	4,062.77	4.52E+01	1.32E+02	25%
	600-800	14	1,741.66	1.43E+01	5.02E+01	50%
	800-1000	8	1,354.74	1.27E+00	1.62E+00	100%
	1,000-1,200	9	1,106.89	5.69E-02	3.24E-03	100%
	Total	101	12,278.47	7.65E+01	2.02E+02	19%
Pribilof Canyon[b]	200-400	10	1,157.64	5.26E+02	8.61E+04	56%
	400-600	5	705.08	2.20E+02	1.04E+04	46%
	600-800	5	591.27	6.69E+01	1.53E+03	58%
	800-1000	3	552.73	3.99E+00	1.59E+01	100%
	1,000-1,200	5	535.67	0.00E+00	0.00E+00	-
	Total	28	3,542.39	8.17E+02	9.80E+04	38%
Pribilof-Zhemchug inter-canyon[b]	200-400	7	903.78	2.54E+01	2.69E+02	65%
	400-600	6	886.11	1.27E+01	7.60E+01	69%
	600-800	6	910.26	9.91E+00	8.07E+01	91%
	800-1000	4	732.35	2.80E+00	7.83E+00	100%
	1,000-1,200	2	675.52	0.00E+00	0.00E+00	
	Total	25	4,108.02	5.08E+01	4.34E+02	41%
Zhemchug Canyon[b]	200-400	9	1,236.27	1.21E+02	1.94E+03	36%
	400-600	5	730.35	0.00E+00	0.00E+00	-
	600-800	4	693.95	0.00E+00	0.00E+00	-
	800-1000	4	707.59	0.00E+00	0.00E+00	-
	1,000-1,200	3	662.42	0.00E+00	0.00E+00	-
	Total	25	4,030.58	1.21E+02	1.94E+03	36%
Zhemchug-Navarin inter-canyon[a]	200-400	3	423.71	1.25E+01	1.56E+02	100%
	400-600	3	426.73	7.50E+00	5.62E+01	100%
	600-800	4	431.83	0.00E+00	0.00E+00	-
	800-1000	3	551.99	0.00E+00	0.00E+00	-
	1,000-1,200	2	570.14	0.00E+00	0.00E+00	-
	Total	15	2,404.40	2.00E+01	2.12E+02	73%
Perenets/Zhemchug Canyons[c]	200-400	15	2,595.79	2.02E+00	4.06E+00	100%
	400-600	10	1,705.76	2.21E+01	3.00E+02	78%
	600-800	5	917.49	0.00E+00	0.00E+00	-
	800-1000	5	645.17	0.00E+00	0.00E+00	-
	1,000-1,200	2	496.42	0.00E+00	0.00E+00	-
	Total	37	6,360.63	2.41E+01	3.04E+02	72%

a. Partially in Pribilof District.
b. Entirely in Pribilof District.
c. Not in Pribilof District.

Table 6. Summary of contents of 1,351 pot lifts sampled by observers during the 2001 Pribilof District golden king crab fishery (total fishery pot lifts was 4,262).

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
arrowtooth flounder	11	0	0	0	0
basket star	49	0	0	0	0
bigmouth sculpin	2	0	0	0	0
brittle star unident.	1	0	0	0	0
dusky rockfish	2	0	0	0	0
flatfish unident.	4	0	0	0	0
giant octopus	4	0	0	0	0
golden king crab	0	3506	3374	10771	10717
graceful decorator crab	1	0	0	0	0
Greenland halibut (or Greenland turbot)	3	0	0	0	0
grenadier (rattail) unident.	1	0	0	0	0
grooved Tanner crab	0	0	24	0	0
hair crab	0	0	0	19	0
hairy triton (or Oregon triton)	8	0	0	0	0
hermit crab unident.	16	0	0	0	0
hybrid C. bairdi	0	1	0	0	0
hybrid Tanner crab	0	0	2	0	0
Pacific cod	62	0	0	0	0
Pacific halibut	496	0	0	0	0
Pacific lyre crab	2	0	0	0	0
Pacific ocean perch	4	0	0	0	0
Pribilof neptune (or Pribilof whelk)	6	0	0	0	0
prowfish	4	0	0	0	0
redbanded rockfish	1	0	0	0	0
red king crab	0	0	3	0	0
rockfish unident.	4	0	0	0	0
sablefish (or black cod)	2	0	0	0	0
scarlet king crab	0	0	0	1	0
sculpin unident.	225	0	0	0	0
sea anemone unident.	1	0	0	0	0
sea cucumber unident.	2	0	0	0	0
sea urchin unident.	2	0	0	0	0
skate unident.	17	0	0	0	0
snailfish unident.	58	0	0	0	0
snail unident.	255	0	0	0	0
snow crab	0	0	0	13	0
spinyhead sculpin	40	0	0	0	0
starfish unident.	30	0	0	0	0
Tanner crab	0	7	99	1	0
yelloweye rockfish	1	0	0	0	0
yellow Irish lord	112	0	0	0	0

Table 7. Summary of contents of 1,504 pot lifts sampled by observers during the 2002 Pribilof District golden king crab fishery (total fishery pot lifts was 5,279).

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
arrowtooth flounder	197	0	0	0	0
basket star	53	0	0	0	0
brittle star unident.	39	0	0	0	0
Coral unident.	5	0	0	0	0
eelpout unident.	2	0	0	0	0
flatfish unident.	13	0	0	0	0
giant octopus	3	0	0	0	0
golden king crab	0	2842	4913	11562	11485
graceful decorator crab	1	0	0	0	0
Greenland halibut (or Greenland turbot)	21	0	0	0	0
grenadier (rattail) unident.	1	0	0	0	0
grooved Tanner crab	0	27	276	259	0
hair crab	0	0	2	14	0
hermit crab unident.	16	0	0	0	0
hybrid C. bairdi	0	0	2	0	0
jellyfish unident.	3	0	0	0	0
Kamchatka flounder	1	0	0	0	0
lampshell unident.	3	0	0	0	0
limpet unident.	1	0	0	0	0
Pacific cod	49	0	0	0	0
Pacific halibut	615	0	0	0	0
Pacific lyre crab	2	0	0	0	0
Pacific ocean perch	2	0	0	0	0
Pribilof neptune (or Pribilof whelk)	22	0	0	0	0
prowfish	1	0	0	0	0
red-tree coral	1	0	0	0	0
rockfish unident.	6	0	0	0	0
rougheye rockfish	1	0	0	0	0
sablefish (or black cod)	16	0	0	0	0
scarlet king crab	0	0	1	1	0
sculpin unident.	111	0	0	0	0
sea anemone unident.	3	0	0	0	0
sea cucumber unident.	5	0	0	0	0
sea pen or sea whip unident.	1	0	0	0	0
sea urchin unident.	5	0	0	0	0
shortspine thornyhead	2	0	0	0	0
shrimp unident.	1	0	0	0	0
skate unident.	6	0	0	0	0
snailfish unident.	8	0	0	0	0
snail unident.	169	0	0	0	0
snow crab	0	2	0	6	0
sponge unident.	50	0	0	0	0
starfish unident.	24	0	0	0	0

Tanner crab	0	11	52	1	0
triangle Tanner crab	0	0	5	0	0
walleye pollock	1	0	0	0	0
yellowfin sole	1	0	0	0	0
yellow Irish lord	17	0	0	0	0

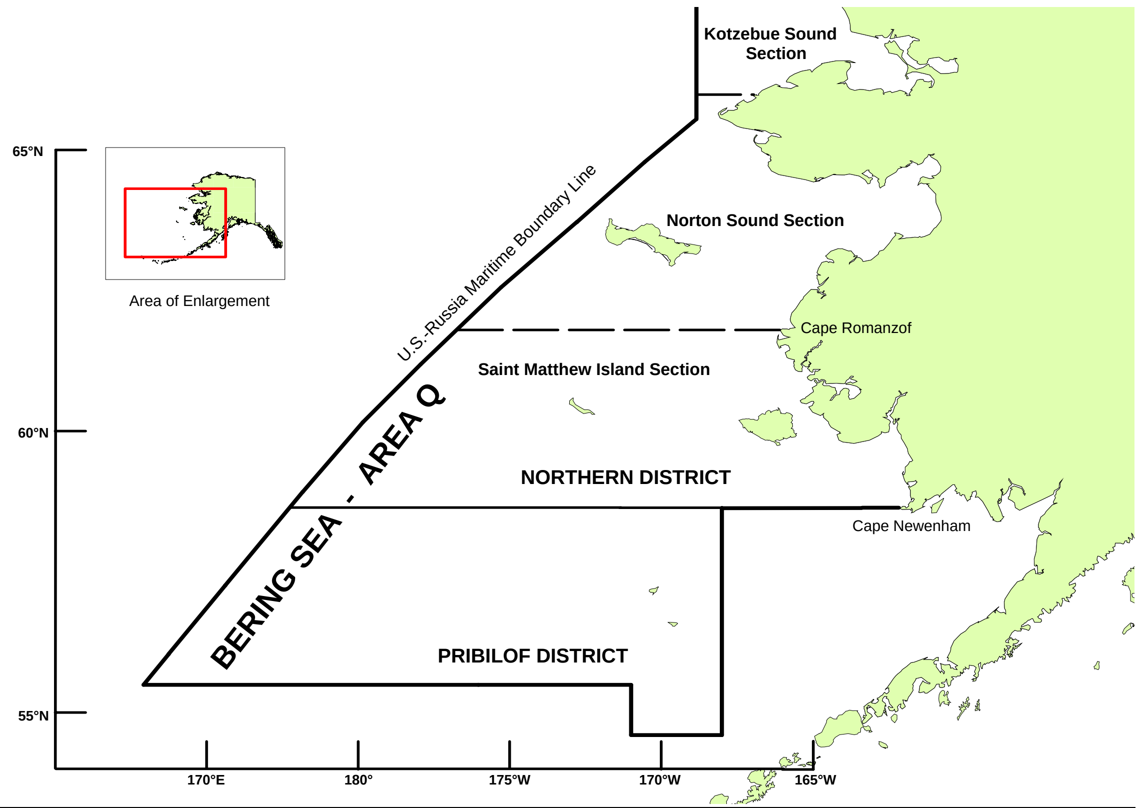

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Bowers et al. 2008).

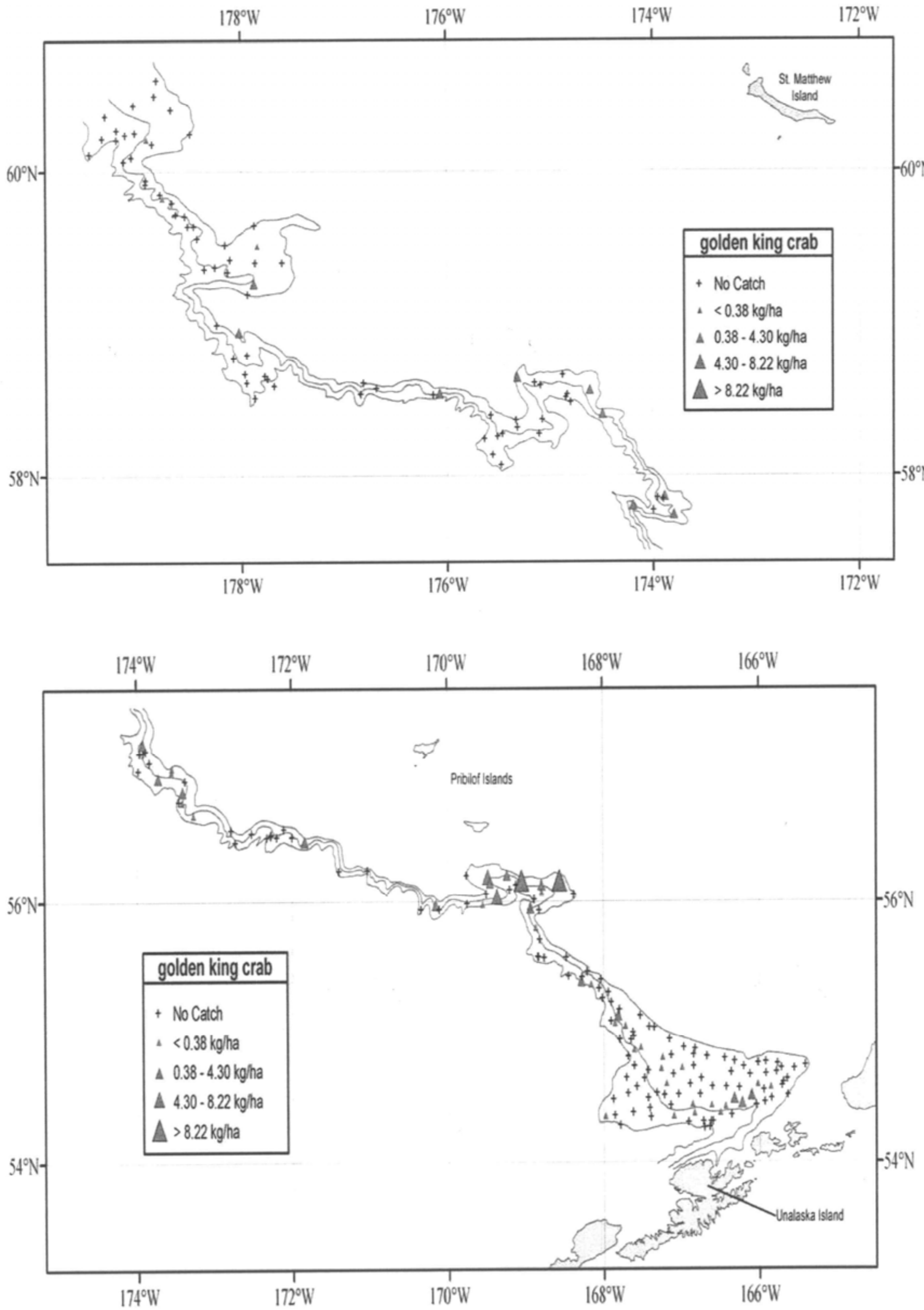

Figure 2. Distribution and relative abundance of golden king crabs from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey. Relative abundance is categorized by no catch, sample CPUE less than the mean CPUE, between the mean CPUE and two standard deviations above the mean CPUE, between two and four standard deviations above the mean CPUE, and greater than four standard deviations above the mean CPUE (from Figure 79 *in* Hoff and Britt 2005).

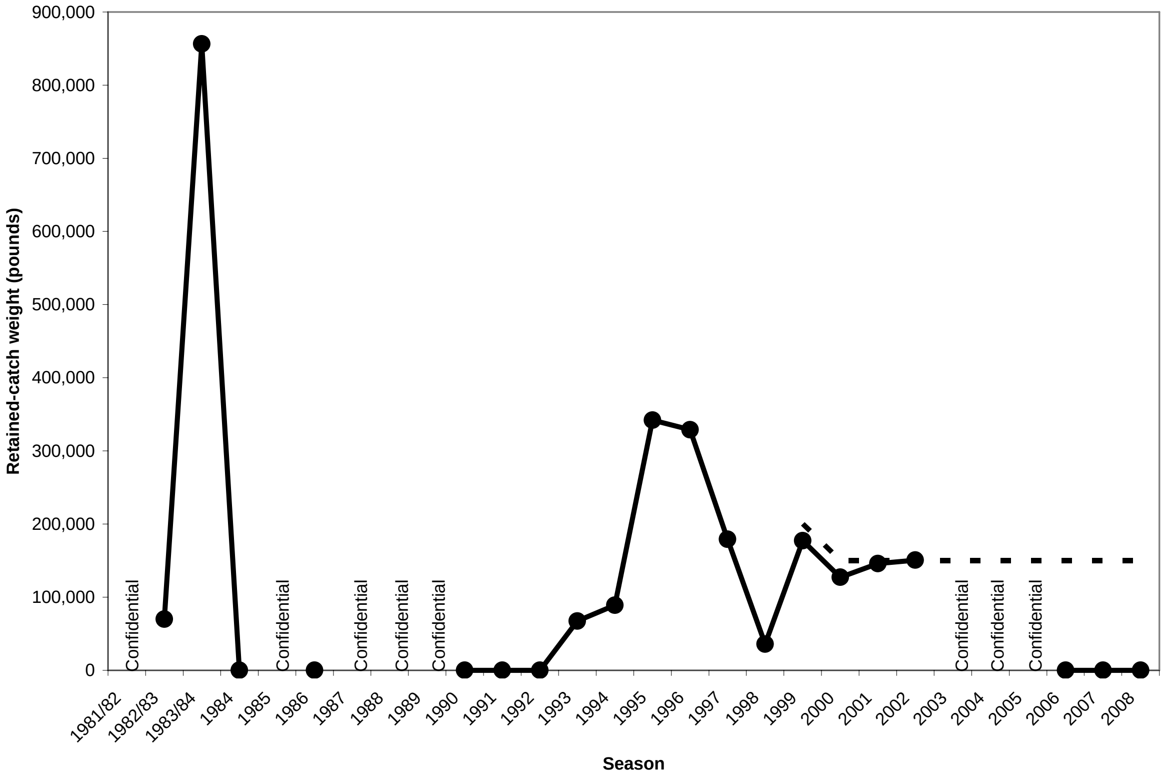

Figure 3. Retained catch (pounds; filled circles and solid line) during the 1981/82 through 2008 Pribilof Islands golden king crab fishery seasons compared with the GHL established for the fishery during the 1999–2008 seasons (dashed line; see Table 1).

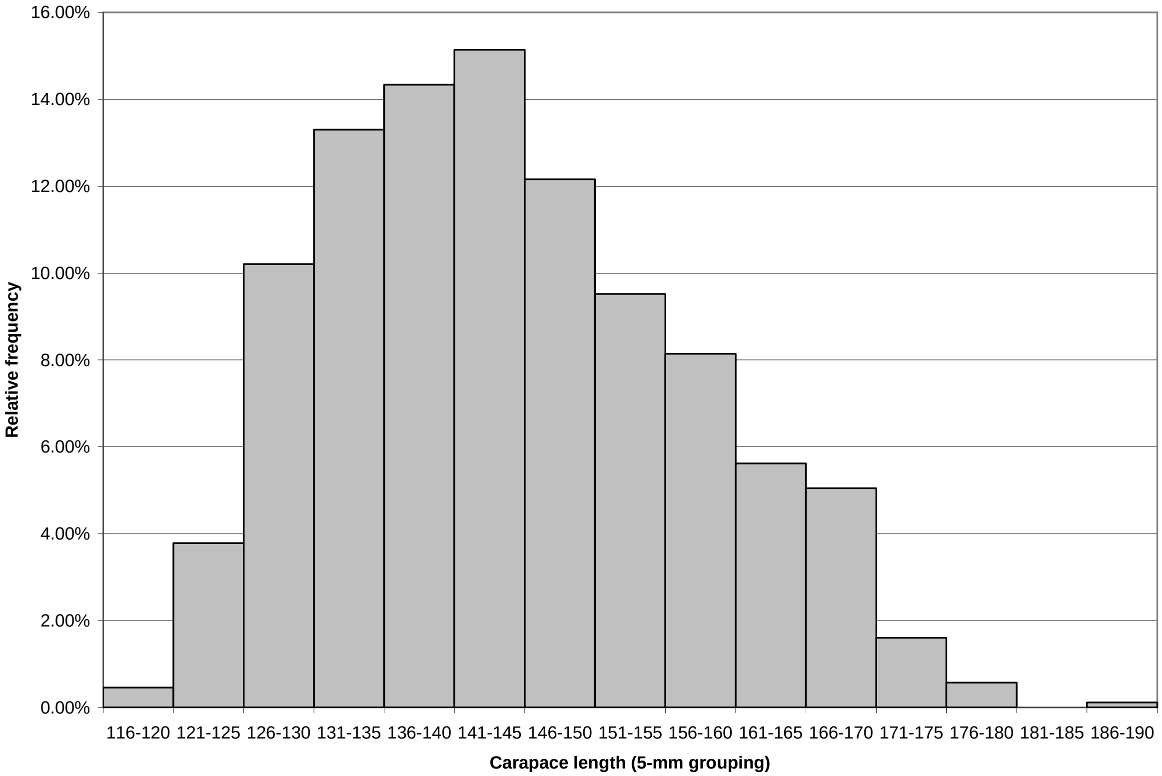

Figure 4. Relative frequency distribution for carapace length (mm) of retained golden king crabs sampled by season during the 2002 Pribilof Islands golden king crab fishery (N= 872; data from ADF&G shellfish observer database, Kodiak, April 2008).

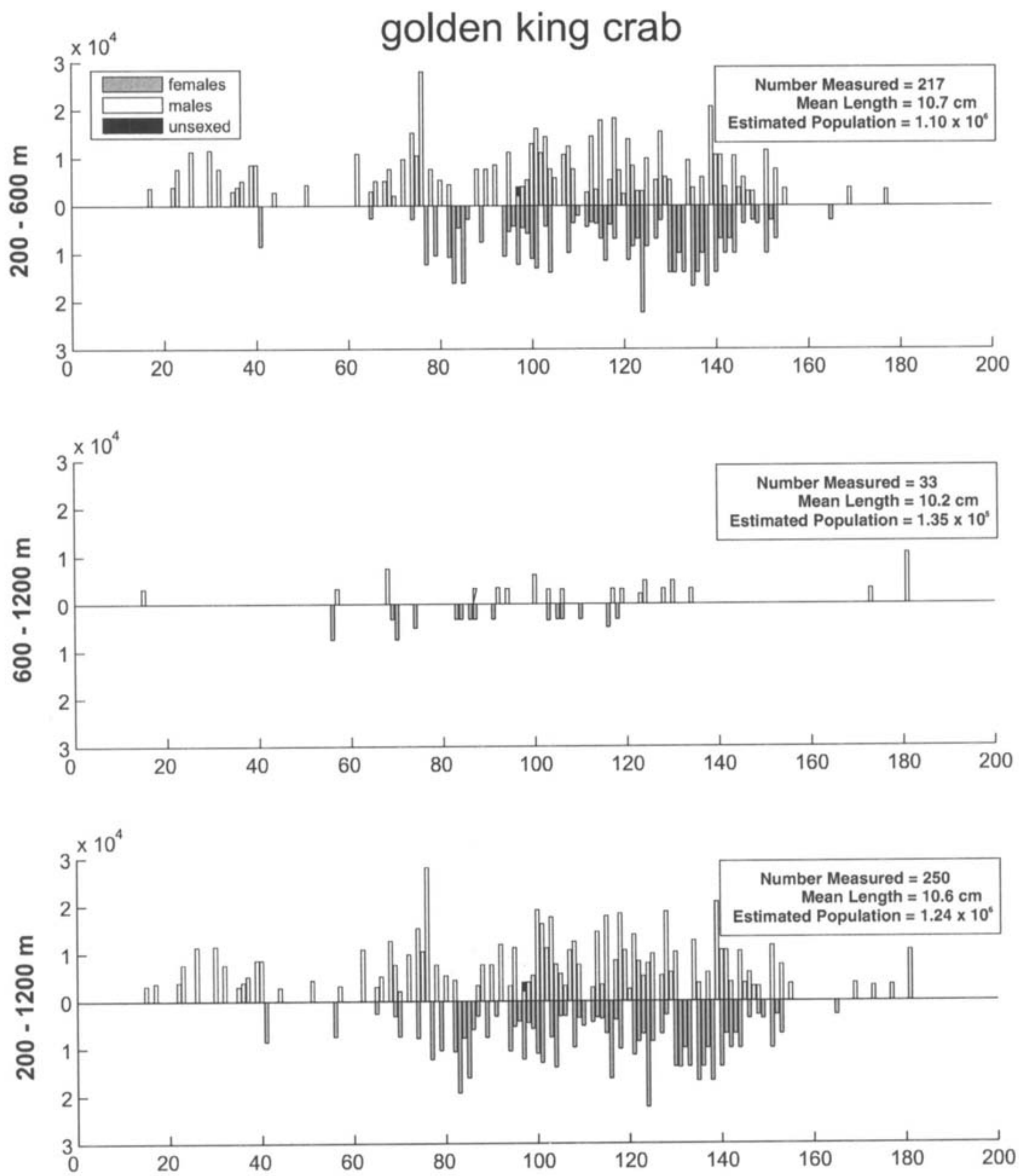

Figure 5. Size composition of the estimated golden king crab population from the 2004 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey (all areas) by depth zone. The abscissa is scaled as total carapace length in millimetres and the ordinate represents the estimated total population.

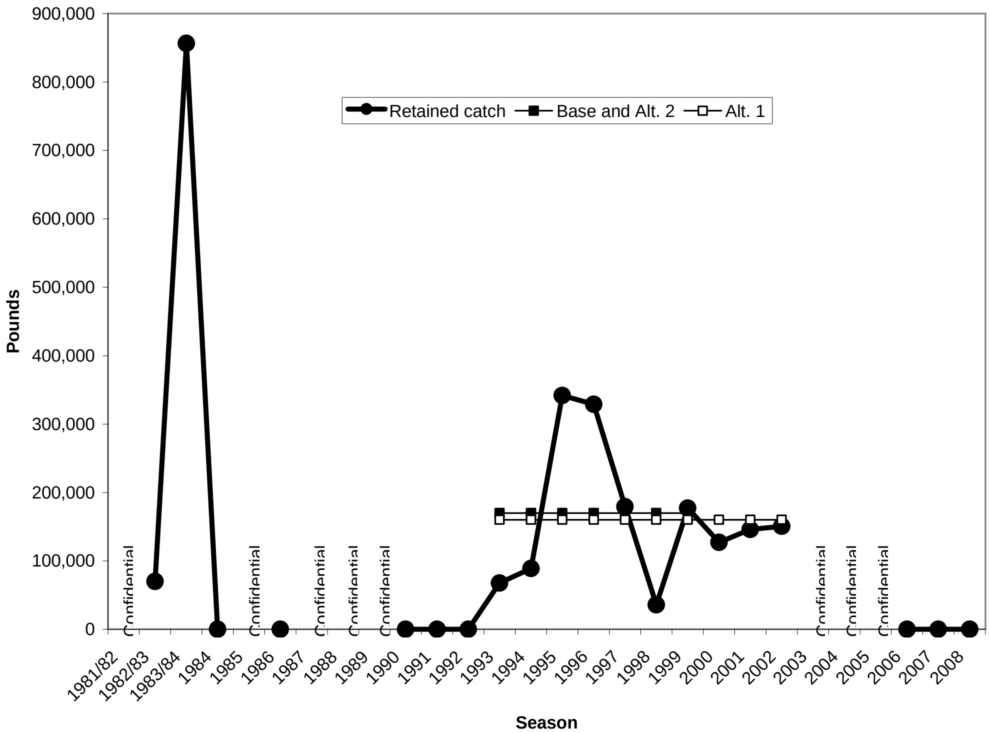

Figure 6. Alternative retained-catch OFLs (Base and Alternatives 1–2) compared with actual historical fishery retained catch for the Pribilof Islands golden king crab fishery, 1981/82–1983/84 and 1984–2008 (see Table 1 and section E.3.b).

