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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

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Introduction

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

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Unlike brachyurans, red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts and copulation occurs within hours. During copulation, the male inverts the female so they are abdomen to abdomen then the male extends his fifth pair of periopods to deposit sperm on the female's gonopores. After copulation, eggs are fertilized as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967), however Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al, (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).

Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006) and estimates vary. Siddeek et al. (2002) reviewed natural mortality estimates from various sources and summarized that natural mortality estimates based upon tag-recapture data varies from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size and that estimates based upon trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, but crabs <125 mm CL had higher natural mortality. Utilizing the same data sets, Zheng et al. (1995) concluded natural mortality is bowl shaped over length and varies over time. Using newer tag-recovery data than is reported above, Siddeek et al. (2002) estimated natural mortality of Bristol Bay red king crab males to range from 0.54 to 0.70, however they conclude that these estimates appear high considering the longevity of red king crab. Natural mortality has been set at 0.2 for Bering Sea king crab stocks (NPFMC 1998).

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 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 2007, 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 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 red king crabs (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, 2007). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment is on average 17.5 mm irrespective of size (Weber 1974).

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

Fishery

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the Sate of Alaska through a federal king and Tanner crab Fishery Management Plan (FMP) (NPFMC 1998). There is no harvest strategy for the Pribilof district red king crab fishery in State regulation. 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 due to 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 GHL of 3.4 million pounds was set and 2.6 million pounds were harvested and in 1994 the GHL was 2 million pounds and 1.3 million pounds were harvested (Table 1) (Bowers et al. 2008). Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The combined red and blue king crab GHLs from 1996 though 1998 were 2.5, 1.8, 1.5, and 1.25 million pounds and corresponding red king crab harvests were 0.87, 0.20, 0.76, 0.51 million pounds (Table 1) (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 Pribilof red and blue king crab which was implemented in 1998. The Alaska Department of Fish and Game manages the crab CDQ fisheries and the Central Bering Sea Fishermen's Association (CBSFA) is allocated 100% of the Pribilof red and blue king crab. Due to fishery closures, Pribilof red king crab were only harvested under a CDQ in 1998 where 3.5% of the overall GHL was allocated to the CDQ resulting in 35,958 pounds, harvest data is confidential due to limited participation in the fishery (Table 1) (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 the negative effects of trawl gear.

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

The highest catches of Pribilof red king crab during the last 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 to the east of St. Paul Island has had the highest catches, followed by the areas southeast, west and southwest of the Island (personal communication, Robert K. Gish, ADFG).

Pribilof Island red king crab GHL/TAC and CDQ allocations, harvests and deadloss are summarized in Table 1.

Data

Total catch for the Pribilof District red king crab fishery is summarized in Table 1 and 2. Fishing effort is summarized in Table 3 and bycatch loss is summarized in Table 4. Survey biomass estimates for mature male and female biomass and legal mal biomass are in Table 5.

Because crabs are difficult to age, length at age and weight at age information is not available. Weight at length data for eastern Bering Sea red king crab is currently being collected by NMFS Shellfish Assessment Program and results are as follows (NMFS, unpublished data):

Ovigerous females (n = 438, CL range: 79-163 mm): $W = 0.00081138 * CL^{2.697412}$

Nonovigerous females (n = 155, CL range: 18-145 mm): $W = 0.00036852 * CL^{3.081298}$

Males (n = 1026, CL range: 48-198 mm): $W = 0.00033293 * CL^{3.143922}$

Analytic Approach

Tier-4 OFL Control Rule and OFL-Determination

In the Environmental Assessment proposed as Amendment 24 to the BSAI King and Tanner Crab fishery management plan (NPFMC 2008), Tier-4 stocks are characterized as those where essential life-history information and understanding are 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. Such modeling approaches serve the basis for deriving the annual status determination criteria to assess stock status and to establish harvest control rules.

In Tier-4, a default value of M and a scaler Gamma (γ) are used in OFL setting. The proxy B_{MSY} represents the level of equilibrium stock biomass indicative of providing maximum sustainable yield (MSY) to the fisheries exploited at $F_{MSY.}$ 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}). We also consider its estimation as a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock. In Tier-4, the F_{OFL} is calculated as the product of γ and M, where M is the instantaneous rate of natural mortality. The EA defines a default value of gamma = 1.0. Gamma is allowed to be less than or greater than unity and, in such instances, the resultant overfishing limit can be more or less biologically conservative than fishing at the rate M. Use of the scaler γ is intended to allow adjustments in the overfishing definitions to account for differences in the biomass measures used in the EA analyses. However, since Tier-4 stocks are information-poor by definition, the EA states that γ should not be set to a value that would provide less biological conservation and more risk-prone overfishing definitions without defensible evidence that the stock could support fishing at levels in excess of M. The resultant overfishing limit for Tier-4 stocks is the total catch OFL that includes expected retained plus discard/bycatch losses. For Tier-4 stocks, a minimum stock size threshold (MSST) is specified; if current MMB drops below MSST, the stock is considered to be overfished.

