DRAFT 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

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

Summary of Major Changes:

- There were no major changes to the proposed 2009 OFL calculation methods.
- All allusions to 2009 data are assumed based on planned surveys and analyses.
- Additional alternative B_{MSY}^{prox} years applied for the September 2008 OFL setting process will be included for review.

SSC comments October 2008:

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.

SSC comments June 2008:

The SSC supports the crab plan team recommendation for designating the Pribilof Islands red king crab as a tier 4 stock. While the SSC accepts the range of survey years (1991 to 2007) selected by the Plan Team for determining an average mature male biomass as the reference biomass level, the SSC would also like to see calculations of OFL based on the full time series of biomass estimates beginning in 1980. The SSC also requests that the catch-survey model be resurrected to provide biomass estimates for this stock in future stock assessment reports.

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.
- 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.
- In general comments to all authors, the June 2008 SSC recommended development of analyses for choice of gamma for all stock assessments. This will be addressed at the May 13-14 workshop for potential inclusion in the September CPT final SAFE.
- In general comments to all authors, the June 2008 SSC recommended expanded ecosystem sections to include prey and predator interactions. Expanded ecosystem sections were not considered during this assessment cycle to focus efforts on model development, ACL implementation, and survey data.

Summary

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

Year	Total Catch OFL	Biomass (MMB_{mating})	TAC	Retained Catch	Total catch
2006/07	na	13.87	0	0	0.024
2007/08	na	14.70	0	0	0.008
2008/09	3.32	9.26*	0	X	X
2009/10	X	X*			

*projected

Tier	4
Stock Status Level	a
F_{OFL}	0.18
B_{MSY}^{proxy}	X million lbs of MMB_{mating}
Years	1991 to 2008
2009/2010 projected MMB_{mating}	X million lbs
2009/2010 projected MMB_{mating}/MMB_{MSY}	X
Gamma	1
M	0.18
2009/2010 total catch OFL	X million lbs

Introduction

Red king crabs, *Paralithodes camtschaticus* (Tilesius, 1815) are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58° 39' N lat.), west of 168° W long., east of the United States – Russian convention line of 1867 as amended in 1991, north of 54° 36' N lat. between 168° 00' N and 171° 00' W. long and north of 55° 30'N lat. between 171° 00' W. long and the U.S.-Russian boundary (Figure 1).

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Unlike brachyurans, red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts and copulation occurs within hours. During copulation, the male inverts the female so they are abdomen to abdomen 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).

Fishery

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the Sate of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crabs *Paralithodes platypus* being targeted (Figure 2). A red king crab fishery in the Pribilof District opened for the first time in September 1993 following an increase in the abundance of red king crabs observed around the Pribilof Islands during the 1993 NMFS summer crab and groundfish trawl survey. For the 1993 fishery a Guideline Harvest Level (GHL) of 3.4 million lbs was set and 2.6 million lbs were harvested and in 1994 the GHL was 2 million lbs and 1.3 million lbs were harvested (Bowers et al. 2008). Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The combined red and blue king crab GHLs from 1996 though 1998 were 2.5, 1.8, 1.5, and 1.25 million lbs and corresponding red king crab harvests were 0.87, 0.20, 0.76, 0.51 million lbs (Bowers et al. 2008). From 1999 to 2008/09 the Pribilof fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof blue king crab was declared overfished in September of 2002 and is still considered overfished (Bowers et al. 2008).

The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof red and blue king crab fisheries which was implemented in 1998. The Alaska Department of Fish and Game manages the crab CDQ fisheries and the Central Bering Sea Fishermen’s Association (CBSFA) is allocated 100% of the Pribilof red and blue king crab. Due to fishery closures, Pribilof red king crab were only harvested under a CDQ in 1998 where 3.5% of the overall GHL was allocated to the CDQ resulting in 35,958 lbs, harvest data is confidential due to limited participation in the fishery (Bowers et al. 2008).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 3) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

Pribilof red king crabs occur as bycatch in the eastern Bering Sea snow crab (*Chionocetes opilio*), eastern Bering Sea Tanner crab (*Chionocetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof blue king crab fisheries. Many of these fisheries have been closed or recently re-opened so the opportunity to catch Pribilof red king crab is limited. The Bering Sea snow crab fishery has remained opened but ADF&G observers have not recorded any red king in their sampled pots during the last two fishing seasons (Barnard and Burt 2007, 2008). The eastern Bering Sea Tanner crab fishery recently re-opened west of 166^{o} longitude (the fishery was closed from 1997-2004). ADF&G observers recorded 1.0 red king crab per sampled pot during the 2005/2006 fishery, but only 0.08 during the 2006/2007 fishery (Barnard and Burt 2007, 2008). The Bering Sea hair crab fishery has been closed since 2001, and the Pribilof blue king crab fishery has been closed since 1999. In addition, Pribilof red king crab catch has been limited in groundfish trawl fisheries since 1995 because of the Pribilof Islands Habitat Conservation Area trawl closure. Non-directed catch still exists in groundfish pot and hook and line fisheries (see 2009 Data).

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

2009 Data

Survey Data

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

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

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

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 1, Figure 5). In 2009, Pribilof Islands District red king crab were observed in X of the X stations in the Pribilof District high-density sampling area (Chilton et al. in press, Figure 6). The density of legal-sized males (>138 mm CL) caught at a station ranged from 71 to 1,666 crab/nm^2. Legal-sized male red king crab were caught at 7 stations in the Pribilof District high-density sampling area and were estimated at 1.2 ± 1.1 million crab, which is a decrease of 25% from the 2007 abundance estimate (Figure 7).