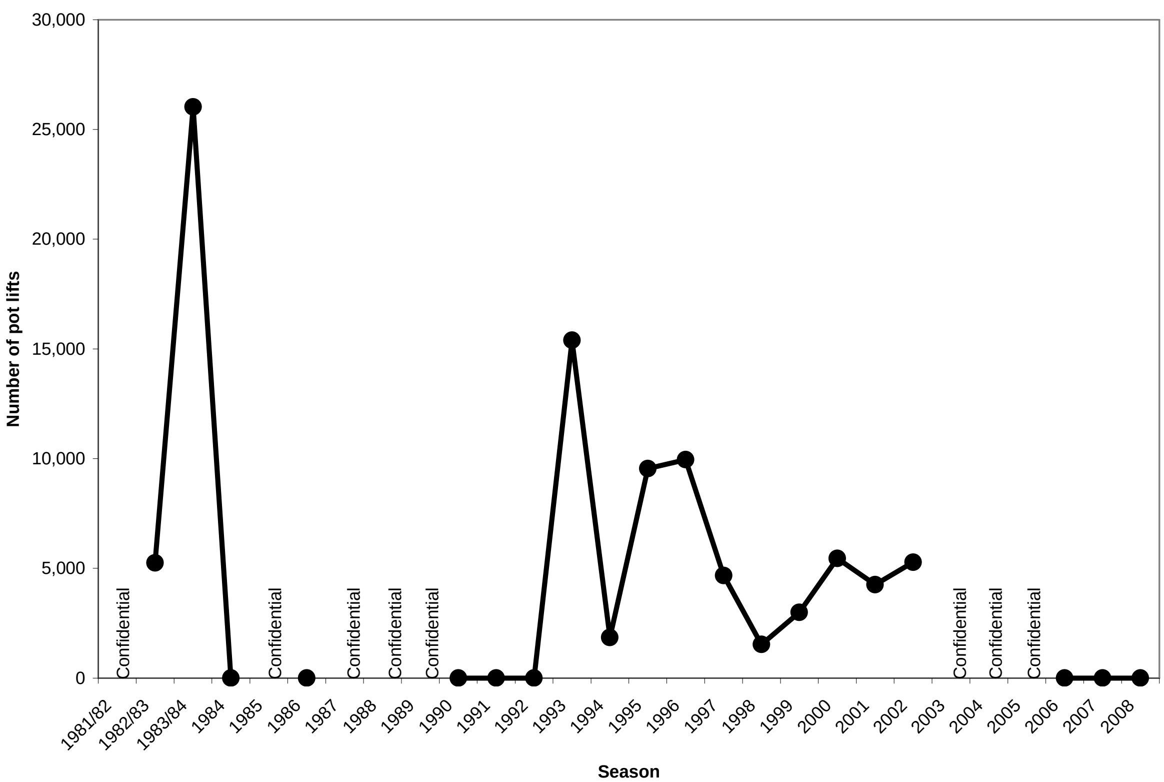

Figure 7. Number of pot lifts performed in the Pribilof District golden king crab fishery, 1981/82–1983/84 and 1984–2008 (see Table 1).

Adak Red King Crab

September 2009 Crab SAFE Report Chapter

Douglas Pengilly, ADF&G, Kodiak

Executive Summary

1. **Stock:** Red king crab (*Paralithodes camtschaticus*)/Adak (the Aleutian Islands, west of 171° W longitude)

2. Catches:
The domestic fishery has been prosecuted since 1960/61 and was opened every season through the 1995/96 season. Peak harvest occurred during the 1964/65 season with a retained catch of 21-million pounds. During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between 172° W longitude and 179° 15' W longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of 179° 15' W longitude began to account for a larger portion of the retained catch. Retained catch during the 10-year period 1985/86–1994/95 averaged 0.943-million pounds, but the retained catch during the 1995/96 season was only 0.039-million pounds. During the 1995/96 through 2008/09 seasons, the fishery was opened only occasionally. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99, three commissioner's permit fisheries in limited areas during 2000/01–2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 0.500-million pounds during the 2002/03 and 2003/04 seasons. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude) and the last two commercial seasons (the 2002/03 and 2003/04 seasons) were opened only in the Petrel Bank area. Retained catch in the last two commercial fishery seasons was 0.506-million pounds (2002/03) and 0.479-milliion pounds (2003/04). The fishery has been closed through the 2008/09 season since the end of the 2003/04 season. Non-retained catch of red king crabs occurs in the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in the groundfish fisheries. Estimated annual weight of bycatch mortality during the 1995/96–2008/09 seasons averaged 0.003-million pounds in crab fisheries and 0.024-million pounds during groundfish fisheries. Estimated weight of annual total fishery mortality during 1995/96–2008/09 averaged 0.116-million pounds; the average annual retained catch during that period was 0.090-thousand pounds.

3. Stock biomass:
Estimates of past or present stock biomass are not available. There is no assessment model developed for this stock and standardized stock surveys have been too limited in geographic scope and too infrequent to provide a reliable index of abundance for the entire red king crab population in the Adak Area.

4. Recruitment:
Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. The fishery has been closed since the end of the 2003/04 season due to apparent poor recruitment. A pot survey conducted by ADF&G in the Petrel Bank area (roughly, 179° W longitude to 179° E longitude) in 2006 provided no evidence of strong recruitment.

5. Management performance:
No overfished determination (i.e., MSST) is possible for this stock given the lack of biomass information. Overfishing did not occur during the 2008/09 fishing year. See table, below.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a,c]
2005/06	N/A	N/A	Closed	0	0.004	N/A
2006/07	N/A	N/A	Closed	0	0.004	N/A
2007/08	N/A	N/A	Closed	0	0.011	N/A
2008/09	N/A	N/A	Closed	0	0.014	0.46
2009/10	N/A	N/A	TBD	TBD	TBD	TBD

a. Millions of pounds.
b. Includes handling mortality of discarded bycatch.
c. Retained-catch OFL.

6. **<u>Basis for the OFL</u>:** See table, below.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality
2008/09	5	1985/86-2007/08[a]	0.18[b]
2009/10	5	TBD	0.18[b]

a. OFL was for retained catch and was determined by the average of the retained catch for these years.
b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.

7. **<u>A summary of the results of any rebuilding analyses</u>:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **<u>Changes to the management of the fishery</u>:** None.

2. **<u>Changes to the input data</u>:**
   - Retained catch data has been updated with the results of the (closed) 2008/09 season.

3. **<u>Changes to the assessment methodology</u>:** None.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:**
   - The OFL for 2008/09 was 0.46-million pounds of retained catch and was estimated by the average annual retained catch (including deadloss) for the period 1985/86–2007/08. The recommended retained-catch OFL for 2009/10 is 0.50-million pounds and was estimated as the average retained catch (including deadloss) for the period 1984/85–2007/08.
   - New to this assessment are total catch estimates for the 1995/96–2008/09 seasons, which were computed by applying assumed handling mortality rates to the estimated biomass of bycatch during crab fisheries and federal groundfish fisheries to obtain an estimate of discard mortality in all fisheries and adding that to the biomass of the retained catch. This new information is presented here so that the CPT in May 2010 and SSC in June 2010 may consider establishment of a total-catch OFL for this stock in 2010/11. Computation of total catch was afforded by new availability of estimates of bycatch during federal groundfish fisheries that were summarized by crab-fishing years. Average annual total catch for the period 1995/96–2008/09 was estimated to be 0.12-million pounds.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general</u>:**

- CPT, September 2008: Only two general comments by the CPT pertain to a Tier 5 assessment,
    - i. *"The team agreed that assessment documents presented to September meetings should be the "track changes" version of the May assessments, to facilitate evaluating changes from the version."*
      Response: There was no May 2009 version of this assessment. A "track changes" version applied to the September 2008 assessment would be a real mess due to the substantial change in standard outline for assessments (see below).
    - ii. *"A checklist of the items which should be included in stock assessments on which the OFL determinations are based should be developed. This checklist would include a table of survey estimates (and their associated CVs) by year. Having a standard approach to reporting assessment results will help the review process as well as how the work of the team is documented."*
      Response: This assessment was prepared according to "Appendix C: A Guide to the Preparation of Bering Sea and Aleutian Islands Crab SAFE Report Chapters" developed during the CPT's Alaska Crab Stock Assessment Workshop of May 2009.
- SSC, October 2008: "*The SSC commends the CPT for the detailed review of the revised stock assessments conducted at its September meeting. In particular, the SSC supports the CPT's intention to compile the checklist of items to be included in stock assessment documents as a template for authors. The SSC especially appreciates the CPT's identification of the need to include tables of annual survey estimates of abundance, including a standardized measure of precision."*
    - Response: This report follows the template for assessment documents that has been developed since October 2008. However, annual survey estimates of abundance and associated estimates of precision are not available for this stock.
- CPT, May 2009: Only one general comment by the CPT pertained to a Tier 5 assessment: *"The timing for final assessments for Tier 5 stocks should be done annually in May and only brought back to the CPT as an agenda item in September should there be new information over the summer and/or modification to the CPT recommendation from the SSC. This year the other two Tier 5 assessments (Adak RKC and PIGKC) will be finalized in September; next year they will be on the May schedule."*
    - Response: This is the last final assessment for Adak red king crab that will occur in September.
- SSC, June 2009: The SSC made two general comments on BSAI crab assessments, one of which did not pertain to Tier 5 stocks. The other general comment was: *"The SSC encourages stock assessment authors and the Plan Team to discuss whether there is evidence for a common year that corresponds with a shift in recruitment across stocks. If there is not a single year, then evidence should be examined for a number of years that are common across groups of species or areas."*
    - Response: Discussion on this issue has yet to occur.

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

- CPT, September 2008: *"The CPT requested that the assessment author analyse a total catch OFL for the next assessment cycle."*
    - Response: This request was superseded by the CPT recommendation of May 2009 (see below). However, estimates of total fishery mortality (pounds of retained catch plus pounds of estimated fishery bycatch mortality) are presented in this assessment for the time period for which such data are available, the 1995/96–2008/09 seasons, and average annual total fishery mortality has been estimated for the periods 1995/96–2007/08 and 1995/96–2008/09 (see Table 4) so that the CPT in May 2010 and SSC in June 2010 may consider establishment of a total-catch OFL for 2010/11.
- SSC, October 2008: *"The SSC notes that the procedure for setting the OFL in the upcoming assessment cycle should be reviewed to address the undesirable attributes of the current method, including erratic swings in MSY resulting from the inclusion of zero catches if the fishery remains closed, and the lack of rationale for excluding the 1984/85 catch. The catch*

history illustrates that directed fishing can occur on this stock and that recent high levels of catch cannot be sustained. There is an urgent need for systematic survey data for this stock, to move the stock from Tier 5 to Tier 4. The SSC recommends that analysts design a survey that would provide reliable biomass estimates. In addition, the analysts should provide an estimate of the cost and amount of crab required to implement either an industry cooperative test fishery or an agency directed survey."

- Response:
  - i. With regard to addressing "the undesirable attributes of the current method, including erratic swings in MSY resulting from the inclusion of zero catches if the fishery remains closed": A) If "inclusion of zero catches if the fishery remains closed" means "inclusion of zero catches if the fishery remains closed *in the future*," then the change in MSY resulting by inclusion of zero catches would be predictable, not erratic. However, erratic or predictable, such changes in MSY due to continued fishery closure post-2007/08 are protected against by freezing the years considered through 2007/08 as recommended by the CPT in May 2009 (see sections E.3.a,b). B) If "inclusion of zero catches if the fishery remains closed" means "inclusion of zero catches *in those years of the history of the fishery that the fishery was* closed," that issue was addressed by the SSC in June 2008, when the SSC recommended including "… periods of high and low catches, including periods when the fishery was closed because of conservation concerns [because] [t]hese catches likely reflect fluctuations in stock abundance." This assessment follows the June 2008 advice of the SSC by including the catch during years of fishery closures to compute the average retained catch (see sections E.3.a,b).
  - ii. With regard to excluding the 1984/85 catch from the computation of MSY: As noted in the 2008 SAFE, exclusion of the pre-1985/86 catch data was recommended by NPFMC (2007). The argument of NPFMC (2007) was that, because of an assumed 8-year lag between hatching during the 1976/77 "regime shift" and growth to legal size, only years post-1984 should be used to compute the average catch. Inclusion of the 1984/85 data raises the new question of whether data from pre-1984/85 should be included. Nonetheless, the catch data from 1960/61–1984/85 are available and average catches using data from those seasons are considered in this assessment (see sections E.3.a,b).
  - iii. With regard to design and cost of stock assessment surveys to provide reliable biomass estimates: A pot survey for red king crabs in the Petrel Bank area has been designed and will be implemented by ADF&G in November 2009. The geographic boundaries of the Adak red king crab stock range across 19 degrees of longitude (roughly 700 nm). The upcoming survey, however, will cover only depths to 150 fm within the encompassed Petrel Bank and waters adjacent to Semisopochnoi Island bounded by 51º 50' N latitude to the south, 52º 47' N latitude to the north, 179º 18' W longitudes to the east, and 179º 46' E longitude to the west; that encompasses the area that accounted for 77% to 95% of the total annual Adak red king crab harvests for the 1990/91–1995/96 seasons and all of the harvest during the 2000/01–2003/04 seasons. The results of the 2009 November pot survey will not provide immediate data for an estimate of the biomass of red king crabs in the Petrel Bank area. If such surveys are performed regularly, however, the data collected could eventually be used to estimate biomass through development of a stock-assessment model. The survey will provide information on size distribution, stock distribution, and densities relative to the 2006 survey performed by ADF&G in the area and relative to the fisheries and surveys performed by industry in the early 2000's. Cost of the five-week period to perform the survey (not including the regular-time salary

and benefits for ADF&G staff to prepare for, serve as biologists on, and report on the survey) is $316.4-thousand ($243.3-thousand is for the cost of a vessel charter).

iv. With regard to the amount of crab required to implement an industry cooperative test fishery: ADF&G received a request from industry in June 2009 for a commissioner's permit to fish for red king crabs in the Adak area without any retention of crabs in order to "allow for an industry funded survey of the Western Aleutians for the purpose of collecting information regarding the distribution and stock status of Adak red king crab." Details on the proposed industry-funded survey are still being worked out as of this writing (6 August 2009), but the initial proposal from industry is for a vessel to fish the Petrel Bank area, as well as areas west of Petrel Bank (six statistical areas between 179º E longitude 175º E longitude) with 10 7X or 8X crab pots, one of which would be rigged with web to retain smaller crabs; data would be collected by an onboard fishery observer.

- CPT, May 2009: *"The team recommends establishing an OFL for this stock consistent with the approach recommended by the SSC last year (as a retained catch and freezing years considered through 2007/08)."*
    - Response: Alternatives of a retained-catch OFL computation with the years considered frozen at 2007/08 are presented (see sections E.3.a,b).
- SSC, June 2009: Not applicable. An Adak red king crab stock assessment report was not reviewed by SSC at the June 2009 meeting.

C. Introduction

1. **Scientific name:** *Paralithodes camtschaticus*, Tilesius, 1815

2. **Description of general distribution:**

The general distribution of red king crabs is summarized by NMFS (2004):

> Red king crab are widely distributed throughout the BSAI, GOA, Sea of Okhotsk, and along the Kamchatka shelf up to depths of 250 m. Red king crab are found from eastern Korea around the Pacific rim to northern British Columbia and as far north as Point Barrow (page 3-27).
>
> Most red and blue king crab fisheries occur at depths from 50-200 m, but red king crab fisheries in the Aleutian Islands sometimes extend to 300 m (page 3-41).
>
> Red king crab is native to waters of 300 m or less extending from eastern Korea, the northern coast of the Japan Sea, Hokkaido, the Sea of Okhotsk, through the eastern Kamchatkan Peninsula, the Aleutian Islands, the Bering Sea, the GOA, and the Pacific Coast of North America as far south as Alice Arm in British Columbia. They are not found north of the Kamchatkan Peninsula on the Asian Pacific Coast. In North America red king crab range includes commercial fisheries in Norton Sound and sparse populations extending through the Bering Straits as far east as Barrow on the northern coast of Alaska. Red king crab have been acclimated to Atlantic Ocean waters in Russia and northern Norway. In the Bering Sea, red king crab are found near the Pribilof Islands and east through Bristol Bay; but north of Bristol Bay (58

> degrees 39 minutes) they are associated with the mainland of Alaska and do not extend to offshore islands such as St. Matthew or St. Laurence Islands (pages 3-41–42).

Commercial fishing for Adak red king crabs during the last two prosecuted seasons (2002/03 and 2003/04) was opened only in the Petrel Bank area and effort during those two seasons typically occurred at depths of 60–90 fathoms (110–165 m); average depth of pots fished in the Aleutian Islands area during the 2002/03 season was 68 fathoms (124 m; Barnard and Burt 2004) and during the 2003/04 season was 82 fathoms (151 m; Burt and Barnard 2005). In the 580 pot lifts sampled by observers during the 1996/97–2006/07 Aleutian Islands golden king crab fishery that contained one or more red king crab, depth was recorded for 578 pots. Of those, the deepest recorded depth was 266 fathoms (486 m) and 90% of pot lifts had recorded depths of 100–200 fathoms (183–366 m); no red king crabs were present in any of the 6,465 pot lifts sampled during the 1996/97–2006/07 Aleutian Islands golden king crab fishery with depths >266 fathoms (486 m; ADF&G observer database, Dutch Harbor, April 2008).

Although the Adak Registration Area is no longer defined in State regulation, in this chapter we will refer to the area west of 171° W longitude within the Aleutian Islands king crab Registration Area O as the "Adak Area". The Aleutian Islands king crab Registration Area O is described by Bowers et al (2008, page 4) as follows (see also Figure 1):

> The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W longitude), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W longitude, north to 55° 30' N latitude, and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990 [Figure 1]. Area O encompasses both the waters of the Territorial Sea (0-3 nautical miles) and waters of the Exclusive Economic Zone (3-200 nautical miles).

From the 1984/85 season until the March 1996 Alaska Board of Fisheries meeting, the Aleutian Islands king crab Registration Area O as currently defined had been subdivided at 171° W longitude into the historic Adak Registration Area R and the Dutch Harbor Registration Area O. The geographic boundaries of the Adak red king crab stock are defined here by the boundaries of the historic Adak Registration Area R; i.e., the current Aleutian Islands king crab Registration Area O, west of 171° W longitude.

3. <u>Evidence of stock structure</u>:

Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crabs originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51° 51' N latitude, 176° 39' W longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)."

We know of no analyses of genetic relationships among red king crab from different locations within the Adak Area. However, given the expansiveness of the Adak Area and the canyons between some islands that are deep (>1,000 m) relative to the depth zone restrictions of red king crabs (see above), at least some weak structuring within the Adak red king crab stock would be expected. McMullen and Yoshihara (1971) reported the following on male red king crabs that were tagged in February 1970 on the Bering Sea and Pacific Ocean sides of Atka Island and recovered in the subsequent fishery season:

> Fishermen landing tagged crabs were questioned carefully concerning the location of recapture. In no instance did crabs migrate through ocean passes between the Pacific Ocean and Bering Sea.

4. <u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crabs fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987, McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen 1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crabs:

> Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season.

McMullen and Yoshihara (1971) reported that from 804 female red king crabs (79–109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crabs in the western Aleutians appeared to begin mating at 83 millimeters carapace length and virtually all females appeared to be mature at 102 millimeters length." Blau (1990) estimated size at maturity for Adak Area red king crab females as the estimated CL at which 50% of females are mature (SM50; as evidenced by presence of clutches of eggs or empty) according to a logistic regression: 89-mm CL (SD = 2.6 mm). Size at maturity has not been estimated for Adak Area male red king crabs. However, because the estimated SM50 for Adak Area red king crab females is the same as that estimated for Bristol Bay red king crab females (Otto et al. 1990), the estimated maturity schedule used for Bristol Bay red king crab males (see SAFE chapter on Bristol Bay red king crab) could be applied to males in the Adak stock as a proxy.

Little data is available on the molting and mating period for red king crabs specifically in the Adak Area. Among the red king crabs captured by ADF&G staff for tagging on the south side of Amlia Island (173° W longitude to 174° W longitude) in the first half of April 1971, males and females were molting, females were hatching embryos, and mating was occurring (McMullen and Yoshihara 1971). The spring mating period for red king crabs is known to last for several months, however. For example, although mating activity in the Kodiak area apparently peaks in April, mating pairs in the Kodiak area have been documented from January through May (Powell et al. 2002). Due to the season timing for the commercial fishery, little data on reproductive condition of Adak red king crab females have been collected by at-sea fishery observers that can be used for evaluating the mating period. For example, of the 3,211 mature females that were examined during the 2002/03 and 2003/04 red king crab seasons in the Petrel Bank area, both of which seasons were restricted to late October, only 10 were scored as "hatching."

Data on mating pairs of red king crabs collected from the Kodiak area during March–May of 1968 and 1969 showed that size of the females in the pairs increased from March to May, indicating that females tend to release their larvae and mate later in the mating season with increasing age (Powell et al. 2002). Size of the males in those mating pairs did not increase with later sampling periods, but did show a decreasing trend in estimated time since last molt. In all the data on mating pairs collected from the Kodiak area during 1960–1984, the proportion of males that were estimated to have not recently molted prior to mating decreased monthly over the mating period (Powell et al. 2002). Those data suggest that males that do not molt early in the mating period have an advantage in mating early in the mating period, when smaller, younger mature females and the primiparous females tend to ovulate, and that males that do molt early in the mating period participate in the later mating period, when the larger, older females tend to be mated.

5. <u>Brief summary of management history</u>:

A complete summary of the management history is provided in the ADF&G Area Management Report appended to this SAFE and in Bowers et al. (2008, pages 6–11). The domestic fishery for red king crabs in the Adak Area began with the 1960/61 season (Bowers et al. 2008). Retained catch of red king crabs in the Aleutians west of 172º W longitude averaged 11.60-million pounds during the 1960/61–1975/76 seasons, with a peak harvest of 21.19-million pounds in the 1964/65 season (Table 1, Figure 2). Guideline harvest levels (GHL; sometimes expressed as ranges, with an upper and lower GHL) for the fishery have been established for most seasons since the 1970s (Bowers et al. 2008; Figure 3). The fishery was closed for the 1976/77 season in the area west of 172º W longitude, but reopened for the 1977/78–1995/96 seasons. Average retained catch during the 1977/78–1995/96 seasons (for the area west of 172º W longitude prior to the 1984/85 season and for the area west of 171º W longitude since the 1984/85 season) was 1.04-million pounds; the peak harvest during that period was 1.98-million pounds for the 1983/84 season. During the mid-to-late 1980s, significant portions of the catch during the Adak red king crab fishery occurred west of 179º E longitude or east of 179º W longitude, whereas most of the retained catch was harvested from the Petrel Bank area (179° W longitude to 179° W longitude) during the 1990/91–1994/95 seasons (Figure 4). The Adak red king crab fishery was closed for the 1996/97 season following the diminishing harvests of the preceding two seasons that did not reach the lower GHL. Due to concerns about low stock levels and poor recruitment, the fishery has been opened only intermittently since 1996/97 (Bowers et al. 2008). The fishery was closed for the 1996/97–1997/98 seasons, closed in the Petrel Bank area for the 1998/99 season, closed for the 1999/2000 season, restricted to the Petrel Bank area for the 2000/01–2003/04 seasons (except for an ADF&G-Industry survey in the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery), and closed for the 2004/05–2008/09 seasons. Management history since the 1996/97 closure is summarized in the table below. The peak harvest since the 1996/97 season was 0.51-million pounds, which occurred in the 2002/03 season.

Season	Change in management measure
1996/97–1997/98	• Fishery closed
1998/99	• GHL of 15,000 pounds (for exploratory fishing) with fishery closed in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude)
1999/00	• Fishery closed
2000/01	• Fishery closed • Catch retained during ADF&G-Industry survey of Petrel Bank area conducted as commissioner's permit fishery, Jan–Feb 2001
2001/02	• Fishery closed • Catch retained ADF&G-Industry survey of Petrel Bank area conducted as commissioner's permit fishery, November 2001
2002/03	• Fishery opened with GHL of 500,000 pounds restricted to Petrel Bank area • ADF&G-Industry survey of the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery (4 legal males captured in 1,085 pot lifts)
2003/04	• Fishery opened with GHL of 500,000 pounds restricted to Petrel Bank area
2004/05–2008/09	• Fishery closed

A summary of relevant fishery regulations and management actions pertaining to the Adak red king crab fishery is provided below.

Only males of a minimum legal size may be retained by the commercial red king crab fishery in the Adak Area. By State of Alaska regulation (5 AAC 34.620 (a)), the minimum legal size limit is 6.5-inches (165 mm) carapace width (CW), including spines. A carapace length (CL) ≥138 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Except for the years 1968–1970, the minimum size has been 6.5-inches CW since 1950; in 1968 there was a "first-season" minimum size of 6.5-inches CW and a "second-season" minimum size of 7.0-inches and in 1969–1970 the minimum size was 7.0-inches CW (Donaldson and Donaldson 1992).

Red king crabs may be commercially fished only with king crab pots (as defined in 5 AAC 34.050). Pots used to fish for red king crabs in the Adak Area must, since 1996, have at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized red king crabs and may not be longlined (5 AAC 34.625 (e)).

By State of Alaska regulation (5 AAC 34.610 (a)) the Adak red king crab commercial fishing season is from October 15 to February 15, unless closed by emergency order.

The Adak Area red king crab fishery west of 179° W longitude has been managed since the 2005/06 season under the Crab Rationalization program (50 CFR Parts 679 and 6805). The Adak Area red king crab fishery in the area east of 179° W longitude was not included in the Crab Rationalization program (Bowers et al 2008). Fishing for red king crabs in the area between 172° W longitude and 179° W longitude in the Aleutian Islands is limited to vessels 90 feet or less in overall length (5 AAC 34.610 (d)). Additionally, there is a pot limit of 250 pots per vessel for vessels fishing for red king crabs in the Petrel Bank area (5 AAC 34.625 (d)).

The Adak red king crab fishery was closed for the 1996/97–1997/98 seasons. The following area closures and harvest restrictions have been applied to the red king crab fishery in the Adak Area since the 1998/99 season:

- The 1998/99 season for red king crab in the Adak Area was open east of 179° W longitude with a guideline harvest level (GHL) of 5,000 pounds and west of 179° E longitude with a GHL of 10,000 pounds, but was closed between 179° W longitude and 179° E longitude.
- ADF&G-Industry pot surveys for red king crabs were conducted in January—February 2001 (the 2000/01 season) and November 2001 (the 2001/02 season) under the restrictions of a commissioner's permit fishery in the Petrel Bank area (north of 51° 45' N latitude and between 179° W longitude and 179° E longitude; Bowers et al 2008, Bowers et al. 2002). The Adak Area was closed to commercial red king crab fishing outside of the designated survey area.
- The 2002/03 season opened in those waters of king crab Registration Area O between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (the Petrel Bank area; Bowers et al 2008) with a GHL of 500,000 pounds. Additionally, an ADF&G-Industry pot survey for red king crabs was conducted in November 2002 under the restrictions of a commissioner's permit fishery in the vicinity of Adak, Atka, and Amlia Islands to assess the Adak red king crab stock in the area between 172° W longitude and 179° W longitude (Granath 2003). The remaining area outside of the Petrel Bank area and the designated survey area in the Adak Area was closed to commercial red king crab fishing during the 2002/03 season.
- The 2003/04 season opened in those waters of king crab Registration Area O between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (the so-called "Petrel Bank area"; Bowers et al 2008). The remaining area in the Adak Area was closed to commercial red king crab fishing during the 2003/04 season.

D. Data

1. <u>Summary of new information</u>:

- Retained catch (0 pounds) during the (closed) 2008/09 season has been added to the retained catch time series.
- Estimated bycatch (weight) of red king crabs by sex-size during the 1995/96 Adak red king crab and golden king crab seasons and the 2008/09 Aleutian Islands golden king crab season has been added to the time series of estimates of bycatch during crab fisheries.
- Estimated bycatch of red king crabs during federal groundfish fisheries in reporting areas 541, 542, and 543 for the 1992/93–2008/09 seasons is presented.
- Estimated weight of total fishing mortalities of red king crabs for the 1995/96–2008/09 seasons, partitioned into retained catch, bycatch mortality in crab fisheries, and bycatch mortality in federal groundfish fisheries is presented.

2. <u>Data presented as time series</u>:

a. <u>Total catch</u> and b. <u>Information on bycatch and discards</u>:

- The 1960/61–2007/08 time series of retained catch (number and pounds of crabs harvested, including deadloss), effort (vessels, landings, and pot lifts), average weight of landed crabs, average carapace length of landed crabs, and CPUE (number of landed crabs captured per pot lift) is presented in Table 1. Although summaries of these data at the geographical level of ADF&G statistical area are presently available back to the 1980/81 season, the conventions for defining and naming statistical areas changed between the 1984/85 and 1985/86 seasons. The statistical areas as defined and named from 1985/86 to present can be directly related to 1º degree longitude by 30' latitude areas, allowing for partitioning and mapping the data geographically.
    - The 1960/61–2008/09 time series of retained catch (pounds of landed crabs) is presented graphically in Figure 2.
- The 1995/96–2008/09 times series of weight of retained legal males and estimated weight of non-retained legal male, non-retained sublegal male, and non-retained female red king crabs in the Adak Area during commercial crab fisheries is given in Table 2. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of red king crabs by applying a weight-at-length estimator (see below). Estimates of bycatch prior to the 1995/96 season are not given due to non-existence of data or to limitations on bycatch sampling during the crab fisheries. Prior to 1988/89 there was no fishery observer program for Aleutian Islands crab fisheries and during the 1988/89–1994/95 seasons observers were required only on vessels processing king crabs at sea, including catcher-processor vessels. Due to the limited number of observed vessels, the observer data from the directed Adak red king crab fishery in the 1990/91 and 1992/93–1994/95 seasons and golden king crab fishery in the 1993/94 and 1994/95 seasons are confidential. During the 1995/96–2004/05 seasons, observers were required on all vessels fishing for king crabs in the Aleutian Islands area at all times that a vessel was fishing. With the advent of the Crab Rationalization program in the 2005/06 season, all vessels fishing for golden king crabs in the Aleutian Islands area are now required to carry an observer for a period during which 50% of the vessel's harvest was obtained during each trimester of the fishery; observers continue to be required at all times a vessel is fishing in the red king crab fishery west of 179° W longitude. All king crabs that were captured as bycatch during the Aleutian Islands golden king crab fishery by a vessel while an observer was on board during the 2001/02–2002/03 and 2004/05–2008/09 seasons were counted and recorded for capture location and biological data.
- The 1992/93–2008/09 time series of weight bycatch of red king crabs in the Adak Area (reporting areas 541, 542, and 543; i.e., Aleutian Islands west of 170° W longitude) during federal groundfish fisheries by gear type (fixed or trawl) is provided in Table 3.
- The 1995/96–2008/09 time series of estimated weight of total fishery mortalities of red king crabs in the Adak Area, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries, is provided in Table 4. Bycatch mortality was estimated by applying assumed handling mortality rates to the estimates of bycatch in Tables 2 and 3. Following Siddeek et al. (2009), the handling mortality rate of king crabs captured and discarded during Aleutian Islands king crab fisheries

was assumed to be 0.2. Following Foy et al. (2009), the handling mortality of king crabs captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crabs captured by trawls during groundfish fisheries was assumed to be 0.8.

