

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:

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

Responses to SSC Comments:

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

Summary

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

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

*projected

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

Introduction

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

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Unlike brachyurans, red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts and copulation occurs within hours. During copulation, the male inverts the female so they are abdomen to abdomen then the male extends his fifth pair of pereopods 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 coxopods of the third pereopods. 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 $<125 \text{ mm CL}$. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and will be changed to 0.18 with Amendment 24.

The reproductive cycle of Pribilof Islands red king crabs has not been established, however in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous Bristol Bay red king crab females (brooding their first egg clutch) extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990) resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for eastern Bering Sea red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age, during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment is on average 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

Fishery

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the State 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. 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 GHGs 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 GHG. The combined red and blue king crab GHGs from 1996 through 1998 were 2.5, 1.8, 1.5, and 1.25 million lbs and corresponding red king crab harvests were 0.87, 0.20, 0.76, 0.51 million lbs (Bowers et al. 2008). From 1999 to 2006/07 the Pribilof fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof blue king crab was declared overfished in September of 2002 and is still considered overfished (Bowers et al. 2008).

The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof red and blue king crab fisheries which was implemented in 1998. The Alaska Department of Fish and Game manages the crab CDQ fisheries and the Central Bering Sea Fishermen's Association (CBSFA) is allocated 100% of the Pribilof red and blue king crab. Due to fishery closures, Pribilof red king crab were only harvested under a CDQ in 1998 where 3.5% of the overall GHG 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 2) 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° longitude (the fishery was closed from 1997-2004). ADF&G observers recorded 1.0 red king crab per sampled pot during the 2005/2006 fishery, but only 0.08 during the 2006/2007 fishery (Barnard and Burt 2007, 2008). The Bering Sea hair crab fishery has been closed since 2001, and the Pribilof blue king crab fishery has been closed since 1999. In addition, Pribilof red king crab catch has been limited in groundfish trawl fisheries since 1995 because of the Pribilof Islands Habitat Conservation Area trawl closure. Non-directed catch still exists in groundfish pot and hook and line fisheries (see 2008 Data).

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

catches, followed by the areas southeast, west and southwest of the Island (personal communication, Robert K. Gish, ADFG).

2008 Data

Survey Data

The 2008 NOAA Fisheries EBS bottom trawl survey results (Chilton et al. in press) are included in this SAFE report. Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock. Weight (equation 1) and maturity (equation 2) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass (million lbs).

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

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

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 1). In 2008, Pribilof Islands District red king crab were observed in eight of the 41 stations in the Pribilof District high-density sampling area (Chilton et al. in press). The density of legal-sized males (>138 mm CL) caught at a station ranged from 71 to 1,666 crab/nm². 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.

Fishery Data-ADF&G pot fisheries

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

Retained pot fishery catches (live and deadloss landings data) are provided for 1993/1994 to 1998/1999 (Table 2 and 3; Bowers et al. 2008), the seasons when red king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons red king crab and blue king crab were fished under the same Guideline Harvest Level (GHL). There was no GHL and therefore zero retained catch in the 2007/2008 fishing season.

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

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

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

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

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 4, Bowers et al. 2008) although data may be incomplete for some of these fisheries. Prior to 1998 limited observer data exists for catcher-processor vessels only so non-retained catch before this date is not included here. In 2008, 0.003, 0.004, and 0.005 million lbs of sublegal males, legal males, and females, respectively, were incidentally caught in the Tanner crab fishery (Table 4).

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

The 2007/2008 NOAA Fisheries Regional Office (J. Mondragon, NMFS, personal communication) assessments of non-retained catch from all groundfish fisheries are included in this SAFE report. Groundfish catches of crab are reported for all male and female combined by federal reporting areas. For Pribilof Islands red king crab, Areas 513 and 521 are included. It is noted that due to the extent of Area 513 into the Bristol Bay District, groundfish non-retained crab catches for Pribilof Islands red king crab may be overestimated. Current efforts are underway to provide data on a more fine spatial scale to correct this error. To estimate sex ratios for 2008 catches, sex ratios by size and sex from the 2008 EBS bottom trawl survey were applied. To assess crab mortalities in these groundfish fisheries a 50% handling mortality rate was applied to pot and hook and line estimates and an 80% handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been discriminated by each year's survey proportions (Table 4). In 2007/2008, 0.011 million lbs of male and female red king crab were caught in groundfish fisheries which is lower than the 0.037 million lb estimate of non-retained crab catch in 2006/2007 pot, trawl, and hook and line groundfish fisheries.