Fishery Data-ADF&G pot fisheries

The 2008/2009 ADF&G assessments of retained and non-retained catch from all pot fisheries are included in this SAFE report (D. Barnard and D. Pengilly, ADF&G, personal communications).

Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (Table 2 and 3; Figure 8; Bowers et al. 2008), the seasons when red king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons red king crab and blue king crab were fished under the same Guideline Harvest Level (GHL). There was no GHL and therefore zero retained catch in the 2008/2009 fishing season.

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight (lbs) was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was calculated from length frequency tables where the CL (mm) was converted to g (see equation 3: males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 4).

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

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

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

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 4; Figure 9; Bowers et al. 2008) although data may be incomplete for some of these fisheries. Prior to 1998 limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here. In 2009, X, X, and X million lbs of sublegal males, legal males, and females, respectively, were incidentally caught in the Tanner crab fishery (Table 4).

Fishery Data-AKRO groundfish pot, trawl, and hook and line fisheries

The 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 4, Figure 10). In 2008/2009, X million lbs of male and female red king crab were caught in groundfish fisheries which is X than the 0.011 million lb estimate of non-retained crab catch in 2007/2008 pot, trawl, and hook and line groundfish fisheries.

Analytic Approach

Although a catch survey analysis has been used for assessing the stock in the past, the OFL control rule and OFL determination in 2009 were based on MMB_{mating} relative to the EBS bottom trawl survey and incorporated commercial catch and at-sea observer data. A catch survey analysis is proposed for future consideration (Appendix 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).

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

In Tier 4, Maximum Sustainable Yield is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, environmental conditions and fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets. In Tier 4, the fishing mortality that, if applied over the long-term, would result in MSY is approximated by F_{MSY}^{proxy}. The MSY stock size (B_{MSY}) is based on mature male biomass at mating (MMB_{mating}) which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of the complicated female crab life history, unknown sex ratios, and male only fishery. The B_{MSY}^{proxy} represents the equilibrium stock biomass that provides maximum sustainable yield (MSY) to a fishery exploited at F_{MSY}^{proxy}.. B_{MSY} can be estimated as the average biomass over a specified period that satisfies these conditions (i.e., equilibrium biomass yielding MSY by an applied F_{MSY}). This is also considered a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock. The current stock biomass reference point for status of stock determination is MMB_{mating}.

In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} (Figure 11) to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure 11) where Stock Status Level (level a, b or c; equations 5-7) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

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

The mature stock biomass ratio β where $B/B_{MSY}^{prox} = 0.25$ represents the critical biomass threshold below which directed fishing mortality is set to zero. The parameter α determines the slope of the non-constant portion of the control rule line and was set to 0.1. Values for α and β where based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where B is greater than β includes the product of a scalar (**γ**) and M (equations 5 and 6) where the default **γ** value is 1 and M for Bering Sea red king crab is 0.18. The value of **γ** may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

To project a total catch OFL for the upcoming crab fishing season, the F_{OFL} is estimated by an iterative solution that maximizes the projected F_{OFL} and projected catch based on the relationship of B to B_{MSY}^{prox}. B is approximated by MMB at mating (equation 8).

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

where,

MMB_{Survey} is the mature male biomass at the time of the survey,
$e^{-PM(sm)}$ is the survival rate from the survey to mating.

B_{MSY}^{prox} for the 2009 assessment was calculated as 1) the average MMB_{mating} from 1991 to 2007 given that previous years were indicative of a stock at depressed levels and the current years will include stock highs and lows and 2) the average MMB_{mating} for the entire survey period 1980 to 2007.

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

Projected MMB_{Mating} =

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

where,

MMB_{Survey} is the mature male biomass at the time of the survey,
$e^{-PM(sm)}$ is the survival rate from the survey to mating.
PM(sm) is the partial M from the time of the survey to mating (8 months),

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

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

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

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, the F_{OFL} control rule resulting in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as 0.5 B_{MSY}^{prox}; if current MMB at the time of mating drops below MSST, the stock is considered to be overfished.

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

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

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

OFL Control Rule and Determination Results

For 2009/2010, two levels of B_{MSY}^{prox} were defined. $B_{MSY}^{prox}{}_1$=X million lbs of MMB_{mating} derived as the mean of 1991 to 2008 and is recommended by the authors, CPT and SSC. $B_{MSY}^{prox}{}_2$=X million lbs derived mean of 1980 to 2008 which was requested by the SSC for comparison purposes. The stock demonstrated highly variable levels of MMB_{mating} during both of these periods likely leading to uncertain approximations of B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

Male mature biomass at the time of mating for 2009/2010 is estimated at X 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, [$B/B_{MSY}^{prox}{}_1$=X, F_{OFL}=0.18] and [$B/B_{MSY}^{prox}{}_2$=X, 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 X million lbs of crab and legal male catch OFLs were estimated at X million lbs of crab for both options. The projected exploitation rates based on full retained catches up to the OFL for LMB and $MMB_{fishery}$ under for both B_{MSY}^{prox} options are: X and X respectively.