- The 1995/96–2008/09 time series of estimates weight of total fishery mortalities of red king crabs in the Adak Area, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries (Table 4) is presented graphically in Figure 5.

c. Catch-at-length:
Retained catch-at-length data is available for the red king crab fishery in the Adak Area for the 1984/85–1995/96 and 2002/03–2003/04 seasons and are presented as relative-frequency graphs in Figure 6. Data is not presented for crabs retained during the 1999/2000 season or the 2000/01–2001/02 seasons because landings during those seasons were made during either restricted exploratory fishing or during ADFG-Industry surveys.

d. Survey biomass estimates: Not available; there is no program for regular performance of standardized surveys sampling from the entirety of the stock range.

e. Survey catch at length:
The size-shell relative-frequency distribution, by sex, of red king crabs captured during the 2006 ADF&G pot survey for red king crabs in the Petrel Bank area, the only such data from a standardized survey for Adak red king crabs that are available (similar data are not available from the 1975–1977 surveys), is presented in Figure 7. The survey data is from 170 stations, covering an area of approximately 3,970 km^2, that were fished at depths of 23–139 fathoms (42–254 m) on Petrel Bank and Petrel Spur. Each station consisted of four pots arrayed approximately 0.125 nmi (0.23 km) apart. Each pot measured 7 ft x 7 ft x 2.8 ft (2.1 m x 2.1 m x 0.9 m), was fitted with 2.75-in (70-mm) stretch mesh on all webbing, and had two opposing tunnel openings measuring 8 in x 36 in (0.2 m x 0.9 m). Soak times during the survey ranged from 24.2 hours to 44.6 hours. See Gish 2007.

f. Other data time series:
Data on CPUE (number of retained crabs per pot lift) during the red king crab in the Adak Area are available for the 1972/73–2008/09 seasons (see Table 1). That time series is plotted with the weight of retained catch in Figure 8. Data from the 1998/99 season (during which fishing was restricted to be outside of the Petrel Bank area) and the 2000/01 and 2001/02 ADF&G-Industry surveys are included in the graph.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):
Growth per molt was estimated for Adak Area male red king crabs by Vining et al. (2002) based on information received from recoveries during commercial fisheries of tagged red king crabs released in the Adak Island to Amlia Island area during the 1970s (Table 5). 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 6 and 7).

b. Weight-at length or weight-at-age (by sex):
Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crabs according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.000361 and B = 3.16 for males and A = 0.022863 and B = 2.23382; note that although the estimated parameters, A and B, are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to pounds by dividing by 453.6.

c. Natural mortality rate:

Natural mortality rate has not been estimated specifically for red king crab in the Adak Area. NPFMC (2007) assumed a natural mortality rate of M =0.18 for king crabs species.

4. **<u>Information on any data sources that were available, but were excluded from the assessment:</u>**
   - Distribution of effort and catch during 2006 ADF&G Petrel Bank red king crab survey (Gish 2007).
   - Sex-size distribution of catch and distribution of effort and catch during the January/February 2001 and November 2001 ADF&G-Industry red king crab survey of the Petrel Bank area (Bowers et al. 2002) and ADF&G-Industry red king crab pot survey conducted as a commissioner's permit fishery in November 2002 in the Adak Island and Atka-Amlia Islands areas (Granath 2003).
   - Observer data on size distribution and geographic distribution of bycatch of red king crabs in the Adak red king crab fishery and the Adak/Aleutian Islands golden king crab fishery, 1988/89–2008/09 (ADF&G observer database).
   - Summary of data collected by ADF&G Adak red king crab fishery observers or surveys during 1969–1987 (Blau 1993).

E. Analytic Approach

1. **<u>History of modeling approaches for this stock</u>:** This is a Tier 5 stock; there is no assessment model and no history of assessment modelling approaches for this stock.

2. **<u>Model Description</u>:**

Subsections a–i are not applicable to a Tier 5 sock.

There is no regular survey of this stock. No assessment model for the Adak Area red king crab stock exists and none is in development. Accordingly, it has been recommended by NPFMC (2007) and by the CPT and SSC in 2008 that the Adak Area red king crab stock be managed as a Tier 5 stock. For Tier 5 stocks only an OFL is estimated, because it is not possible to estimate MSST without an estimate of biomass, and "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (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."

Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which nontarget fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926) and the CPT in September 2009 recommended examining a total-catch OFL. Hence alternative configurations for the Tier 5 model are limited to: 1) a retained-catch versus total-catch OFL, and 2) alternative time periods for computing the average catch (whether retained or total). Nonetheless, the CPT in May 2009 recommended a retained-catch OFL for 2009. The important questions to resolve when choosing from among alternative time periods for computing average catch (whether retained or total) as an estimate of OFL are:

1. Over what time period in the history of the fishery was the retained catch "representative of the production potential of the stock?"
2. In choosing the time period, what available information should be used when considering "the required risk aversion for stock conservation?"
3. In choosing the time period, what available information should be used when considering "utilization goals?"

Considerations in choosing the time period that is "representative of the production potential of the stock" include the choice of a time period that represents prevailing environmental conditions. In that regard NPFMC (2007) suggested using the years post-1984 to calculate a retained-catch OFL; that suggestion was based on an assumed 8-year lag between hatching and growth to legal size and a environmental "regime shift" that occurred in 1976/77. The changes in distribution of fishery effort and catch that have occurred during the history of the fishery (see section C.5 and Figure 4) may also be indicative of changes in prevailing environmental conditions over the Adak Area.

Changes in management practices over the history of the fishery (e.g., establishment of GHLs and fishery or area closures; see section C.5) that can constrain or otherwise affect the annual retained catch are also an important consideration here. From the comparison between the retained catch with the GHLs in Figure 3, it would appear that, except for seasons when the fishery was closed and the 2002/03 and 2003/04 seasons, the catch during the 1973/74–1995/96 seasons was generally not constrained by a GHL or upper limit of a GHL range. In that regard, NPFMC (2007) suggested excluding fishery data after 1994 from computation of a retained-catch OFL because, since 1995, "… the fishery was closed, fishing effort was less than 10% of the average, or fishing was allowed in only a small part of the fishing ground." On the other hand, the SSC in June 2008 recommended including data after the 1994/95 season because "… periods of high and low catches, including periods when the fishery was closed because of conservation concerns [because] [t]hese catches likely reflect fluctuations in stock abundance."

Data availability is another consideration. Retained catch data for the Adak red king crab fishery is available back to the 1960/61 season, but for the 1960/61–1983/84 seasons the data can only be summarized for the areas west and east of 172º W longitude (recall that the Adak Area as defined here is the Aleutian Islands area west of 171º W longitude; see sections C.5 and D.2). Hence, although average retained catch can be computed with data including that from the 1960/61–1983/84 seasons, the average catch from that period would not include whatever catch occurred between 171º W longitude and 172º W longitude. Data availability also affects the choice of whether a retained-catch OFL or a total-catch OFL is used for this stock because estimates of annual total fishery mortality are available only back to the 1995/96 season (see section D.2).

When considering time periods intended to represent "the production potential of the stock," an additional fundamental question to resolve is, "Does 'the production potential of the stock' mean:

1. 'the production potential of the stock' under current environmental conditions, regardless of the actual current condition of the stock itself?

   or

2. 'the production potential of the stock' at the current condition of the stock?"

The answer to that question is needed to determine whether the time period chosen is limited only to the more recent past or includes years in the more distant past that may not be representative of the stock's current condition. The size frequency distribution of retained catch during the most recent fishery seasons (2002/03 and 2003/04; Figure 6) and results of the 2006 ADF&G pot survey (Gish 2007) indicate that recruitment to the stock has been poor during this decade. Hence catch data in the more distant past is likely not representative of the stock's current productivity. However, the basis for the SSC's June 2009 recommendation on the 2008 OFL for this stock (i.e., that it was intended to "be a more appropriate proxy for the long-term average production potential") aligns most with the first interpretation of what is meant by "the production potential of the stock."

With regard to considering "the required risk aversion for stock conservation" when determining the OFL, the SSC in June 2008 suggested that, "The OFL should be the most appropriate proxy for MSY, and risk aversion is more appropriately applied when setting harvest levels." Note that that suggestion again aligns most with the first interpretation, above, of what is meant by "the production potential of the stock."

Guidance for considering "utilization goals" has been lacking except for the SSC (June 2009) noting that a larger retained-catch OFL, as opposed to a bycatch-only OFL for this stock, would "… allow continued ADF&G-Industry surveys, which have taken as much as 154,000 lbs."

3. <u>Model Selection and Evaluation</u>:

a. <u>Description of alternative model configurations:</u>

Four alternative configurations for computing average retained catch to estimate a retained-catch OFL for 2009/10 were considered and are described in the table below (The "Base" and Alternatives 1–3). A total-catch OFL estimate (Alternative 4) is also presented so that the CPT in May 2010 and SSC in June 2010 may consider establishment of a total-catch OFL for 2010/11. Each alternative follows the recommendation of the SSC (June 2008) to include years of fishery closures and the CPT (May 2009) to freeze the years considered at 2007/08.

Model	Retained- vs. Total-catch	Time Period (n of years)	Description/Comments
Base	Retained	1985/86–2007/08 (23)	• Determined the 2008/09 OFL • Assumes 8 year lag from hatching to legal size and 1976/77 "regime shift" (NPFMC 2007) • "Lack of rationale for excluding the 1984/85 catch" (SSC, October 2008)
Alt. 1	Retained	1984/85–2007/08 (24)	• Addresses "lack of rationale for excluding the 1984/85 catch" (SSC, October 2008) • 1984/85 season is first that Adak Area is defined as west of 171º W longitude
Alt. 2	Retained	1977/78–2007/08 (31)	• 1977/78 is first season after 1976/77 closure; longer time period than Base or Alt. 1. o 1976/77 season is a "break" between high retained catches of 1960s–early 1970s and lower retained catches beginning in 1977/78. • Retained catch for 1977/78–1983/84 seasons is for area west of 172º W longitude
Alt. 3	Retained	1960/61–2007/08 (48)	• Longest time period possible • Average catch during 1960/61–1975/76 is 10X greater than for 1977/78–1995/96 • Retained catch for 1960/61–1983/84 seasons is for area west of 172º W longitude
Alt. 4[a]	Total	1995/96–2007/08 (13)	• Addresses CPT (September 2008) request to examine a total-catch OFL • Longest continuous time period for computing total-catch OFL • May be more representative of current conditions than long-term average production potential • Shortest time period considered • Directed fishery closed for 8 of 13 years

a. Presented here so that the CPT in May 2010 and SSC in June 2010 may consider establishment of a total-catch OFL for 2010/2011.

Each of those alternatives could also be expanded to include 2008/09 in the time period considered; effects of including 2008/09 are considered in section 3.b, below.

b. Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:

See the table, below.

Model	Retained-vs. Total-catch	Time Period (n of years)	Resulting OFL (millions of pounds)
Base	Retained	1985/86–2007/08 (23)	0.46[a]
Alt. 1	Retained	1984/85–2007/08 (24)	0.50[a]
Alt. 2	Retained	1977/78–2007/08 (31)	0.67[a]
Alt. 3	Retained	1960/61–2007/08 (48)	4.30[a]
Alt. 4[b]	Total	1995/96–2007/08 (13)	0.12[c]

a. The OFL resulting from extending the time period to include 2008/09 can be obtained by multiplying this OFL by n/(n+1), where n is the number of years for the time period.
b. Presented here so that the CPT in May 2010 and SSC in June 2010 may consider establishment of a total-catch OFL for 2010/2011.
c. The OFL resulting from extending the time period to include 2008/09 is the same when rounded to the nearest 0.01-million pounds.

c. Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:

All alternatives assume that catch is indicative of stock productivity without any regard to harvest restraints (GHLs, TACs, fishery closures, etc) that were imposed by management during the history of the fishery. The reality of that assumption was discussed in section E.2–Model Description.

Alternative 3 is the simplest alternative in that it computes only the mean of the retained catch (i.e., assumes no bycatch mortality), with minimum assumptions on changes in potential productivity of the stock over the history of the fishery and minimum assumptions on area that the reported catch occurred in. Alternative 3 is judged by the assessment author to be an unrealistic retained-catch OFL.

Alternative 2 adds more realism by taking large-scale changes in retained catch during the fishery history as evidence of large-scale changes in stock productivity. A large scale change in retained catch occurred in the history of the fishery, with the fishery closure in 1976/77 marking the demarcation; average annual retained catch during 1960/61–1975/76 was 11.60-million pounds, whereas the average annual retained catch during 1977/78–2007/08 was 0.67-million pounds. Alternative 2 still assumes that there is no bycatch mortality and ignores changes in the boundaries defining the Adak Area that occurred between 1983/84 and 1984/85. Moreover, retained catch data is available only at the level of "west of 172° W longitude" for the period 1977/78–1979/80 and at the level of statistical areas that are difficult to partition geographically for the period 1980/81–1984/85.

Alternative 1 makes no assumptions on the area of retained catch by using only retained-catch data reported for the area west of 171° W longitude during 1984/85–2007/08, although the 1984/85 data is retrievable only at the level of statistical areas that are difficult to partition geographically. On the other hand, Alternative 1 still assumes that there is no bycatch mortality and does not attempt to specifically address the potential effects on productivity of a 1976/77 regime shift, although the difference in that regard from the Base Alternative may be negligible.

The Base Alternative estimates OFL as the average annual retained catch during 1985/86–2007/08 in an attempt to address the potential effects on productivity by assuming an 8 year lag from hatching to legal size and a 1976/77 regime shift. The Base Alternative still assumes that there is no bycatch mortality.

Alternative 1 is judged by the author to provide a retained-catch OFL that balances the simplicity of Alternative 2 and attempted realism of the Base Alternative.

Alternative 4 is a total-catch OFL and is presented here so that the CPT in May 2010 and SSC in June 2010 may consider establishment of a total-catch OFL for 2010/11. A total-catch OFL is more realistic than a retained-catch OFL because it makes the more realistic assumption that bycatch mortality occurs. However, to estimate the total-catch OFL, Alternative 4 must estimate bycatch, make assumptions on handling mortality, and use the most restricted time period of all alternatives, 1995/96–2007/08. See section E.3.f for a discussion on reliability of bycatch estimation and handling mortality assumptions.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***

- Estimates of total retained catch (pounds) during a season are from fish ticket landings recorded at landings and are assumed here to be correct.
- Estimates of bycatch during crab fisheries are based on data obtained by pot lifts sampled by observers. The bycatch estimates (in terms of number of crabs captured per pot lift by sex-size class) have high precision (CVs<10%) and the sampling and estimation generally is accurate to within 6% (Barnard and Burt 2008).
- Estimates of biomass of bycatch use a length-to-weight estimator for red king crabs provided in NPFMC (2007) applied to the size distribution of crabs in pot lifts sampled by observers. The length-to-weight estimator is assumed to be accurate and the size distribution of sampled crabs is assumed to accurately reflect the size distribution of all crabs that occur as bycatch during the crab fisheries.
- The handling mortality rates used to estimate bycatch mortality are those that have been judged as credible for other assessments (Siddeek 2009, Foy and Rugolo 2009).

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** See section E.3.c, above.

4. **Results (best model(s)):**

a. ***List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties:*** Not applicable.

b. ***Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):*** Not applicable.

c. ***Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible):*** Infromation requested for this subsection is not applicable to a Tier 5 stock. Alternative retained-catch OFLs are graphed relative to actual retained catch during history of fishery in Figure 9.

d. ***Evaluation of the fit to the data:*** Not applicable for Tier 5 stock.

e. ***Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments):*** Not applicable for Tier 5 stock.

f. ***Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):*** Not applicable for Tier 5 stock.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5: Retained-catch OFL estimated by average retained catch over a specified period (as recommended by CPT in May 2009; see section B.2).
   - Recommended time period for computing retained-catch OFL: 1984/85–2007/08.
     - The time period follows the May 2009 recommendation of the CPT by freezing the end of the time period considered at 2007/08 (see section B.2). The inclusion of 1984/85 in the time period acknowledges the SSC's October 2008 opinion that there was a lack of rationale for not including 1984/85 in the time period used for the 2008 OFL (1985/86–2007/08; see section B.2). The time period 1984/85–2007/08 provides the longest time period through 2007/08 during which retained-catch data can be retrieved from the area west of 171° W longitude (as the Adak Area is now defined). This time period excludes the pre-1976/77 period, during which time the average retained catch was 11.60-million pounds – an order of magnitude greater than the annual retained catch in any year following 1976/77. Given the level of precision about the assumed time from hatching to legal size (8 years; NPFMC 2007) and the assumed timing at which a mid-1970s regime shift occurred in the Adak Area (1976/77; NPFMC 2007), this time period also reasonably accommodates the attempt to base the chosen time period on prevailing environmental conditions.

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable for Tier 5 stock.

3. **Specification of the OFL:**

a. ***Provide the equations (from Amendment 24) on which the OFL is to be based:***

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. ***Basis for projecting MMB to the time of mating:*** Not applicable for Tier 5 stock.

c. ***Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring:*** See table below.

Year	MSST	Biomass (MMB)	TAC	Retained Catch[a]	Total Catch[a,b]	OFL[a]
2005/06	N/A	N/A	Closed	0	0.004	N/A
2006/07	N/A	N/A	Closed	0	0.004	N/A
2007/08	N/A	N/A	Closed	0	0.011	N/A
2008/09	N/A	N/A	Closed	0	0.014	0.46[c]
2009/10	N/A	N/A	TBD	TBD	TBD	0.50[d]

a. Millions of pounds.
b. Includes handling mortality of discarded bycatch.
c. Retained-catch OFL established for 2008/09.
d. Retained-catch OFL recommended by author for 2009/10.

4. **<u>Recommendation for F_{OFL}, OFL total catch (or OFL retained catch) for the coming year</u>:**

Recommended OLF = 0.50-million pounds, retained-catch.

G. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

H. Data Gaps and Research Priorities

This fishery has a long history, with the domestic fishery dating back to 1960/61. However, much of the data on this stock prior to the early-mid 1980s is difficult to retrieve for analysis. Fishery data summarized to the level of statistical area are presently not available prior to 1980/81. Changes in definitions of fishery statistical areas between 1984/85 and 1985/86 also make it difficult to assess geographic trends in effort and catch over much of the fishery's history. An effort to compile all fishery data and other written documentation on the stock and fishery and to enter all existing fishery, observer, survey, and tagging data into a database that allows for analysis of all data from the stock through the history of the fishery would be very valuable.

The SSC (October 2008; see section B.2) has noted the need for systematic surveys to obtain the data to estimate the biomass of this stock. Surveys on this stock have, however, been few and the geographic scope of the surveyed area is limited. Aside from the pot surveys performed in the Adak-Atka area during the mid-1970s (ADF&G 1978, Blau 1993), the only standardized survey for red king crabs performed by ADF&G was performed in November 2006 and was limited to the Petrel Bank area (Gish 2007). ADF&G will perform a systematic pot survey in the Petrel Bank area again on November 2009. ADF&G-Industry surveys, conducted as limited fisheries that allowed retention of captured legal males under provisions of a commissioner's permit have been performed in limited areas of the Adak Area: during January–February 2001 and November 2001 in the Petrel Bank area (Bowers et al. 2002) and during November 2002 in the Adak-Atka-Amlia area (Granath 2003). A limited Industry survey without any retention of crabs is planned for a portion of the Adak Area in 2009/10 (see section B.2).

Trawl surveys are preferable relative to pot surveys for providing density estimates, but crab pots may be the only practical gear for sampling king crabs in the Aleutians. Standardized pot surveys are a prohibitively expensive approach to surveying the entire Adak Area. Surveys or exploratory fishing performed by Industry in cooperation with ADF&G, with or without allowing retention of captured legal males, reduce the costs to agencies. Agency-Industry cooperation can provide a means to obtain some information on distribution and density during periods of fishery closures. However, there can be difficulties in assuring standardization of procedures during ADF&G-Industry surveys (Bowers 2002). Moreover, costs of performing a survey have resulted in incompletion of ADF&G-Industry surveys (Granath 2003). Hence surveys performed by Industry in cooperation with ADF&G cannot be expected to provide sampling over the entire Adak Area during periods of limited stock distribution and overall low density, as apparently currently exists.

I. Ecosystem Considerations

1. Ecosystem Effects on Stock:

a. Prey availability/abundance trends (historically and in the present and foreseeable future): Existence and availability of such information is not known to the author.

b. Predator population trends (historically and in the present and foreseeable future): Existence and availability of such information is not known to the author.

c. Changes in habitat quality (historically and in the present and foreseeable future): Existence and availability of such information is not known to the author.

2. Fishery Effects on the Ecosystem

a. Fishery-specific bycatch of HAPC biota marine mammals and birds, and other sensitive non-target species:

A summary of bycatch during the 2002/03–2003/04 Adak red king crab fisheries are provided in Tables 8 and 9. Note that, due to closure of the fishery, there was no bycatch in the fishery during 2004/05–2008/09.

b. Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components:

Existence and availability of such information is not known to the author. Note that, the fishery – when opened – since the 1990s has been concentrated in the Petrel Bank area, typically at depths of 60–90 fathoms (110–165 m; see section C.2). Due to closure of the fishery, there has been no effect during 2004/05–2008/09.

c. Fishery-specific effects on amount of large size target crab:

The fishery can only retain males ≥ 6.5-inches carapace width. Bycatch of sublegal males has been low relative to catch of legal males in the most recent seasons (see Table 5), presumably due to low availability of sublegal males. Hence the fishery, when prosecuted, would be expected to decrease the amount of large size males. However, without background information on the available biomass of large size males, the magnitude of the effect cannot be estimated. Note that, due to closure of the fishery, there has been no effect during 2004/05–2008/09.

d. Fishery-specific contribution to discards:

Estimated contribution of discards of red king crabs of the Adak red king crab fishery relative to the Aleutian Islands golden king crab fishery during 1995/96–2008/09 is provided in Table 2. See Table 3 for comparison with the estimated bycatch of Adak red king crabs in federal groundfish fisheries during 1992/93–2008/09. Note that, due to closure of the fishery, there has been no contribution from the fishery during 2004/05–2008/09.

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

Existence and availability of such information is not known to the author. Note that, due to closure of the fishery, there has been no effect during 2004/05–2008/09.

f. Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance):

Number of pot lifts per season during 1969/70–2008/09 is plotted in Figure 10. Note that the geographic distribution of fishery effort has changed during this time period and that the fishery has been concentrated in the Petrel Bank area since 1990/91 (see section C.5).

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Table 1. Aleutian Islands, Area O, red king crab commercial fishery data, 1960/61–2007/08, partitioned into the Adak area (west of 172º W longitude prior to 1984/85 and west of 171º W longitude since 1984/85) and the Dutch Harbor area (from Bowers et al. 2008); though not included in this table, note that the fishery was closed for the 2008/09 season.

		Number of					Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1960/61	East of 172° W	NA	NA	NA	NA	NA	NA	NA	NA	NA
	West of 172° W	4	41	NA	NA	2,074,000	NA	NA	NA	NA
	TOTAL									
1961/62	East of 172° W	4	69	NA	NA	533,000	NA	NA	NA	NA
	West of 172° W	8	218	NA	NA	6,114,000	NA	NA	NA	NA
	TOTAL		**287**			**6,647,000**				
1962/63	East of 172° W	6	102	NA	NA	1,536,000	NA	NA	NA	NA
	West of 172° W	9	248	NA	NA	8,006,000	NA	NA	NA	NA
	TOTAL		**350**			**9,542,000**				
1963/64	East of 172° W	4	242	NA	NA	3,893,000	NA	NA	NA	NA
	West of 172° W	11	527	NA	NA	17,904,000	NA	NA	NA	NA
	TOTAL		**769**			**21,797,000**				
1964/65	East of 172° W	12	336	NA	NA	13,761,000	NA	NA	NA	NA
	West of 172° W	18	442	NA	NA	21,193,000	NA	NA	NA	NA
	TOTAL		**778**			**34,954,000**				
1965/66	East of 172° W	21	555	NA	NA	19,196,000	NA	NA	NA	NA
	West of 172° W	10	431	NA	NA	12,915,000	NA	NA	NA	NA
	TOTAL		**986**			**32,111,000**				
1966/67	East of 172° W	27	893	NA	NA	32,852,000	NA	NA	NA	NA
	West of 172° W	10	90	NA	NA	5,883,000	NA	NA	NA	NA
	TOTAL		**983**			**38,735,000**				
1967/68	East of 172° W	34	747	NA	NA	22,709,000	NA	NA	NA	NA
	West of 172° W	22	505	NA	NA	14,131,000	NA	NA	NA	NA
	TOTAL		**1,252**			**36,840,000**				
1968/69	East of 172° W	NA	NA	NA	NA	11,300,000	NA	NA	NA	NA
	West of 172° W	30	NA	NA	NA	16,100,000	NA	NA	NA	NA
	TOTAL					**27,400,000**				
1969/70	East of 172° W	41	375	NA	72,683	8,950,000	NA	NA	NA	NA
	West of 172° W	33	435	NA	115,929	18,016,000	6.5	NA	NA	NA
	TOTAL		**810**		**188,612**	**26,966,000**				
1970/71	East of 172° W	32	268	NA	56,198	9,652,000	NA	NA	NA	NA
	West of 172° W	35	378	NA	124,235	16,057,000	NA	NA	NA	NA
	TOTAL		**646**		**180,433**	**25,709,000**				
1971/72	East of 172° W	32	210	1,447,692	31,531	9,391,615	7	46	NA	NA
	West of 172° W	40	166	NA	46,011	15,475,940	NA	NA	NA	NA
	TOTAL		**376**		**77,542**	**24,867,555**				
1972/73	East of 172° W	51	291	1,500,904	34,037	10,450,380	7	44		
	West of 172° W	43	313	3,461,025	81,133	18,724,140	5.4	43	NA	NA
	TOTAL		**604**	**4,961,929**	**115,170**	**29,174,520**	**5.9**	**43**		
1973/74	East of 172° W	56	290	1,780,673	41,840	12,722,660	7.1	43	NA	NA
	West of 172° W	41	239	1,844,974	70,059	9,741,464	5.3	26	148.6	NA
	TOTAL		**529**	**3,625,647**	**111,899**	**22,464,124**	**6.2**	**32**		

(Continued)

Table 1. page 2 of 3.