Analytic Approach

Although a catch survey analysis has been used for assessing the stock in the past, the OFL control rule and OFL determination in 2008 were based on MMB at mating relative to the EBS bottom trawl survey and incorporated commercial catch and at-sea observer data. Based on available data, the author, the Crab Plan Team, and the Science and Statistical Committee all recommend that this stock should be classified as a Tier 4 stock for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008).

Tier 4 stocks are characterized as those where essential life-history and recruitment information are lacking. Although a full assessment model cannot be specified for Tier 4 stocks, or stock-recruitment relationship defined, sufficient information is available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Reliable estimates of current survey biomass, instantaneous M, and historical fishery and survey

performance are explicit in a Tier 4 assessment. This approach provides the annual status determination criteria to assess stock status and to establish harvest control rules.

In Tier 4, Maximum Sustainable Yield is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, environmental conditions and fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets. In Tier 4, the fishing mortality that, if applied over the long-term, would result in MSY is approximated by F_{MSY}^{proxy} . The MSY stock size (B_{MSY}) is based on mature male biomass (MMB) at mating which serves as an approximation for egg production. MMB 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.

In the Tier 4 OFL-setting approach, the “total catch OFL” and the “retained catch OFL” are calculated by applying the F_{OFL} (Figure 3) 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 3) 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}^{prox} .

$$\begin{array}{ll} \text{Stock Status Level:} & \underline{F_{OFL}}: \\ \text{a. } B/B_{MSY}^{prox} > 1.0 & F_{OFL} = \gamma \cdot M \end{array} \quad (5)$$

$$\text{b. } \beta < B/B_{MSY}^{prox} \leq 1.0 \quad F_{OFL} = \gamma \cdot M [(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)] \quad (6)$$

$$\text{c. } B/B_{MSY}^{prox} \leq \beta \quad F_{directed} = 0; F_{OFL} = F_{MSY} \quad (7)$$

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 were based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where B is greater than β includes the product of a scalar (γ) and M (equations 5 and 6) where the default γ value is 1 and M for Bering Sea red king crab is 0.18. The value of γ may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

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

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

where,

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

B_{MSY}^{prox} for the 2008 assessment was calculated as 1) the average MMB at 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 for the entire survey period 1980 to 2007.

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

Projected $MMB_{Mating} =$

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

where,

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

$PM(sm)$ is the partial M from the time of the survey to mating (8 months),

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

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

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

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

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

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

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

OFL Control Rule and Determination Results

For 2008/2009, two levels of B_{MSY}^{prox} were defined. $B_{MSY}^{prox}_1 = 8.66$ million lbs of MMB at mating derived as the mean of 1991 to 2007 and is recommended by the authors, CPT and SSC.

$B_{MSY}^{prox_2}$ =5.91 million lbs derived mean of 1980 to 2007 which was requested by the SSC for comparison purposes. The stock demonstrated highly variable levels of MMB during both of these periods likely leading to uncertain approximations of B_{MSY} . Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to a limited number of tows with crab catches.

Male mature biomass at the time of mating for 2008/2009 is estimated at 9.26 million lbs for both $B_{MSY}^{prox_1}$ and $B_{MSY}^{prox_2}$ options. The B/B_{MSY}^{prox} ratios and F_{OFLs} corresponding to the two biomass reference options are, respectively, [$B/B_{MSY}^{prox_1}=1.07$, $F_{OFL}=0.18$] and [$B/B_{MSY}^{prox_2}=1.57$, $F_{OFL}=0.18$]. For both biomass reference options B/B_{MSY}^{prox} is < 1 , therefore the stock status level is a (equation 5). For the 2008/2009 fishery, total catch OFLs were estimated at 3.32 million lbs of crab and legal male catch OFLs were estimated at 1.81 million lbs of crab for both options. The projected exploitation rates based on full retained catches up to the OFL for LMB and MMB under for both B_{MSY}^{prox} options are: 0.182 and 0.197 respectively.