Red king crabs in the Pribilof Islands have been historically harvested with blue king crabs and are currently the dominant of the two species in this area. There are concerns as to the low reliability of survey biomass estimates, and the high levels of blue king crab incidental catch mortality that would occur in a directed Pribilof Islands red king crab fishery.

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

Projected Total Catch OFL	**X million lbs**
Projected MMB_{mating}	**X million lbs**
Projected Legal Male catch OFL at fishery	**X million lbs**
Projected Exploitation Rate on MMB	**X**
Projected Exploitation Rate on LMB	**X**

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

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

Fishery Effects on the Ecosystem

Bycatch information from the Pribilof district king crab fishery is scant due to limited observer coverage during the years of the fishery. The percent of the fleet observed was 1.8 in 1993, 0.8 in 1995 and 0.0 for every other year (Boyle and Schwenzfeier 2002); therefore it is difficult to estimate the fishery-specific contribution to the bycatch of prohibited and forage species. The Pribilof district king crab fishery does not occur in any areas designated as Habitat Areas of Particular Concern (HAPC) (NPFMC 2003). NMFS conducted Endangered Species Act (ESA) Section 7 Consultations-Biological Assessments on the impact of the Bering Sea and Aleutian Island FMP crab fisheries on marine mammals (NMFS 2000) and on seabirds (NMFS 2002). NMFS concluded that the crab fisheries are not likely to result in the direct take or compete for prey for the protected marine mammal species, destroy or adversely modify designated Steller sea lion critical habitat, adversely affect listed seabirds or destroy or adversely modify designated critical habitat. The only plausible biological interaction between the crab fisheries and threatened and endangered seabirds identified in the biological assessment is vessel strikes by seabirds, but NMFS (2002) concluded that available evidence is not sufficient to suggest that these interactions occur in today's fisheries and limit recovery of seabirds.

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

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

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

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

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

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

Table 3. Fishing effort during Pribilof Islands District commercial red king crab fisheries, 1993-2007/08 (Bowers et al. 2008)

Season	Number of Vessels	Number of Landings	Number of Pots Registered	Number of Pots Pulled
1993	112	135	4,860	35,942
1994	104	121	4,675	28,976
1995	117	151	5,400[a]	34,885
1996	66	90	2,730[a]	29,411
1997	53	110	2,230[a]	28,458
1998	57	57	2,398[a]	23,381
1999-2007/08	Fishery Closed			

