DRAFT 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

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

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 were used to incorporate the entire survey data set.

SSC comments June 2008

Estimates of abundance from the annual NMFS trawl survey are available for this stock, but there are large uncertainties in the area-swept abundance estimates. Nevertheless, it is clear that the stock is currently at extremely low levels of abundance. ADF&G is developing a catch-survey analysis model, but the model has not been reviewed. The SSC agrees with the Plan Team's recommendation to place the stock in Tier 4, using area-swept survey abundance estimates averaged over the periods 1980-84 and 1990-97 as a proxy for BMSY, and a default value of gamma = 1 to determine OFL. The SSC encourages the development of the catch-survey analysis model for next year's assessment to obtain more stable abundance estimates.

There were no SSC comments specific to Pribilof blue king crab from October 2008.

Responses to SSC Comments:

- 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 blue king crab

Year	Total Catch OFL	Biomass (MMB_{mating})	TAC	Retained Catch	Total catch
2006/07	na	0.33	0	0	0.014
2007/08	na	0.66	0	0	0.014
2008/09	0.004	0.25*	0	X	X
2009/10	X	X*			

*projected for Stock Status determination

Tier	4
Stock Status Level	c
F_{OFL}	0
B_{MSY}^{proxy}	X million lbs of MMB_{mating}
Years	1980 to 1984 and 1990 to 1997
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 (non-directed)

Introduction

Scientific name and description of general distribution

Blue king crab (*Paralithodes platypus*) are anomurans in the family Lithodidae which also includes the red king crab (*Paralithodes camtschaticus*) and golden or brown king crab (*Lithodes aequispinus*) in Alaska. Blue king crabs occur off Hokkaido in Japan, with disjunct populations occurring in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are known from the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and the outer parts of Norton Sound. In the remainder of the Bering Sea, they are found in the waters off St. Matthew Island and the Pribilof Islands. In more southerly areas as far as southeastern Alaska in the Gulf of Alaska, blue king crabs are found in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). This disjunct, insular distribution of blue king crab relative to the similar but more broadly distributed red king crab is likely the result of post-glacial period increases in water temperature that have limited the distribution of this cold-water adapted species (Somerton 1985). Factors that may be directly responsible for limiting the distribution include the physiological requirements for reproduction, competition with the more warm-water adapted red king crab, exclusion by warm-water predators, or habitat requirements for settlement of larvae (Somerton 1985; Armstrong et al 1985, 1987).

Description of management units

During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab were managed under the Bering Sea king crab Registration Area Q Pribilof District, which has as its southern boundary a line from 54° 36’ N lat., 168° W long., to 54° 36’ N lat., 171° W long., to 55° 30’ N lat., 171° W. long., to 55° 30’ N lat., 173° 30’ E long., as its northern boundary the latitude of Cape Newenham (58° 39’ N lat.), as its eastern boundary a line from 54° 36’ N lat., 168° W long., to 58° 39’ N lat., 168° W long., to Cape Newenham (58° 39’ N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008)

(Figure 2). In the Pribilof District, blue king crab occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

Stock structure

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

Life history

Blue king crab are similar in size and appearance, except for color, to the more widespread red king crab, but are typically biennial spawners with lesser fecundity and somewhat larger sized (*ca.* 1.2 mm) eggs (Somerton and Macintosh 1983; 1985; Jensen et al. 1985; Jensen and Armstrong 1989; Selin and Fedotov 1996). Red king crab are annual spawners with relatively higher fecundity and smaller sized (*ca.* 1.0 mm) eggs. Blue king crab fecundity increases with size, from approximately 100,000 embryos for a 100-110 mm CL female to approximately 200,000 for a female >140-mm CL (Somerton and MacIntosh 1985). Blue king crab have a biennial ovarian cycle with embryos developing over a 12 or 13-month period depending on whether or not the female is primiparous or multiparous, respectively (Stevens 2006a). Armstrong et al. (1985, 1987), however, estimated the embryonic period for Pribilof blue king crab at 11-12 months, regardless of previous reproductive history and Somerton and MacIntosh (1985) placed development at 14-15 months. It may not be possible for large female blue king crabs to support the energy requirements for annual ovary development, growth, and egg extrusion due to limitations imposed by their habitat, such as poor quality or low abundance of food or reduced feeding activity due to cold water (Armstrong et al. 1987, Jensen and Armstrong 1989). Both the large size reached by Pribilof Islands blue king crab and the generally high productivity of the Pribilof area, however, argue against such environmental constraints. Development of the fertilized embryos occurs in the egg cases attached to the pleopods beneath the abdomen of the female crab and hatching occurs February through April (Stevens 2006b). After larvae are released, large female Pribilof blue king crab will molt, mate, and extrude their clutches the following year in late March through mid April (Armstrong et al. 1987).

Female crabs require an average of 29 days to release larvae, and release an average of 110,033 larvae (Stevens 2006b). Larvae are pelagic and pass through four zoeal larval stages which last about 10 days each, with length of time being dependent on temperature; the colder the temperature the slower the development and vice versa (Stevens et al 2008). Stage I zoeae must find food within 60 hours as starvation reduces their ability to capture prey (Paul and Paul 1980) and successfully molt. Zoeae consume phytoplankton, the diatom *Thalassiosira* spp. in particular, and zooplankton. The fifth larval stage is the non-feeding (Stevens et al. 2008) and transitional glaucothoe stage in which the larvae take on the shape of a small crab but retain the ability to swim by using their extended abdomen as a tail. This is the stage at which the larvae searches for appropriate settling substrate, and once finding it, molts to the first juvenile stage and henceforth remains benthic. The larval stage is estimated to last for 2.5 to 4 months and larvae metamorphose and settle during July through early September (Armstrong et al. 1987, Stevens et al. 2008).

Blue king crab molt frequently as juveniles, growing a few mm in size with each molt. Unlike red king crab juveniles, blue king crab juveniles are not known to form pods. Female king crabs typically reach sexual maturity at approximately five years of age while males may reach maturity one year later, at six years of age (NPFMC 2003). Female size at 50% maturity for Pribilof blue king crab is estimated at 96-mm carapace length (CL) and size at maturity for males, as estimated from size of chela relative to CL, is estimated at 108-mm CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for those males larger than 100 mm CL (NOAA 2005).

Longevity is unknown for the species, due to the absence of hard parts retained through molts with which to age crabs. Estimates of 20 to 30 years in age have been suggested (Blau 1997). Natural mortality for male Pribilof blue king crabs has been estimated at 0.34-0.94 with a mean of 0.79 (Otto and Cummiskey 1990) and a range of 0.16 to 0.35 for Pribilof and St. Matthew Island stocks combined (Zheng et al. 1997). An annual natural mortality of 0.2 for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek at al 2002).