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

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

Projected Total Catch OFL	3.32 million lbs
Projected MMB at Mating	9.26 million lbs
Projected Legal Male catch OFL at fishery	1.81 million lbs
Projected Exploitation Rate on MMB	0.18
Projected Exploitation Rate on LMB	0.20

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

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

Predator population trends

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

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

biomass has been in a slow decline but has remained high and stable in recent years (Wilderbuer et al. 2007).

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

Changes in habitat quality

The past decade has been warmer in the Bering Sea, however winter and spring 2007 surface air temperatures were colder than normal and 2006 was close to normal, but these cold anomalies are not in the range of pre-1977 temperatures (Wang et al. 2008). In the Bering Sea, a northward biogeographical shift is being observed in response to a retreat of cold ocean temperatures and atmospheric forcing (Overland and Stabeno 2004). Distribution changes of Pribilof Islands red king crab has not been studied, however the distribution of ovigerous red king crab in southeastern Bering Sea shifted to the northeast during the late 1970s and early 1980s and this distribution change coincided with increased early summer near-bottom temperatures (Loher and Armstrong 2005). Water temperature may be important 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 system, during low pressure the brood strength is reduced (Tyler and Kruse 1996; Zheng and Kruse 2000). Gish (2006) suggested that the lack of king crab recruitment in the Pribilof Islands area may be the result of a large-scale environmental event affecting abundance and distribution.

Ice cover has changed in the Bering Sea including the area around the Pribilof Islands. In 1972 through 1976, ice cover remained around St. Paul Island for more than a month (Schumacher et al. 2003). Spring 2007 was cold and sea ice lasted for almost 2 months just north of the Pribilof Islands which is close to normal conditions observed from 1979 through 1999 and in contrast to the warm years of 2000-2005 (Wang et al. 2008). In the Bering Sea, if seasonal ice pack were to decrease in extent or melt earlier, a shift from ice-edge blooms to later open-water blooms may cause long-term declines in sediment organic matter (Lovvorn et al. 2005). In these shelf systems, much of the production from spring blooms at the retreating ice edge sink to the bottom with little grazing by zooplankton, therefore supporting abundant benthic communities (Overland and Stabeno 2004; Lovvorn et al. 2005). The importance of this settled phytoplankton to the macrobenthos will partially determine the effects of long-term changes in ice cover (Lovvorn et al. 2005). The presence of sea ice in 2007 along with below normal ocean

temperatures likely resulted in the first ice edge bloom since 1999 (Wang et al. 2008). The changes in ice cover on the benthic community of the Pribilof Islands are not well understood.

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

Fishery Effects on the Ecosystem

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

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

The extent that pot gear impacts benthic habitat is not well know and most likely depends on the substrate. It is likely that habitat is affected during both setting and retrieval of pots, but little research has been done. There is no evidence that pot gear adversely affects mud and sandy substrates where red king crab are primarily fished (NMFS 2004). It has been estimated that for each pot set 49 ft² 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 ft² possibly impacted by pot gear which is 0.0% of the Bering Sea shelf (NMFS 2004).

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Table 1. Mature 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.

Year	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)
	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. 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	CDQ	Total
	10 ⁶ lbs	10 ⁶ lbs	10 ⁶ lbs
1979/1980			
1980/1981			
1981/1982			
1982/1983			
1983/1984			
1984/1985			
1985/1986			
1986/1987			
1987/1988			
1988/1989			
1989/1990			
1990/1991			
1991/1992			
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 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				Groundfish Fisheries Both sexes 10 ⁶ lbs
	Legal non-retained 10 ⁶ lbs	All EBS Pot Fisheries			
		Sublegal male 10 ⁶ lbs	All Female 10 ⁶ lbs	Total (all crab) 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