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

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

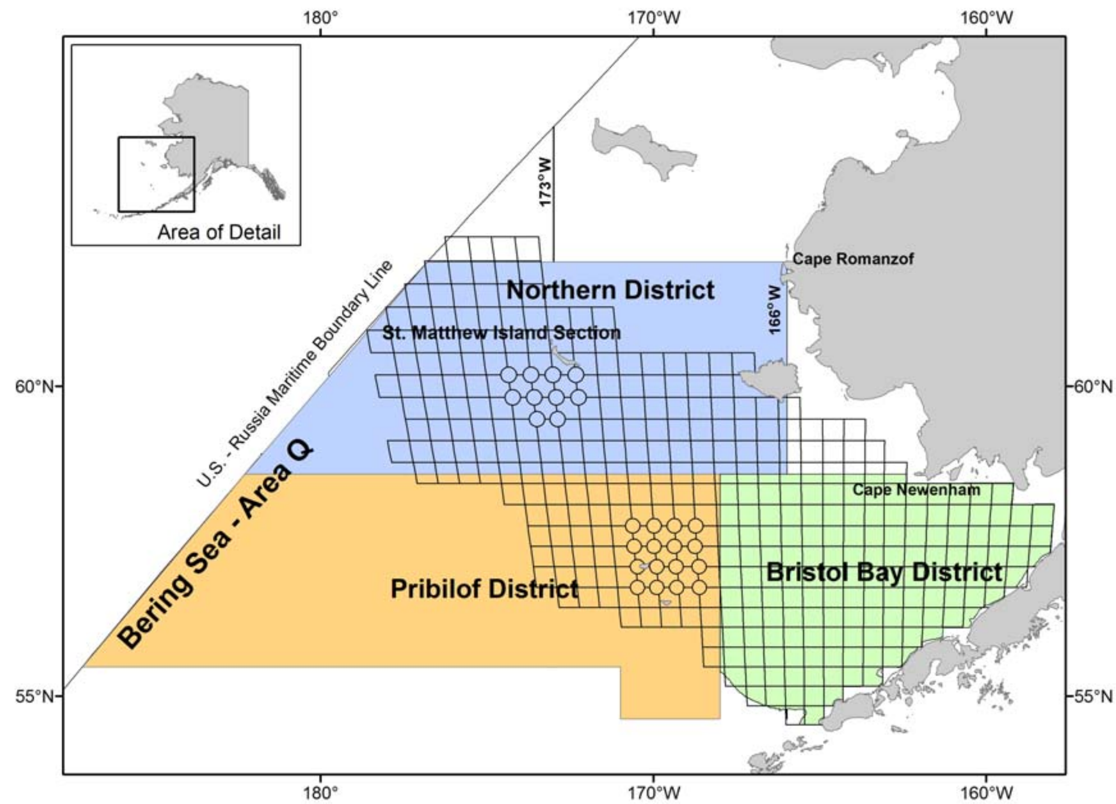

Figure 1. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

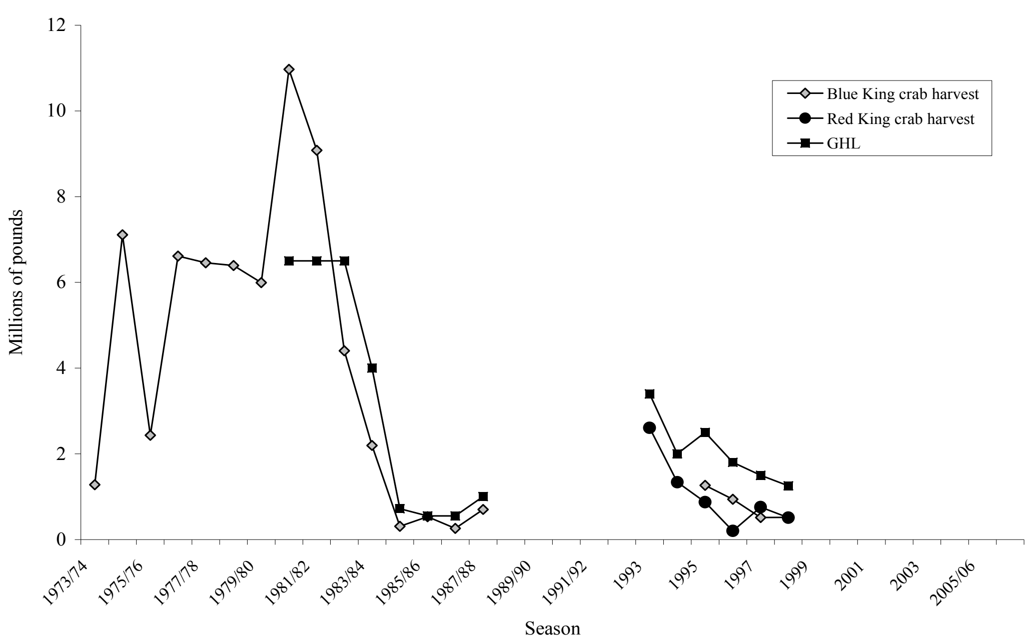

Figure 2. Historical harvests and GHLs for Pribilof Island red king crab (Bowers et al. 2007).

