2011 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

R.J. Foy
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA

Executive Summary

*highlighted text will be filled in with new survey and catch data prior to the September 2011 meeting.

1. Stock: Pribilof Islands blue king crab, *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been steady or decreased in recent years to current levels near 0.5 t (0.001 million lbs).
3. Stock biomass: Stock biomass in recent years was decreasing between the 1995 and 2008 survey, and after a slight increase in 2009, there was a decrease in most size classes in 2010.
4. Recruitment: Recruitment indices are not well understood for Pribilof blue king crab. Pre-recruit have remained relatively consistent in the past 10 years although may not be well assessed with the survey.
5. Management performance:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2008/09	2,105 (4.64)	113[A] (0.25)	0	0	0.5 (0.001)	1.81 (0.004)	
2009/10	2,105 (4.64)	513[B] (1.13)	0	0	0.5 (0.001)	1.81 (0.004)	
2010/11		286[C] (0.63)				1.81 (0.004)	
2011/12		x[D]					

All units are tons (million pounds) of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2009/10 and is hence overfished. Overfishing did not occur during the 2009/10 fishing year.

Notes:
A – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches
B – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches
C – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches
D – Based on survey data available to the Crab Plan Team in September 2011

6. Basis for 2011/2012 OFL projection:

Year	Tier	B_{MSY} t (10^6 lbs)	Current MMB_{mating} t (10^6 lbs)	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality yr^{-1}	P*
20011/12	4c	4,210 (9.28)	286 (0.63)	0.07	1.0	1980/1981-1984/1985 & 1990/1990-1997/1998	0.18	

7. The OFL distribution will be developed approximating the log normal distribution.
8. Basis for the ABC recommendation…..Recommended and maxABC.

9. Rebuilding analyses results summary: The Pribilof Island blue king crab stock was declared overfished on September 23, 2002. The minimum required rebuilding time with 50% probability is 9 years (2011) and the maximum rebuilding time is 10 years (2012). As a result of not making adequate progress towards rebuilding a new rebuilding plan was initiated in 2009/2010. The current draft of the rebuilding plan is in review with final action expected in fall 2011.

Summary of Major Changes:

1. Management: There were no major changes to the 2010/2011 management of the fishery.
2. Input data: The crab fishery retained and discard catch time series was updated with 2009/2010 data.
3. Assessment methodology: There were no changes to assessment methodology. A draft catch and survey model was developed in 2010/2011 and will continue development based on February 2011 modeling workshop recommendations.. Assessment methodology for ABC calculations was included.
4. Assessment results: The projected MMB decreased in this assessment and remained below the MSST. Therefore, the OFL remained low with no directed fishery. Total catch in 2009/2010 was 0.5 t.

Responses to SSC and CPT Comments

SSC comments June 2010:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The SSC agrees with the CPT recommendation for management of Pribilof Islands blue king crab under Tier 4, where γ=1, M=0.18, and using the 1980 through 1984 and 1990 through 1997 time periods to determine the average MMB as a proxy for B_{MSY}. The SSC reiterates our request from June 2009 that an analysis be included in the revised rebuilding plan to examine information on stock separation from the St. Matthew Island blue king crab stock. The SSC continues to look forward to the implementation of a catch-survey analysis for this stock.

Responses to SSC Comments: Stock separation discussed with an additional analysis in the rebuilding plan document. CSA model in development.

SSC comments October 2010:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

The OFL method and tier determination were approved by the SSC for this stock in June 2010. As with the similar red king crab assessment for the Pribilof Islands, the SSC appreciates the concise nature of the document. The SSC agrees with the CPT that an average of recent survey biomasses be examined when computing the OFL. The SSC continues to look forward to the implementation of a catch-survey analysis for this stock.

Responses to SSC Comments: Methodology for an average biomass from recent years provided. CSA model in development.

CPT comments May 2010:

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

- *The 'Total Crab @ survey' column in Table 4 is incorrect and needs to be recalculated.*
- *Equation 3 is the same as equation 1 and needs to be corrected for females.*
- *Reorganize the chapter so that it is in standard format of text, tables, and figures.*
- *All tables on page 1 should be updated for final assessment in September 2010.*

Responses to CPT Comments: Each point addressed.

<u>CPT comments September 2010:</u>

General remarks pertinent to this assessment

none

Specific remarks pertinent to this assessment

none

Responses to CPT Comments: *none*

Introduction

1. **Blue king crabs,** *Paralithodes platypus*

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

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab were managed under the Bering Sea king crab Registration Area Q Pribilof District, which has as its southern boundary a line from 54° 36' N lat., 168° W long., to 54° 36' N lat., 171° W long., to 55° 30' N lat., 171° W. long., to 55° 30' N lat., 173° 30' E long., as its northern boundary the latitude of Cape Newenham (58° 39' N lat.), as its eastern boundary a line from 54° 36' N lat., 168° W long., to 58° 39' N lat., 168° W long., to Cape Newenham (58° 39' N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

3. **Stock structure -** Stock structure of blue king crabs in the North Pacific is largely unknown. To assess the potential relationship between blue king crab in the Pribilof Islands and St. Matthew, the author consulted the AFSC report entitled "Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans" by Spencer et al. (In Prep). Per this document, aspects of blue king crab harvest and abundance trends, phenotypic characteristics, behavior, movement, and genetics will be considered. Is was also, noted that ~200 samples were collected in 2009 and 2010 to support a genetic study on blue king crab population structure by a graduate student at the University of Alaska. Additional collections will take place in 2011.