Fishery

Description of fishery

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

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

Information on bycatch and discards

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

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

Summary of historical catch distributions

The king crab fishery in the Pribilof District began in 1973 with a reported catch of 1.3 million pounds by eight vessels. Landings increased during the 1970s and peaked at a harvest of 11.0 million pounds in the 1980/81 season with an associated increase in effort to 110 vessels (ADF&G 2008). A decline in landings followed, and by 1988 the fishery was closed. In 1993 new regulations set pot limits based on vessel length for crab fisheries in the Bering Sea. In the Pribilof District pot limits were set at 50 pots for vessels over 125 feet overall length and 40 pots for vessels at or under 125 feet in overall length.

In 1995, an increase in blue king crab abundance and a continued harvestable surplus of red king crabs resulted in a combined red and blue king crab GHL of 2.5 million pounds (ADF&G 2008). The fishery was reopened and a total of 1,154,386 pounds was landed in that year. Following 1995, declines in the stock resulted in a closure from 1999 to present. The Pribilof blue king crab stock was declared overfished in September of 2002 and the Alaska Department of Fish and Game developed a rebuilding harvest strategy as part of the North pacific Fisheries Management Council's (NPFMC) comprehensive rebuilding plan for the stock (Zheng and Pengilly 2003).

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

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

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

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 1, Figure 6). In 2009, Pribilof Island District blue king crab were observed in

X of the X 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 X station north of St. Paul Island with a density of X crab/nm^2 (Figure 8). The 2009 abundance estimate of legal sized males X from 2008 to X ± X million crab, well below the average of 0.6 million crab for the previous 20 years.

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 1973/1974 to 2008/2009 (Table 2; Figures 9 and 10; Bowers et al. 2008), including the 1973/1974 to 1987/1988 and 1995/1996 to 1998/1999 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons blue king crab and red king crab were fished under the same Guideline Harvest Level (GHL). There was no GHL and therefore zero retained catch in the 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 (Figure 11). Catch weight (lbs) was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was calculated from length frequency tables where the CL (mm) was converted to g (see equation 3: males: A=0.000329, B=3.175; females: A=0.114389, B=1.9192), multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 4).

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

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

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 1996/1997 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 3, Bowers et al. 2008) although data may be incomplete for some of these fisheries. Prior to 1998, limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here. In 2009, X, X, and X million lbs of sublegal males, legal males, and females, respectively, were incidentally caught in the Tanner crab fishery (Table 3).

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

The 2008/2009 NOAA Fisheries Regional Office assessments of non-retained catch from all groundfish fisheries are included in this SAFE report (Figure 12; J. Mondragon, NMFS, personal communication). Groundfish catches of crab are reported for all males and females combined by federal reporting areas. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 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 3). In 2008/2009, X million lbs of male and female blue king crab were caught in groundfish fisheries which is the same as the estimate of non-retained crab catch in 2006/2007 groundfish fisheries. In the groundfish fisheries, 98% of the non-retained crab catch occurred in the Pacific cod pot fishery followed by 1% in the yellowfin sole trawl fishery, <1% in the flathead trawl fishery, and <1% in the Pacific cod longline fishery.

Analytic Approach

Although a catch survey analysis has been used for assessing the stock in the past, the OFL control rule and OFL determination in 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 author, the Crab Plan Team, and the Science and Statistical Committee all recommend that this stock should be classified as a Tier 4 stock for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008).

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

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

In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} (Figure 13) to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure 13) where Stock Status Level (level a, b or c; equations 5-7) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

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

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

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

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

where,

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

B_{MSY}^{prox} for the 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 2008.

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

Projected MMB_{Mating} =

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

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

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

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

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

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

μ_{LMB} = [Total LMB retained and non-retained catch] / $LMB_{Fishery}$ (11)

μ_{MMB} = [Total MMB retained and non-retained catch] / $MMB_{Fishery}$ (12)

OFL Control Rule and Determination Results

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. $B_{MSY}^{prox}{}_2$=X 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 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, [$B/B_{MSY}^{prox}{}_1$=0.03, F_{OFL}=0.00] and [$B/B_{MSY}^{prox}{}_2$=0.05, F_{OFL}=0.00]. For both biomass reference options B/B_{MSY}^{prox} is $< \beta$, therefore the stock status level is c, $F_{directed} = 0$, and $F_{OFL} \leq F_{MSY}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). If $F_{MSY} = M = 0.18$ then the maximum total catch OFL is 0.36 million lbs at the time of the fishery and 0.34 million pounds at the time of mating. Alternative total catch OFL calculations were explored to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality. The first alternative was to set the total catch OFL at the maximum non-directed total catch mortality in the past 10 years which was 0.016 million lbs in 1999/2000. The second alternative recommendation was a total catch OFL equivalent to the 2007/2008 proportion of total crab catch mortalities to the 2007/2008 survey total crab biomass estimate applied to the 2008/2009 survey total crab biomass estimate. This was 0.02 million lbs of crab which reflects the increase in total Pribilof Island blue king crab due to survey increases in female crab. The third and preferred alternative was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/2006 which was 0.004 million lbs. This period was after a targeted fishery and did not include the most recent 2006/2007 and 2007/2008 changes to the groundfish fishery that led to increased blue king crab bycatch. Appendix 2 is a final alternative to calculate a total catch OFL using a surplus yield estimate for Pribilof Islands blue king crab revealing that losses to natural mortality (and any other losses not accounted for by the catch estimates) over the period considered in the analyses exceeded recruitment during this period.

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

Projected Total Catch OFL (non-directed only)	**X million lbs**
Projected MMB_{mating} (for Stock Status determination)	**X million lbs**
Projected MMB_{mating} (with non-directed mortality)	**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 Stock

1) Prey availability/abundance trends

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

2) Predator population trends

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

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

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

Coincident with the stock decline of Pribilof blue king in the early 1980s, the abundance of cod and flatfishes increased dramatically in the late 1970s and early 1980s and has generally been high ever since; the influx of rock sole in the Pribilof Islands area has been particularly high (NPFMC 2003). A cause and effect relationship between the decline in Pribilof blue king crab stock and the increase in the stocks of groundfish that are predators of and competitors with blue king crab remains speculative, however. Time series analysis of year classes of blue king crab and selected EBS fish stocks (Pacific cod, yellowfin sole, rockfish) have not revealed any correlation between groundfish predation or competition and the decline in blue king crab stocks (Zheng and Kruse 2000).