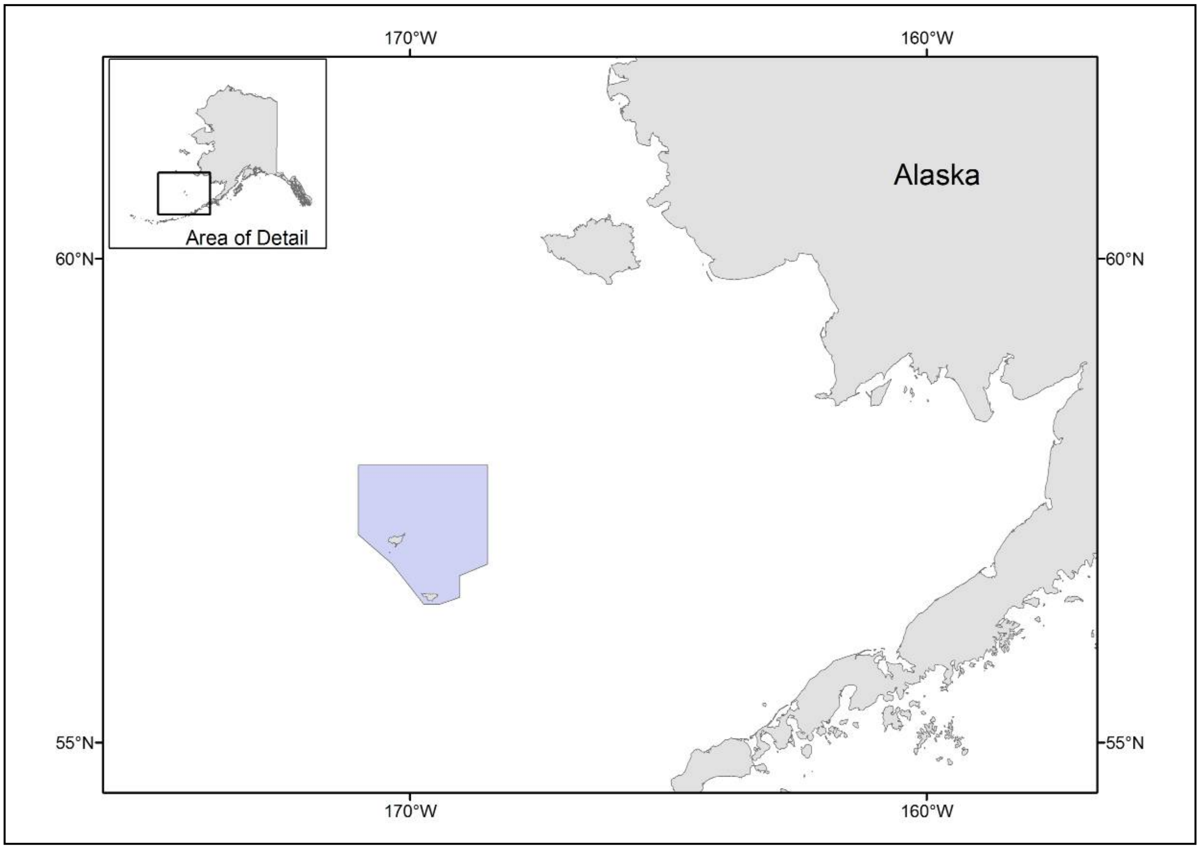

Figure 3. The shaded area shows the Pribilof Islands Habitat Conservation area

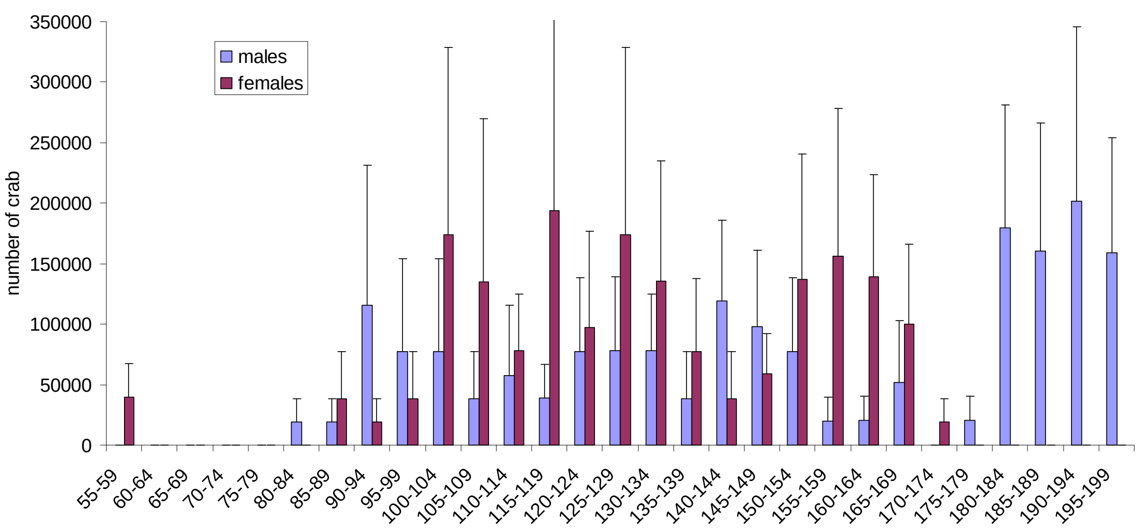

Figure 4. Distribution of average (SE) counts of Pribilof Island red king crab in 5 mm length bins.

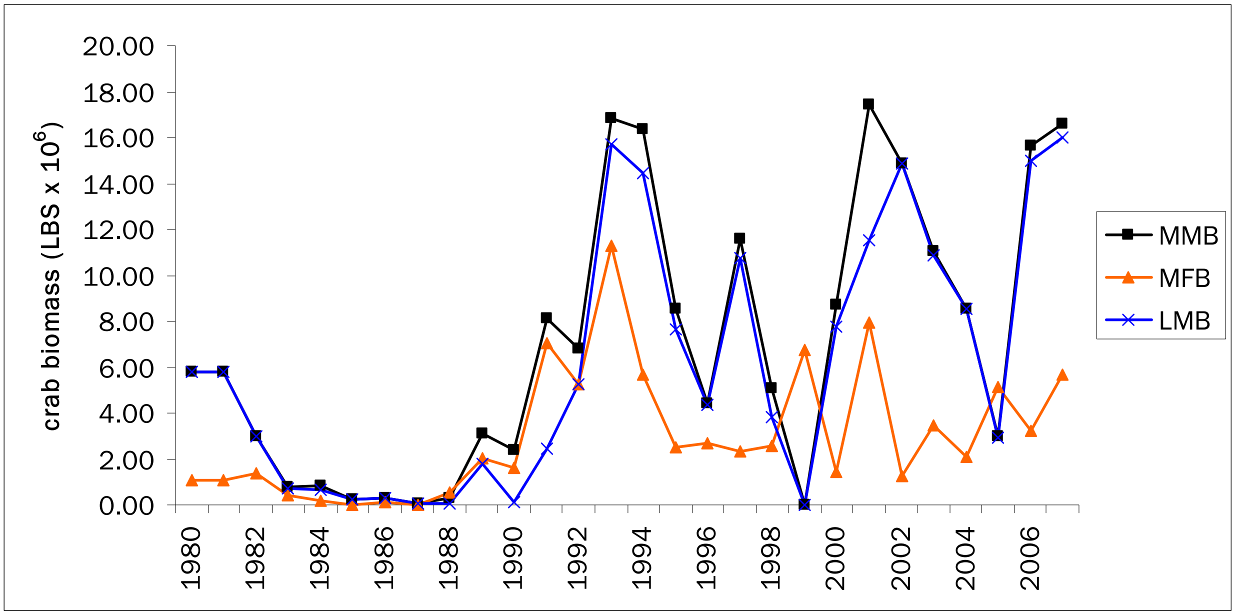

Figure 5. Historical trends of Pribilof Island red king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