   To address the potential for species interactions between blue king crab and red king crab as a potential reason for PIBKC shifts in abundance and distribution, we compared the spatial extent of both speices in the Pribilof Islands from 1975 to 2009 (Figure 3). In the early 1980's when red king crab first became abundant, blue king crab males and females dominated the 1 to 7 stations where the species co-occurred in the Pribilof Islands District (Figure 3A). Spatially, the stations with co-occurance were all dominated by blue king crab and broadly distributed around the Pribilof Islands (Figure 4A). In the 1990's the red king crab population biomass increased substantially as the blue king crab population biomass decreased. During this time period, the number of stations with co-occurance remained around a max of 8 but they were equally dominated by both blue king crab ands red king crab sugggesting a direct overlap in distribution at the scale of a survey station (Figure 3A). Spatially during this time period, the red king crab dominated stations were dispersed around the Pribilof Islands (Figure 4B). Between 2001 and 2009 the blue king crab population has decreased dramatically while the red king crab have fluctuated (Figure 3B). Interstingly, the number of stations dominated by blue king crab is similar to those dominated by red king crab for both males and females suggesting continued competition for similar habitat (Figure 3A). Spatially the only stations dominated by blue king crab exist to the north and east of St. Paul Island (Figure 4C). It is noted that although the blue king crab protection measures also afford protection for the red king crab in this region, the red king crab stocks continue to fluctuate even considering the uncertainty in the survey.

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

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

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

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

5. **Management history -** The king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (Figure 5). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season with an associated increase in effort to 110 vessels (ADF&G 2008). Following 1995, declines in the stock resulted in a closure from 1999 to present. The Pribilof blue king crab stock was declared overfished in September of 2002 and the Alaska Department of Fish and Game developed a rebuilding harvest strategy as part of the North Pacific Fishery Management Council's (NPFMC) comprehensive rebuilding plan for the stock. The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990, ADF&G 2008). The fishery was male only, and legal size was >16.5 cm carapace width (NOAA 1995). Guideline harvest level (GHL) was 10 percent of the abundance of mature male or 20 percent of the number of legal males (ADF&G 2006).

   Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 6) 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.

   Blue king crab in the Pribilof District can occur as bycatch in the following crab fisheries: the eastern Bering Sea snow crab (*Chionoecetes opilio*), the eastern Bering Sea Tanner crab

(*Chionoecetes bairdi*), the Bering Sea hair crab (*Erimacrus isenbeckii*), and the Pribilof red and blue king crab. In addition, blue king crab are bycatch in flatfish and Pacific cod fisheries.

Data

1. The standard survey time series data updated through 2010 and the standard groundfish discards time series data updated through 2010 were used in this assessment. The crab fishery retained and discard catch time series was updated with 2009/2010 data.

2. a. Total catch:

   Crab pot fisheries

   Retained pot fishery catches (live and deadloss landings data) are provided for 1973/1974 to 2009/2010 (Table 1), including the 1973/1974 to 1987/1988 and 1995/1996 to 1998/1999 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/1996 to 1998/1999 seasons blue king crab and red king crab were fished under the same GHL. There was no total allowable catch (TAC) and therefore zero retained catch in the 2009/2010 fishing season

   b. Bycatch and discards:

   Crab pot fisheries

   Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was calculated from length frequency tables where the CL (mm) was converted to g (see equation 1: males: A=0.000329, 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 2).

   $$\text{Weight (g)} = A * \text{CL(mm)}^{B} \quad (1)$$

   $$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (2)$$

   Finally, weights were the product of average weight, CPUE, and total pot lifts in the fishery. 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 2009/2010, Pribilof blue king crab were not incidentally caught in any crab fishery (Table 2).

   Groundfish pot, trawl, and hook and line fisheries

The 2009/2010 NMFS Alaska Region assessments of non-retained catch from all groundfish fisheries are included in this SAFE report (J. Mondragon, NMFS, personal communication). Groundfish catches of crab are reported for all males and females combined by federal reporting areas. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 2008 to June 2010. 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 2010 catches, sex ratios by size and sex from the 2010 EBS bottom trawl survey were applied. To assess crab mortalities in these groundfish fisheries a 50% handling mortality rate was applied to pot and hook and line estimates and an 80% handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been discriminated by each year's survey proportions (Table 2).

In 2009/2010, 0.9 t of male and female blue king crab were caught in groundfish fisheries. The catch was in non-pelagic trawls (61%), longline (22%), and pot (18%) fisheries. The targeted species in these fisheries were yellowfin sole (51%), Pacific cod (39%), and flathead sole (10%).

c. Catch-at-length: NA

d. Survey biomass:
The 2010 NMFS EBS bottom trawl survey results (Chilton et al. in press) are included in this SAFE report (Table 3, Figure 7). Abundance estimates of male and female crab are assessed for 5 mm length bins and for total abundances for each EBS stock (Figure 8). Weight (equation 1) and maturity (equation 3) schedules are applied to these abundances and summed to calculate mature male, female, and legal male biomass (t).

$$\text{Proportion mature male} = 1/(1 + (3.726 * 10^{15}) * e^{((CL(mm)+2.5) * -0.332)}$$
$$\text{Proportion mature female} = 1/(1 + (8.495 * 10^{13}) * e^{((CL(mm)+2.5) * -0.332)} \qquad (3)$$

Historical survey data are available from 1980 to the present when survey and data analyses were standardized (Table 3).