Mortality is also ascribed to ghost fishing of lost crab pots and groundfish pots. The term ghost fishing describes continued fishing by lost or derelict gear. Crab caught in ghost or lost pots may die of starvation; however, the impact of ghost fishing on crab stocks remains unknown. To reduce starvation mortality in lost pots, crab pots have been required to be fitted with degradable escape mechanisms such as cotton thread or twine since 1977. Pots without escape mechanisms could continue to catch and kill crabs for many years and High and Worlund (1979) estimated an effective fishing life of 15 years for king crab pots. Testimony from crabbers and pot manufacturers indicate that all pots currently fished in Bering Sea crab fisheries contain escape mechanisms (NPFMC 2007).

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

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

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

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

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

4) Disease

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

Fishery Effects on the Ecosystem

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

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

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

2) Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components.

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

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

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

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

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

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

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

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

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

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

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

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

	Retained catch		
	OA/IFQ 10^6 lbs	CDQ 10^6 lbs	Total 10^6 lbs
1973/1974	1.277		1.277
1974/1975	7.107		7.107
1975/1976	2.434		2.434
1976/1977	6.611		6.611
1977/1978	6.457		6.457
1978/1979	6.396		6.396
1979/1980	5.995		5.995
1980/1981	10.970		10.970
1981/1982	9.081		9.081
1982/1983	4.405		4.405
1983/1984	2.193		2.193
1984/1985	0.307		0.307
1985/1986	0.528		0.528
1986/1987	0.259		0.259
1987/1988	0.701		0.701
1988/1989			
1989/1990			
1990/1991			
1991/1992			
1992/1993			
1993/1994			
1994/1995			
1995/1996	1.385		1.385
1996/1997	0.937		0.937
1997/1998	0.512		0.512
1998/1999	0.518		0.518
1999/2000			
2000/2001			
2001/2002			
2002/2003			
2003/2004			
2004/2005			
2005/2006			
2006/2007			
2007/2008			

Table 3. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2008; D. Barnard and D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Discard/bycatch				
	All EBS Pot Fisheries				Groundfish Fisheries
	Legal non-retained 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					0.149
1992/1993					0.209
1993/1994					0.070
1994/1995					0.008
1995/1996					0.006
1996/1997		0.0018		0.0018	0.004
1997/1998					0.048
1998/1999	0.0051	0.0010	0.0082	0.0143	0.010
1999/2000	0.0077	0.0095	0.0043	0.0215	0.009
2000/2001					0.005
2001/2002					0.013
2002/2003					0.001
2003/2004					0.001
2004/2005					0.002
2005/2006			0.0001	0.0001	0.003
2006/2007			0.0002	0.0002	0.027
2007/2008			0.0003	0.0003	0.027

Table 4. Ecosystem effects on Pribilof blue king crab

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton, phytoplankton, benthic infauna	Stomach contents, plankton surveys	Stable, though phytoplankton varies inter-annually	Possible concern
Predator population trends			
Marine mammals (Sea otters)	Population trends vary by location	Not likely to affect surveyed stock	No concern
Birds	NA	NA	No concern
Fish (Pollock, Pacific cod, halibut)	Stable	stable	Possible concern
Changes in habitat quality			
Temperature regime	Cold-water restricted species so warming trends could limit population	Likely to affect surveyed stock	Definite concern
Winter-spring environmental conditions	Affects larval survival	Affects timing of larval release and timing of molt intervals	Definite concern
Production	Affects larval survival	Inter-annual variability dependent on a number of climatic conditions	Definite concern

Pribilof blue king crab effects on ecosystem

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Likely minor impact	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Likely minor impact	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	No impact	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern

Fishery concentration in space and time	Low exploitation rate by predators; possible impact on fecundity	Little detrimental effect on predators; possible impact on fecundity	No concern for predators; possible concern for fecundity
Fishery effects on amount of large size target fish	High exploitation rate	Natural fluctuation	Definite concern
Fishery contribution to discards and offal production	unknown	data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	unknown	NA	Possible concern