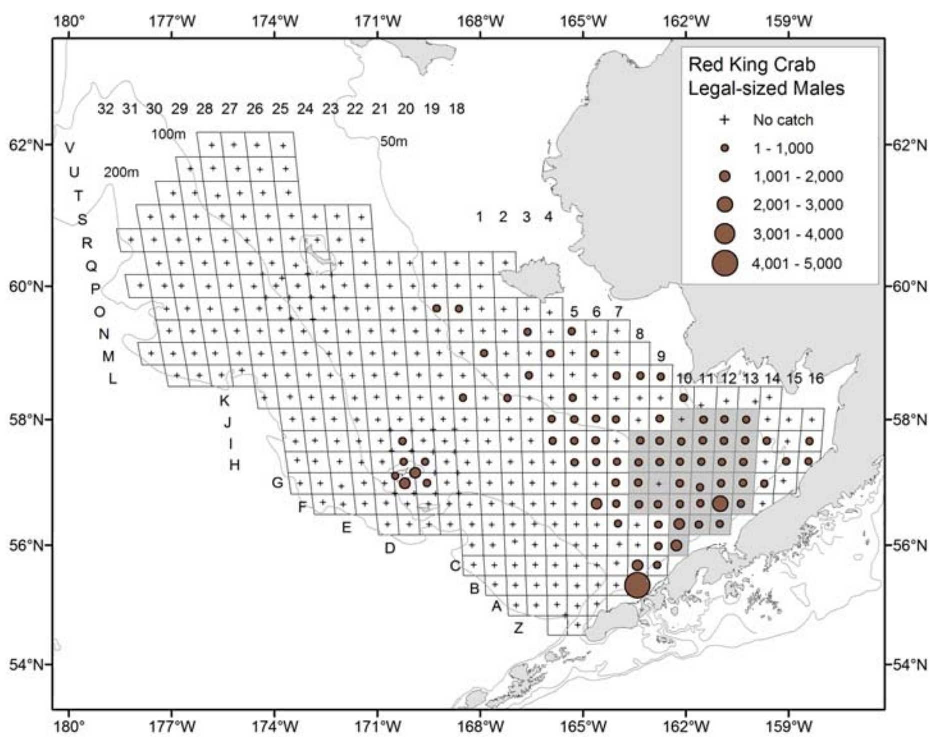

Figure 6. 2008 EBS bottom trawl survey distribution and relative abundance of legal size red king crab males.

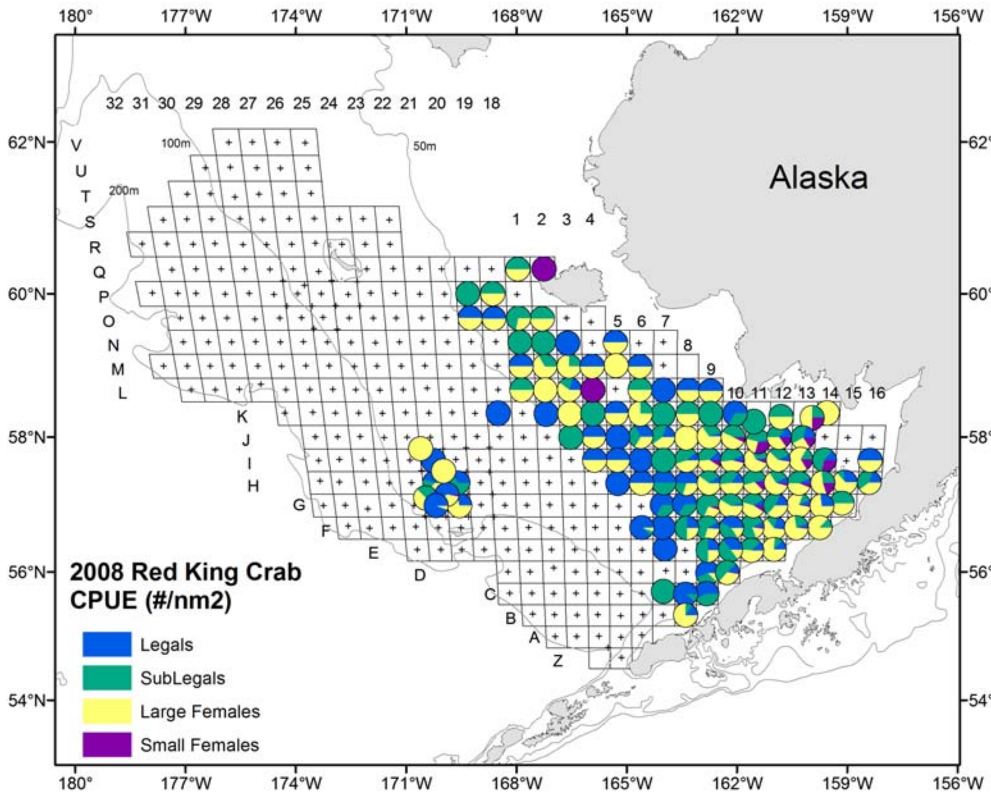

Figure 7. 2008 EBS bottom trawl survey size class distribution of red king crab.