In 2010, Pribilof Island District blue king crab were observed in 8 of the 41 stations in the Pribilof District, all of which were in the high-density sampling area (Chilton et al. in press, Figure 10). Legal-sized males were caught at three stations east of St. Paul Island and one station north of St. George, with a density ranging from 62 to 71 crab/nmi^2 . The 2010 abundance estimate of legal-sized males was 202 ± 191 t, representing 48% of the total male biomass and below the average of 1,663 ± 1,589 t for the previous 20 years (Figure 7). Blue king crab mature males were caught at five stations in the Pribilof District high-density sampling representing 77% of the total male abundance. Immature male blue king crab were caught at two stations representing the remaining 33% of the total male biomass in the Pribilof District. Mature female blue king crab were caught at five stations in the Pribilof District high-density sampling area with a biomass estimate of 352 ± 428 t representing 81% of the total female biomass. Sixteen of the 28 female blue king crab sampled during the survey were brooding uneyed or eyed embryos. While eight of the females were immature and in softshell condition, 50% of the mature females were new hardshell crab all with newly extruded embryos while 50% were oldshell females of which 60% were brooding eyed embryos and 40% had empty egg cases.

Analytic Approach

1. **History of modeling approaches**
   A catch survey analysis has been used for assessing the stock in the past and is in development.

Calculation of the OFL

1. Based on available data, the authors, the Crab Plan Team, and the Science and Statistical Committee all recommend that this stock should be classified as a Tier 4 stock for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008).

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

   The mature stock biomass ratio β where $B/B_{MSY}^{prox} = 0.25$ represents the critical biomass threshold below which directed fishing mortality is set to zero (Figure 11). The parameter α determines the slope of the non-constant portion of the control rule line and was set to 0.1. Values for α and β where based on sensitivity analysis effects on B/B_{MSY}^{prox} (NPFMC 2008). The F_{OFL} derivation where B is greater than β includes the product of a scalar (**γ**) and M (equations 5 and 6) where the default **γ** value is 1 and M for Bering Sea blue king crab is 0.18. The value of **γ** may alternatively be calculated as F_{MSY}/M depending on the availability of data for the stock.

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

3. OFL specification:
   a. In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL). The F_{OFL} is derived using a Maximum Fishing Mortality Threshold (MFMT) or F_{OFL} Control Rule (Figure 11) where Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current mature stock biomass (B) to B_{MSY}^{proxy}.

Stock Status Level:	F_{OFL}:	
a. $B/B_{MSY}^{prox} > 1.0$	$F_{OFL} = \gamma \cdot M$	(4)
b. $\beta < B/B_{MSY}^{prox} \leq 1.0$	$F_{OFL} = \gamma \cdot M\,[(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$	(5)

c. $B/B_{MSY}^{prox} \leq \beta$ $F_{directed} = 0; F_{OFL} \leq F_{MSY}$ (6)

B_{MSY}^{prox} for the 2010 assessment was calculated as 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.

b. The MMB_{Mating} projection is based on application of M from the 2010 NMFS trawl survey (July 15) to mating (February 15) and the removal of estimated retained, bycatch, and discarded catch mortality (equation 7). Catch mortalities are estimated from the proportion of catch mortalities in 2009/2010 to the 2010 survey biomass.

$$MMB_{Survey} \cdot e^{-PM(sm)} - \text{(projected legal male catch OFL)} - \text{(projected non-retained catch)} \quad (7)$$

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

c. To project a total catch OFL for the upcoming crab fishing season, the F_{OFL} is estimated by an iterative solution that maximizes the projected F_{OFL} and projected catch based on the relationship of B to B_{MSY}^{prox}. B is approximated by MMB at mating (equation 7).

For a total catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the total crab biomass at the fishery (equation 8).

$$\text{Projected Total Catch OFL} = [1 - e^{-Fofl}] \cdot \text{Total Crab Biomass}_{Fishery} \quad (8)$$

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

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

$$\mu_{LMB} = \text{[Total LMB retained and non-retained catch]} / LMB_{Fishery} \quad (9)$$

$$\mu_{MMB} = \text{[Total MMB retained and non-retained catch]} / MMB_{Fishery} \quad (10)$$

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL
2008/09	4.64	0.25[A]	0	0	0.001	0.004
2009/10	4.64	1.13[B]	0	0	0.001	0.004
2010/11		0.63 [C]				0.004
2011/12		X [D]				

All units are tons of crabs and the OFL is a total catch OFL for each year. The stock was below MSST in 2009/10 and is hence overfished. Overfishing did not occur during the 2009/10 fishing year.

Notes:

A – Based on survey data available to the Crab Plan Team in September 2008 and updated with 2008/2009 catches

B – Based on survey data available to the Crab Plan Team in September 2009 and updated with 2009/2010 catches

C – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches

D – Based on survey data available to the Crab Plan Team in September 2011

4. Specification of the retained catch portion of the total catch OFL:

   a. For a retained catch OFL, the annual fishing mortality rate (F_{OFL}) is applied to the legal crab biomass at the fishery (equation 11).

   $$\text{Projected Retained Catch OFL} = [1 - e^{-Fofl}] \cdot \text{Legal Crab Biomass}_{Fishery} \qquad (11)$$

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

5. Recommendations:

   For 2009/2010, B_{MSY}^{prox}=4,210 t 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. 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 2010/2011 is estimated at 286 t for B_{MSY}^{prox}. The B/B_{MSY}^{prox} ratio and F_{OFL} corresponding to the biomass reference option is 0.07 and F_{OFL}=0.00. 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). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008). The preferred alternative was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/2006 which was 1.81 t. 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.