		Number of					Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1974/75	East of 172° W	87	372	1,812,647	71,821	13,991,190	7.7	25		
	West of 172° W	36	97	532,298	32,620	2,774,963	5.2	16	148.6	NA
	TOTAL		**469**	**2,344,945**	**104,441**	**16,766,153**	**7.1**	**22**		
1975/76	East of 172° W	79	369	2,147,350	86,874	15,906,660	7.4	25		
	West of 172° W	20	25	79,977	8,331	411,583	5.2	10	147.2	NA
	TOTAL		**394**	**2,227,327**	**95,205**	**16,318,243**	**7.3**	**23**		
1976/77	East of 172° W	72	226	1,273,298	65,796	9,367,965 [f]	7.4	19		
	East of 172° W	38	61	86,619	17,298	830,458 [g]	9.6	5	NA	NA
	West of 172° W	FISHERY CLOSED								
	TOTAL		**287**	**1,359,917**	**83,094**	**10,198,423**	**7.5**	**16**		
1977/78	East of 172° W	33	227	539,656	46,617	3,658,860 [f]	6.8	12		
	East of 172° W	6	7	3,096	812	25,557 [h]	8.3	4	NA	NA
	West of 172° W	12	18	160,343	7,269	905,527	5.7	22	152.2	NA
	TOTAL		**252**	**703,095**	**54,698**	**4,589,944**	**6.5**	**13**		
1978/79	East of 172° W	60	300	1,233,758	51,783	6,824,793	5.5	24	NA	NA
	West of 172° W	13	27	149,491	13,948	807,195	5.4	11	NA	1,170
	TOTAL		**327**	**1,383,249**	**65,731**	**7,631,988**	**5.5**	**21**		
1979/80	East of 172° W	104	542	2,551,116	120,554	15,010,840	5.9	21	NA	NA
	West of 172° W	18	23	82,250	9,757	467,229	5.7	8	152	24,850
	TOTAL		**565**	**2,633,366**	**130,311**	**15,478,069**	**5.9**	**20**		
1980/81	East of 172° W	114	830	2,772,287	231,607	17,660,620 [f]	6.4	12	NA	NA
	East of 172° W	54	120	182,349	30,000	1,392,923 [h]	7.6	6		
	West of 172° W	17	52	254,390	20,914	1,419,513	5.6	12	149	54,360
	TOTAL		**1,002**	**3,209,026**	**282,521**	**20,473,056**	**6.4**	**11**		
1981/82	East of 172° W	92	683	741,966	220,087	5,155,345	6.9	3	NA	NA
	West of 172° W	46	106	291,311	40,697	1,648,926	5.7	7	148.3	8,759
	TOTAL		**789**	**1,033,277**	**260,784**	**6,804,271**	**6.6**	**4**		
1982/83	East of 172° W	81	278	64,380	72,924	431,179	6.7	1		
	West of 172° W	72	191	284,787	66,893	1,701,818	6.0	4	150.8	7,855
	TOTAL		**469**	**349,167**	**139,817**	**2,132,997**	**6.1**	**3**		
1983/84	East of 172° W	FISHERY CLOSED								
	West of 172° W	106	248	298,958	60,840	1,981,579	6.6	5	157.3	3,833
1984/85	East of 171° W	FISHERY CLOSED								
	West of 171° W	64	106	196,276	48,642	1,296,385	6.6	4	155.1	0
1985/86	East of 171° W				FISHERY CLOSED					
	West of 171° W	35	82	156,097	29,095	868,828	5.6	5	152.2	0
1986/87	East of 171° W	FISHERY CLOSED								
	West of 171° W	33	69	126,204	29,189	712,543	5.7	4	NA	800
1987/88	East of 171° W	FISHERY CLOSED								
	West of 171° W	71	103	211,692	43,433	1,213,892	5.7	5	148.5	6,900

(Continued)

Table 1. page 3 of 3.

Season	Locale	Number of				Harvest[b,c]	Average			Deadloss[c]
		Vessels[a]	Landings	Crabs[b]	Pots Lifted		Weight[c]	CPUE[d]	Length[e]	
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 - 2007/08		FISHERY CLOSED								

Note: NA = Not available.

[a] Many vessels fished both east and west of 171° W long., thus total number of vessels reflects registrations for entire Aleutian Islands.

[b] Deadloss included.

[c] In pounds.

[d] Number of legal crabs per pot lift.

[e] Carapace length in millimeters.

[f] Split season based on 6.5 inch minimum legal size.

[g] Split season based on 8 inch minimum legal size.

[h] Split season based on 7.5 inch minimum legal size.

[i] January/February 2001 Petrel Bank survey (fish ticket harvest code 15).

[j] Those waters of king crab Registration Area O between 179° E long., 179° W long., and north of 51° 45' N lat.

[k] November 2001 Petrel Bank survey (fish ticket harvest code 15).

Table 2. Weight (in pounds) of retained legal males and estimated weight of non-retained legal male, non-retained sublegal male, and non-retained female red king crabs in the Adak Area during commercial crab fisheries by season for the 1995/96–2008/09 seasons.

	Adak red king crab fishery				AI golden king crab fishery			
	Retained	Non-retained						Total
	legal	Legal	Sublegal		Legal	Sublegal		non-
Season	male	male	male	Female	male	male	Female	retained
1995/96[a]	38,941	0	20,669	27,624	0	2,047	314	50,654
1996/97[b]	0	0	0	0	3,292	2,024	666	5,982
1997/98[b]	0	0	0	0	178	579	179	936
1998/99[b,c]	5,900	-	-	-	747	138	186	1,071
1999/00[b]	0	0	0	0	161	756	93	1,010
2000/01[b]	76,562	0	771	374	365	274	35	1,819
2001/02[b]	153,961	174	6,574	8,369	19,995	0	364	35,476
2002/03[b]	505,642	1,658	6,027	17,432	21,738	355	512	47,722
2003/04[b]	479,113	631	6,597	7,962	9,425	6,352	6,686	37,653
2004/05[b]	0	0	0	0	2,143	210	0	2,353
2005/06[b]	0	0	0	0	189	0	49	239
2006/07[b]	0	0	0	0	323	117	50	491
2007/08[b]	0	0	0	0	615	1,819	561	2,995
2008/09[d]	0	0	0	0	285	69	73	427
Average	90,009	189	3,126	4,751	4,247	1,053	698	13,448

a. Non-retained bycatch estimates by D. Pengilly using bycatch number estimates in Boyle et al. 1996, 1997 and size frequency data in ADF&G crab observer database, Kodiak, 12 August 2009.

b. Sources for non-retained bycatch weight estimates for 1996/97–2007/08 are as were listed in Table 5 of the Adak Red King Crab chapter of the 2008 SAFE.

c. Data on non-retained bycatch of red king crabs during the red king crab fishery not available (see Moore et al. 2000).

d. Non-retained bycatch estimates by D. Pengilly using data from the ADF&G crab observer database, Kodiak, 10 August 2009.

Table 3. Estimated annual weight (pounds) of discarded bycatch of red king crabs (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1992/93–2008/09 (summary of the data provided by J. Mondragon, NMFS-Alaska Region Office through R. Foy AFSC, Kodiak Laboratory, 7 August 2009).

Season	Fixed Gear	Trawl Gear
1992/93	65	42
1993/94	1,312	88,384
1994/95	2,993	22,792
1995/96	5,804	15,289
1996/97	2,874	44,662
1997/98	3,819	11,717
1998/99	10,143	45,532
1999/00	37,765	27,973
2000/01	2,697	13,879
2001/02	5,340	59,552
2002/03	11,295	73,027
2003/04	3,577	9,151
2004/05	791	12,930
2005/06	3,546	2,359
2006/07	6,781	617
2007/08	16,971	2,630
2008/09	10,778	10,290
Average	7,444	25,931

Table 4. Estimates of total fishery mortality (pounds) for red king crabs in the Adak Area, 1995/96–2008/09, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries.

		Bycatch mortality		
Season	Retained Catch	Crab Fisheries[a]	Groundfish Fisheries[b]	Total
1995/96	38,941	10,131	15,133	64,205
1996/97	0	1,196	37,167	38,363
1997/98	0	187	11,283	11,470
1998/99[c]	5,900	214	41,497	47,611
1999/00	0	202	41,261	41,463
2000/01	76,562	364	12,452	89,378
2001/02	153,961	7,095	50,312	211,368
2002/03	505,642	9,544	64,069	579,256
2003/04	479,113	7,531	9,109	495,753
2004/05	0	471	10,740	11,210
2005/06	0	48	3,660	3,708
2006/07	0	98	3,884	3,982
2007/08	0	599	10,590	11,189
2008/09	0	8	13,621	13,629
Average, 1995/96–2007/08	96,932	2,898	23,935	123,766
Average, 1995/96–2008/09	90,009	2,698	23,198	115,904

a. Bycatch mortality during crab fisheries was computed by applying an assumed handling mortality rate of 0.2 to the estimates of total bycatch weight in the "Total non-retained" column of Table 2.

b. Bycatch mortality during groundfish fisheries was computed by applying an assumed handling mortality rate of 0.5 to the estimates of bycatch weight in the "Fixed Gear" column of Table 3 and an assumed handling mortality rate of 0.8 to the estimates of bycatch weight in the "Trawl Gear" column of Table 3.

c. No bycatch data was available from the small (5,900 pound retained catch) 1998/99 directed fishery for red king crab (see Table 2).

Table 5. 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[a]		Nov-Dec 1971-1973[b]		Nov-Dec 1973, Jan-Mar 1975[c]		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[d]	-0.01	0.044	0.08	0.112	-0.07	0.033	0.13	0.151	0.03	0.134
Standard Deviation[e]	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

a. Also includes one recovery in February 1970 and one recovery in January 1973.
b. Also includes one recovery in February 1973, two recoveries in January 1975, and one recovery in March 1975.
c. Also includes one recovery in February 1974, one recovery in September 1974, one recovery in November 1977, and one recovery in March 1978.
d. Mean of measurement error.
e. Standard deviation of measurement error.

Table 6. Logit parameter estimates, slope (β) and intercept (α), 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 (β) Estimate	Slope (β) SE	Intercept (α) Estimate	Intercept (α) 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 7. 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 8. Summary of contents of 596 pot lifts sampled by observers during the 2002/03 Adak (“Petrel Bank”) red king crab fishery (total fishery pot lifts was 3,786).

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
Anthomastus sp.	5	0	0	0	0
arrowtooth flounder	1	0	0	0	0
Atka mackerel	39	0	0	0	0
basket star	2	0	0	0	0
bivalve unident.	4	0	0	0	0
brittle star unident.	3	0	0	0	0
Coral unident.	6	0	0	0	0
Cyclohelia sp.	1	0	0	0	0
dusky rockfish	1	0	0	0	0
giant octopus	23	0	0	0	0
golden king crab	0	17	31	4	0
graceful decorator crab	2	0	0	0	0
hair crab	0	19	136	31	0
hairy triton (or Oregon triton)	1	0	0	0	0
hermit crab unident.	22	0	0	0	0
Hind's scallop (or reddish scallop)	125	0	0	0	0
hybrid C. opilio	0	1	0	0	0
hydrocoral unident.	6	0	0	0	0
hydroid unident.	25	0	0	0	0
leech unident.	1	0	0	0	0
mussel unident.	2	0	0	0	0
northern rockfish	1	0	0	0	0
Pacific cod	13	0	0	0	0
Pacific halibut	4	0	0	0	0
Pacific lyre crab	2403	0	0	0	0
Pribilof neptune (or Pribilof whelk)	7	0	0	0	0
Primnoidae Group I	20	0	0	0	0
red king crab	0	1028	364	8337	8303
red-tree coral	1	0	0	0	0
rockfish unident.	1	0	0	0	0
scallop unident.	1479	0	0	0	0
sculpin unident.	107	0	0	0	0
sea anemone unident.	3	0	0	0	0
sea cucumber unident.	3	0	0	0	0
sea urchin unident.	4	0	0	0	0
skate unident.	7	0	0	0	0
snailfish unident.	1	0	0	0	0
snail unident.	4	0	0	0	0
soft coral unident.	7	0	0	0	0
sponge unident.	58	0	0	0	0
starfish unident.	30	0	0	0	0
stony coral unident.	21	0	0	0	0
Stylaster sp.	4	0	0	0	0
Tanner crab	0	162	93	0	0
tunicate unident.	2	0	0	0	0
weathervane scallop	354	0	0	0	0
yellow Irish lord	120	0	0	0	0

Table 9. Summary of contents of 932 pot lifts sampled by observers during the 2003/04 Adak ("Petrel Bank") red king crab fishery (total fishery pot lifts was 5,774).

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
Alaska plaice	1	0	0	0	0
Anthomastus sp.	6	0	0	0	0
arrowtooth flounder	2	0	0	0	0
Atka mackerel	196	0	0	0	0
basket star	8	0	0	0	0
bivalve unident.	41	0	0	0	0
Black coral unident.	2	0	0	0	0
brittle star unident.	557	0	0	0	0
bryozoan unident.	112	0	0	0	0
Calcigorgia sp.	2	0	0	0	0
Caryophyllia sp.	2	0	0	0	0
chiton unident.	2	0	0	0	0
circumboreal toad crab	4	0	0	0	0
Clavularia sp.	6	0	0	0	0
Coral unident.	6	0	0	0	0
Cup coral unident.	12	0	0	0	0
Cyclohelia sp.	35	0	0	0	0
Distichopora sp.	6	0	0	0	0
dusky rockfish	5	0	0	0	0
Errinopora sp.	1	0	0	0	0
flatfish unident.	3	0	0	0	0
giant octopus	20	0	0	0	0
golden king crab	0	126	2	11	2
great sculpin	2	0	0	0	0
hair crab	0	36	257	47	0
hairy triton (or Oregon triton)	5	0	0	0	0
hermit crab unident.	24	0	0	0	0
Hind's scallop (or reddish scallop)	847	0	0	0	0
hybrid C. bairdi	0	0	1	0	0
hydrocoral unident.	148	0	0	0	0
invertebrate unident.	2	0	0	0	0
jellyfish unident.	7	0	0	0	0
Kamchatka coral (or bubblegum coral)	12	0	0	0	0
leech unident.	13	0	0	0	0
lyre whelk	1	0	0	0	0
northern rockfish	4	0	0	0	0
Pacific cod	22	0	0	0	0
Pacific halibut	8	0	0	0	0
Pacific lyre crab	4071	0	0	0	0
Pacific ocean perch	2	0	0	0	0
Pacific oyster	1	0	0	0	0
Primnoidae Group I	11	0	0	0	0
Primnoidae unident.	2	0	0	0	0
prowfish	1	0	0	0	0
red king crab	0	2186	787	9327	9315
rockfish unident.	3	0	0	0	0
rock sole unident.	4	0	0	0	0
scale worm unident.	4	0	0	0	0
scallop unident.	930	0	0	0	0

-Continued-

Table 9. page 2 of 2.

Species or species group	Non-crab	Crab, female	Crab, sub-legal	Crab, legal	Crab, marketed
sculpin unident.	99	0	0	0	0
sea anemone unident.	10	0	0	0	0
sea cucumber unident.	6	0	0	0	0
sea spider unident.	1	0	0	0	0
sea urchin unident.	8	0	0	0	0
skate unident.	14	0	0	0	0
snailfish unident.	2	0	0	0	0
snail unident.	7	0	0	0	0
soft coral unident.	6	0	0	0	0
spinyhead sculpin	4	0	0	0	0
sponge unident.	351	0	0	0	0
starfish unident.	45	0	0	0	0
Stylaster sp.	124	0	0	0	0
Tanner crab	0	54	64	0	0
tube worm unident.	8	0	0	0	0
tunicate unident.	16	0	0	0	0
walleye pollock	12	0	0	0	0
weathervane scallop	110	0	0	0	0
worm unident.	21	0	0	0	0
yellowfin sole	1	0	0	0	0
yellow Irish lord	326	0	0	0	0

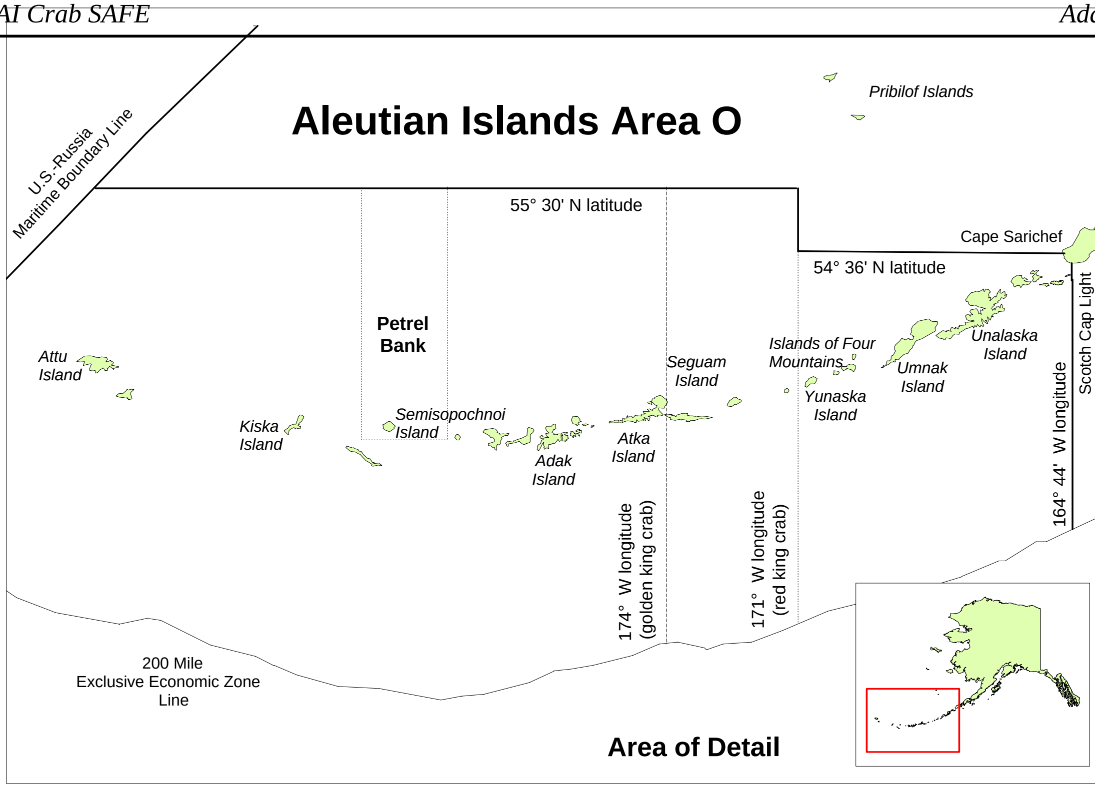


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Bowers et al 2008).

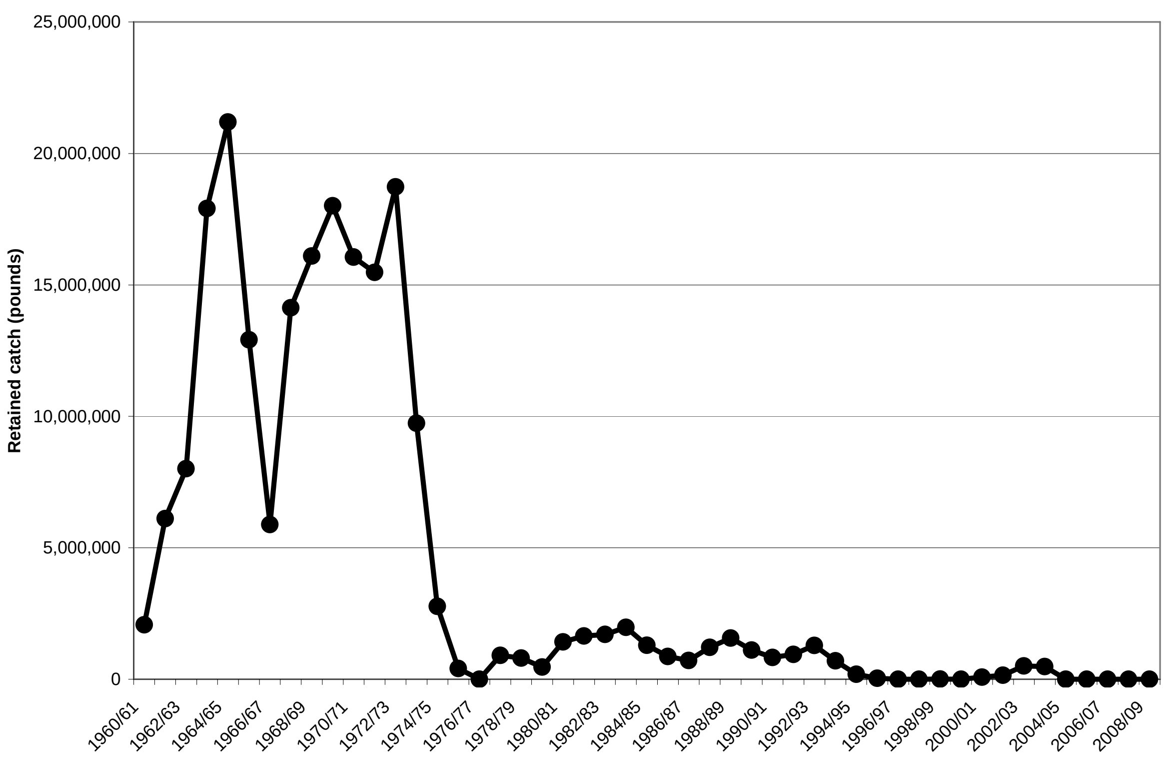


Figure 2. Retained catch in the Adak red king crab fishery, 1960/61–2008/09 (catch is for the area west of 172º W longitude during 1960/61–1983/84 and for the area west of 171º W longitude during 1984/85–2008/09; see Table 1).

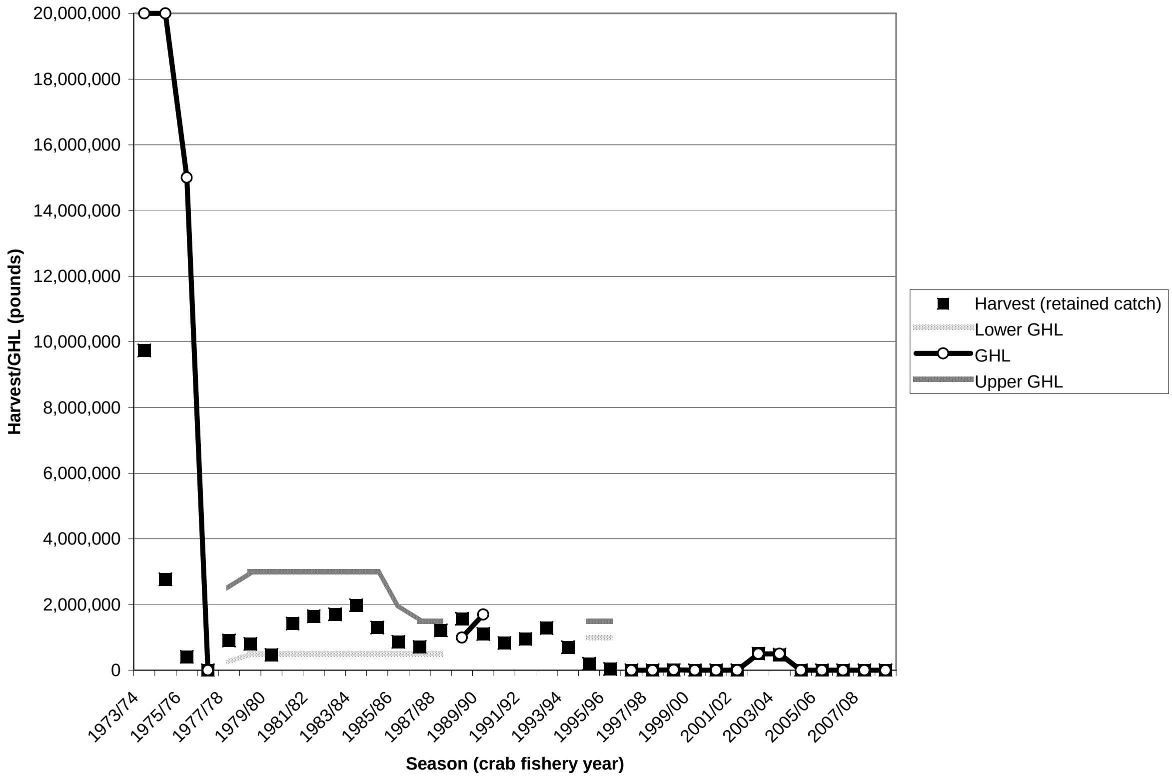


Figure 3. Guideline harvest levels (GHL, pounds) for the 1973/74–2007/08 Adak red king crab fishery seasons, with retained catch (harvest, pounds); the retained catch graphed for the 2000/01–2001/02 seasons does not include the catch retained during ADF&G-Industry surveys of the Petrel Bank area.; the 1973/74–1975/76 GHL also included incidental catch of golden king crabs (from Tables 1-1 and 1-2 in Bowers et al. 2008).

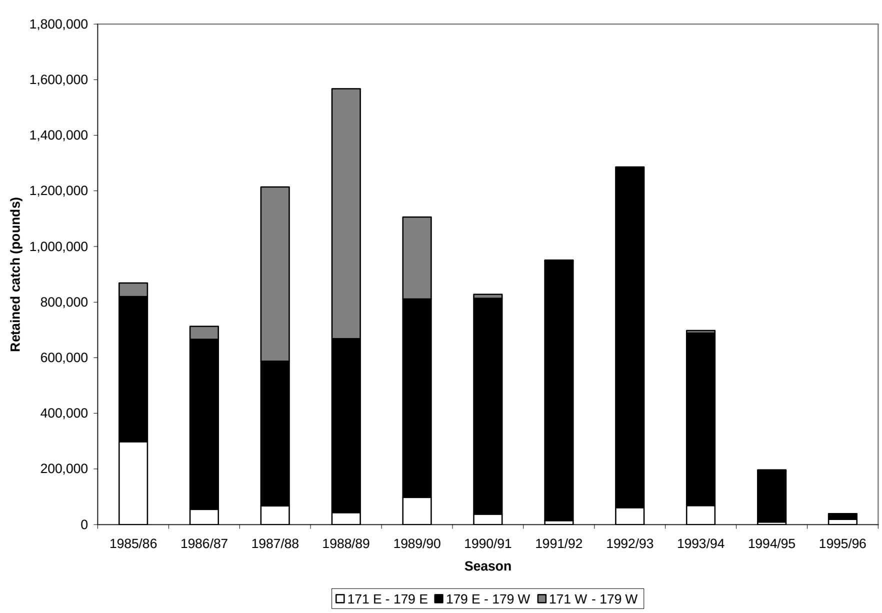


Figure 4. Retained catch (pounds) in the Adak red king crab fishery for the 1984/85–1995/96 seasons, partitioned into three longitudinal zones (171º W longitude to 179º W longitude, 179º W longitude to 179º E longitude, and 179º E longitude to 171º E longitude; from ADF&G fish ticket summary provided by F. Bowers, ADF&G).

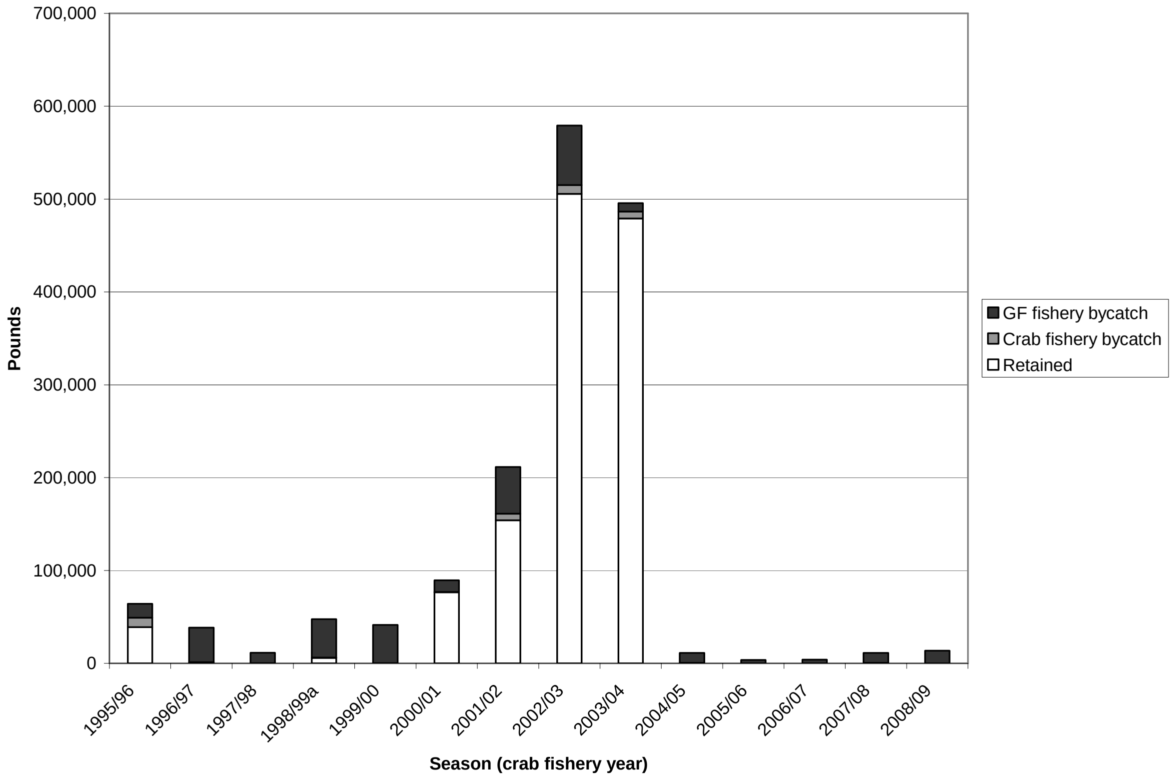


Figure 5. Estimates of total fishery mortality (pounds) for red king crabs in the Adak Area, 1995/96–2008/09, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries (see Table 4).