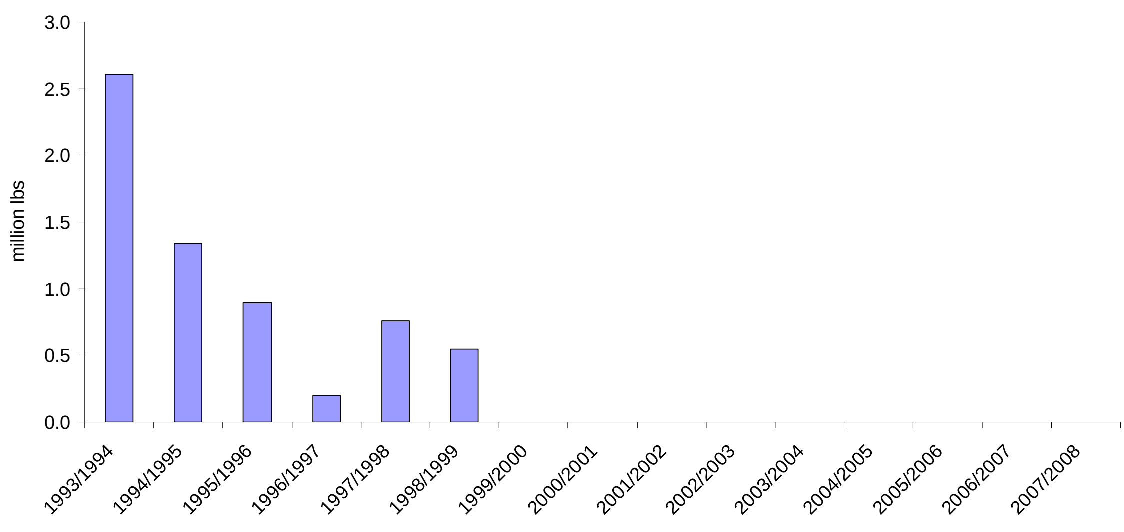

Figure 8. Retained catches from directed fisheries for Pribilof Islands District red king crab.

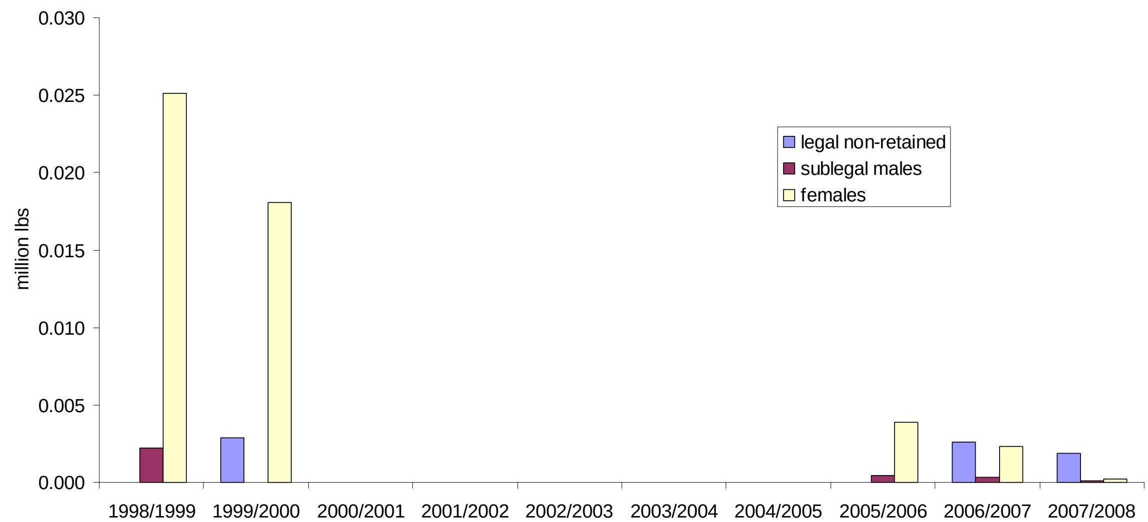

Figure 9. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the total catches.

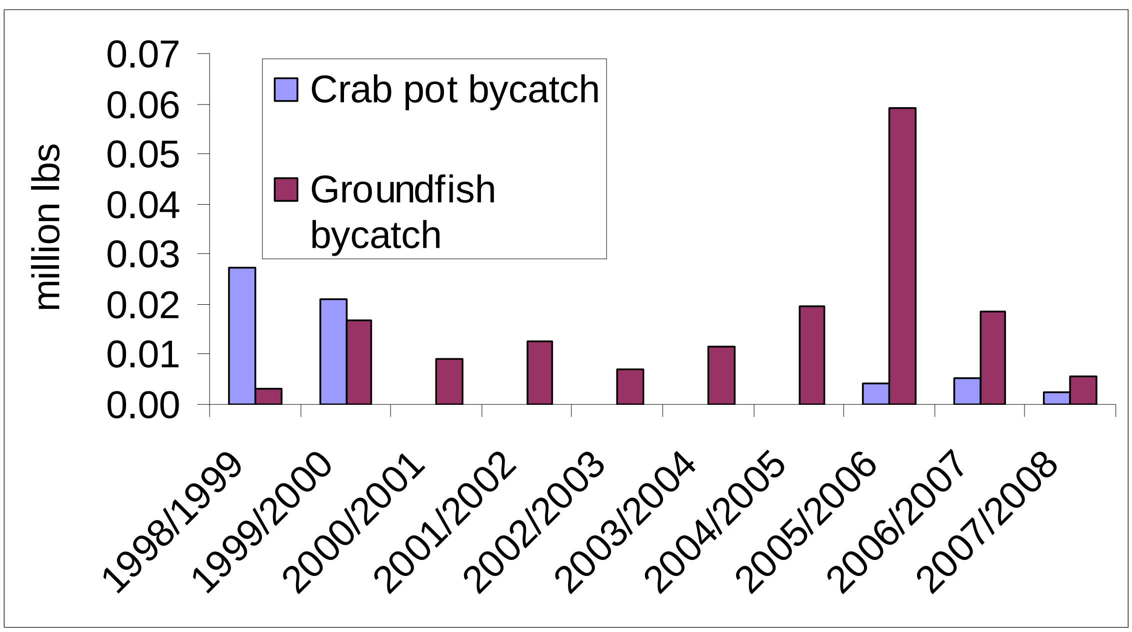

Figure 10. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the total catches.