Calculation of the ABC

1. Specification of the probability distribution of the OFL used in the ABC: A distribution for the OFL which quantifies uncertainty will be constructed using bootstrapping methods approximating the lognormal distribution. This involves generating values for *M* and annual MMB_{mating} (e.g. by assuming that MMB is log-normally distributed and *M* is normally distributed) and for each simulation calculating the OFL using the standard methods in section 3 of the OFL Specification section above. The OFL distribution for Pribilof Island blue king crab is skewed to the right due to the patchy spatial distribution and small abundance which affects the variability of density estimates among trawl survey stations. This lognormal distribution suggests that use of the mean value (as opposed to the median) of the distribution would be appropriate as it changes with greater variability.

2. List of variables related to scientific uncertainty considered in the OFL probability distribution: Compared to other BSAI crab stocks, the uncertainty associated with the estimates of stock size and OFL for Pribilof Islands blue king crab is very high due to insufficient data and the small distribution of the stock relative to the survey sampling density. The coefficient of variation for the estimate of mature male biomass from the surveys for the most recent year is 0.713 and has ranged between 0.168 and 0.799 in since the 1980 peak in biomass. The coefficient of variation for the estimate of mature male biomass for the most recent year from the stock assessment used for the 2010 ACL analysis was 0.271.

3. List of additional uncertainties considered for alternative σ_b applications to the ABC.
   Several sources of uncertainty are not included in the measures of uncertainty reported as part of the stock assessment:
   - Survey catchability and natural mortality uncertainties are not estimated but are rather pre-specified.
   - F_{msy} is assumed to be equal to γM when applying the OFL control rule while γ is assumed to be equal to 1 and M is assumed to be known.
   - The model on which the projections are based is still in development and has yet to be reviewed by the CPT.
   - The coefficients of variation for the survey estimates of abundance for this stock are very high.
   - B_{msy} is assumed to be equivalent to average mature male biomass between 1991 and 2008. However, stock biomass has fluctuated greatly and targeted fisheries only occurred from 1973-1987 and 1995-1998 so considerable uncertainty exists with this estimate of B_{msy}.

   Additional uncertainty will be included in the application of the ABC by adding the uncertainty components as $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$. Given the relative amount of information available for Pribilof Island's blue king crab, the author recommended ABC includes an additional σ_b of 0.4.

4. Author recommended ABC and if less than maxABC provide rationale for establishing less than maximum permissible: The maxABC and the author recommended ABC will be provided here.

Rebuilding Analyses

Under the current rebuilding plan, this stock has to recover to the B_{MSY} proxy in 2011/2012 and 2012/2013 to be defined as rebuilt. As the 2009/10 mature male biomass was smaller than B_{MSY} and has not shown signs of recovery in an adequate timeframe, the stock will likely fail to recover as planned. The current draft of the rebuilding plan is in review with final action expected in Fall 2011.

Average Biomass

Taking an average biomass across previous years to calculate the MMB in the most recent year was considered to reduce the effect of high uncertainty in the survey based area swept estimates (Figure 12). A range of years from 2 to 7 resulted in mean MMB over the time series from 2,014 to 2,176 t (Table 4). Using an average biomass of 4 to 7 years resulted in the highest deviations from -313 to -382 t and dampened the distribution so that biomass peaks were skewed from the observed values. The 3 year average appears to balance the deviations between the observed and averaged while reducing the annual variation in the MMB and is recommended as the new methods for estimating MMB.

Literature Cited

Alaska Department of Fish and Game (ADF&G). 2006. 2006-2008 commercial king and tanner crab fishing regulations. Alaska Department of Fish and Game, Juneau, AK. 160 pp.

Alaska Department of Fish and Game (ADF&G). 2008. Annual Management Report for the Commercial and Subsistence Shellfish Fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2006/07. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries, Fishery Management Report 08-02, Kodiak.

Armstrong, D.A., J.L. Armstrong, G. Jensen, R. Palacios, and G. Williams. 1987. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 67:1-278.

Armstrong, D.A., J.L. Armstrong, R. Palacios, G. Jensen, and G. Williams. 1985. Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands. Pp. 211-229 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Blau, F. S. 1997. Alaska king crabs: wildlife notebook series. Alaska Department of Fish and Game. http://www.adfg.state.ak.us/pubs/notebook/shellfsh/kingcrab.php, last accessed April 8, 2008.

Chilton, E.A., C.E. Armistead, and R.J. Foy. In press. The 2010 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-XXX, 96 p.

Feder, H., K. McCumby and A.J. Paul. 1980. The Food of Post-larval King Crab, *Paralithodes camtschatica*, in Kachemak Bay, Alaska (Decapoda, Lithodidae). Crustaceana, 39(3): 315-318.

Feder, H.M., and S.C. Jewett. 1981. Feeding interactions in the eastern Bering Sea with emphasis on the benthos. Pages 1229-1261 *in*: Hood, D.W. and J.A. Calder (eds.). The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, Office of Marine Pollution and Assessment.

Hawkes, C.R., T.R. Myers, and T.C. Shirley. 1985. The prevalence of the rhizocephalan *Briarosaccus callosus* Boschma, a parasite in blue king crabs, *Paralithodes platypus*, of southeastern Alaska. *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks. Pp. 353-364.

High, W.L., and Worlund, D.D. 1979. Escape of king crab, *Paralithodes camtschatica*, from derelict pots. NOAA Tech. Rep. No. NMFS SSRF-734.