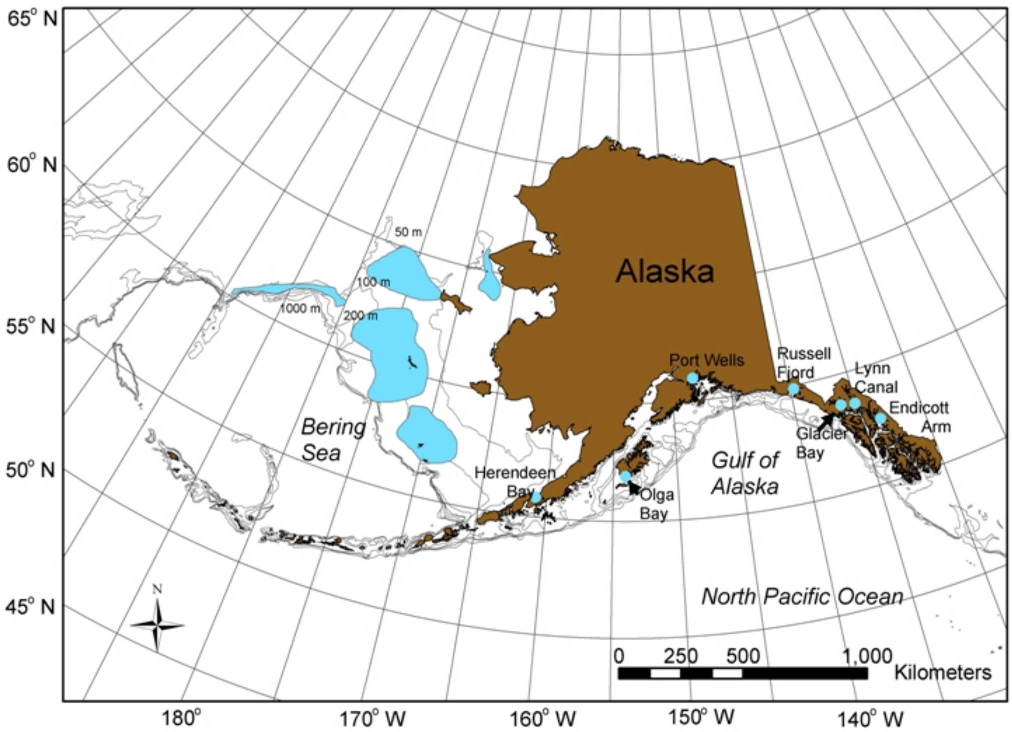

Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

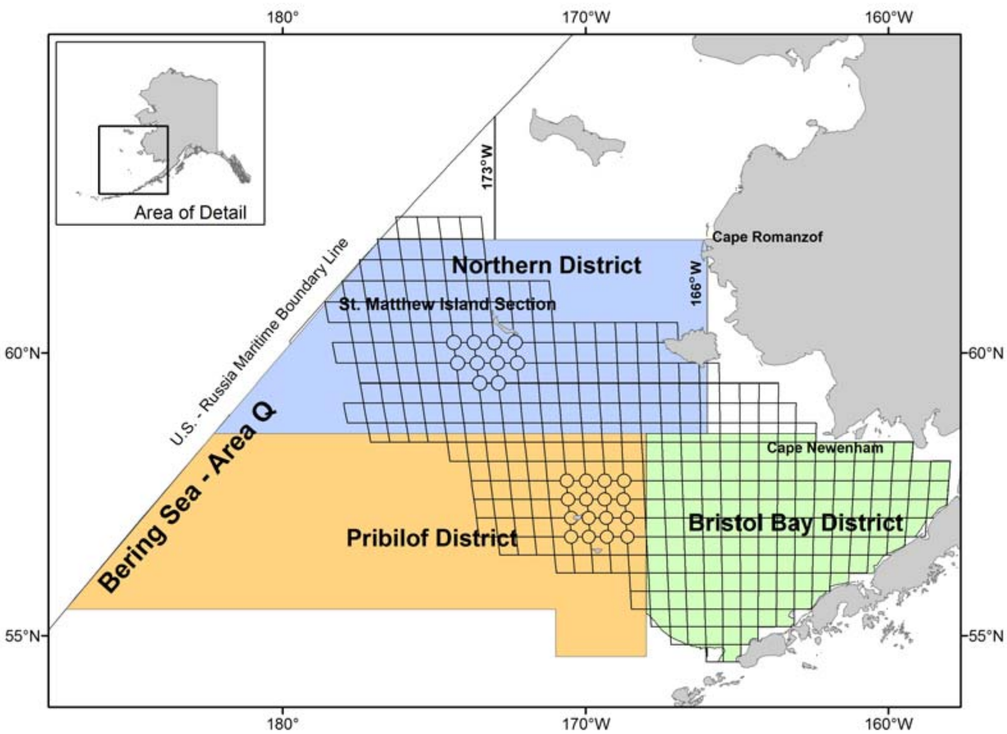

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

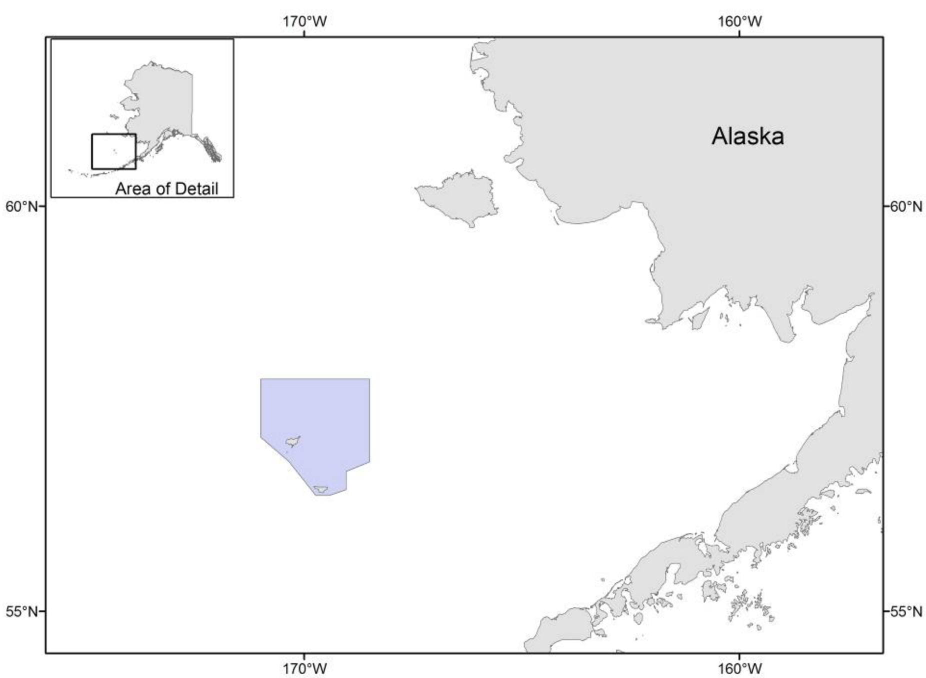

Figure 3. The Pribilof Islands Area Habitat Conservation Zone. Trawl fishing is prohibited year-round in this zone.

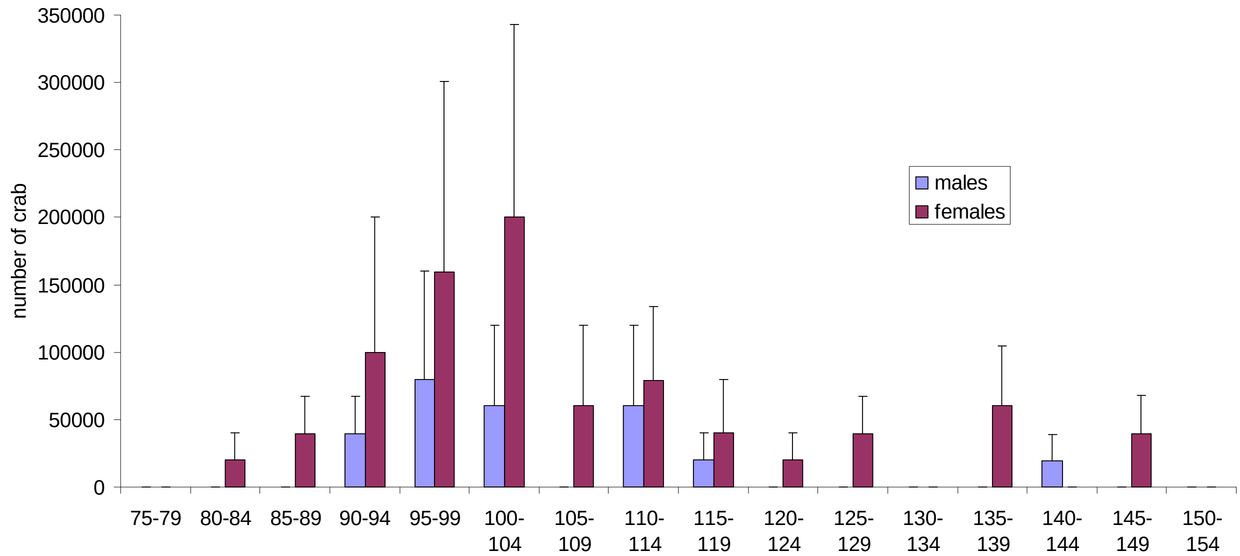

Figure 4. Distribution of average (SE) counts of Pribilof Island blue king crab in 5 mm length bins.