For Tier-4 stocks, the F_{OFL} is derived using and F_{OFL} Control Rule (Figure 3) according to whether current mature stock biomass metric (B) is a member of 1 of 3 stock status levels (a, b or c) in the following algorithm. The stock biomass level beta (β) represents a minimum threshold below which directed fishing mortality is set to zero. The parameter alpha (α) moderates the slope of the non-constant portion of the control rule. For biomass levels levels $\beta < B \leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B/ B_{MSY}. The value of M is 0.23 for eastern Bering Sea Tanner crab. In the EA analysis for Tier-3 stocks (*Chionoecetes opilio* and *Paralithodes camtschaticus*), a B_{MSY} proxy reference value (B_{REF}) equal to 35% of the maximum spawning potential of the unfished stock was specified. For Tier-4 stocks, a reference biomass value (B_{REF}) must be specified. The OFL algorithm is:

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

OFL Model Structure

In this Tier-4 OFL-setting approach, LMB at the time of the fishery ($LMB_{Fishery}$) and MMB at both the time of the fishery ($MMB_{Fishery}$) and mating (MMB_{Mating}) are estimated as:

$$LMB_{Fishery} = LMB_{Survey} \cdot e^{-PM(sf)} \quad (1)$$

$$MMB_{Fishery} = MMB_{Survey} \cdot e^{-PM(sf)} \quad (2)$$

$$MMB_{Mating} = MMB_{Survey} \cdot e^{-PM(sf)} \quad (3)$$

where,

LMB_{Survey} is the legal male biomass at the time of the survey,

$LMB_{Fishery}$ is the legal male biomass at the time of the fishery,
MMB_{Survey} is the mature male biomass at the time of the survey,
$MMB_{Fishery}$ is the mature male biomass at the time of the fishery,
PM(sf) is the partial M from the time of the survey to the fishery (6 months),
PM(sm) is the partial M from the time of the survey to mating (8 months),
$e^{-PM(sf)}$ is the survival rate from the survey to the fishery,
$e^{-PM(sm)}$ is the survival rate from the survey to mating.

The projected catch overfishing limit and the projected buffered catch overfishing limit are calculated as:

$$\text{Catch OFL} = [1 - e^{-Fofl}] \cdot LMB_{Fishery} \quad (4)$$

$$\text{Buffered Catch OFL} = P_{Buffer} \cdot [1 - e^{-Fofl}] \cdot LMB_{Fishery} \quad (5)$$

where,
P_{Buffer} is the proportion of the Catch OFL set as a catch target,
$[1 - e^{-Fofl}]$ is the annual fishing mortality rate.

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

$$\mu_{LMB} = [\text{Total LMB Losses}] / LMB_{Fishery} \quad (6)$$

$$\mu_{MMB} = [\text{Total MMB Losses}] / MMB_{Fishery} \quad (7)$$

where,
[Total LMB Losses] is the total directed + non-directed losses to LMB,
[Total MMB Losses] is the total directed + non-directed losses to MMB.

Using the F_{OFL} Control Rule (Figure 3), F_{OFL} is determined based on MMB at time of mating after extraction of total catch. Since the ratio of B/B_{REF} is dependent on the magnitude of the extracted catch and the catch OFL upon the estimated F_{OFL}, an iterative solution is found that maximizes the F_{OFL} and catch based on the relationship of MMB at mating to B_{REF}. The total catch OFL includes all sources of fishery-induced removals from the stock – that is, directed retained catch, directed discards, and non-directed pot and trawl bycatch mortalities. Given specification of all component losses, the retained portion of the catch OFL and/or the retained portion of the buffered catch OFL is set as the limit for the directed fishery given the expected non-retained losses.