Jensen, G.C., and D. A. Armstrong. 1989. Biennial reproductive cycle of blue king crab, *Paralithodes platypus*, at the Pribilof Islands, Alaska and comparison to a congener, *P. catschatica*. Can. J. Fish. Aquat. Sci., 46:932-940.

Jensen, G.C., D.A. Armstrong and G. Williams. 1985. Reproductive biology of the blue king crab, Paralithodes platypus, in the Pribilof Islands. Pp. 109-122 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Livingston, P.A., and B.J. Goiney, Jr. 1993. Food habits of North Pacific marine fishes: a review and selected bibliography. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-54, 81 p.

Mueter, F.J. and M.A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecological Applications 18:309–320.

Nakanishi, T. 1987. Rearing Condition of Eggs, Larvae and Post-Larvae of King Crab. Bull. Jap. Sea Reg. Fish. Res. Lab. 37: 57-161.

NMFS. 2005. APPENDIX F.3. ESSENTIAL FISH HABITAT ASSESSMENT REPORT for the Bering Sea and Aleutian Islands King and Tanner Crabs. NOAA Fisheries, Juneau, AK. 35pp.

NPFMC (North Pacific Fishery Management Council). 2003. Environmental assessment for amendment 17 to the fishery management plan for the king and tanner crab fisheries in the Bering Sea/Aleutian Islands a rebuilding plan for the Pribilof Islands blue king crab stock. North Pacific Fishery Management Council Anchorage, 101 pp.

NPFMC (North Pacific Fishery Management Council). 2008. Environmental Assessment for Amendment 24 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands: to revise overfishing definitions. Anchorage, Alaska 194 p.

NPFMC. 2008. Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2008 Crab SAFE. North Pacific Fishery Management Council Anchorage, 259pp.

Otto, R.S and P.A. Cummiskey. 1990. Growth of adult male blue king crab (*Paralithodes platypus*). pp 245-258 *in:* Proceeding of the the International Symposium on King and Tanner Crabs:, Alaska Sea Grant Report No 90-04, University of Alaska, Fairbanks, AK.

Palacios, R., D.A. Armstrong, J.L. Armstrong, and G. Williams. 1985. Community analysis applied to characterization of blue king crab habitat around the Pribilof Islands. Pp. 193-209 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Paul, A. J. and J. M. Paul. 1980. The Effect of Early Starvation on Later Feeding Success of King Crab Zoeae. J. Exp. Mar. Bio. Ecol., 44: 247-251.

Selin, N.I., and Fedotov, P.A. 1996. Vertical distribution and some biological characteristics of the blue king crab *Paralithodes platypus* in the northwestern Bering Sea. Mar. Biol. 22: 386-390.

Shirley, S.M., T. C. Shirley and T. E. Myers. 1985. Hymolymph studies of the blue (*Paralithodes platypus*) and golden (*Lithodes aequispina*) king crab parasitized by the rhizocephalan barnacle *Briarosaccus callosus*. *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks. Pp. 341-352.

Siddeek, M.S.M., L.J. Watson, S.F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data. pp 51-75 *in:* Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant Report No 02-01, University of Alaska, Fairbanks, AK.

Somerton, D.A. 1985. The disjunct distribution of blue king crab, *Paralithodes platypus*, in Alaska: some hypotheses. Pp. 13-21 *in:* Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Somerton, D.A., and R. A. MacIntosh. 1983. The size at sexual maturity of blue king crab, *Paralithodes platypus*, in Alaska. Fishery Bulletin, 81(3):621-628.

Somerton, D.A., and R. A. MacIntosh. 1985. Reproductive biology of the female blue king crab *Paralithodes platypus* near the Pribilof Islands, Alaska. J. Crustacean Biology, 5(3): 365-376.

Sparks, A.K., and J.F. Morado. 1985. A preliminary report on the diseases of Alaska king crabs. in: Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No. 85-12, University of Alaska Fairbanks. Pp. 333-339.

Stevens, B. G. and K. M. Swiney. 2005. Post-settlement effects of habitat type and predator size on cannibalism of glaucothoe and juveniles of red king crab *Paralithodes camtschaticus*. J. Exp. Mar. Bio. Ecol. 321(1): 1-11.

Stevens, B.S. 2006a. Embryo development and morphometry in the blue king crab *Paralithodes platypus* studied by using image and cluster analysis. J. Shellfish Res., 25(2):569-576.

Stevens, B.S. 2006b. Timing and duration of larval hatching for blue king crab *Paralithodes platypus* Brandt, 1850 held in the laboratory. J. Crustacean Biology, 26(4):495-502.

Stevens, B.S., S.L. Persselin and J.A. Matweyou. 2008. Survival of blue king crab *Paralithodes platypus* Brandt, 1850, larvae in cultivation: effects of diet, temperature and rearing density. Aquaculture Res., 39:390-397.

Zheng, J., and D. Pengilly. 2003. Evaluation of alternative rebuilding strategies for Pribilof Islands blue king crabs. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 5J03-10, Juneau.

Zheng, J., and Kruse, G. H. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science, 57: 438–451.

Zheng, J., M.C. Murphy and G.H. Kruse. 1997. Application of a catch-survey analysis to blue king crab stocks near Pribilof and St. Matthew Islands. Alaska Fish. Res. Bull. 4(1):62-74.

Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2008; D. Pengilly, ADF&G, personal communications).