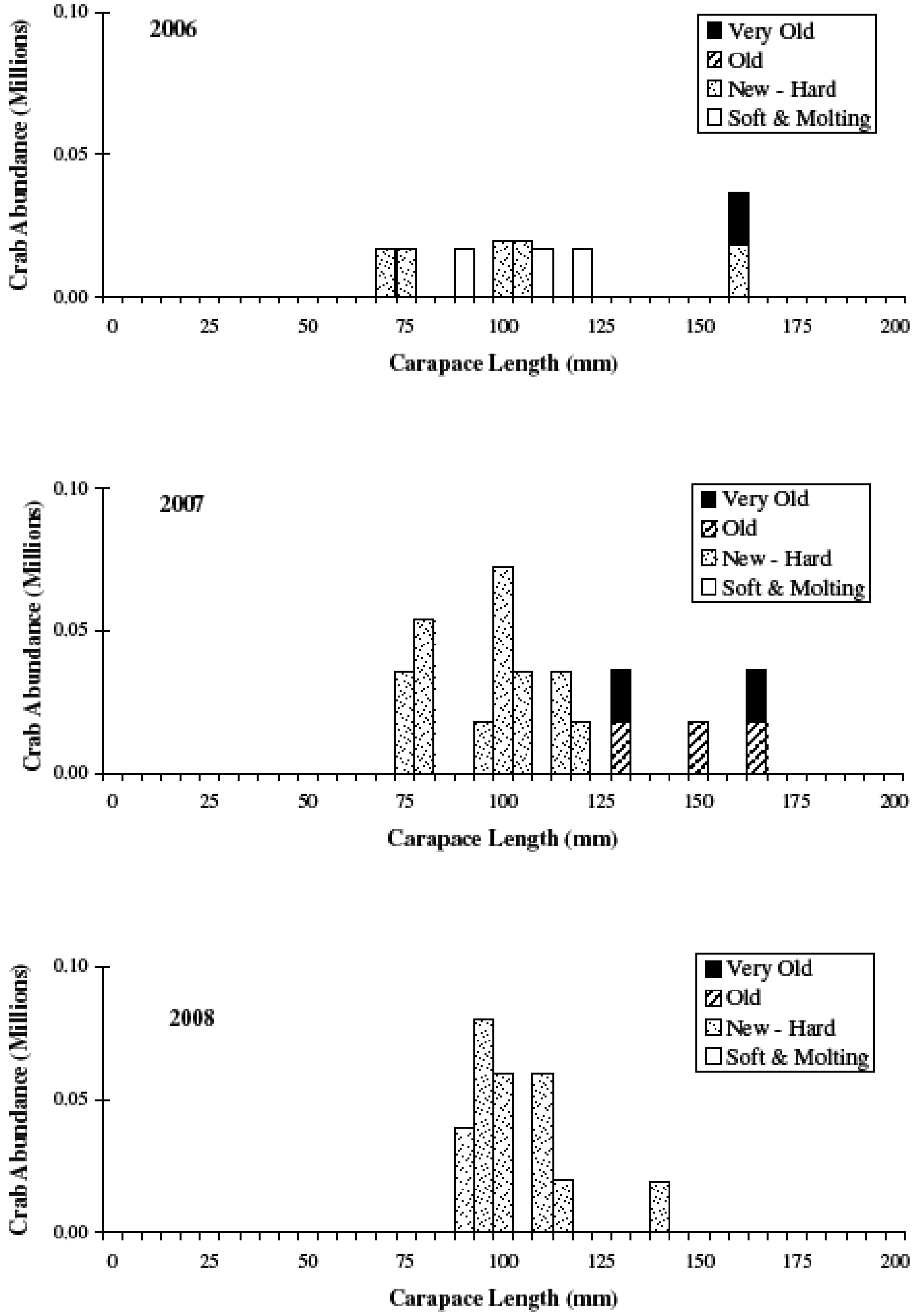

Figure 5. Distribution of average (SE) counts of Pribilof Island blue king crab in 5 mm length bins from 2006 to 2008.

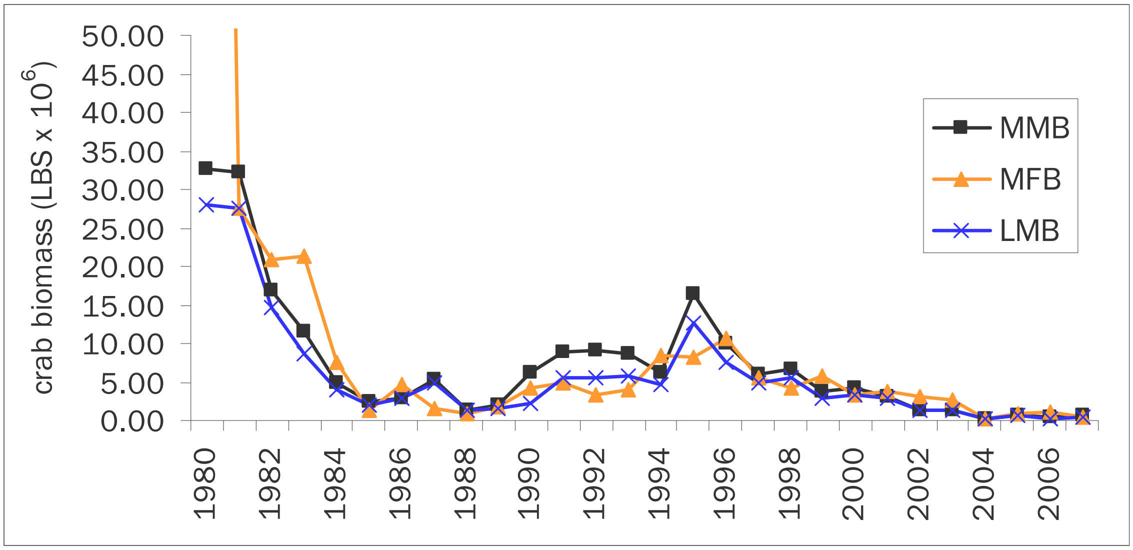

Figure 6. Historical trends of Pribilof Island blue king crab mature male biomass, mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