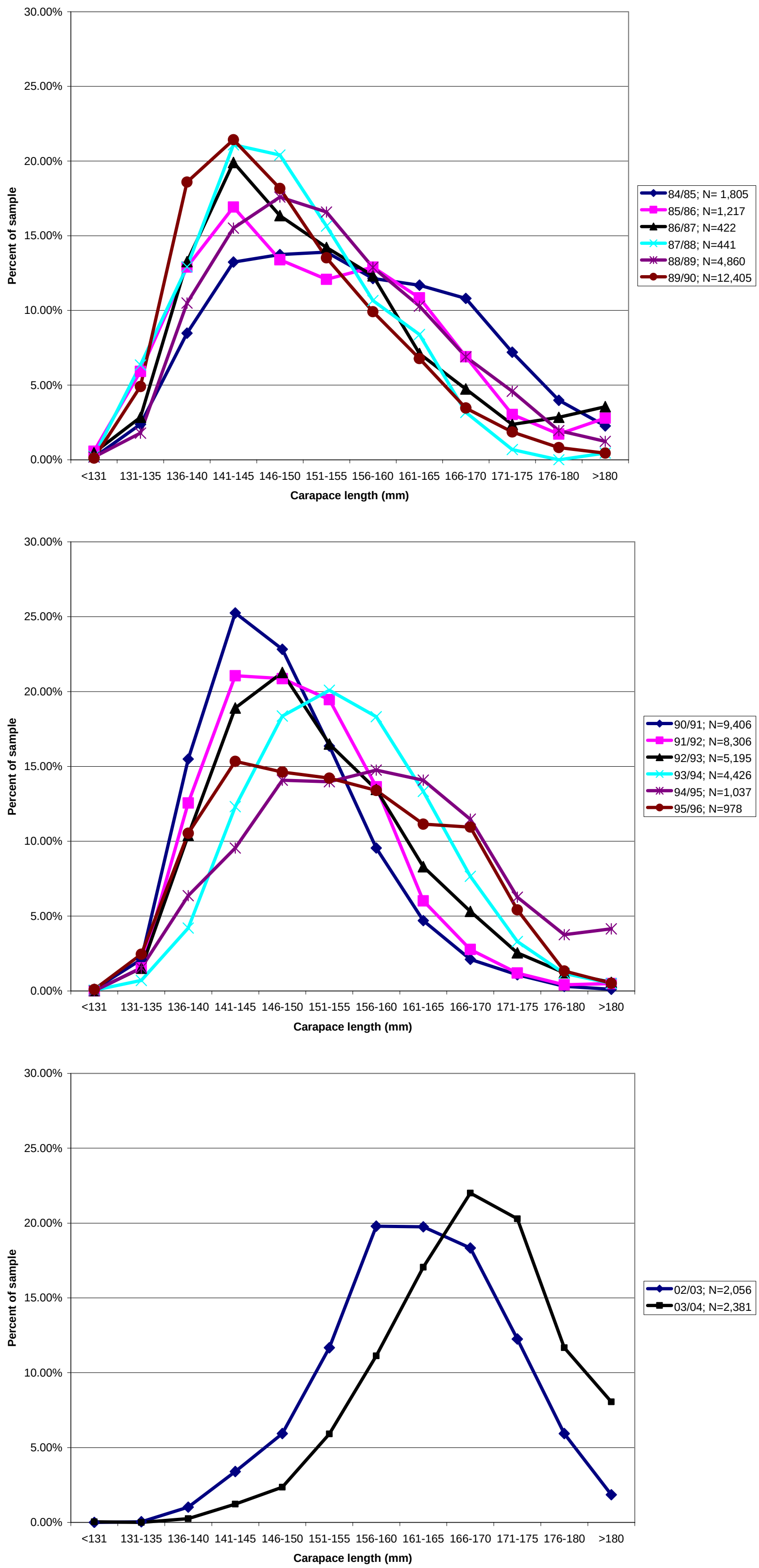


Figure 6. Percent frequency in 5-mm carapace length groupings of retained red king crabs sampled from the landed catch during the 1984/85–1995/96 and 2002/03–2003/04 red king crab fishery seasons in the Adak Area (data from ADF&G observer database, Kodiak, summarized by D. Pengilly).

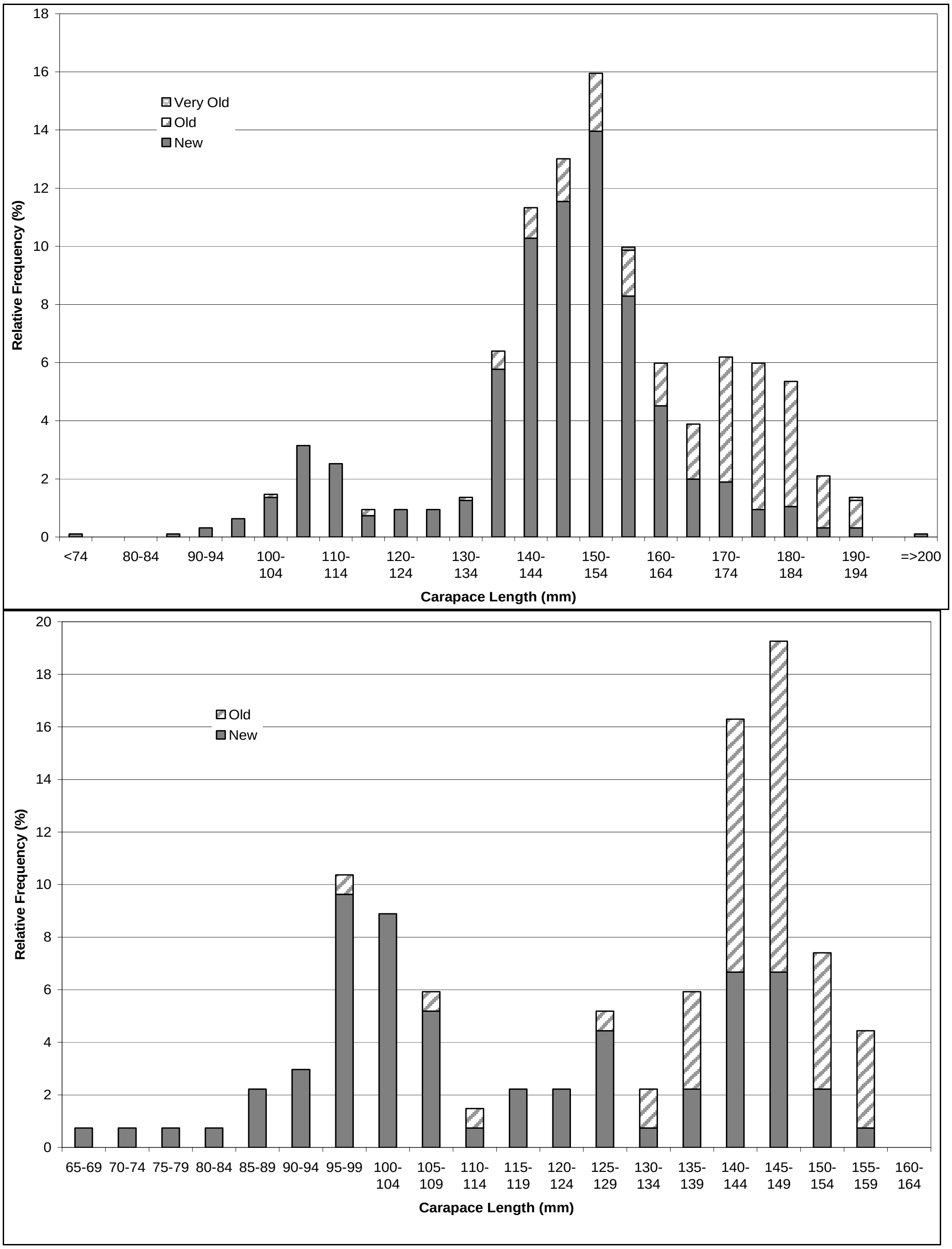


Figure 7. The size-shell relative-frequency distribution of male (top panel; N=955) and female (bottom panel; N=139) red king crabs by 5-mm carapace length groups captured during the 2006 ADF&G pot survey for red king crabs in the Petrel Bank area.

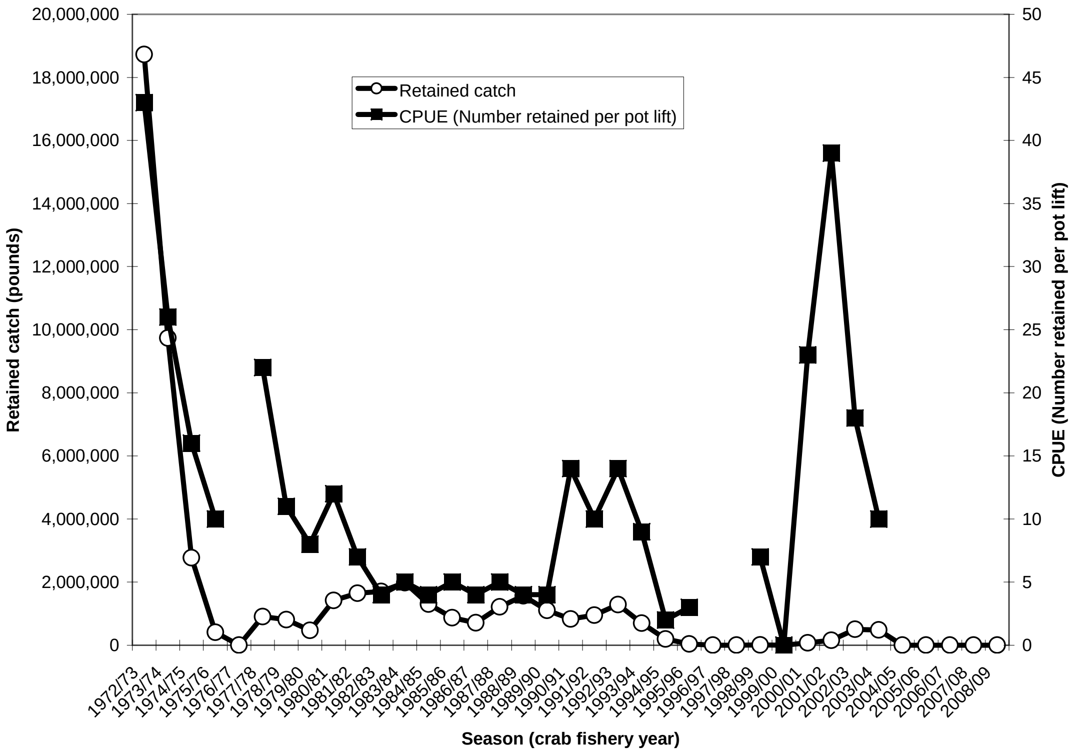
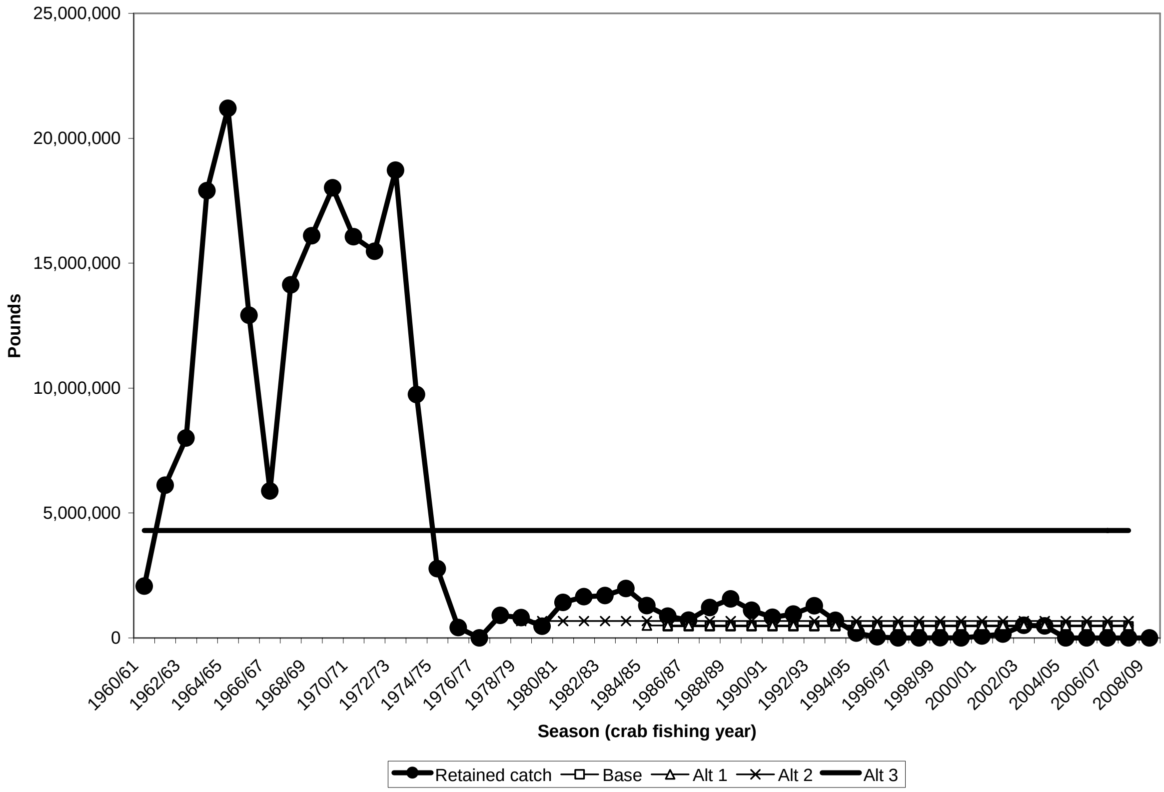


Figure 8. Retained catch (pounds) and CPUE (number of retained crabs per pot lift) of red king crabs during the 1972/73–2008/09 fishery seasons for red king crabs in the Adak Area (see Table 1). Data for the 1972/73–1983/84 seasons is from the area west of 172º W longitude; data since the 1984/85 season is from the area west of 171º W longitude. Fishing was closed in the Petrel Bank area (i.e., between 179º W longitude and 179º E longitude) for the 1998/99 season, whereas fishing was restricted to the Petrel Bank area during the 2000/01–2003/04 seasons. The 2000/01 and 2001/02 data are from the 2000/01 and 2001/02 ADF&G-Industry surveys of the Petrel Bank area that were performed under provisions of a commissioner's fishery permit.



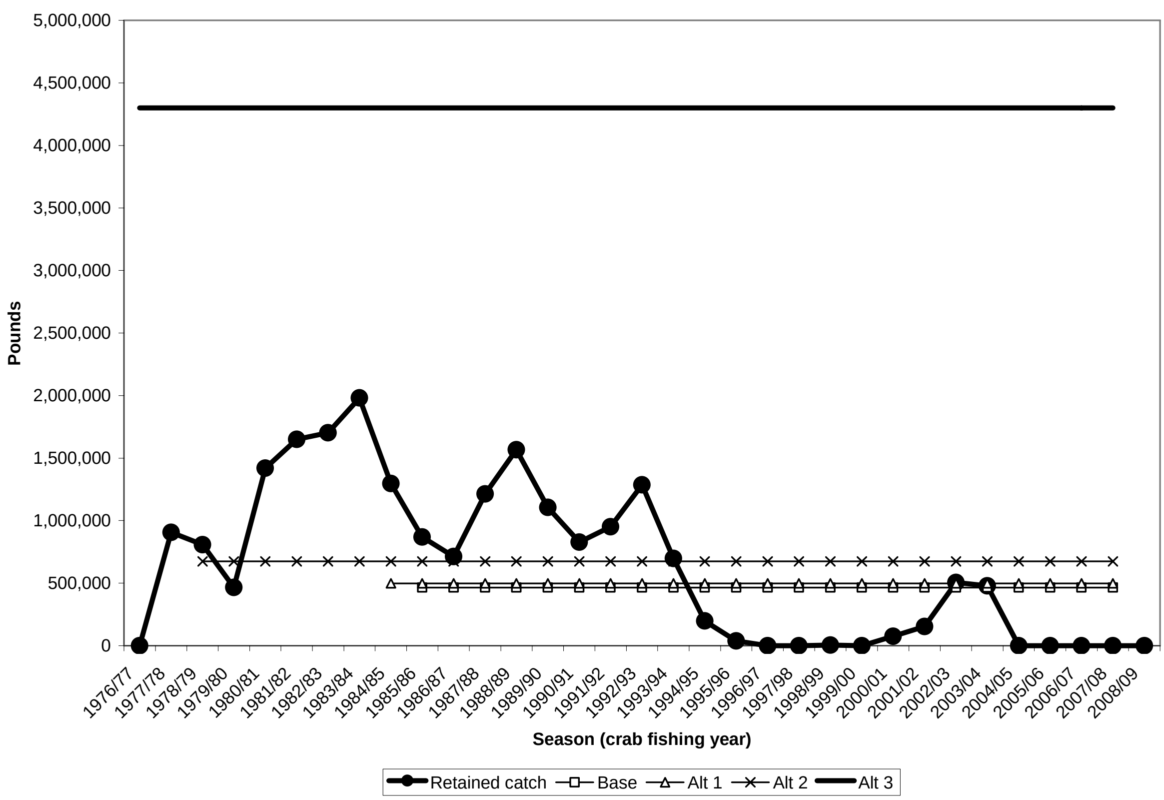


Figure 9. Alternative retained-catch OFLs (Base and Alternatives 1–3) compared with actual historical fishery retained catch for the Adak red king crab fishery, 1960/61–2008/09 in the top panel and 1976/77–2008/09 in the bottom panel (see Table 1 and section E.3.b).

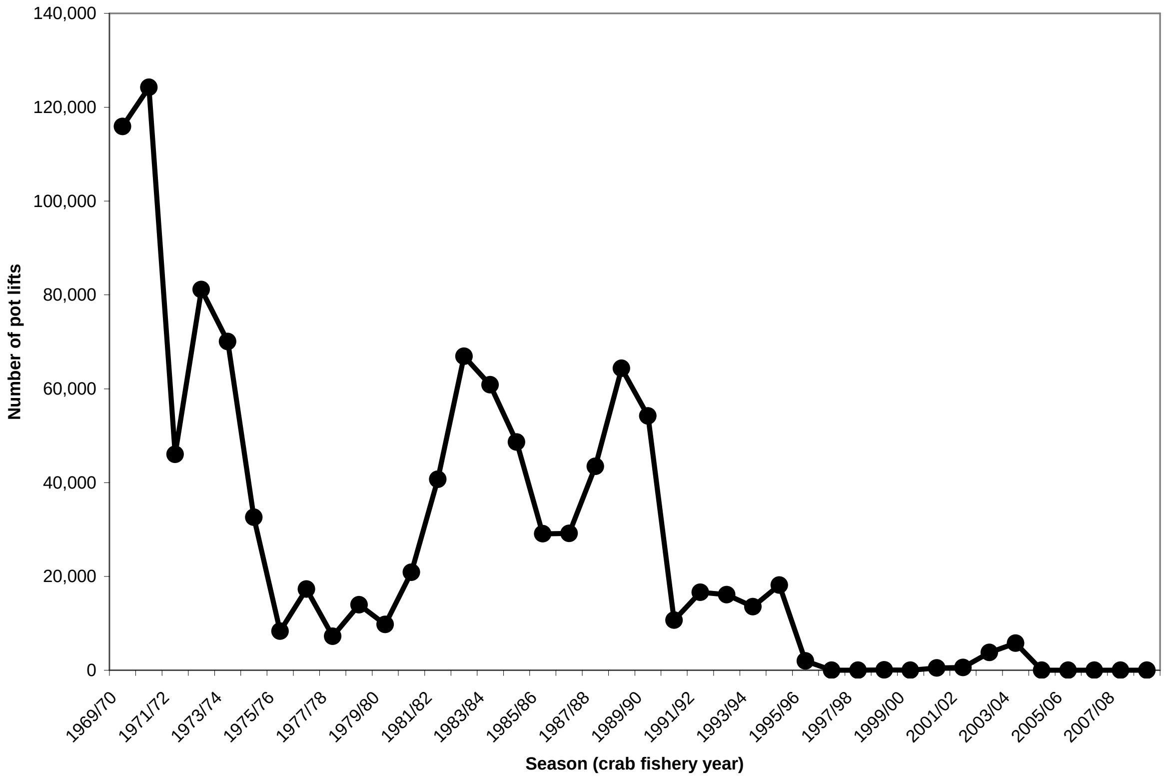


Figure 10. Number of pot lifts performed in the Adak red king crab fishery, 1969/70–2008/09 (see Table 1).

Report of the Alaska Crab Stock Assessment Workshop[1]

EXECUTIVE SUMMARY

- A crab stock assessment workshop took place from 13-14 May 2009 at the Alaska Fisheries Science Center. Participation was by members of the Crab Plan Team (CPT) for the North Pacific Fishery Management Council (NPFMC), crab assessment authors, and other scientists involved in stock assessment and fishery management in Alaska.
- A set of guidelines was developed prior to the meeting and revised as needed during the workshop. These guidelines will form the basis for the May 2010 round of stock assessments, and will be refined from time-to-time to reflect the needs of the CPT and the NPFMC.
- A set of diagnostics and plots to assist the CPT in evaluating model fits was developed based on presentations by speakers with experience of stock assessments of species other than crab, as well as applications of candidate diagnostics to three representative crab stocks. These diagnostics are included in the set of guidelines for stock assessments.
- The original basis for the OFL control rule for Tier 4 stocks, $F_{MSY} \sim \gamma M$, was outlined and several alternative methods for determining γ for crab stocks were presented. None of these methods can be adopted at present, but example applications will be presented at the May 2010 CPT meeting.
- A series of recommendations were identified, defined as those to be implemented by the May 2010 CPT meeting and those which are longer-term.

A. INTRODUCTORY ITEMS

André Punt welcomed the participants (see Appendix A for a list of attendees) and outlined the Terms of Reference for the workshop:

(1) To standardize the crab stock assessments and assessment reporting to the extent possible given the inherent differences in the crab stocks and available data.

(2) To improve the crab stock assessments by resolving issues related to how data sources are weighted when an assessment includes several data sources (including the issues of diagnostics, residuals, and λ weighting).

(3) To determine how to calculate overfishing levels for Tier 4 stocks, including how to estimate γ, the natural mortality multiplier used to approximate F_{MSY}.

(4) To produce a workshop report that provides guidance to assessment authors to improve existing assessment models (snow crab, Bristol Bay red king crab, St. Matthew blue king crab, and Norton Sound red king crab) and to develop assessment models for stocks with sufficient data (Eastern Bering Sea Tanner crab, Aleutian Islands Golden king crab).

Punt noted that the workshop would only address items (1) – (3) and that a workshop report would be produced following the workshop. The report from the workshop, addressing item 4, will be presented at the September 2009 meeting of the CPT. The

[1] Prepared by André Punt and Doug Kinzey

draft agenda (Appendix B) was accepted without change, noting that the timing of agenda items would be modified as needed.

B. STOCK ASSESSMENT REPORTING

André Punt introduced a draft set of guidelines for the structuring of assessment documents. The draft was based on the groundfish terms of reference for stock assessments, similar documents used for Pacific Fishery Management Council stock assessments, and comments during past CPT meetings. The guidelines are aimed at authors producing reports reviewed by the CPT and other management bodies, and are intended to facilitate interpretation and review of assessments.

Workshop participants reviewed the draft set of guidelines, and several modifications were suggested. The final version of the document (Appendix C) was adopted intersessionally by CPT members.

The CPT noted that the guidelines do not indicate requirements for providing Acceptable Biological Catches (ABCs) and Annual Catch Limits (ACLs) in the crab stock assessment. The guidelines will need to be updated once these requirements are known. These guidelines are seen as a "living document" and will be updated as needed.

The workshop participants noted that stock assessment reports should include the model configuration (and associated data sources) on which management advice was based in the previous year. The status quo from the previous year provides a default that the CPT can select as the basis for management advice if updated or revised models appear to be unacceptable. Furthermore, the workshop **recommended** that the incremental affects of each change to a model and/or the data on which the assessment is based needed to be evaluated. This can be achieved by comparing results using the previously accepted model configuration against results after incorporating each new data source or model structural change. This process cannot be followed in all cases, for example, when a stock moves among Tiers, but every effort should be made to produce this type of diagnostic.

The workshop noted the importance of archiving of the software, data files, and assessment results so that, for example, historical retrospective analyses can be conducted. At present, this archiving is done by individual assessment authors, but there would be benefits if it was done at the agency level. In addition, software development would be enhanced if "version control" software was used – this helps to keep track of the changes made incrementally to assessment software, and is particularly useful when several assessment scientists are amending the same software.

Appendix C lists suggested model outputs and diagnostics statistics. Development of software which "automatically" produces the required plots and tables would make the process of model review (and report drafting) more effective. In this respect, the R routines developed by Dr Mike Prager and others (X2R; http://cran.r-project.org/contrib/extra/x2r/00ReadMe-X2R.html) which link ADMB output and R might provide a starting point for such software.

The discussions regarding stock assessment reporting focused on issues related to conducting stock assessments and calculating OFLs. However, ecosystem and economic information should also be included. It was noted that the extent to which ecosystem considerations are included in stock assessment reports was inconsistent among assessments, and that much of the information in these sections was outdated and perhaps even irrelevant for providing current management advice. The workshop recognized the need for, and the value of, a thorough evaluation of ecosystem considerations for crab stocks, but also recognized that there was been insufficient time for assessment authors to do the necessary work owing to the substantial model development work in recent years.

The workshop consequently **recommended** that a two step process be undertaken to improve the analyses of ecosystem considerations:

(1) Development of a separate, general document which outlines the issues (such as the impact of climate change, physical factors, etc.) affecting all crab stocks and the general impacts of crab fisheries on other aspects of the ecosystem.
(2) Development of specific ecosystem considerations chapters for each species, highlighting information and issues specific to each crab stock.

The workshop **recommended** that the overview document be developed before the May 2010 CPT meeting, with the May 2010 meeting including time to review this document. Bob Foy indicated the NOAA Kodiak Lab would take the lead in developing the ecosystem document.

C. DATA WEIGHTING AND DIAGNOSTICS

André Punt noted that stock assessments results depend on how the data sources are weighted. Consideration of the relative weighting of different data sources is most important when the data appear to be in conflict (although in that case, it is also important to show results for subsets of the data which are consistent). Data weighting also impacts the perceived precision of the outcomes from assessments.

Data overweighting systematically improves estimate perceived precision, and will consequently bias selection of preferred methods. In general, using the raw sample sizes (e.g., number of crabs measured) for size or age composition data, and sample standard deviations for indices of abundance will overweight the data because: (a) non-random selection of sampling units and clustering of the population will underestimate uncertainty if raw sample sizes are used for data weight, and (b) systematic effects are not represented in sampling standard deviations (e.g. serially-correlated temperature impacts on survey catch rates).

André noted that the ideal diagnostic statistics and plots for evaluating data weighting should:

(1) allow inconsistencies between data and model predictions to be identified;
(2) be simple to view and understand (particularly by non-modellers);
(3) be automatically produced by the assessment software (so that diagnostics can be produced "on the fly" during assessment reviews); and
(4) allow ready identification of overdisperson (in the observation error variances for the abundance indices and the effective sample sizes for the compositional data) and whether assumptions on recruitment variability are supported by the assessment results.