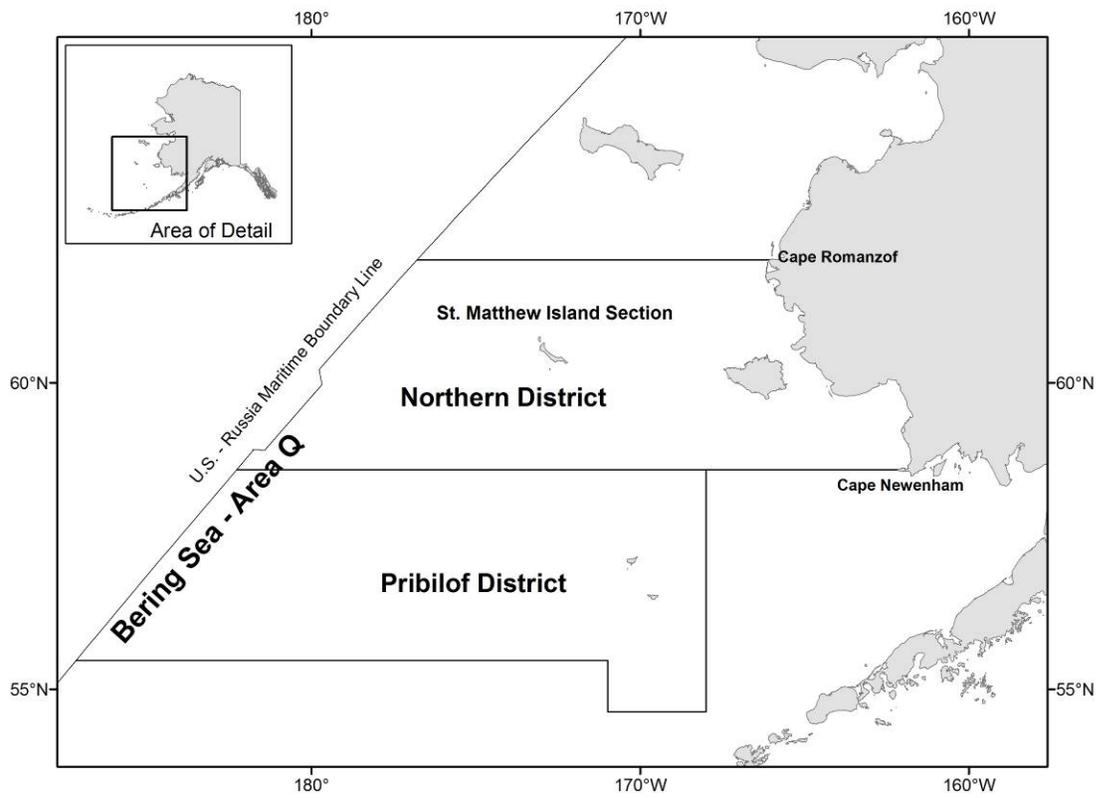


Figure 1. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

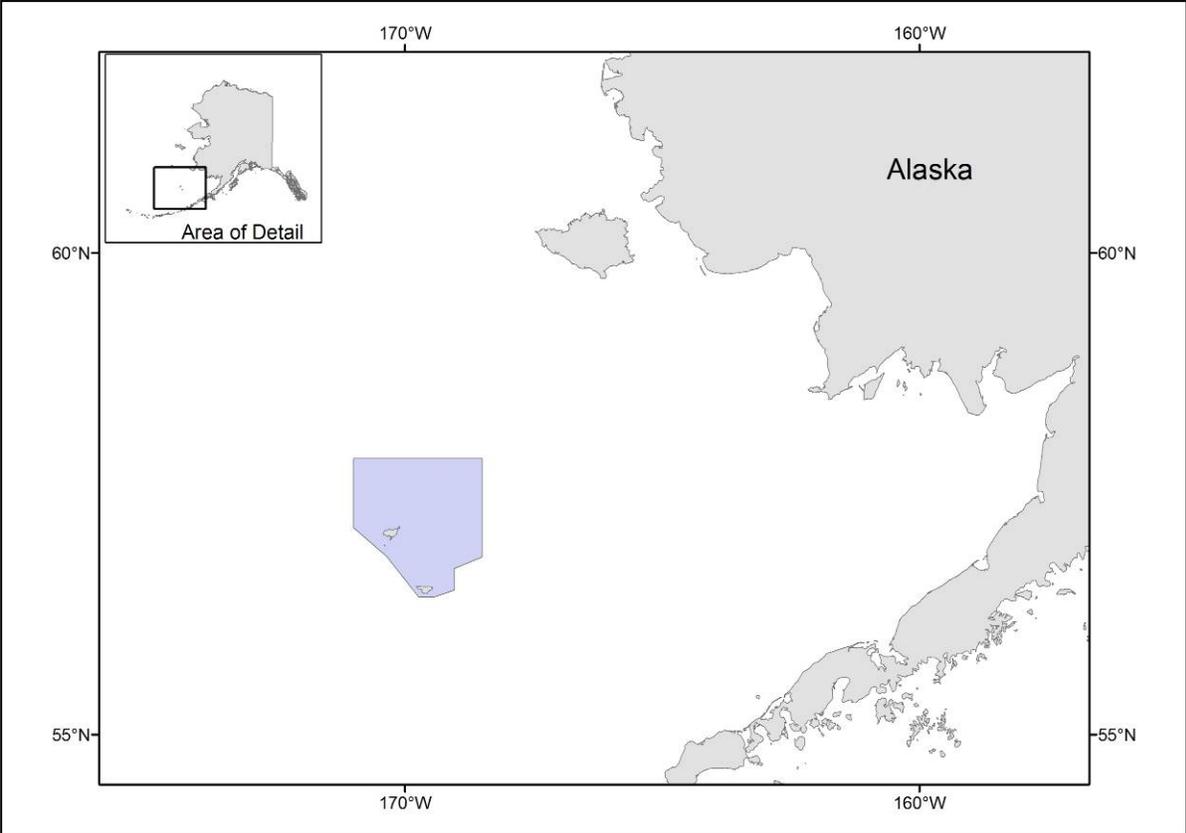