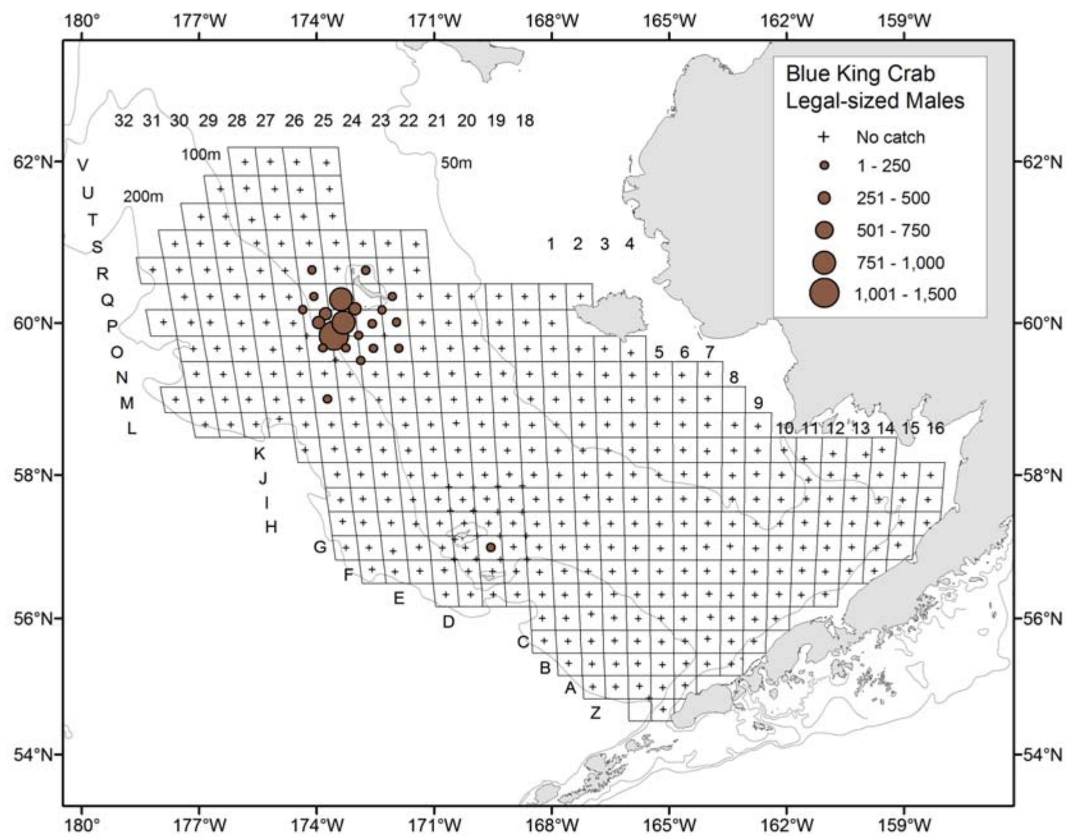

Figure 7. Location and relative abundance of blue king crab in the eastern Bering Sea (2008 NMFS bottom trawl survey data).

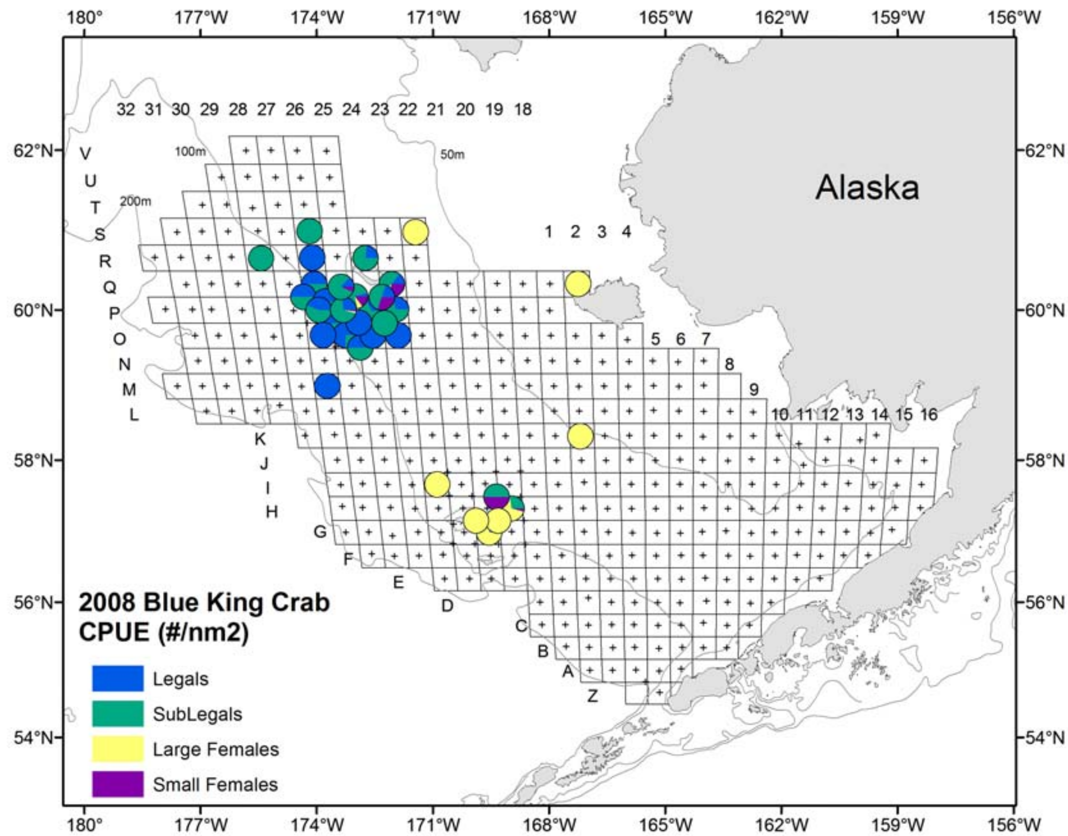

Figure 8. 2008 EBS bottom trawl survey size class distribution of blue king crab.