Year	Catch (count)	Catch (t)	Avg CPUE (legal crab count/pot)
1973/1974	174,420	581	26
1974/1975	908,072	3225	20
1975/1976	314,931	1102	19
1976/1977	855,505	2998	12
1977/1978	807,092	2930	8
1978/1979	797,364	2903	8
1979/1980	815,557	2722	10
1980/1981	1,497,101	4976	9
1981/1982	1,202,499	4119	7
1982/1983	587,908	2000	5
1983/1984	276,364	993	3
1984/1985	40,427	141	3
1985/1986	76,945	240	3
1986/1987	36,988	118	2
1987/1988	95,130	318	2
1988/1989	0	0	0
1989/1990	0	0	0
1990/1991	0	0	0
1991/1992	0	0	0
1992/1993	0	0	0
1993/1994	0	0	0
1994/1995	0	0	0
1995/1996	190,951	626	5
1996/1997	127,712	426	4
1997/1998	68,603	231	3
1998/1999	68,419	236	3
1999/2000	0	0	0
2000/2001	0	0	0
2001/2002	0	0	0
2002/2003	0	0	0
2003/2004	0	0	0
2004/2005	0	0	0
2005/2006	0	0	0
2006/2007	0	0	0
2007/2008	0	0	0
2008/2009	0	0	0
2009/2010	0	0	0

Table 2. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District blue king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2008; D. Pengilly, ADF&G; J. Mondragon, NMFS).

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (t)	Sublegal male (t)	Female (t)	All fixed (t)	All Trawl (t)
1991/1992	0.00	0.00	0.00	0.05	4.94
1992/1993	0.00	0.00	0.00	0.45	48.63
1993/1994	0.00	0.00	0.00	0.05	27.40
1994/1995	0.00	0.00	0.00	0.05	5.49
1995/1996	0.00	0.00	0.00	0.05	1.04
1996/1997	0.00	0.45	0.00	0.05	0.05
1997/1998	0.00	0.00	0.00	0.73	0.09
1998/1999	1.36	0.45	1.81	9.89	0.05
1999/2000	1.81	2.27	0.91	0.41	0.05
2000/2001	0.00	0.00	0.00	0.05	0.05
2001/2002	0.00	0.00	0.00	0.41	0.05
2002/2003	0.00	0.00	0.00	0.05	0.23
2003/2004	0.00	0.00	0.00	0.18	0.18
2004/2005	0.00	0.00	0.00	0.41	0.05
2005/2006	0.00	0.00	0.05	0.18	1.09
2006/2007	0.00	0.00	0.05	0.09	0.05
2007/2008	0.00	0.00	0.05	2.00	0.09
2008/2009	0.00	0.00	0.00	0.09	0.36
2009/2010	0.00	0.00	0.00	0.18	0.41

Table 3. Pribilof Islands District blue king crab abundance, mature biomass, and legal male biomass (t), and totals estimated based on the NMFS annual EBS bottom trawl survey.

Year	Mature males @ survey t	Mature males @ mating t	Legal Males @ survey t	Total males @ survey t	Total females @ survey t
1980/1981	14801	8151	12701		
1981/1982	14601	8831	12501		
1982/1983	7688	4822	6609		
1983/1984	5221	3633	3928		
1984/1985	2232	1837	1801		
1985/1986	1139	771	875		
1986/1987	1288	1025	1270		
1987/1988	2390	1801	2250		
1988/1989	635	562	630		
1989/1990	916	812	721		
1990/1991	2799	2481	1039		
1991/1992	3992	3511	2508		
1992/1993	4159	3651	2499		
1993/1994	3960	3497	2622		
1994/1995	2830	2508	2100		
1995/1996	7480	6006	5779		
1996/1997	4509	3574	3461		
1997/1998	2771	2218	2250		
1998/1999	3062	2477	2472		
1999/2000	1692	1497	1329		
2000/2001	1878	1665	1529		
2001/2002	1438	1275	1261		
2002/2003	617	544	585		
2003/2004	608	540	581		
2004/2005	132	118	50		
2005/2006	345	308	345		
2006/2007	177	154	127		
2007/2008	345	304	186	463	295
2008/2009	132	113	45	259	789
2009/2010	581	513	168	685	635
2010/2011	322	286	204	422	431

Table 4. Mean, standard deviation (SD) and deviations for alternative average year options for calculating MMB in the most recent year.

	0yr	2yr	3yr	4yr	5yr	7yr
Mean (t)	2242	2176	2095	2045	2014	2014
SD	2254	2034	1774	1579	1415	1184
Mean deviation		-131	-284	-342	-382	-313
SD deviation		654	946	1111	1265	1308
Mean Absolute Deviation		447	679	831	931	1069