Figure 2. The shaded area shows the Pribilof Islands Habitat Conservation area

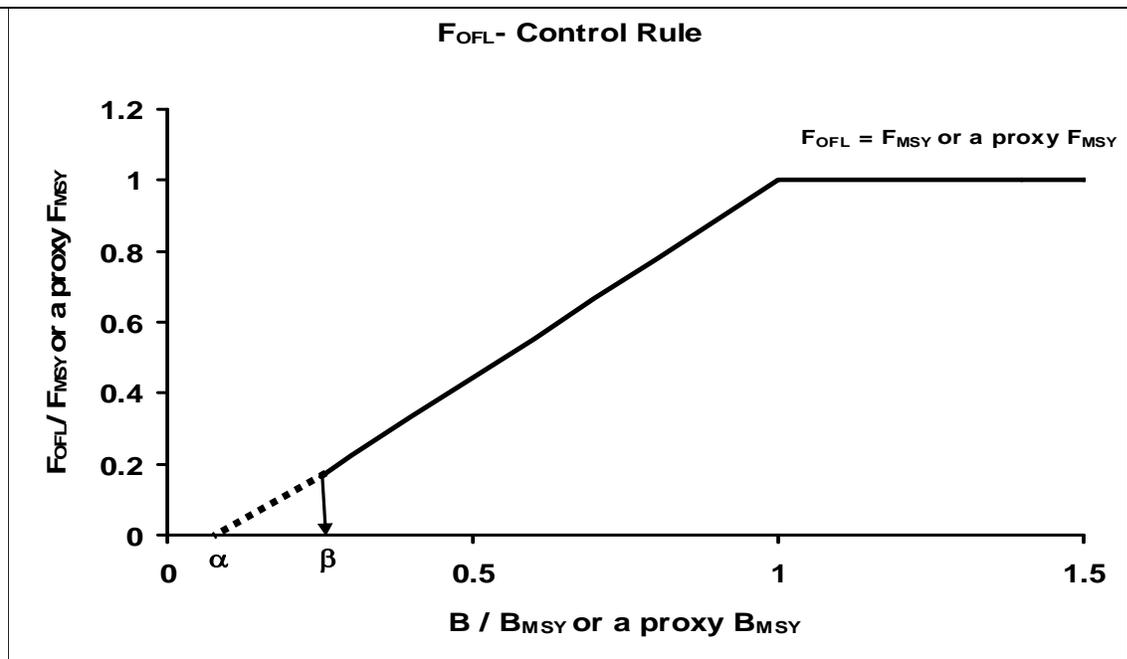


Figure 3. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β .