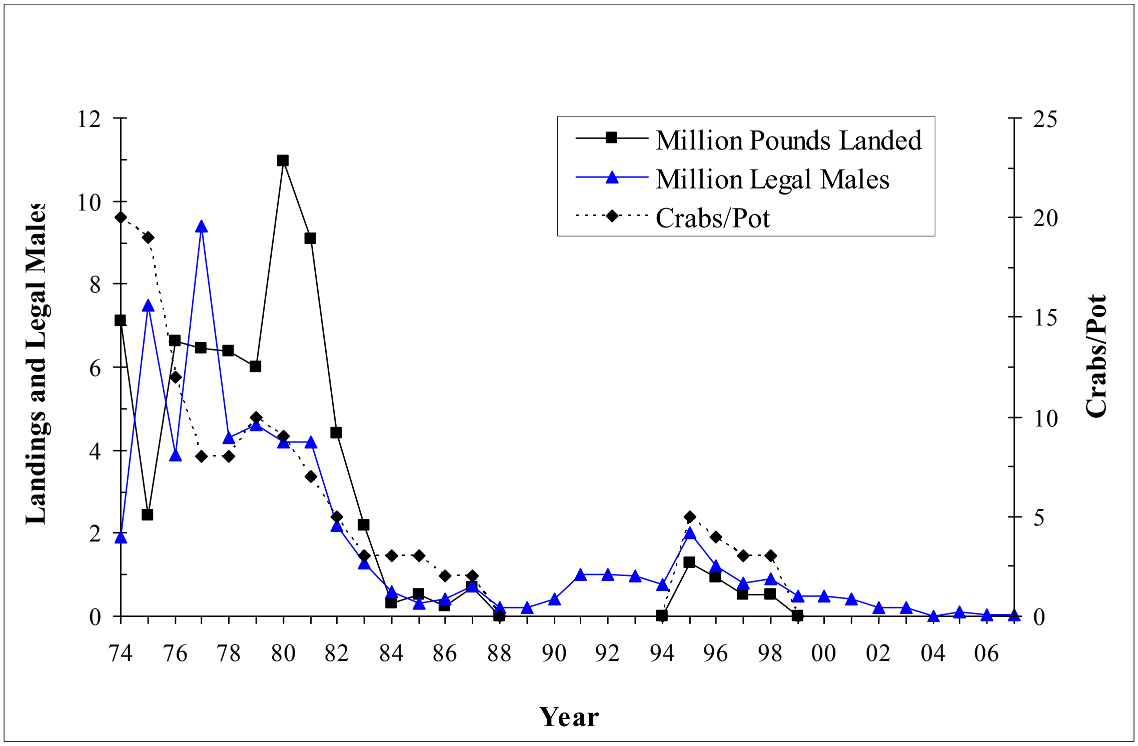

Figure 9. Historical harvests, CPUEs for Pribilof Island blue king crab (Bowers et al. 2007) and the NMFS EBS bottom trawl survey trends in legal male abundance.

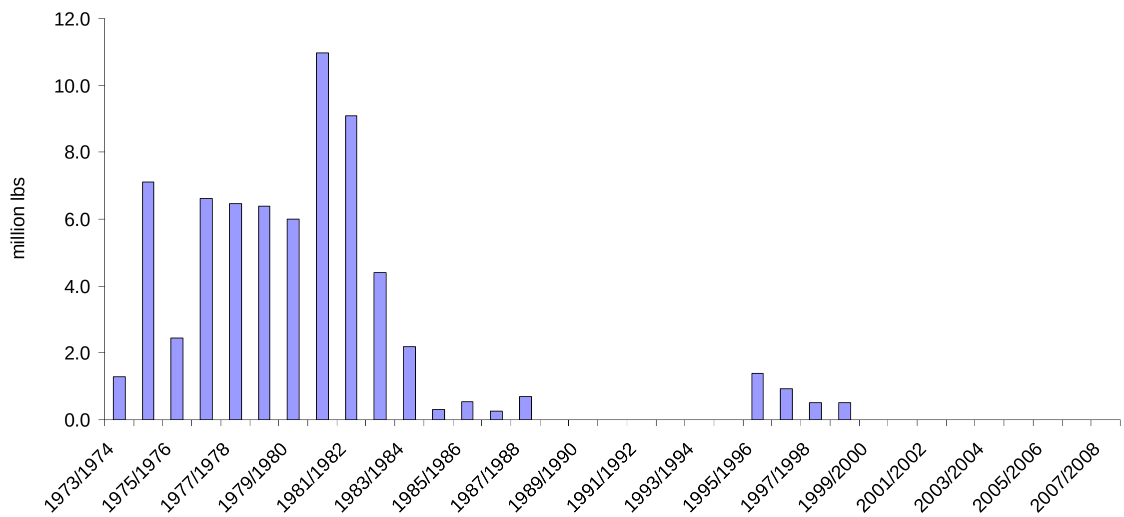

Figure 10. Retained catches from directed fisheries for Pribilof Islands District blue king crab

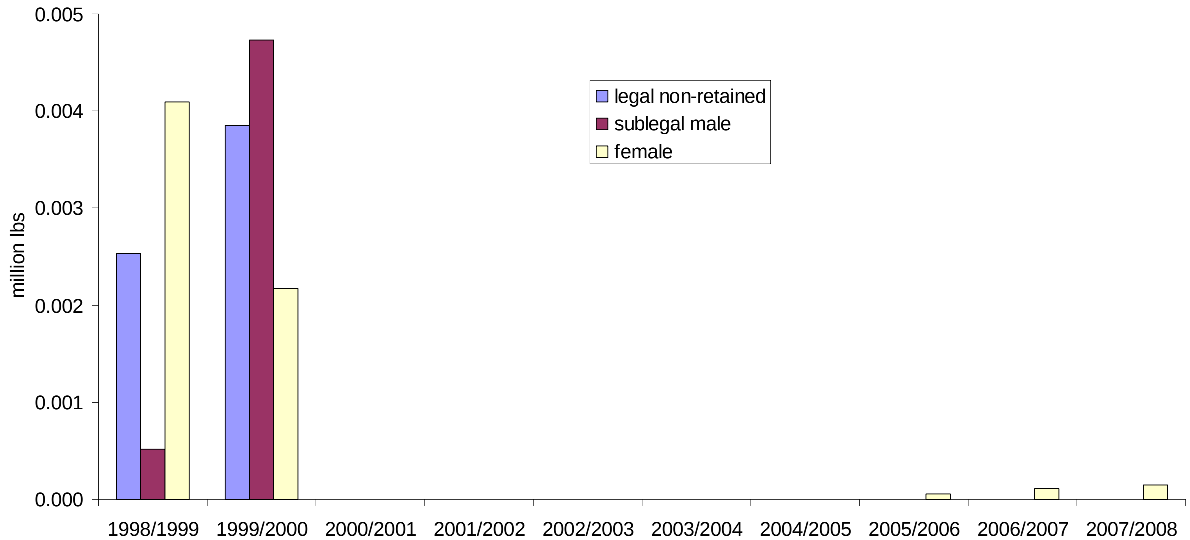

Figure 11. Non-retained catches from directed and non-directed fisheries for Pribilof Islands District blue king crab.