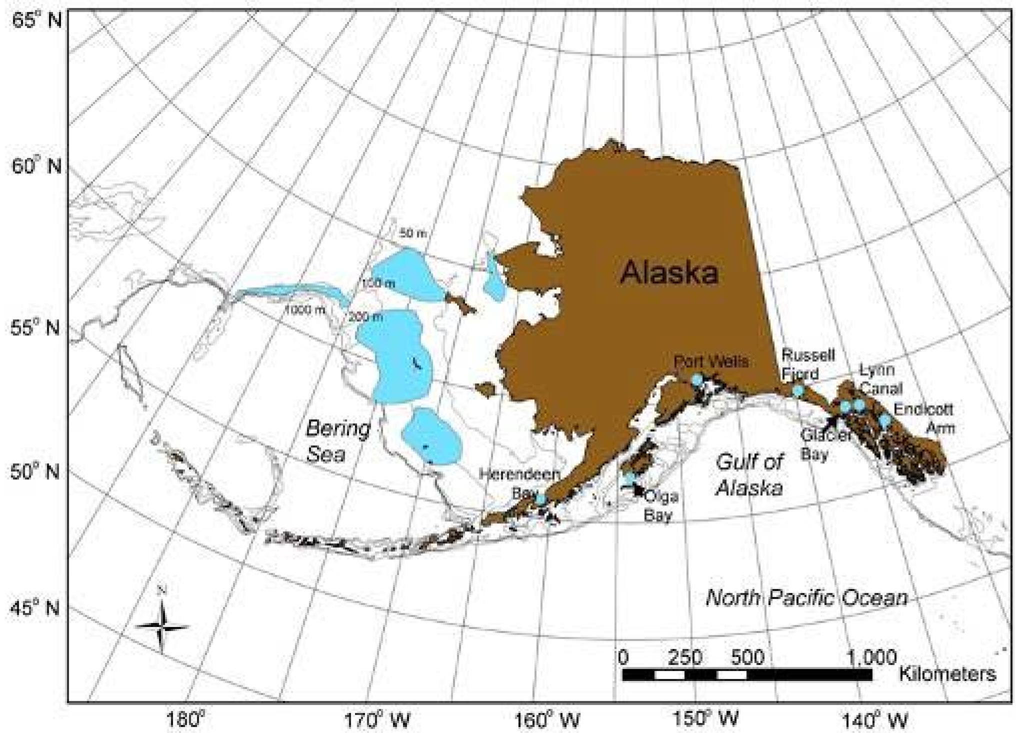

Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

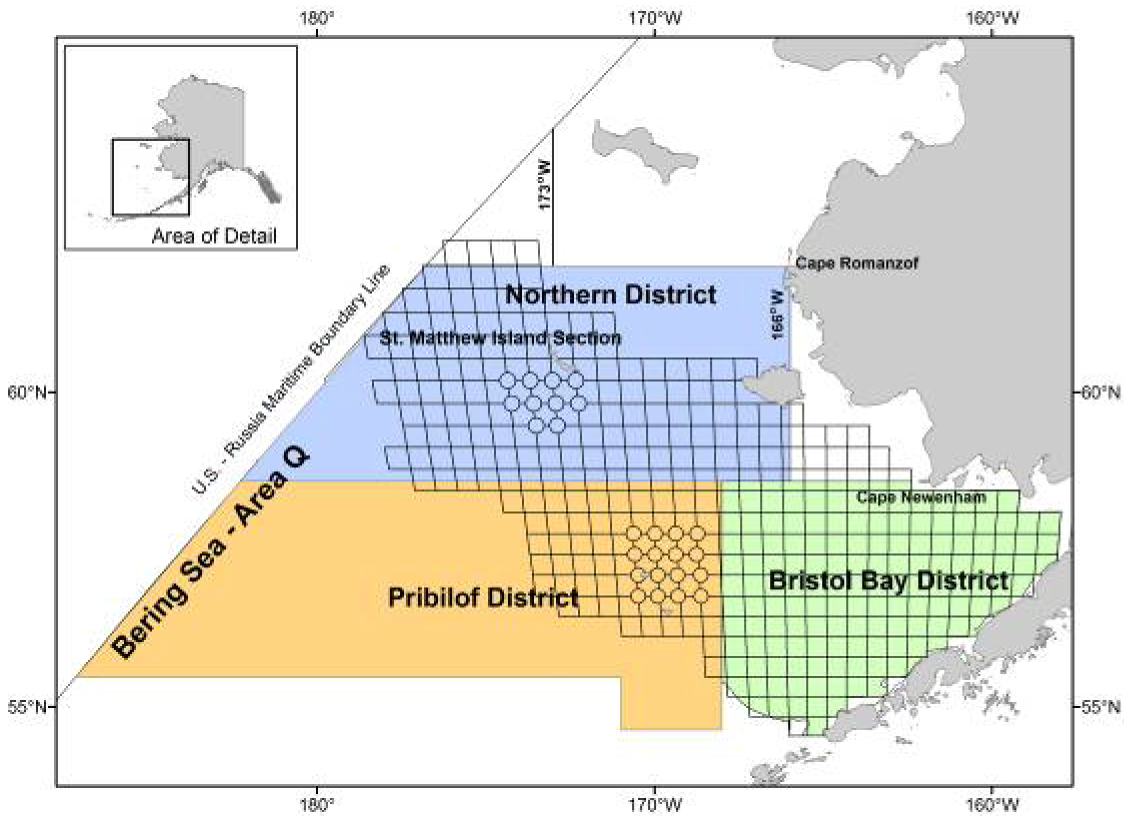

Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District.