OFL-Setting Results

The 2007/08 OFLs:

For 2007, two levels of B_{REF} are defined. B_{REF1}=8.90 million pounds of male mature biomass derived as the mean of 1991-2007. B_{REF2}=10.32 million pounds derived mean of 1991-95 plus 2000-07. The stock demonstrated widely varying levels of MMB during these periods. The trawl survey found crabs highly concentrated and indices of male biomass are characterized by very poor precision. Survey estimates are highly influenced by the results of a limited number of tows with positive crab catches. Substantial uncertainty exists in these data and the suitability of these time periods for estimating a proxy for equilibrium stock biomass B_{MSY}. It is uncertain if either B_{REF} proxy adequately estimates the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries.

We used a buffer value of 0.80 to illustrate a level of catch OFL that reduces the risk of exceeding the overfishing limit. For both B_{REF} model scenarios, gamma was set at the default value of 1.0. Given precautionary fishery management principles, we find no evidence that would justify a gamma in excess of 1.0 or fishing at an F_{OFL} rate greater than M.

Male mature biomass at the time of mating for 2007 is estimated at 12.50 million pounds for both B_{REF1} and B_{REF2} options. The B/B_{REF} ratios and F_{OFLs} corresponding to the two biomass reference options are , respectively, [B/B_{REF1}=1.40, F_{OFL}=0.18] and [B/B_{REF2}=1.21, F_{OFL}=0.18]. For the 2007 fishery, we estimated catch OFLs of 2.48 million pounds of legal male biomass for both options. After adjusting for projected discard/bycatch mortalities to LMB, the retained portion of the respective catch OFLs is 2.25 million pounds. The expected exploitation rates on LMB and MMB associated with the F_{OFL} for both options is: $\mu_{LMB} = 0.165$; $\mu_{MMB} = 0.159$.

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 biomass estimates, and that unacceptable levels of blue king crab incidental catch and bycatch mortality would occur in a directed Pribilof Islands red king crab fishery. As a result of this and considering the poor blue king crab stock condition, we recommend the fishery not open in 2007.

Reference points for both B_{REF} options (Catch and biomass estimate are in millions of pounds).

Projected Buffered Catch OFL:	1.983683
Projected Catch OFL:	2.479604
MMB @ Mating:	12.498942
OFL/MMB @ Fishery:	0.158815
OFL/Legal Males @ Fishery:	0.164730
OFL Split:	
Retained Part of OFL:	2.252589
Directed Discards:	0.002874
Non-Directed Discards:	0.224141
Retained Part of Buffered OFL:	1.756669

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

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

Predator population trends

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

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

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

Changes in habitat quality

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

Recruitment trends for red king crabs in Alaska may be partly related to decadal shifts in climate and physical oceanography. Strong year classes for eastern Bering Sea red king crab were observed when temperatures were low and weak year classes occurred when temperatures were high, but temperature alone cannot explain year class strength trends for red king crab (Zheng and Kruse 2000). In Bristol Bay, there is a relationship between red king crab brood strength and the intensity of the Aleutian Low atmospheric pressure system, during low pressure the brood strength is reduced (Tyler and Kruse 1996; Zheng and Kruse 2000). Gish (2006) suggested that the lack of king crab recruitment in the Pribilof Islands area may be the result of a large-scale environmental event affecting abundance and distribution.

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

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

Fishery Effects on the Ecosystem

Bycatch information from the Pribilof district king crab fishery is scant due to limited observer coverage during the years of the fishery. The percent of the fleet observed was 1.8 in 1993, 0.8 in 1995 and 0.0 for every other year (Boyle and Schwenzfeier 2002), therefore it is difficult to estimate the fishery-specific contribution to the bycatch of prohibited and forage species. The Pribilof district king crab fishery does not occur in any areas designated as Habitat Areas of Particular Concern (HAPC) (NPFMC 2003). NMFS conducted Endangered Species Act (ESA) Section 7 Consultations-Biological Assessments on the impact of the Bering Sea and Aleutian Island FMP crab fisheries on marine mammals (NMFS 2000) and on seabirds (NMFS 2002) and 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 the removal of large male crabs from the population, and the effects of the fishery on the age-at maturity and fecundity of the stock. Additionally, information is not available on the fishery-specific contribution to discards and offal production.

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

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Table 1. Pribilof District commercial red king crab fishery data, 1993-2007/08 (Bowers et al. 2008)

Season	GHL/TAC[a]	Harvest[a,e]	CDQ[c,d]	Harvest	Deadloss[d]
1993	3.4[b]	2.61			472
1994	2[b]	1.34			2,929
1995	2.5[c]	0.87			15,348
1996	1.8[c]	0.20			319
1997	1.5[c]	0.76			18,807
1998	1.25[c]	0.51	35,958	Confidential	8,703
1999-2007/08		Fishery Closed		Fishery Closed	

[a] Millions of pounds
[b] For red king crab; fishery closed to blue king crab
[c] For combined red and blue king crab
[d] In pounds
[e] Deadloss included

Table 2. Legal crab biomass (LBS x 10^6) landed (directed OA/IFQfishery).