C.1 Presentation summaries

C.1.1 Pete Hulson

Data weighting corresponds to the uncertainty in observations that are fit in stock assessment models to estimate population parameters. An intuitive interpretation of data weighting is that the weighting term used in the objective function is inversely proportional to the dataset uncertainty. A general formulation of the objective function, O, is:

$$O = \sum_{X} \lambda_x G\left(Y_x, \hat{Y}_x\right) \quad (1)$$

where λ_x is the weighting term and $G(Y_x,\hat{Y}_x)$ is some function that relates the observations, Y_x, to the model predictions, $\hat{Y}_x$. The combination of the weighting term and function G is defined as a likelihood function for some assumed statistical distribution, often evaluated as the negative log-likelihood.

Two primary structures of data are fitted in stock assessment models: (1) index data (e.g., survey biomass, catch-per-unit-effort, total fishery catch); and (2) compositional data (e.g., catch-at-age and/or catch-at-length, survey proportions-at-age/length). A lognormal distribution is often (but not always) used to fit index data, and after omitting constants the likelihood is given by:

$$\lambda_x G\left(Y_x, \hat{Y}_x\right) \cong \frac{1}{\sigma_{Y_x}^2}\left(Y_x - \hat{Y}_x\right)^2 \quad (2)$$

In this case, the weighting term λ_x is interpreted as the inverse of variance of the observed index data. A multinomial likelihood is often used for compositional data, and can be evaluated as:

$$\lambda_x G\left(Y_x, \hat{Y}_x\right) \cong n_x \sum_{a} Y_{a,x} \ln \hat{Y}_{a,x} \quad (3)$$

where the weighting term is interpreted as the sample size, n_x.

While these are theoretical definitions for the dataset weighting, uncertainty in observations is usually unknown for fishery data. Standard practice is for the stock assessment scientist to pre-specify the weighting term used in the objective function. The literature does provide some more objective methods to determine weighting. For index data, the weighting can be determined by:

(1) sampling uncertainty (Sullivan *et al.*, 1999);
(2) expert opinion (Merritt and Quinn, 2000); or
(3) model estimation (Kimura, 1989; Maunder and Starr, 2003)

For compositional data, an effective sample size replaces the sample size as the weighting. The effective sample size is usually smaller than the actual sample size due to violations of multinomial processes that cause over-dispersion of the data. Some methods used to define effective sample sizes for multinomially-distributed data include:

(1) setting all effective sample sizes to 400 (Fournier and Archibald, 1982);
(2) sample size, capped at 1000 (Fournier *et al.*, 1998);
(3) setting all effective sample sizes to 200 (Methot, 2000);
(4) setting the annual effective sample size to the square root of annual sample size (Hanselman *et al*., 2007);

(5) estimating the effective sample size within the model as a parameter (Fournier *et al*., 1990);
(6) using iterative estimation (McAllister and Ianelli, 1997);
(7) estimating the effective sample size based on sampling uncertainty (Crone and Sampson, 1998); and
(8) estimating the effective sample size based on the Dirichlet distribution (Williams and Quinn, 1998).

C.1.2 Jim Ianelli

Jim Ianelli (AFSC) discussed data influences on statistical models of different complexity and presented examples of "historical" retrospective analyses. Jim noted that he has included "traditional" retrospective analyses (applying the same model to reduced datasets) in previous assessments. The presentation emphasized two scenarios. The first scenario involved a simulated two-index model where trend is the parameter of interest. This two-index model simultaneously analyzed a "noisy" declining index and a relatively precise index with no trend. Given equal weights and estimating both the variance terms and the trends resulted in a fit that effectively ignored the noisy index (very similar results occurred when the variances were pre-specified). When the weights were changed (and variances estimated), a bimodal likelihood profile caused the model to focus on the heavier weighted index and ignore the second index. This bimodality disappeared when variances were pre-specified. In conclusion: (a) variances should be estimated (implicitly or explicitly) with caution; (b) residuals should always be examined; and (c) model specifications should be examined.

A second scenario examined the influence of new data on determination of biological reference points (e.g., the ABC) for the Eastern Bering Sea pollock stock. In 2008, the ABC was quite sensitive to new data because the stock was below the target level and the harvest control rule ratchets down acceptable fishing mortality rates. Options for fitting models to different data sources were presented.

As an alternative for evaluating "effective N" for compositional data, the observed mean age (or length) for a given year and gear can be plotted with implied confidence bounds using:

$$Var\left(\bar{X}\right) = \frac{\sigma^2}{n} \tag{4}$$

(where σ is the standard deviation and *n* is the sample size) and then compared with model predicted mean age (or length).

C.1.3 Martin Dorn

The assessment for Gulf of Alaska pollock is an integrated assessment that uses trend data from multiple surveys, and age composition data from the fishery and from fishery-independent surveys. Given that data come from different sources, not all data sets are equally informative about stock status. An initial step in any assessment is a careful look at the data before fitting models, with attention given to identifying contradictory data. The pollock assessment involves an age-structured population model using maximum likelihood estimation to fit available data. Arbitrary data weighting terms (λs) are not used for likelihood components; instead more specific likelihood-related terms are used. For trend data modelled with a log-normal likelihood, the survey CV (or log standard error) is the basic measure of uncertainty. For compositional data modelled with multinomial likelihoods, the input sample size is the basic measure of uncertainty. This approach makes it possible to evaluate goodness of fit using standard summary statistics. The root mean squared error, $RMSE = \sqrt{\frac{1}{n}\sum(\ln(obs) - \ln(pred))^2}$, where n is the number of data points, is used to summarize the fit to a survey time series. For compositional data, the effective sample size, $effN = \frac{\sum p\,(1-p)}{\sum (obs-pred)^2}$, where p is the proportion, is often used. For model tuning the input survey CVs and multinomial sample sizes are adjusted to be comparable to the summary statistics of model output. Any tuning should preserve the differences in uncertainty within data sets, such as annual survey estimates with unusually high CVs, or age-composition samples with low sample sizes. A pragmatic approach for model tuning should make input and output statistics commensurate, but also acknowledge that good reasons may exist for accepting some lack of model fit, for instance when deciding to use contradictory data sets.

C.1.4 Cathy Dichmont

Two case studies from Australia were provided for discussion. The example, of the Northern Prawn Fishery (NPF) highlighted different diagnostics and how likelihoods can be set up to include, amongst others, effective sample sizes. The NPF is a multi-species tropical fishery targeting short-lived shrimp species. The two "fleets" in this fishery catch a group of overlapping species. Management is based on a target reference point intended to maximise discounted profit over a 25-year period. The limit reference point is biologically based. Available data include catch and effort by species since 1970, catch size-composition data from observers, biannual survey indices of abundance and associated size-composition data (since 2002), and economic survey data. The size-structured population dynamics model operates on a weekly time step. The catch likelihood assumes that the square root of the observed catch is normally distributed. The survey index includes two variance components: sampling and "other" error. This is because the observed survey variance is smaller than the true variance. The size-composition likelihood assumes that the length-frequency data are multinomially distributed about the model predictions. It also accounts for an effective sample size parameter, which is a corrected sample size (smaller than the raw sample size) that takes the fact that size measurements are correlated (e.g. through schooling behaviour) and therefore the length-frequency data provide less information than if the samples were randomly selected from the population (see Folmer and Pennington (2000)). Tagging data are used to estimate growth (Punt *et al*., 2009). Growth from size class i to j is assumed to follow a normal distribution, but one where the variance parameter for sizes less than the size at maximum selection may differ from that for sizes greater than the size at maximum selection. In this example there are many residuals to look at - multiple data sources, weekly time step, 3 species, 2 fleets, 2 sexes. Example diagnostics were shown, such as summarising over some of the components e.g. year, week.

The second example, school whiting in the South East Scalefish and Shark Fishery (SESSF), demonstrates the impacts of different data sources on changes to the likelihood weightings. The SESSF is a multi-species and multi-fleet fishery. The school whiting assessment is based on Stock Synthesis 2 (SS2). Two state fleets

(Danish Seine and otter trawl) fleet fish this resource. Data sources include logbook catch and effort by fleet, onboard observer length-frequency (discard rate) data, fish market length-frequency data (1983-89), port-based length-frequency data, standardised catch rates for the Danish seine fleet, age-at-length data, age-frequency data, information on age reading error, and discard rates (2004-present). This age- and length-structured assessment uses the iterative weighting method available in SS2: the CV of Danish seine fleet catch rates is iteratively adjusted so that the observed CV is the same as the expected CV, and the length and age data weightings are set using iterative reweighting of these data (to match input and output effective sample sizes). A plot of effective and observed sample size was shown as a diagnostic test. Extensive sensitivity tests of the management outputs, such as present stock status and recommended biological catch, are routinely conducted. These tests include halving and doubling the weighting on catch rates, length frequency data and age composition data to examine the sensitivity of the results to these data sources.

C.1.5 André Punt

André noted that the CPT has had difficulty interpreting "bubble plots" (plots of standardized residuals based on fits to the size-composition data from surveys and the catch). He therefore introduced a potential algorithm (based on an approach outlined in Peacock (1983)) as a tool for evaluating whether such plots indicate "random" residuals:

(1) Normalize the residuals so that they have mean 0 and variance 1 (whether residuals do or do not have mean 0 and variance 1 should be identified using another test – this test merely addresses the randomness issue).

(2) Denote the residual for year y and size-class k as $r_{y,k}$ and compute the quantity:

$$\tilde{r}_{y,k} = r_{y,k} - \tfrac{1}{8}[\sum_{y'=y-1}^{y+1} \sum_{k'=k-1}^{k+1} r_{y',k'} - r_{y,k}] \tag{5}$$

(3) Compute a cumulative distribution for $\tilde{r}_{y,k}$ based on the observed data and for $\tilde{r}_{y,k}$ had the $r_{y,k}$ been iid N(0,1) random variables.

(4) Plot the two cumulative distributions.

André evaluated this method for a few example patterns (See Appendix D). The meeting welcomed the approach and encouraged additional analyses to further evaluate it.

C.2. Exploratory comparisons

Three of the assessment authors (Jie Zheng, Shareef Siddeek, and Jack Turnock) were requested to conduct analyses for Bristol Bay red king crab (BBRKC), Aleutian Islands golden king crab (AIGKC) [east of 174^0W only], and EBS snow crab, respectively, to explore the value (and implications) of different diagnostic statistics. The workshop agreed that the analyses were for illustrative purposes only and would not impact the decisions made regarding models by the CPT, because there was insufficient time to evaluate any revised model formulations. The requests were:

(1) Provide a list of weights assigned to the indices and compositional data, in the form of standard deviations for the indices and the number of independent samples for the compositional data, and list any other weights in the assessment.

(2) Compute the “effective” sample sizes for the compositional data using the formula:

$$n_y = \sum_l \hat{P}_{y,l}(1-\hat{P}_{y,l}) / \sum_l (P_{y,l} - \hat{P}_{y,l})^2 \tag{6}$$

where n_y is “implied” effective sample size for year *y*;
$P_{y,l}$ is the observed proportion of the catch of animals in length-class *l* during year *y*; and
$\hat{P}_{y,l}$ is the model-estimate of the proportion of the catch of animals in length-class *l* during year *y*.

Plot the assumed (“input”) and “effective” sample sizes

(3) Compute the Root Mean Square Errors (RMSEs) for the fits to the indices using the formula:

$$\sigma = \sqrt{\tfrac{1}{n}\sum_y \left(\ln I_y - \ln \hat{I}_y\right)^2} \tag{7}$$

where I_y is the observed index for year *y*;
$\hat{I}_y$ is the model-estimate corresponding to I_y, and
n is number of data points for index.

(4) Plot the time-trajectory for mature male biomass (at the time of mating) when the weight assigned to each data source (and the weight on the penalty on the extent of inter-annual variation in recruitment) is doubled.

(5) Plot the marginal (over year) observed and predicted distributions of catch (or survey)- proportions at length.

It was not possible for the assessment authors to conduct all of the requested analyses in the time available (overnight), but there were sufficient results (see Appendix E) for the workshop to be able to draw some key conclusions:

- The root mean square errors, RMSEs, about the survey indices were markedly larger than the pre-specified coefficients of variation for these data for EBS snow crab and BBRKC. For example, the RMSE was 0.303 for BBRKC while the pre-specified CV was only 0.2. Similarly, the RMSE for the snow crab survey indices markedly exceeded the pre-specified CVs for these indices.
- There were a few instances where it appears that the implied effective sample sizes for the size-composition data were notably different from the assumed values (for example, the retained catch of AIGKC and the retained catch of BBRKC).
- The results for snow crab were not particularly sensitive to changing the weights assigned to the data. In contrast, varying some of the data weights in the AIGKC assessment had a marked impact on the results.
- There is value in plotting the time-series of implied effective sample sizes, in addition to plotting these using a histogram or as plots of implied versus input effective sample sizes.
- The marginal distributions of catch (and survey) proportions exhibit systematic patterns of deviation for all of these assessments (although not for

all sources of data in each assessment, and the extent to which there is evidence for mis-specification differed among assessments).

C.3. Discussion

All crab assessment models include "penalties" (i.e. constraints on the values for parameters such as annual recruitment and fishing mortality). In discussion, it was noted that this would invalidate both methods for estimating variance using asymptotic methods and approaches for comparing models (including likelihood profile and AIC). It was also noted that it is not valid to compare model fits and outputs for two assessments which use a different mix of data sets.

Jim Ianelli noted the value of comparing the pre-specified value for the variance in recruitment (σ_R) with the variance of the estimates of recruitment from the assessment. He further noted that the variance of the estimates of recruitment from the assessment model will under-estimate the recruitment variance when there is a penalty on recruitment in situations where there is little information on year-class strength

The workshop noted that a variety of ways have been employed for specifying input sample sizes for compositional data in crab assessments, although several other methods exist. The meeting characterized the methods as follows:

(1) a fixed constant (dependent on data-type);
(2) based on bootstrapping using the design of the sampling scheme;
(3) number of hauls, tows, or trips (perhaps approximated by dividing the number of animals sampled by a constant);
(4) as for (3), except that a maximum sample size is also imposed; and
(5) the number of animals sampled divided by the maximum sample size, and multiplied by a pre-specified constant.

The meeting discussed different ways of adjusting the input sample sizes.

(1) Martin Dorn noted that he did not tune his effective sample sizes, but rather examined the input and implied effective sample sizes to check that they are in the same "ballpark". He noted further that he would not necessarily adjust the input CVs for indices even if they were markedly different from the implied CV. For example, two of the indices used in the GOA pollock assessment were in conflict during the early years of the assessment period, which leads to large residuals in both indices, and large implied CVs.
(2) Jim Ianelli noted that he preferred to set weights before applying the model because any "tuning" algorithm relies on the assumption that the population and observation model are correct.
(3) Jim Ianelli noted that when "tuning" the CVs assumed for the indices, it is best to fit the model setting the CVs to pre-specified values during the early phases of the estimation and only adjust these sizes in the final phases of the analyses.

The workshop noted that the multinomial likelihood is not robust to outliers and outliers may therefore have an important impact on the results from stock assessments and hence on the selection of weighting schemes. It **agreed** that there was value in exploring the impact of assuming different likelihood functions, and in particular formulations which should be more robust to outlying observations. Other alternative likelihood functions for index and catch data include assuming that the square roots of the data are normally distributed (e.g. Dichmont *et al*., 2003) and that the data are approximately chi-square distributed. In principle, the effective sample size for a multinomial distribution can be estimated using maximum likelihood, but this requires including all of the “constants” when coding the likelihood function. In this respect, an alternative to the multinomial likelihood would be the Dirichlet distribution (Williams and Quinn, 1998) or the robust likelihood function of Fournier *et al.* (1998).

The workshop discussed how to deal with cases when diagnostics such as those in Section C.2 indicate that assumptions appear to be violated. Two main approaches emerged (although reality will lie between these two philosophies, and both approaches have been applied when conducting assessments of BSAI crab stocks):

(1) The data (or their weighting) are wrong; the solution in this case is to change (generally reduce) the weights assigned to the data (tune the effective sample sizes and survey CVs) until the diagnostics show no problem or, if some of the data sets are in conflict, to present assessments based on subsets of the data which are not in conflict.

(2) The model is wrong; the solution in this case is to change the model (generally allow for more flexibility, such as more time blocks for selectivity and growth) or the likelihood function.

Irrespective of which of these two approaches is taken, the aim should be that the final model is “roughly” consistent in terms of the diagnostics listed above. However, there will be reasons why the data may not be fully consistent with the model in an acceptable assessment (e.g. GOA pollock).

The meeting **agreed** that whenever possible:

(1) weights should be expressed as standard deviations or effective sample sizes to ensure comparability among assessments (these should reflect both the variation in sampling and the validity of the assumptions of the model to the extent possible); and

(2) weights should not be set higher than implied by the extent of sampling error (e.g. by setting the CVs for survey indices lower than the CVs inferred from the data collected from the survey).

The meeting made the following additional **recommendations**:

(1) The stock assessment guidelines should be modified to include the types of diagnostic statistics considered above (see Section E.4.4 of Appendix C).

(2) Sensitivities to weights should be conducted whenever a model is modified, but there is no need to examine this sensitivity very often for “fully developed” models.

(3) André should work with the assessment authors to specify specific scenarios to consider when examining sensitivity to weights.

(4) Consider developing the facility to estimate the extent of “additional variance” for the survey indices (the difference between the assumed and implied CVs) within assessments.

(5) Compare the input and implied values for the extent of variation in recruitment, σ_R.

D. OVERFISHING LEVELS FOR TIER 4 STOCKS

Overfishing is defined as any amount of catch in excess of the OFL. Overfishing for BSAI crab is determined by comparing the OFL, as calculated in the five-Tier system (Table 1), for a crab fishing year with the catch estimated for that year.

The Tier 4 OFL control rule is for stocks where essential life-history and recruitment information, and understanding, are lacking. There is information about basic life-history parameters (e.g. growth, natural mortality, and maturation) and an index of abundance (typically from an assessment model), but no stock-recruitment relationship for stocks in Tier 3, while this information in addition to a reliable stock-recruitment relationship are available for stocks in Tiers 1 and 2 (there are no such BSAI crab stocks at present). There are no reliable estimates of biomass or *M* for Tier 5 stocks. Table 2 lists the ten BSAI crab stocks by Tier level, five of which are currently assigned to Tier 4.

Explicit to Tier 4 are reliable estimates of biomass (either from surveys or an assessment model) and the instantaneous rate of natural mortality, *M*. The proxy for B_{MSY} for Tier 4 stocks is the average biomass of mature males at the time of mating over a specified period. The OFL control rule for Tier 4 stocks involves multiplying *M* by a parameter, γ, to estimate the OFL fishing mortality, F_{OFL}. γ is allowed to be less than or greater than unity. Use of γ is intended to allow "adjustments in the overfishing definitions to account for difference in biomass measures" (Anon, 2008), but also accounts for, for example, differences between the maturity and selectivity patterns. The final rule implementing the revised OFL harvest control rule set the default value for γ at 1, with the understanding that the Council's SSC may recommend a different value for a specific stock or stock complex, as merited by the best available scientific information.

Among the purposes of the workshop was the explicit aim to explore methods for assigning an appropriate value for γ for Tier 4 stocks. Several participants noted that the default for γ of 1 was included in the EA at the NMFS review stage with no supporting analysis. Moreover, values for γ for modelled stocks evaluated in the OFL EA exceeded 2, primarily because of the growth dynamics of crab – a terminal molt for some species and the differences between male maturation and selection to the fishery. Although basing stock status determination on abundance of mature male biomass was viewed as conservative; it was noted that some crab stocks had declined substantially under what appears to have been fairly low levels of fishing mortality. Consequently, appropriate values for Tier 4 stock γ levels remain unresolved.

D.1. Presentation by Terry Quinn

The natural mortality parameter *M* has been used as a proxy for F_{MSY}, dating back to at least the 1960's (e.g., Alverson and Pererya, 1969; Gulland, 1970). However, Deriso (1982) showed that F_{MSY} is less than *M* for many parameter combinations in a delay-difference model. Thompson (1993) showed that fishing mortality should be less than 80% of *M* for spawning biomass per recruit to remain above 30% of the pristine level, one benchmark used as an indicator of an overfished population. Thus, *M* should not be a target but may work as a limit. And this is exactly how *M* is treated in the Tier system for both groundfish (Tier 5) and crab (Tier 4).

Given the complicated life history of crabs and the unusual male-only fishery, it is not known just how far fishing mortality should be set away from M. Therefore, a special coefficient, γ, was included to allow adjustments due to different biomass measures, size limits, harvest strategies, and other potential factors. Thus the OFL fishing mortality for Tier 4 was written as $F_{OFL} = \gamma M$. A crab workshop was held in February/March 2007; the workshop report clarified: "In the new Tier 4 (previously Tier 5), a scalar γ is multiplied by natural mortality. The scalar could be less than or greater than 1 and be more or less conservative than the status quo, depending on stock assessment research for a species. For example, when a change from total mature biomass to some other biomass measure (e.g., based on mature males) is used, the scalar can be applied to account for differences between biomass measures."

Analysis in the Environment Assessment for Amendment 24 (the November 2007 version) to revise overfishing definitions for crab showed that values of γ between 2 and 3 were appropriate for F_{MSY}. There was no default value for γ in the EA reviewed by the Council family in October 2007. However, a default value of 1 was inserted into the Final Environmental Assessment (dated May 2008). It is not clear to me who was involved in deciding on the default value. I could find no discussion of this in SSC emails or reports.

The June 2008 SSC report discussed the preliminary 2008 BSAI crab SAFE produced by the Crab Plan Team, discussed that γ could be less than or greater than 1, and called for more quantitative analysis in future years. The Crab Plan Team produced the revised BSAI crab SAFE in September 2008, in which actual calculations of OFL were made. Of the 10 stocks listed in Table 3 of that document, five were in Tier 4, and the values of γ selected for those in stock status levels a and b (four stocks) were all equal to 1. The rationale for each stock was given in each SAFE chapter, but the common theme was to be conservative in the face of data and population uncertainties. And thus, the SSC has gone along with this approach until better approaches are available.

D.2. Presentation by André Punt

André Punt noted that an objective method was needed to specify an F_{MSY} proxy for use when applying the Tier 4 control rule and that there was also a need to calculate a B_{MSY} proxy for Tier 4 (and 3) stocks. Both of these tasks had been difficult for the CPT in the past. André introduced two methods for calculating F_{MSY}. One of these is based on information about selectivity, growth, maturity and natural mortality and has been applied to data for Tanner crab (Turnock and Rugolo, 2008). The second method estimates F_{MSY} proxies based on survey data and assessment output (Appendix F). André provided an initial analysis of the ability of the latter approach to correctly estimate F_{MSY} (Appendix F). The performance of this second method has not yet been fully evaluated, but it appears that its results are fairly sensitive to the extent of both observation and process error.

André also mentioned that it should be possible to estimate the proxy for B_{MSY} for Tier 3 and 4 stocks (B_{REF}) by projecting the assessment model forward with recruitment selected at random from the years used to define B_{REF} and fishing mortality set equal to the proxy for F_{MSY}. While not ideal because it fails to account for any stock-recruitment effect, this approach determines a B_{MSY} value that is consistent with the F_{MSY} proxy and the recruitments used to define B_{REF} without being influenced by the historical harvest (which may have been zero or unsustainable).

D.3. Discussion

The workshop **agreed** that the values for γ in the EA can only be assumed to apply to stocks other than those for which they were derived if growth, selection and maturity were similar for the stock for which the estimate of γ was derived and the stock for which a value for γ was needed. This is difficult to show in general. However, Amendment 24 to Crab FMP does allow alternative methods for specifying γ, if these can be justified.

In relation to the approach in Appendix F, the meeting noted that the approach is empirical and would require a definition for "male mature biomass". For stocks for which assessments are available, this would be mature male biomass as defined in the assessment while ogives are available to define mature male biomass for surveys. The meeting noted this approach had promise and **recommended** that assessment authors should attempt to apply it. However, it needs to be more fully evaluated, including whether weighting different data points might lead to improved performance (as would be expected if there were no observation and process error).

In relation to the Turnock and Rugolo (2008) method, the meeting noted that it should be possible to compute survey selectivity and male maturity-at-length for most stocks (at least roughly) and proxies for *M* exist for most stocks. However, it may be more difficult to specify growth for several of the Tier 4 stocks. Nevertheless, the meeting **recommended** that assessment authors should attempt to apply this method (see Appendix G for details). As for the method in Appendix F, it is necessary to more fully evaluate this approach. Ultimately, this approach could be applied to all Tier 4 stocks.

Thompson (1992) provides an approach for estimating F_{MSY} using only an assumption about the compensation of the stock-recruitment relationship, *r*, the rate of natural mortality, *M*, and the difference between the age at maturity and the age intercept of the linear weight-at-age equation, *d*. Anon (2009) used this approach to estimate F_{MSY} for snow crab in the Arctic.

In the longer-term, the meeting **recommended** that it would be useful to further investigate the likely range for $F_{35\%}/M$ and F_{MSY}/M for crab stocks. Two approaches identified for this were:

(1) construct generic models for crab stocks and explore how the values for these ratios change as a function of different biological (and fishery) assumptions. The results of this study could be used to assign crab stocks likely ranges for γ based on how they are categorized; and
(2) conduct a meta-analysis of F_{MSY}/M for crab fisheries worldwide.

E. SUMMARY OF RECOMMENDATIONS

E.1. Short-term (by May 2010)

1. Assessments should be based (to the extent possible) on the guidelines in Appendix C.
2. Include the following diagnostics in the stock assessments:
    1. marginal distributions of fits to compositional data;

2. plots of implied and assumed effective sample sizes for compositional data;
3. tables of RMSE values for the abundance indices;
4. q-q plots, histograms of residuals for the compositional data and abundance indices (separately by data series); and
5. results when the weights for each data input are systematically increased / decreased.

3. Avoid the use of λs (emphasis factors) to the maximum extent possible and instead report the weights in the form of CVs or effective Ns.
4. Document the basis for the input effective sample sizes.

E.2 Medium-term (ideally by May 2010)

1. Develop the facility to estimate the additional variation of surveys (add variance to CVs) within assessments (i.e. automatic retuning).
2. Compare input and output values for σ_R.
3. Consider alternative error distributions [e.g. adding small constants / the robust normal likelihood for proportions].
4. Apply the Appendix F and G approaches to all Tier 3 and 4 stocks.
5. Review the ability of the ratio of fishery catches to survey catches (by length) as a way to estimate selection curves (Tier 4 stocks).
6. Compute B_{REF} by projecting models forward under F_{MSY} (all assessed stocks).

E.3 Longer-term

1. Consider the establishment of an assessments methods working group, with participation from assessment scientists working on West Coast and Alaskan stock assessments.
2. Further develop methods for assessing the randomness of bubble plots.
3. Explore the use of the Dirichlet likelihood function.
4. Develop methods which can automatically produce the types of diagnostic statistics listed in Appendix C (e.g. based on an R package).
5. Further simulation testing of the method of Appendix F and the Turnock and Rugolo (2008) approach.
6. Further generic evaluation of $F_{35\%}/M$ and F_{MSY}/M for crab-related life histories.
7. Conduct a meta-analysis of F_{MSY}/M for crab fisheries worldwide.
8. Evaluate the utility of the approach of Thompson (1992) for crab stocks.

F. CLOSING REMARKS

André Punt thanked the participants, especially the assessment authors (Jie, Jack and Siddeek) who conducted overnight analyses and the invited speakers, for what was a very productive workshop, the outcomes of which should help the CPT with its work. He noted that the workshop report would be finalized in the next few months and presented to the September 2009 meeting of the CPT.

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Table 1. Five-Tier System for setting overfishing limits for crab stocks. The tiers are listed in descending order of information availability (Source: NMFS (2008)).

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* $F_{OFL} \le F_{35\%}$ †
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* $F_{OFL} \le F_{\gamma M}$ †
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 $F_{OFL} \le F_{MSY}$ or proxy F_{MSY} will be determined in the development of the rebuilding plan for that stock.

Table 1. Guide for understanding the five-tier system (source: NMFS (2008)).

- 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 $\beta \cdot B_{MSY} < B \leq B_{MSY}$.

Table 2. BSAI crab stocks and their Tier assignments in 2009.