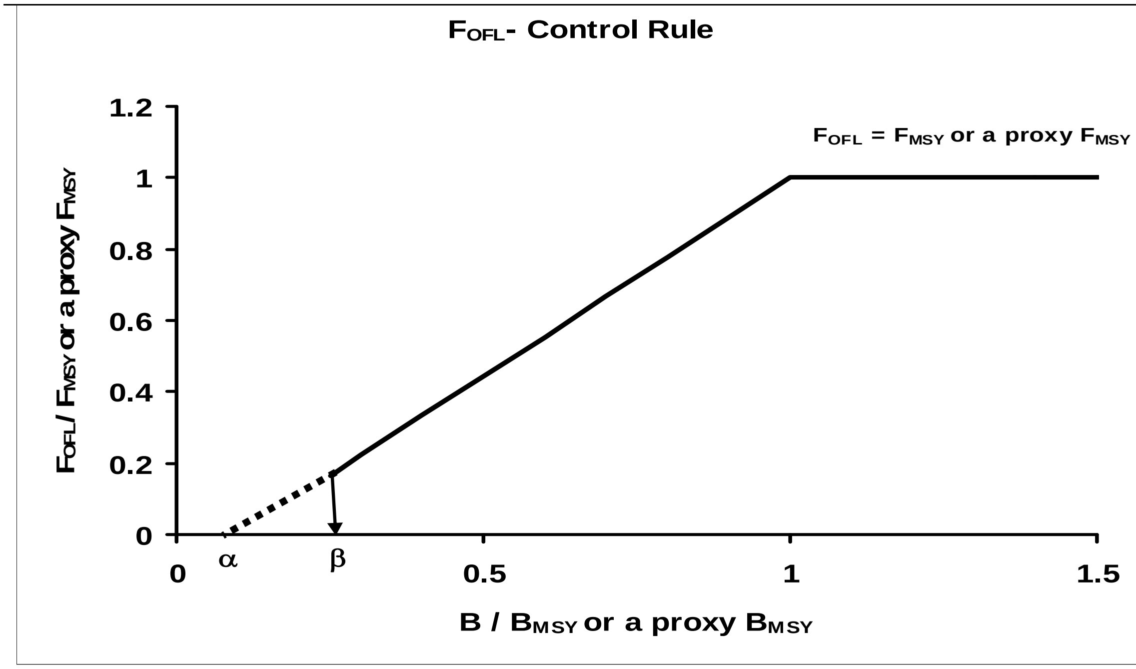

Figure 11. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

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:

$$
\begin{aligned}
P2_t^b &= P2_t\{1-[h\,H2^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
P1_t^b &= P1_t\{1-[h\,H1^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
P2_{t+1} &= P2_t^b[(1-m2_t)+m2_t\,G_{P2,P2}]e^{-M_t}+N_{t+1},\\
P1_{t+1} &= \{P1_t^b[(1-m1_t)+m1_t\,G_{P1,P1}]+P2_t^b\,m2_t\,G_{P2,P1}\}e^{-M_t},\\
R_{t+1} &= (P2_t^b\,m2_t\,G_{P2,R}+P1_t^b\,m1_t\,G_{P1,R})e^{-M_t},\\
P_{t+1} &= (P_t+R_t+P2_t^b\,m2_t\,G_{P2,P}+P1_t^b\,m1_t\,G_{P1,P})e^{-M_t}-C_t\,e^{(y_t-1)M_t},
\end{aligned}
\qquad (1)
$$

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.

Molting probability for prerecruit-1s, $m1_t$, will be modeled 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.

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:

$$
\begin{aligned}
Ln(L) = -\sum_t \{ & [\ln(P2_t QS2+1) - \ln(p2_t+1)]^2 / (2\ln(CV_{p2,t}^2+1)) \\
& + [\ln(P1_t QS1+1) - \ln(p1_t+1)]^2 / (2\ln(CV_{p1,t}^2+1)) \\
& + [\ln(R_t Q+1) - \ln(r_t+1)]^2 / (2\ln(CV_{r,t}^2+1)) \\
& + [\ln(P_t Q+1) - \ln(p_t+1)]^2 / (2\ln(CV_{p,t}^2+1)) \\
& + [\ln(P2_t s2/q+1) - \ln(ip2_t+1)]^2 / (2\ln(CV_{ip2,t}^2+1)) \\
& + [\ln(P1_t s1/q+1) - \ln(ip1_t+1)]^2 / (2\ln(CV_{ip1,t}^2+1)) \\
& + [\ln(R_t/q+1) - \ln(ir_t+1)]^2 / (2\ln(CV_{ir,t}^2+1)) \\
& + [\ln(P_t/q+1) - \ln(ip_t+1)]^2 / (2\ln(CV_{ip,t}^2+1)) + 10\eta_t^2 \},
\end{aligned}
\qquad (3)
$$

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.