Year	Landed crab
1980	0.922
1981	1.274
1982	0.470
1983	0.045
1984	0.000
1985	0.000
1986	0.000
1987	0.000
1988	0.000
1989	0.000
1990	0.000
1991	0.000
1992	0.000
1993	0.379
1994	0.168
1995	0.108
1996	0.200
1997	0.800
1998	0.509
1999	0.000
2000	0.000
2001	0.000
2002	0.000
2003	0.000
2004	0.000
2005	0.000
2006	0.000
2007	0.000

Table 3. Fishing effort during Pribilof 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. Legal red king crab biomass (LBS x 10^6) discard/bycatch loss in EBS pot and groundfish fisheries. Total male catch includes mortality of 0.50 for pot fisheries and 0.80 for groundfish fisheries.

Year	Pot (10^6 LB)	Groundfish (10^6 LB)	Total (10^6 LB)
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992		0.045	0.045
1993		0.016	0.016
1994		0.006	0.006
1995		0.012	0.012
1996		0.008	0.008
1997		0.003	0.003
1998	0.00223	0.004	0.006
1999	0.00287	0.045	0.048
2000		0.005	0.005
2001	0.00001	0.012	0.012
2002		0.019	0.019
2003		0.006	0.006
2004		0.006	0.006
2005	0.00042	0.002	0.003
2006		0.010	0.010
2007		0.221	0.221

Table 5. Mature crab abundance, biomass, and legal male biomass (LBS x 10^6) based on maturity schedule applied to NOAA Fisheries EBS trawl survey CPUE.

	Crabs > 39mm (10^6 Crab)		Mature Crabs (10^6 Crab)		Mature Biomass (10^6 LB)		Legal Male Biomass (10^6 LB)
Year	Male	Female	Male	Female	Male	Female	Male
1980	0.77	0.39	0.73	0.39	5.82	1.07	5.82
1981	0.77	0.39	0.73	0.39	5.82	1.07	5.82
1982	0.32	0.44	0.31	0.43	2.98	1.36	2.98
1983	0.11	0.14	0.09	0.13	0.77	0.42	0.70
1984	0.11	0.05	0.11	0.05	0.81	0.16	0.67
1985	0.03	0.00	0.03	0.00	0.22	0.00	0.22
1986	0.03	0.04	0.03	0.04	0.27	0.11	0.27
1987	0.01	0.02	0.01	0.01	0.09	0.02	0.09
1988	1.47	1.51	0.09	0.23	0.28	0.51	0.08
1989	1.73	2.76	0.70	1.04	3.11	2.05	1.77
1990	3.52	1.42	0.85	0.93	2.40	1.62	0.13
1991	2.65	4.00	2.06	3.59	8.11	7.03	2.45
1992	1.77	2.78	1.36	2.37	6.81	5.22	5.22
1993	3.57	5.12	2.84	4.79	16.84	11.27	15.72
1994	2.95	2.61	2.52	2.30	16.34	5.64	14.46
1995	1.51	1.15	1.24	1.01	8.51	2.54	7.65
1996	0.57	0.95	0.48	0.92	4.43	2.71	4.37
1997	2.64	1.10	1.46	0.82	11.60	2.31	10.76
1998	1.15	1.06	0.81	0.95	5.07	2.56	3.79
1999	0.00	8.20	0.00	2.14	0.02	6.77	0.02
2000	1.52	0.63	1.42	0.59	8.73	1.42	7.76
2001	5.61	3.98	3.49	3.38	17.44	7.96	11.51
2002	1.83	0.44	1.81	0.42	14.88	1.23	14.84
2003	1.38	1.15	1.38	1.14	11.05	3.46	10.85
2004	2.31	1.76	0.88	0.61	8.55	2.09	8.55
2005	0.33	1.39	0.28	1.39	2.98	5.16	2.95
2006	1.54	0.94	1.46	0.89	15.65	3.24	14.97
2007	1.98	1.74	1.75	1.63	16.58	5.69	15.98