Stock	Tier
Bristol Bay red king crab	3
Eastern Bering Sea snow crab	3
Eastern Bering Tanner crab	4
Pribilof Island red king crab	4
Pribilof Island blue king crab	4
St Matthew blue king crab	4
Norton Sound red king crab	4
Aleutian Islands golden king crab	5
Pribilof Islands golden king crab	5
Adak red king crab	5

Appendix A : Participants

Invited Speakers
Catherine Dichmont, CSIRO Marine and Atmospheric Research
Martin Dorn, Alaska Fisheries Science Center, NMFS/NOAA
Peter Hulson, University of Alaska
Jim Ianelli, Alaska Fisheries Science Center, NMFS/NOAA
Terry Quinn, University of Alaska (NFPFMC SSC)

Crab Plan Team members
Bill Bechtol, University of Alaska
Forrest Bowers. Alaska Department of Fish and Game
Wayne Donaldson, Alaska Department of Fish and Game
Bob Foy, Alaska Fisheries Science Center, NMFS/NOAA
Brian Garber-Yonts, Alaska Fisheries Science Center, NMFS/NOAA
Josh Greenburg, University of Alaska
Ginny Eckert, University of Alaska
Gretchen Harrington, NMFS, Alaska Region
Doug Pengilly, Alaska Department of Fish and Game
André Punt, University of Washington
Lou Rugolo, Alaska Fisheries Science Center, NMFS/NOAA
Herman Savikko, Alaska Department of Fish and Game
Shareef Siddeek, Alaska Department of Fish and Game
Diana Stram, North Pacific Fishery Management Council
Jack Turnock, Alaska Fisheries Science Center, NMFS/NOAA

Other participants
Anne Hollowed, Alaska Fisheries Science Center, NMFS/NOAA (NFPFMC SSC)
Clayton Jernigan, NOAA General Council
Doug Kinzey, University of Washington
Pat Livingston, Alaska Fisheries Science Center, NMFS/NOAA (NFPFMC SSC)
James Murphy, University of Washington / Alaska Fisheries Science Center, NMFS/NOAA
Nick Sagalkin, Alaska Department of Fish and Game
Jack Tagart, Tagart Consulting (reprentative of BSFRF)
Doug Woodby, Alaska Department of Fish and Game
Jie Zheng, Alaska Department of Fish and Game

Appendix B: Workshop Agenda

Wednesday May 13		
Administration	8:30 am	• Introductions • Additions to draft agenda and approval of agenda
Stock assessment reporting:		
Stock Assessment TOR	8:45 am	• Punt presentation (30 minutes) • Discussion / modifications • ACL / OFL needs
BREAK	*10:30*	
Stock Assessment TOR	10:45am	• Stock-specific actions • Data rich – snow crab • Data moderate – AI Golden king crab • Data moderate – Norton Sound red king crab
LUNCH	*12:00 pm*	
Data weighting and diagnostics:		
Practices in other assessments	1:00 pm	• Hulson overview (30 minutes) • Ianelli presentation (EBS pollock) (20 minutes) • Dorn presentation (GOA Pollock) (20 minutes) • Dichmont presentation (Australia) (20 minutes)
BREAK	*2:45pm*	
Initial Recommendations	3:00 pm	• Group discussion – what is appropriate for crab • Initial recommendations – data weighting • Initial recommendations – diagnostics • Workplan for overnight analyses
Thursday May 14		
Reprise	8:30am	• Results of overnight analyses • Snow crab (Turnock) • Red king crab (Zheng) • AI Golden king crab (Sideek) • Norton Sound rd king crab (Zheng)
BREAK	*10:30*	
Final recommendations	10:45 am	• Synthesis of examples • Final recommendations – data weighting • Final recommendations – fit diagnostics
LUNCH	*11:45 am*	
Overfishing levels for Tier 4 stocks (calculating Gamma):		
Background and history	12:45 pm	• Quinn presentation (background) (20 minutes) • Current approach (Stram / Punt?) (20 minutes) • Likely stocks for Tier 4 (group)
Proxy approaches to estimating $F_{x\%}$	1:45pm	• Maturity • Selectivity • Natural mortality • Growth
BREAK	*2:45pm*	
Reprise	3:00 pm	• Recommendations
Conclusions	4:00 pm	• Overview of recommendations (Punt) • Plans for September CPT meeting
ADJOURN	4:00 pm	

Appendix C : A Guide to the Preparation of Bering Sea and Aleutian Islands Crab SAFE Report Chapters

A chapter should be produced for the SAFE report for each crab stock, and should include all sections listed in the "Outline of SAFE Report Chapters" below. This Outline is intended to provide a consistent structure and logical flow for stock assessments; using the numbering system outlined below will help to standardize the SAFE document and make the review process for assessments more straightforward. Some variation from this outline is permissible if warranted by limitations of data, analytical methods, or other extenuating circumstances; major deviations from the suggested report structure should, however, be justified. Many of the items under Section E are not appropriate for stocks in Tier 5 (see Table 1 of this Appendix for a list of sections needed for different types of assessments). It is particularly important that all of the items listed under "Calculation of the OFL" be included to the maximum extent possible, in that many of these are critical to the fishery management process. Careful consideration should be given to all applicable SSC and CPT comments from the previous assessment(s).

Important notes:

- This guide does not provide details on what is needed regarding ABCs and ACLs and will need to be modified once these details become available.
- Dates should be specified as “2008” for the 2008 calendar year and “2008/09” for the 2008/09 fishing year. By default crab assessments are based on fishing years, but the notation 2xxx/yy should nevertheless be adopted.
- Fishing mortality values (F) are always full selection fishing mortalities (the F at fishing selection equal to 1.0).

Outline of SAFE Report Chapters

Title page and list of preparers

Executive Summary

1. Stock: species/area.
2. Catches: trends and current levels.
3. Stock biomass: trends and current levels relative to virgin or historic levels, description of uncertainty.
4. Recruitment: trends and current levels relative to virgin or historic levels.
5. Management performance: a table showing estimates of mature male biomass (at the time of mating), overfishing levels (OFL and MSST), TACs, retained catch and discards in all fisheries; show results from 2005/06 to the current year (Table 2 of this Appendix lists examples of how these tables should be constructed for stocks in each Tier)
6. Basis for the OFL: Table listing estimates of M, Tier level, current mature male biomass (MMB, at the time of mating), B_{MSY} (or the proxy thereof) and the basis for the calculation of B_{MSY}, current mature male biomass relative to B_{MSY} (or its proxy), γ, and the basis for calculating average catch; show from 2008/09 to the current year (Table 3 of this Appendix lists examples of how these tables should be constructed for stocks in each Tier).
7. A summary of the results of any rebuilding analyses: table showing the year by which rebuilding is expected to occur, the rebuilding time period, the catch for the next fishing year and probability of recovery to the proxy for B_{MSY} for a range of harvest

strategies (including one for which the probability of recovery within the rebuilding period is 0.5).

A. Summary of Major Changes

1. Changes (if any) to the management of the fishery.
2. Changes to the input data (e.g. specify any new data sources and which data sources have been updated)
3. Changes (if any) to the assessment methodology.
4. Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets of SSC and CPT[2] comments on assessments in general (for each comment that is addressed in the main text, list the comment and give name of the section where it is discussed; if the SSC or CPT did not make any comments on assessments in general, say so).
2. Responses to the most recent two sets of SSC and CPT[2] comments specific to the assessment (for each comment that is addressed in the main text, list the comment and give the name of section where it is discussed; if the SSC or CPT did not make any comments specific to the assessment, say so).

All comments relevant to the assessment and crab assessments in general must be listed. If a comment has not been addressed in the assessment, the comment should be listed and the reasons for not addressing it must be provided.

C. Introduction

1. Scientific name.
2. Description of general distribution (including a map, showing the stock boundary and, if possible, the actual distribution).
3. Evidence of stock structure, if any.
4. Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology).
5. Brief summary of management history. A complete summary of the management history will be provided in the ADF&G Area Management Report appended to the annual SAFE.

D. Data (Items in this section should be presented primarily in tabular form.)

1. Summary of new information (the section should essentially repeat the information provided under Section A.2).
2. Data which should be presented as time series, separately by sex and, depending on the assessment also by maturity state and shell condition (table headers should indicate when the data were extracted, and the source for the data; years should be reported as fishing year 2xxx/yy or calendar year, depending on the fishery concerned):
   a. Total catch, partitioned by strata used in the assessment model, if any.
   b. Information on bycatch and discards. Non-retained catches and discards should ideally be reported using the categories in Table 4 to this Appendix (the table

[2] For an assessment in May, these comments will be from the SSC and CPT meetings in May and September of the previous year. For an assessment in September, these comments will be from the SSC and CPT meetings in May of the current year and September of the previous year.

header should specify the mortality rates applied to discards and bycatch, and whether the values in the table have had these mortality rates applied or not).
   c. Catch-at-length (with sample sizes) for fisheries, bycatch, and discards.
   d. Survey biomass estimates (with measures of uncertainty).
   e. Survey catch-at-length (with sample sizes), as appropriate.
   f. Other time series data (e.g., predator abundance, fishing effort).
3. Data which may be aggregated over time:
   a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state)
   b. Weight-at length or weight-at-age (by sex).
4. Information on any data sources that were available, but were excluded from the assessment.

Notes:

i. Information on length-composition may be more appropriately presented in the form of plots, especially for assessments for which there in a substantial amount of such data.

ii. The reported samples sizes should reflect the actual number of samples; information on the sample sizes assumed when fitting any population models should also be reported.

E. Analytic Approach

1. History of modeling approaches for this stock

In addition to summarizing how assessments methods have changed over time, include a summary of CIE review comments from past reviews and how those comments have been taken into account.

2. Model Description

a. Description of overall modeling approach (e.g., age/size structured versus biomass dynamic, maximum likelihood versus Bayesian). If the model has not been published in its current form, its equations should be listed in full in an Appendix. It there is a technical Appendix, Items b-f below should be included in the appendix, and only a short description of the model and its estimation scheme needs to be included in this section. Specify when the fishery is assumed to occur and, if necessary, provide a table which lists the assumed time of the fishery for each year of the assessment period.

b. Reference for software used (e.g., Synthesis, AD Model Builder).

c. List and description of all likelihood components.

d. Description of how the state of the population at the start of the first year of the assessment period is determined and the size-range that the model covers.

e. Parameter estimation framework:

   i. List all of the parameters which are estimated outside of the assessment (e.g., the natural mortality rate, parameters governing the maturity schedule) along with how the values for these parameters were estimated (methods do not necessarily have to be statistical; e.g., *M* could be estimated by referencing a previously published value).

   ii. List all of the parameters that are estimated conditionally on those described above (e.g., full-selection fishing mortality rates, parameters governing the survey and fishery selectivity schedules, recruitments), indicate any bounds and/or priors placed on these parameters.

iii. List any constraints that imposed on the estimated parameters (including penalties on recruitment and selectivity).

f. Definition of model outputs
   i. Biomass measures (e.g., biomass of animals 50mm and larger). Indicate the assumed time of mating and that of the fishery.
   ii. Recruitment (e.g., number of males and females in the 50-55mm size-class).
   iii. Fishing mortality (e.g., full-selection F multiplied by selectivity for lengths 80 and above). Whether fishing mortality is an exploitation rate or an instantaneous rate should be reported in table headers and the text. The ideal is to report "fishing mortality" as the fully-selected instantaneous fishing mortality rate at the time of the fishery to enhance comparability amongst stock assessments.
g. Critical assumptions and consequences of assumption failures (for example, highlight assumptions regarding *M*, *q* and selectivity, to which assessments are often very sensitive).
h. Changes to any of the above since the previous assessment.
i. Outline of methods used to validate the code used to implement the model and whether the code is available.

3. Model Selection and Evaluation

a. Description of alternative model configurations[3], if any (e.g., alternative *M* values or likelihood weights; use a hierarchical approach where possible (e.g. asymptotic vs domed selectivities, constant vs time-varying selectivities)). The model configuration on which the previous assessment was based must be included in the set of model considered in order to retain comparability with previous assessments[4].
b. Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed.
c. Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models.
d. Convergence status and convergence criteria for the base-case model (or proposed base-case model) such as randomization run results or other evidence of a search for the global best estimates.
e. Table (or plot) of the sample sizes assumed for the compositional data. There are several ways for specify input sample size, including:
   i. the number of animals actually measured;
   ii. a fixed constant (e.g. 500);
   iii. the application of bootstrapping approaches (e.g. Folmer and Pennington, 2000); and
   iv. as for i and iii, with a maximum imposed on the input sample size

   The first, third, and last of these approaches allows the input sample sizes (and hence the weight assigned to the compositional data) to reflect uneven sampling over time. The basis for specifying the input sample sizes should be justified and

[3] For Tier 5 assessments "model configuration" refers to the time period over which the mean catch is computed while for Tier 3 and 4 assessments it includes the time period used to define B_{MSY}/B_{REF}.

[4] This information should be included in the May and September versions of the assessment report. However, for ease of reading, information on model configurations considered but not adopted should be included in an appendix to the assessment report.

analyses conducted (see Section 4.4 below) to justify the final effective sample sizes.

f. Do parameter estimates for all models make sense, are they credible?
g. Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty.
h. Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach). Note that residual analysis is expected for the base-case model below.
i. Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented.

4. Results (best model(s))[5]

Results should be provided for all model runs that the assessment author considers sufficiently plausible that they could form the basis for management advice. Assessment authors should come to the May Crab Plan Team meeting with detailed results for all analyses conducted.

1. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties.
2. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):
    a. All parameters (include recruitments, selectivity parameters, any estimated growth parameters, catchability, etc.).
    b. Abundance and biomass time series, including spawning biomass and MMB.
    c. Recruitment time series (including average recruitment).
    d. Time series of catch divided by biomass..
3. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible):
    a. Fishery and survey selectivities, molting probabilities, and other schedules depending on parameter estimates.
    b. Estimated male, female, mature male, total and effective mature biomass time series (indicate the proxy for B_{MSY} on the relevant plots).
    c. Estimated full selection F over time.
    d. Estimated fishing mortality versus estimated spawning stock biomass, including applicable OFL and maximum F_{target} definitions for the stock (see, for example, Fig. 54 of Turnock and Rugolo, 2008). Graphs of this type are useful to evaluate management performance.
    e. Fit of a stock-recruitment relationship, if feasible.
4. Evaluation of the fit to the data:
    a. Graphs of the fits to observed and model-predicted catches (retained catch and discards), including model-predicted of catches and discards for all years to allow discards to be inferred for years for which data are not available.
    b. Graphs of model fits to survey numbers (include confidence intervals for the data and model predictions).
    c. Graphs of model fits to catch proportions by length (e.g. using bubble and/or line plots).

[5] There may be several "best" models in the May assessment draft, but there should be one "best" model in the September assessment draft.

   d. Graphs of model fits to survey proportions by length (e.g. using bubble and/or line plots).
   e. Marginal distributions for the fits to the compositional data.
   f. Plots of implied versus input effective sample sizes and time-series of implied effective sample sizes.
   g. Tables of the RMSEs for the indices (and a comparison with the assumed values for the coefficients of variation assumed for the indices).
   h. Quantile-quantile (q-q) plots and histograms of residuals (to the indices and compositional data) to justify the choices of sampling distributions for the data.
5. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments).
   a. Retrospective analysis (retrospective bias in base model or models).
   b. Historic analysis (plot of actual estimates from current and previous assessments).
6. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):
   a. The best approach for describing uncertainty depends on the situation. Possible approaches (not mutually exclusive) are:
      i. Sensitivity analyses (tables or figures) that show ending biomass levels, OFLs, and/or likelihood component values obtained while systematically varying (e.g. halving and doubling) the emphasis factors for each type of data (and penalty) in the model.
      ii. Likelihood profiles for parameters or biomass levels.
      iii. CVs for biomass or OFL estimated by bootstrap, the delta method or Bayesian methods.
      iv. Subjective appraisal of the magnitude and sources of uncertainty.
      v. Retrospective and historic analyses (see above).
      vi. Comparison of alternate models and or assumptions (i.e. model structure uncertainty, as evaluated in Section E.3 of this Appendix).
   b. It is important that some qualitative or quantitative information about relative probability be stated if a range of model runs (e.g., based on CV's or alternative assumptions about model structure or recruitment) is used to depict uncertainty. It is important to state that all scenarios (or all scenarios between the bounds depicted by the runs) are equally likely if no statements about relative probability can be made.
   c. Simulation results.

F. Calculation of the OFL

1. Specification of the Tier level and stock status level for computing the OFL, along with the basis for the selection. For Tier 4 and 5 stocks, the rationale for the time period used to define B_{REF} (Tier 4) and the average retained catch used to compute the OFL (Tier 5) needs to be specified.
2. List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan.
3. Specification of the OFL:
   a. Provide the equations (from Amendment 24) on which the OFL is to be based, including the equations used to project discard and bycatch by sex (the

   mathematical specifications for this need to be documented in a peer-reviewed publication or in a technical appendix).
   b. Basis for projecting MMB to the time of mating (the mathematical specifications for this need to be documented in a peer-reviewed publication or in a technical appendix).
   c. Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring (such as B_{REF}, $B_{35\%}$). Include estimates from the present assessment and the assessments since 2006/07. Table 2 of this Appendix lists examples of tables for Tiers 3, 4 and 5.
4. Recommendation for F_{OFL}, OFL total catch (or OFL retained catch) for the coming year. List the OFLs by sector (retained catch, discard in the directed fishery, bycatch in other crab fisheries, the groundfish fishery, etc.), where appropriate.

G. Rebuilding Analyses

Rebuilding analyses should be provided for stocks which are currently under a rebuilding plan.

1. Definition of recovery (including the definition of the proxy for B_{MSY}, the number of years that the biomass needs to exceed the proxy for B_{MSY} for the stock to be recovered).
2. Year in which the rebuilding plan started and the year by which the stock should be recovered to the proxy for B_{MSY}.
3. Specification of the approach used to project the model forward (e.g. assumptions about parameter uncertainty; future recruitment and selectivity; and how discards and bycatch are computed given fishing mortality on mature males).
4. Projections under different levels of fishing mortality on mature males to evaluate the probability of recovery to the proxy for B_{MSY} over time. Results should be produced for (a) no targeted fishing, (b) probabilities of recovery of 0.5, 0.6, 0.7 and 0.8, and (c) a harvest strategy corresponding to 75% of the F_{OFL}.
5. Tables of total catch, retained catch, and probability of recovery against time for the rebuilding strategies listed under 4).
6. A graph of the annual status of the stock relative to the B_{MSY} and MSST from the start of the rebuilding period to the present.

H. Data Gaps and Research Priorities

Information which could feasibly be collected and analyses which should be undertaken to improve the assessment should be included in this section. Ideally, data collection and analysis needs should be listed in priority order.

I. Ecosystem Considerations

Discussion of any ecosystem considerations (e.g., relationships with species listed under the ESA, prohibited species concerns, bycatch issues, refuge areas, and gear considerations).

The following subsections should provide information on how various ecosystem factors might be influencing the stock or how the fishery might be affecting the ecosystem and what data gaps might exist that prevent assessing such effects.

1. Ecosystem Effects on Stock

There are several factors that should be considered for each stock in this subsection. These include:

1. Prey availability/abundance trends (historically and in the present and foreseeable future). These prey trends could affect growth or survival of a target stock.
2. Predator population trends (historically and in the present and foreseeable future). These trends could affect mortality rates over time.
3. Changes in habitat quality (historically and in the present and foreseeable future). These would primarily be changes in the physical environment such as temperature, currents, or ice distribution that could affect stock migration and distribution patterns, recruitment success, or direct effects of temperature on growth.

2. Fishery Effects on the Ecosystem

In this section the following factors should be considered:

1. Fishery-specific bycatch of HAPC biota (in particular, species common to *YourFishery*), marine mammals and birds, and other sensitive non-target species.
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.
3. Fishery-specific effects on amount of large size target crab.
4. Fishery-specific contribution to discards.
5. Fishery-specific effects on age-at-maturity and fecundity of the target species.
6. Fishery-specific effects on EFH non-living substrate (using gear specific fishing effort as a proxy for amount of possible substrate disturbance).

Authors should consider summarizing the results of these analyses into a table as shown below (for example):

Analysis of ecosystem considerations for *YourStock* and the *YourFishery*. The observation column should summarize the past, present, and foreseeable future trends. The interpretation column should provide details on how the trend affects the stock (ecosystem effects on the stock) or how the fishery trend affects the ecosystem (fishery effects on the ecosystem). The evaluation column should indicate whether the trend is of: *no concern, probably no concern, possible concern, definite concern,* or *unknown.*

Ecosystem effects on *YourStock*			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	Stable, data limited	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on pollock	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Probably no concern
Fish (Skate, flatfish, pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to pre-recruit crab mortality	Probably concern (young of the year is not dealt within the model?)
Changes in habitat quality			
Temperature regime	Cold years pollock and other demersal fish distribution towards NW on average	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit crab survival	Probably a number of factors	Causes natural variability
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability low	No concern
***YourFishery* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	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	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Generally patchy	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery effects on amount of large size target fish	Depends on highly variable year-class strength	Natural fluctuation	Probably no concern
Fishery contribution to discards and offal production	Decreasing	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity		NA	Possible concern

J. Literature Cited

Include citations that are relevant to understanding the stock and its status, but are not cited in the report in a special “extra references” section.

Table 1. Requirements for assessments by Tier.

Report Section	Tiers 1-3; Tier 4 (with assessment)	Tier 4 (no assessment)	Tier 5
Executive Summary	Yes	Yes	Yes
A. Summary of Major Changes	Yes	Yes	Yes
B. Responses to SSC and CPT comments	Yes	Yes	Yes
C. Introduction	Yes	Yes	Yes
D. Data	Yes	Yes[1]	Yes[2]
E. Analytical Approach	Yes	Yes[3]	Yes[3]
F. Calculation of the OFL	Yes	Yes	Yes
G. Rebuilding Analyses	Yes[4]	Yes[4]	Yes[4]
H. Data Gaps and Research Priorities	Yes	Yes	Yes
I. Ecosystem Considerations	Yes	Yes	Yes
J. Literature Cited	Yes	Yes	Yes

1 – Items 2c, 2e need not be reported in full
2 – Items 2c -2e need not be reported in full
3 – Limited to plots of survey data and catches
4 – Only for stocks under rebuilding

Table 2. Examples of summary tables of management performance by Tier level (the table is structured for an assessment conducted in September 2009)

(a) Stocks in Tiers 1-3 and those in Tier 4 for which there is an agreed assessment model

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		100[A]	60	40	58	
2006/07		120[B]	60	51	55	
2007/08	230[C]	130[C]	60	55	56	
2008/09	221[D]	219[D]	60	47	55	91
2009/10		280[D]				78

The stock was above MSST in 2008/09 and is hence not overfished. Overfishing did not occur during the 2008/09 fishing year.

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

(b) Stocks in Tier 4 for which there is not an agreed assessment model

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		100[A]	60	40	58	
2006/07		120[B]	60	51	55	
2007/08	230[C]	130[C]	60	55	56	
2008/09	221[D]	219[D]	60	47	55	91
2009/10		280[D]				78

The stock was above MSST in 2008/09 and is hence not overfished. Overfishing did not occur during the 2008/09 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2006 (even though it may have been updated)
B – Based on survey data available to the Crab Plan Team in September 2007 (even though it may have been updated)
C – Based on survey data available to the Crab Plan Team in September 2008 (even though it may have been updated)
D – Based on survey data available to the Crab Plan Team in September 2009

(c) Stocks in Tier 5

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL
2005/06		N/A	60	40	58	
2006/07		N/A	60	51	55	
2007/08	N/A	N/A	60	55	56	
2008/09	N/A	N/A	60	47	55	91
2009/10		N/A				78

No overfished determination is possible for this stock given the lack of biomass information. Overfishing did not occur during the 2008/09 fishing year.

Table 3. Examples of tables that summarize how the OFL was calculated (the table is structured for an assessment conducted in September 2009). The rows for 2008/09 were agreed by the Crab Plan Team in September 2008 and those for 2009/10 were agreed by the Crab Plan Team in September 2010.

(a) Stocks in Tiers 1-3 and those in Tier 4 for which there is an agreed assessment model

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2008/09	3b	231	219.5	0.95	$0.15yr^{-1}$	1978/79-2008/09	$0.25yr^{-1}$
2009/10	3a	234	245.7	1.05	$0.19yr^{-1}$	1978/79-2009/10	$0.25yr^{-1}$

(b) Stocks in Tier 4 for which there is not an agreed assessment model

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	γ	Years to define B_{MSY}	Natural Mortality
2008/09	4b	231	219.5	0.95	1.0	1978/79-2008/09	$0.25yr^{-1}$
2009/10	4a	234	245.7	1.05	0.6	1978/79-2009/10	$0.25yr^{-1}$

(c) Stocks in Tier 5

Year	Tier	Years to define Average catch (OFL)	Natural Mortality
2008/09	5	1978/79-2008/09	$0.25yr^{-1}$
2009/10	5	1978/79-2009/10	$0.25yr^{-1}$

Table 4. Categories for which information on catches and discards should ideally be provided.

Directed pot fishery (males)
Directed pot fishery (females)
Bycatch in other crab fisheries (by sex)
Bycatch in groundfish pot (by sex)
Bycatch in groundfish trawl (by sex)
Bycatch in the scallop fishery

Appendix D : Evaluating for the Method For Evaluating Random Residuals

Figure D.1 summarizes the application of the method for evaluating whether a residual pattern is random. Results are shown for six cases. The first two cases (a and b) are cases in which the residuals are obviously mis-specified. Cases c and d show results for random residuals and cases e and f respectively show results when there are cohort effects (Fig. D1e) and year-effects (Fig. D1f). Application of the two-sample Kologorov-Smirnov test to the six cases leads to p-values of $<10^{-10}$, $<10^{-10}$, 0.8225, 0.9242, 0.06818, and 0.1229 respectively. The apparent low power for case f suggests that there may be value in developing tests for specific alternative hypotheses.

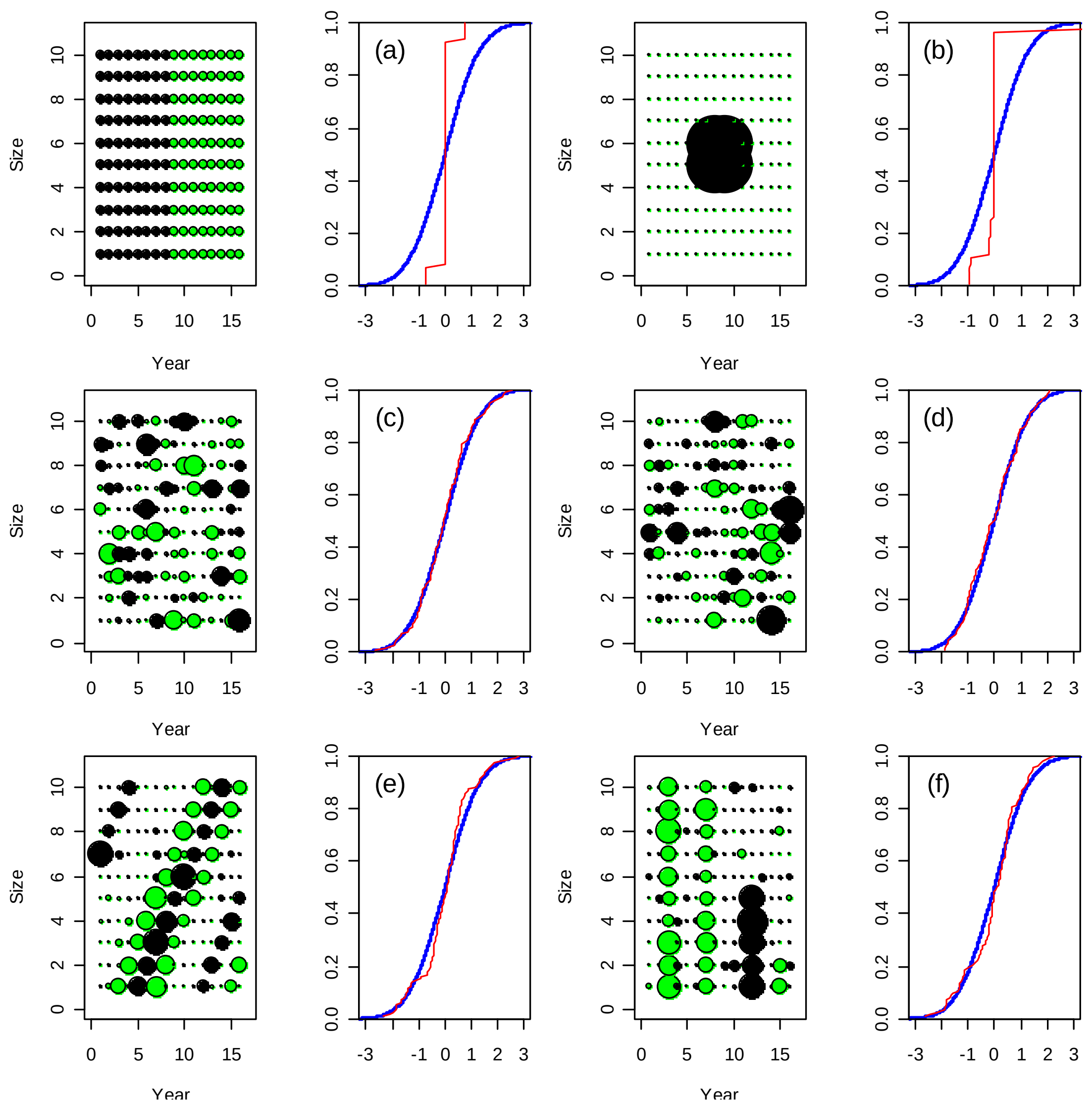

Figure D.1. Results of applying a method for evaluating whether residual patterns are random. The thick line is the null distribution and the thin line is the cumulative distribution of the test statistic.