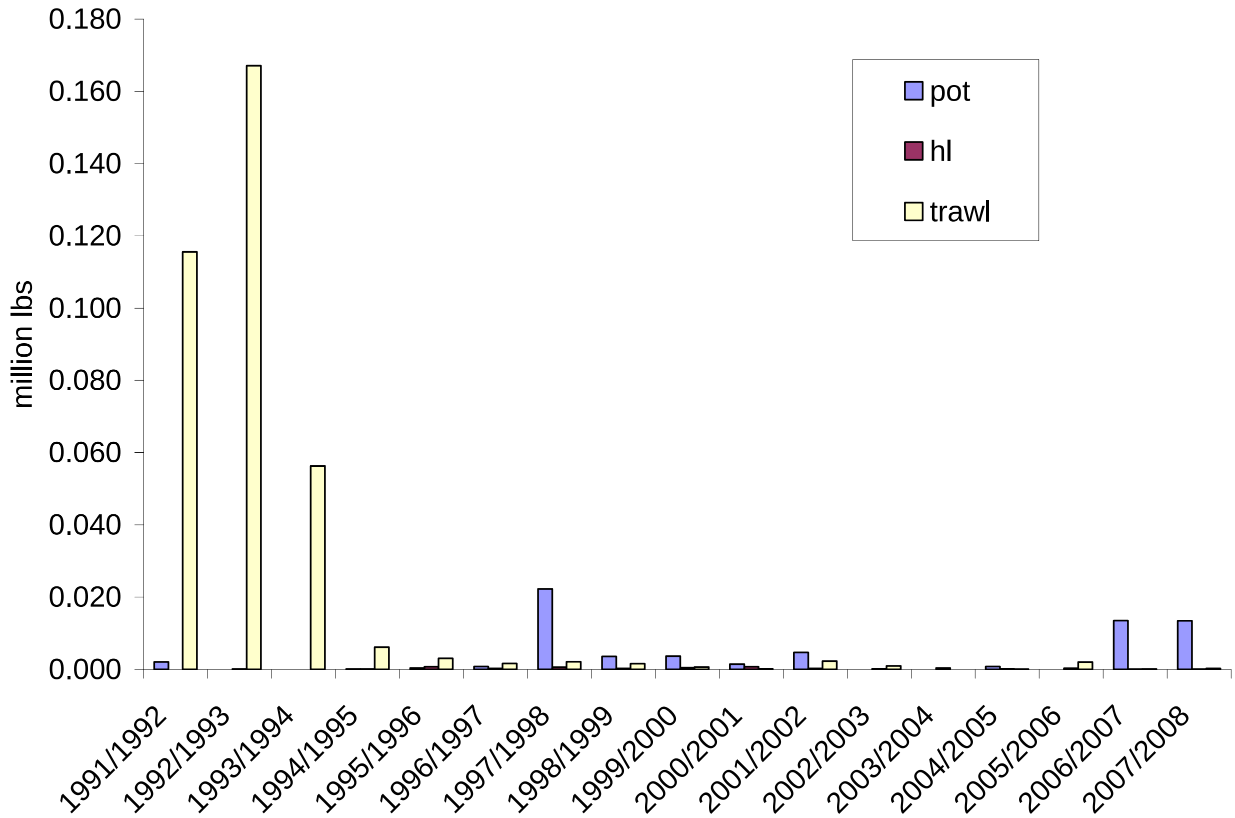

Figure 12. Catch mortalities from non-directed groundfish fisheries for Pribilof Islands District blue king crab in federal reporting area 513. Data for both golden king crab and blue king crab are combined from 1991/1992 to 2002/2003 and then only blue king crab are presented from 2003/2004 to 2007/2008. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the total catches.

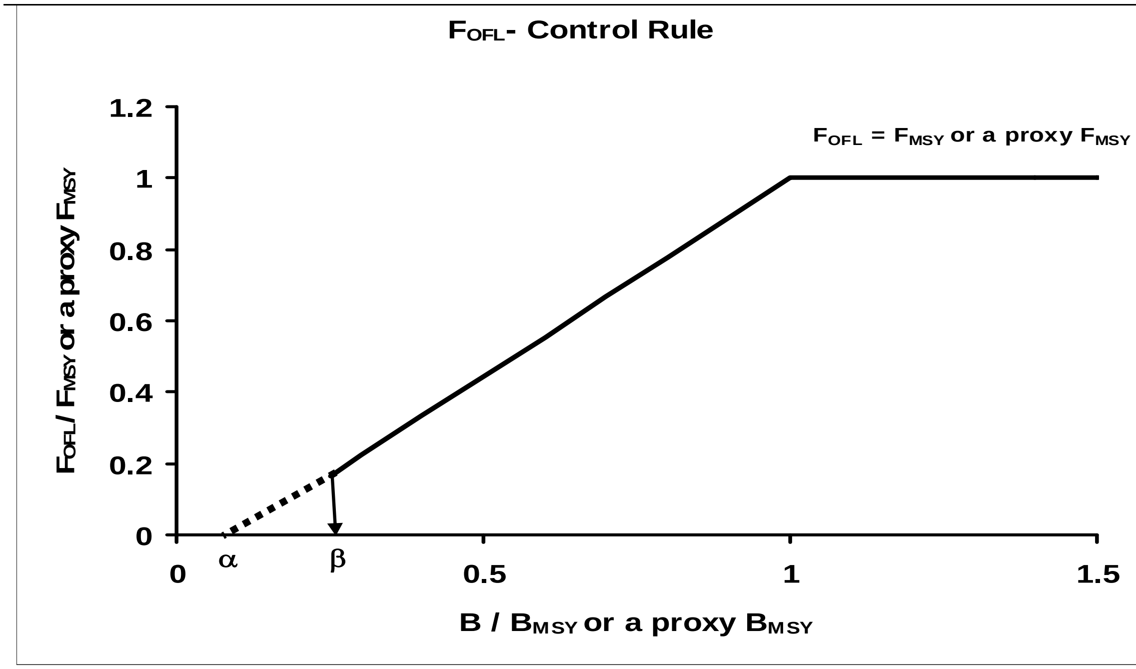

Figure 13. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

Appendix 1. 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:

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

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:

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

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 2. 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:

$$B_{t+1} = B_t + P_t - C_t \qquad (1)$$

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:

$$\hat{P} = \overline{(B_{t+1} - B_t)} - \overline{C}_t \qquad (2)$$

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