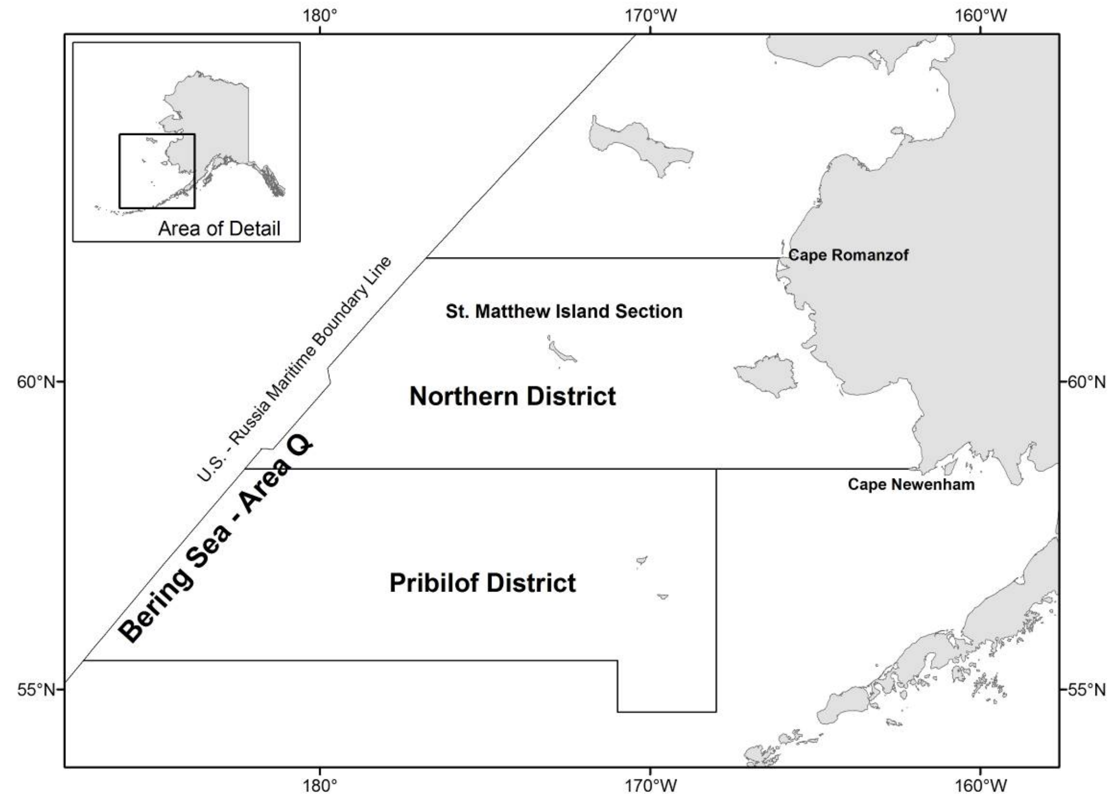

Figure 1. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

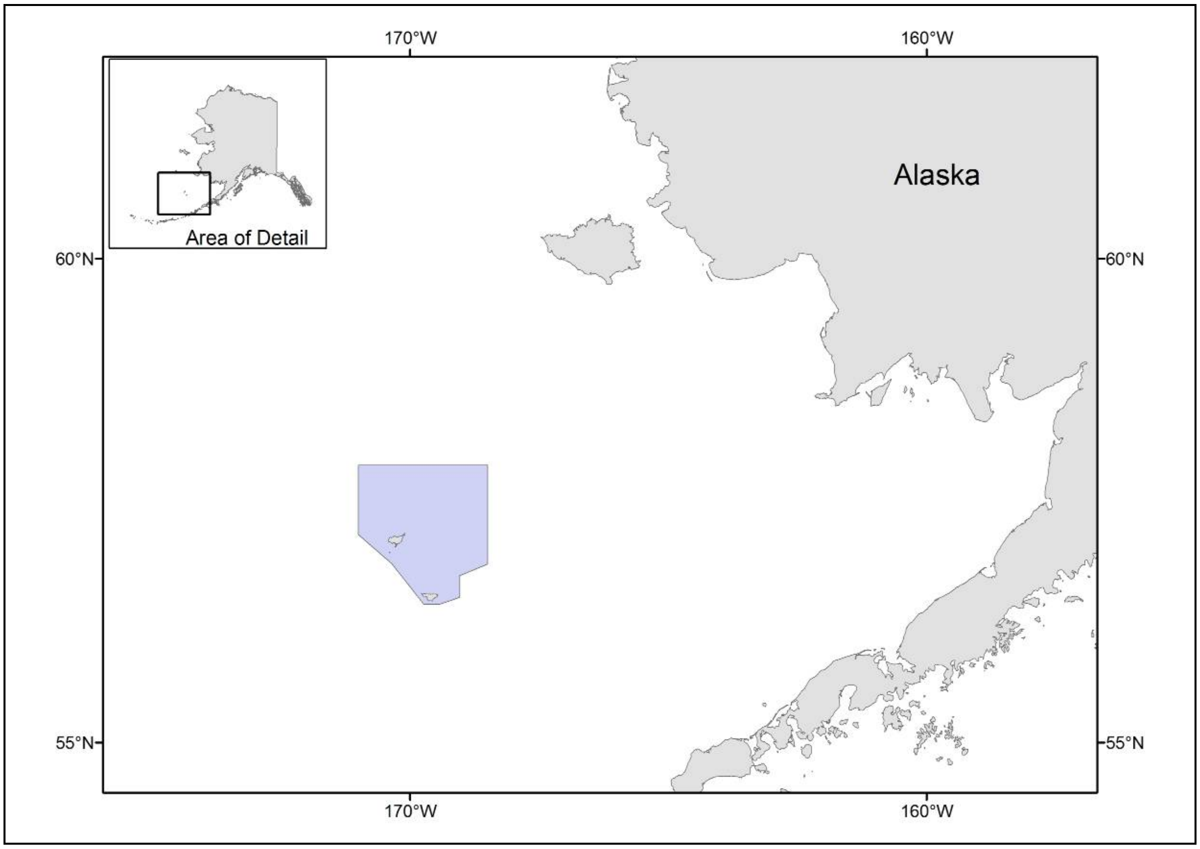