Appendix E : Summary of Diagnostic Plots

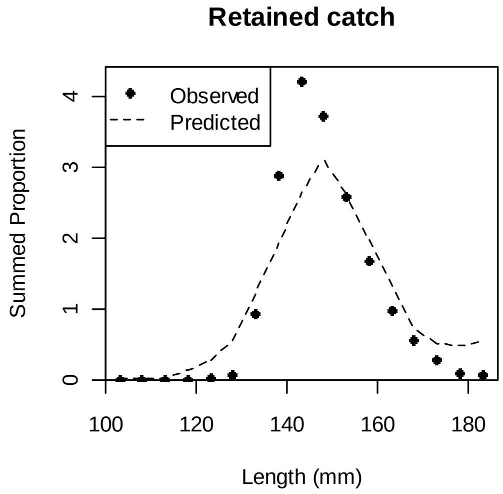

Figure E.1(a). Marginal observed and predicted catch size-compositions for AIGKC.

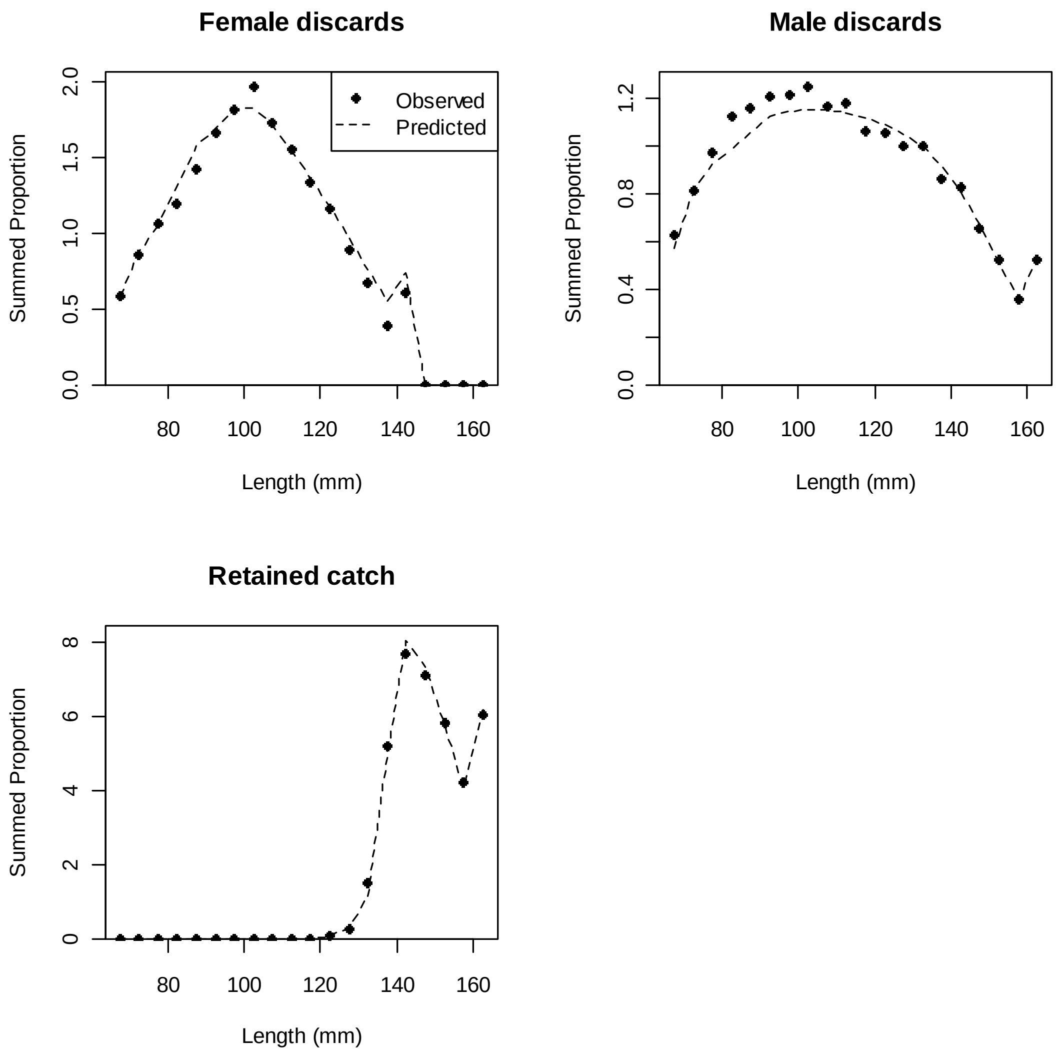

Figure E.1(b). Marginal observed and predicted catch size-compositions for BBRKC.

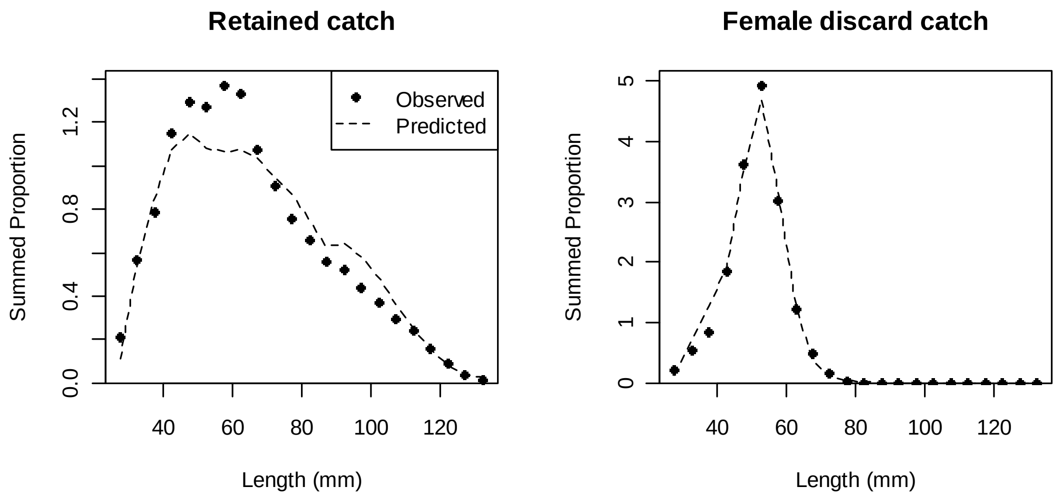

Figure E.1(c). Marginal observed and predicted catch size-compositions for snow crab.

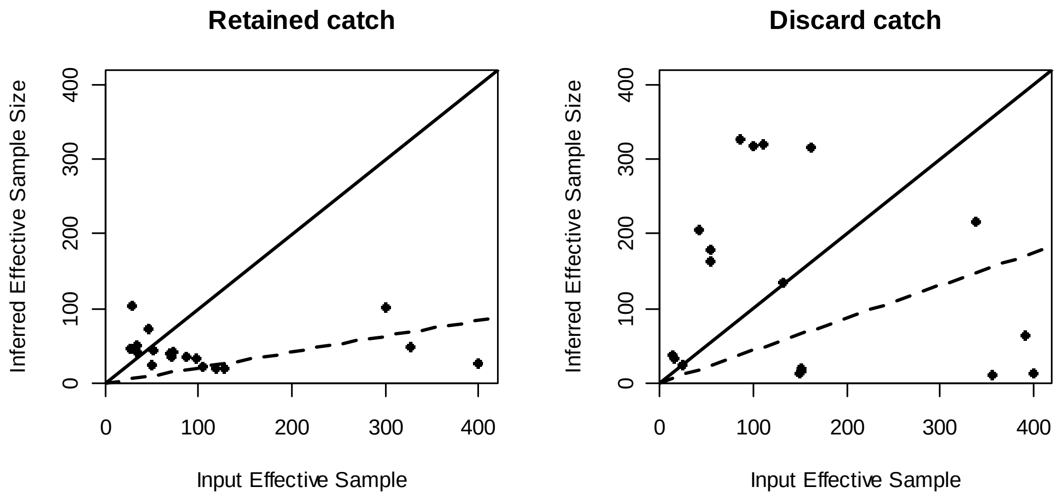

Figure E.2(a) Observed and “implied” effective sample sizes for AIGKC. The dashed line is a fit to the data and the solid line is the 1-1 line.

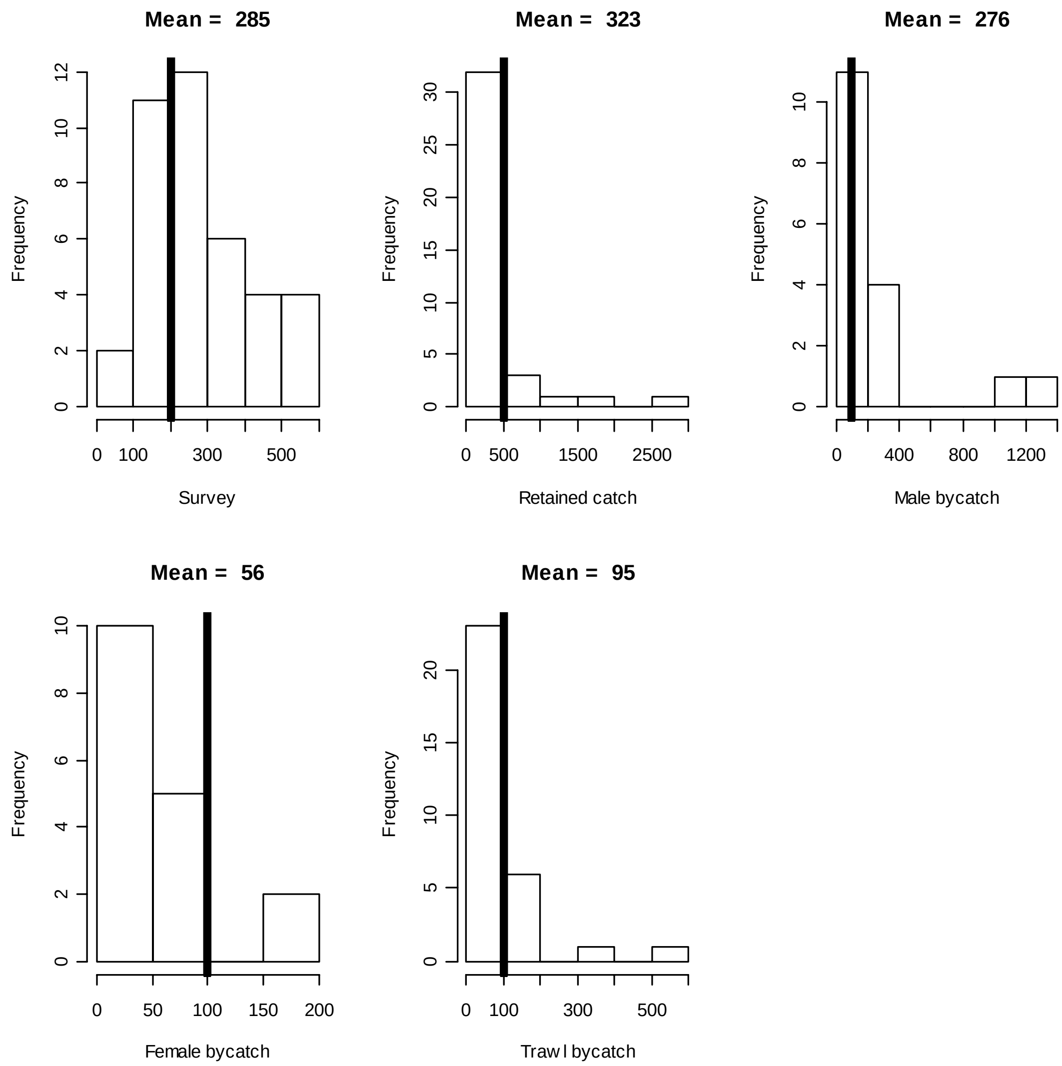

Figure E.2(b) “Implied” sample sizes (bars) and the input value (solid vertical line) for BBRKC.

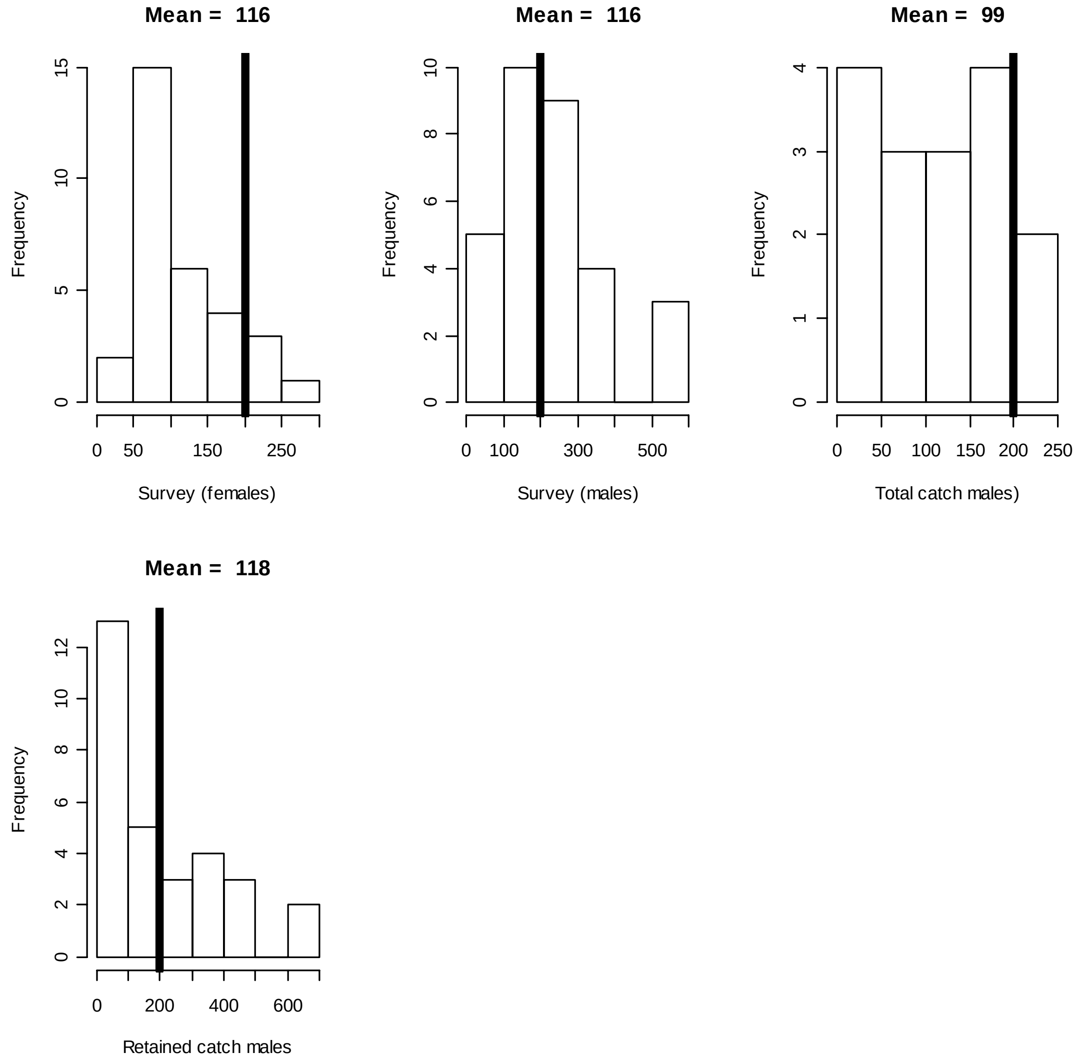

Figure E.2(c) “Implied” effective sample sizes (bars) and the input value (solid vertical line) for snow crab.

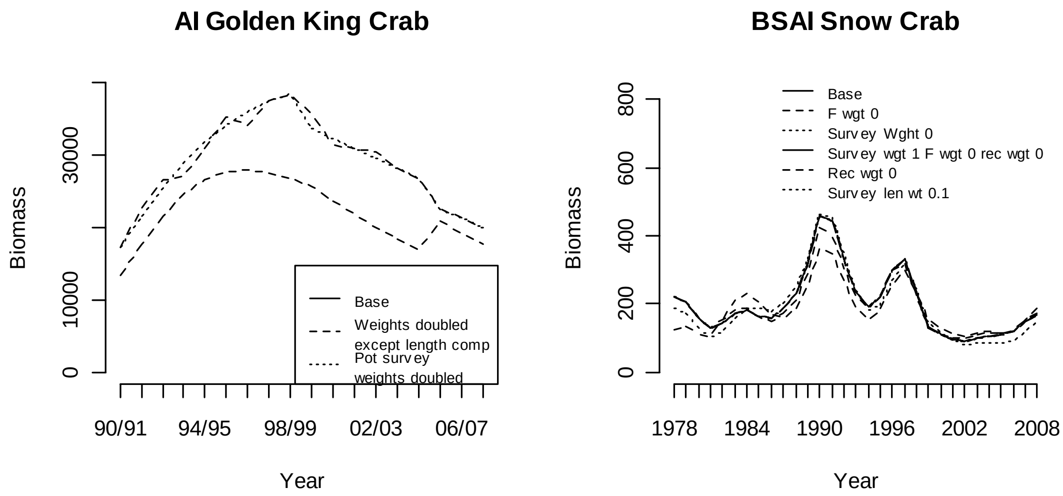

Figure E.3. Sensitivity of the time-trajectories of mature male biomass for AIGKC and snow crab to changing the weights assigned to the data sources.

Appendix F : A Surplus Production Approach to Estimating F_{MSY}

Basic approach

It is possible to estimate surplus production empirically for stocks/species for which estimates of abundance (in units of mature male biomass) are available from surveys or from stock assessments (Hilborn, 2001) using the formula:

$$S_y = B_{y+1} - B_y + C_y \qquad \text{(F.1)}$$

where S_y is the surplus production (in mature male biomass) during year *y*,
B_y is the biomass (in mature male biomass) at the start of year *y*, and
C_y is the catch during year *y*.

The annual surplus production rate is defined as the ratio of the annual surplus production to the average biomass over the year, i.e. $\tilde{S}_y = 2S_y / (B_y + B_{y+1})$. If $\tilde{y}$ is the set of the years which correspond (approximately) to when the stock was close to B_{MSY} then the average value of $\tilde{S}_y$ over the years in $\tilde{y}$ is an estimate of the exploitation rate at which *MSY* is achieved.

Simulation testing

Preliminary testing of the basic approach was conducted using simulation. Simulated biomass series were generated using the equations:

$$B_{y+1} = (B_y + rB_y(1 - B_y / K) - C_y)e^{\varepsilon_y - \sigma_p^2/2} \qquad \varepsilon_y \sim N(0;\sigma_p^2) \qquad \text{(F.2a)}$$

$$C_y = qE_yB_y \qquad E_y \sim e^{\eta_y} \qquad \eta_y \sim N(0;\sigma_E^2) \qquad \text{(F2b)}$$

where r is the intrinsic rate of growth,
K is the carrying capacity,
q is catchability,
σ_p is the extent of process error, and
σ_E is the extent of variability in effort.

The catches were assumed to be measured exactly while the estimates of biomass were assumed to be subject to log-normal measurement error, i.e. $\hat{B}_y = Be^{\phi_y - \sigma_v^2/2}$; $\phi_y \sim N(0;\sigma_v^2)$ where σ_v determines the extent of measurement error. For the purposes of this preliminary investigation, $\tilde{y}$ was defined as the set of years for which $0.3 < \hat{B}_y / K < 0.7$. Table F.1 lists the baseline values for the parameters of the simulation model. Figure F.1 shows plots of the (true) simulated biomass relative to carrying capacity and the left panel of Figure F.2a shows the simulated distribution of estimate of F_{MSY} for the baseline values of the parameters, while Figures F.2b and F.2c shows the impact of there being no process (F.2.b) or observation (F.2c) error.

Table F.1. The baseline values for the parameters of the simulation model

Intrinsic growth rate, r	0.2
Carrying capacity, K	1000
Catchability, q	0.05
Extent of process error, σ_p	0.2
Extent of variability in effort, σ_E	0.2
Extent of survey error, σ_v	0.5

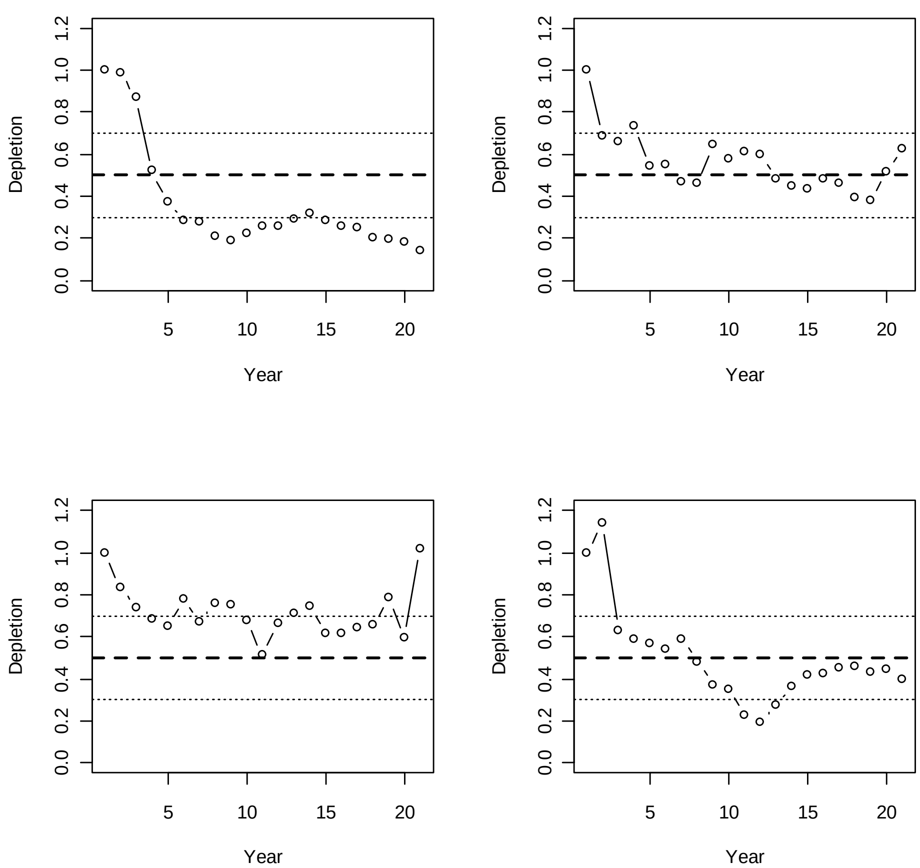

Figure F.1. True simulated biomass relative to carrying capacity (dots) and the range of values used in the calculation of the F_{MSY} (values between the dotted lines).

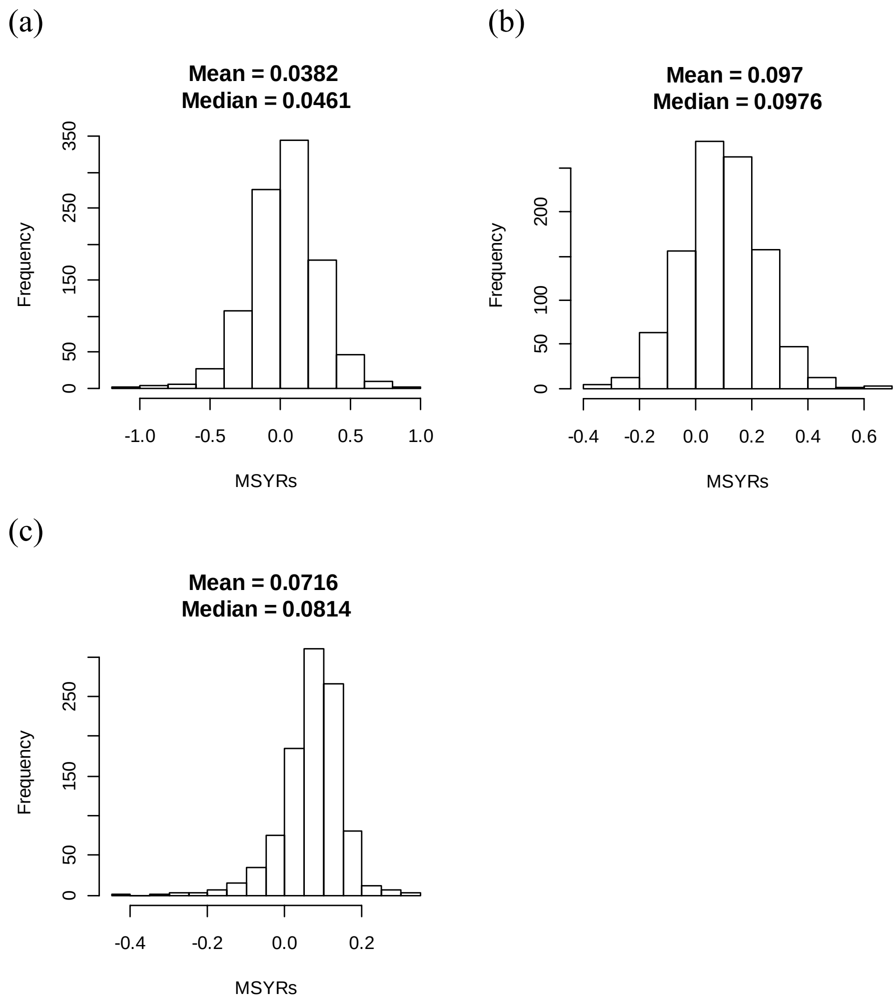

Figure F.2. Estimates of F_{MSY} from simulated data sets: (a) baseline parameter values, (b) no process error, and (c) no measurement error.

Appendix G : An Approach to Estimating Gamma

(After Turnock and Rugolo, 2008)

The F_{MSY} proxy for the control rule is F_{MSY} proxy = γM, where $\gamma = F_{35\%}/M$ so the F_{MSY} proxy = $(F_{35\%}/M) * M$. 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 to estimate the OFL. This value of γ is specific to the $F_{35\%}$ and the estimated fishery selectivities and cannot be used without those fishery selectivities, for example in the product of γ, M, and mature male biomass to estimate the total catch OFL.

Discard and retained selectivities, S_l, can be estimated using the length frequency of the observed catch, the ratio of discarded to retained numbers of crab, and the predicted catch length frequency and numbers (discard and retained) using the recent survey abundance by length projected forward to the time of the fishery. The proportion of males which are mature at length, P_l, and the vector of weights-at-length, w_l, for males can also be inferred from survey data. Given a size transition matrix **X** and a value for natural mortality, M, the population can be projected forward using the equation[6]:

$$\underline{N}_{t+1} = \mathbf{XS}N_t + \underline{R} \tag{G.1}$$

where $\underline{N}_t$ is the numbers at length at the start of year t,

$\underline{R}$ is the recruitment by length-class (set to unity multiplied by the proportion of recruitment that occurs to each size-class),

S is a matrix with $(1-S_l F)e^{-M}$ on the diagonal and zero elsewhere, and

F is fishing mortality

Denoting the equilibrium point of Equation G.1 as $\underline{N}^*(F)$, the mature biomass-per-recruit at the time at mating can be computed as:

$$MMB(F) = \sum_l w_l N_l^*(F)(1-S_l F)e^{-\phi M} \tag{G.2}$$

The value for $F_{35\%}$ is selected so that $MMB(F_{35\%}) / MMB(0) = 0.35$.

[6] The derivation is based on one particular crab life history. The specific forms of Equations G.1 and G.2 will depend on, for example, the number and timing of the various fisheries.