Figure 2. The shaded area shows the Pribilof Islands Habitat Conservation area

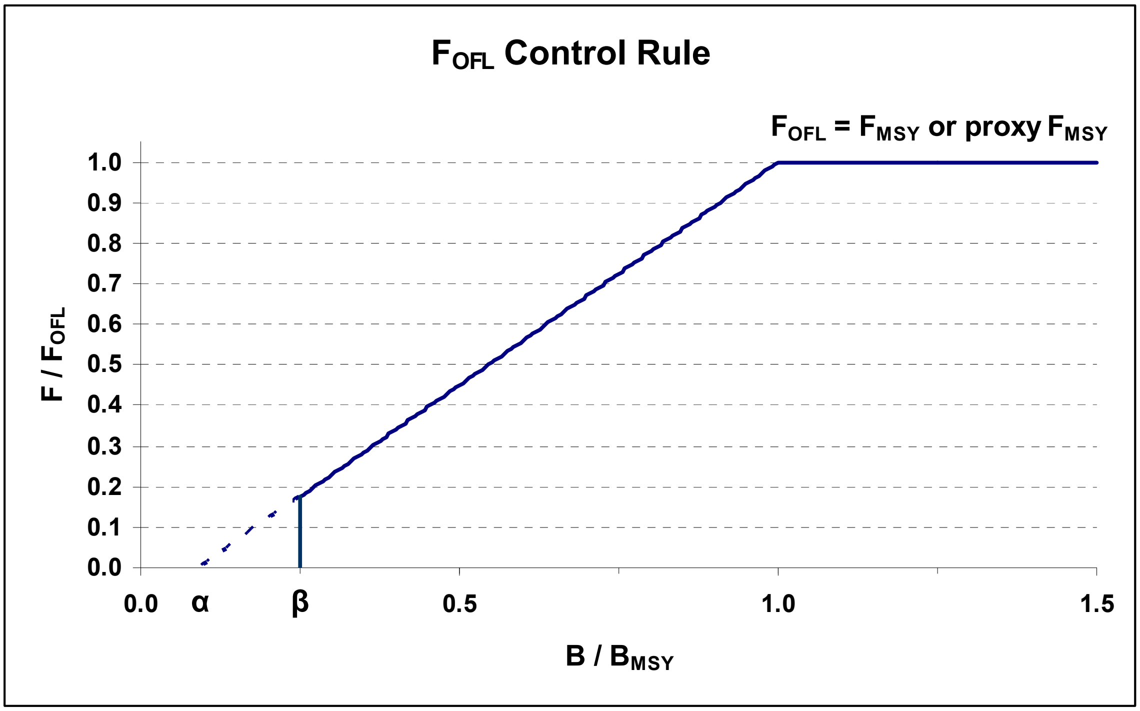

Figure 3. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.