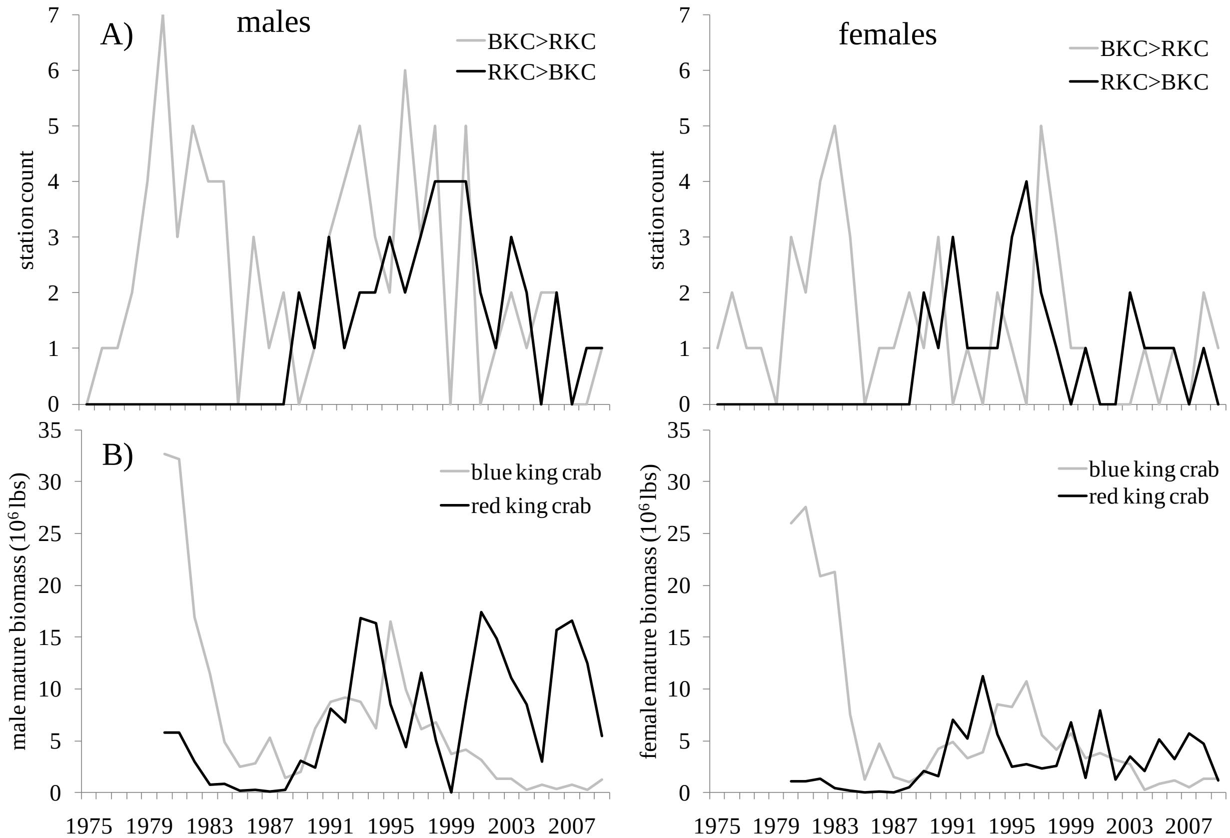

Figure 1. Time series of overlap between blue king crab and red king crab for males and females in the eastern Bering Sea showing A) the number of stations with blue king crab (BKC) or red king crab (RKC) as the dominant species and B) the mature biomass of both species.

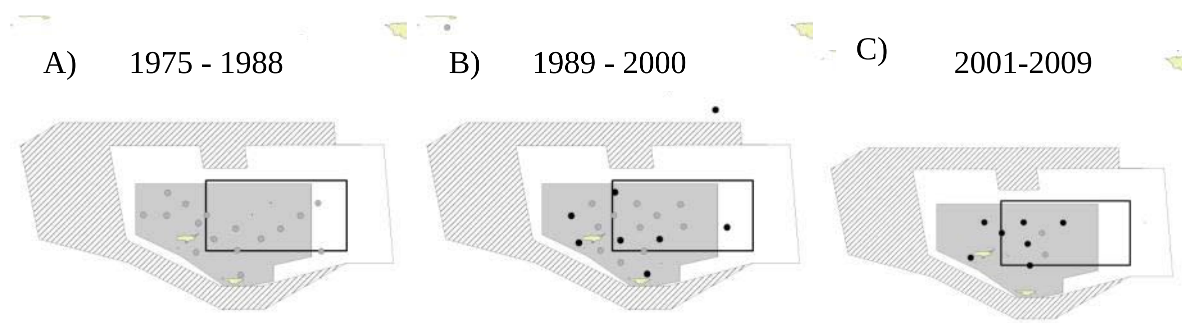

Figure 4. Spatial distribution of stations where there is overlap between blue king crab and red king crab males showing the dominant species (blue king crab=gray circles; red king crab=black circles) corresponding to time periods of major changes in biomass of both species.

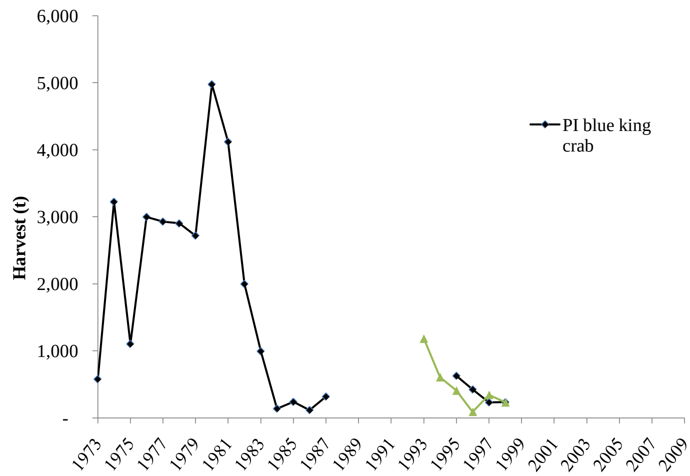

Figure 5. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2007).

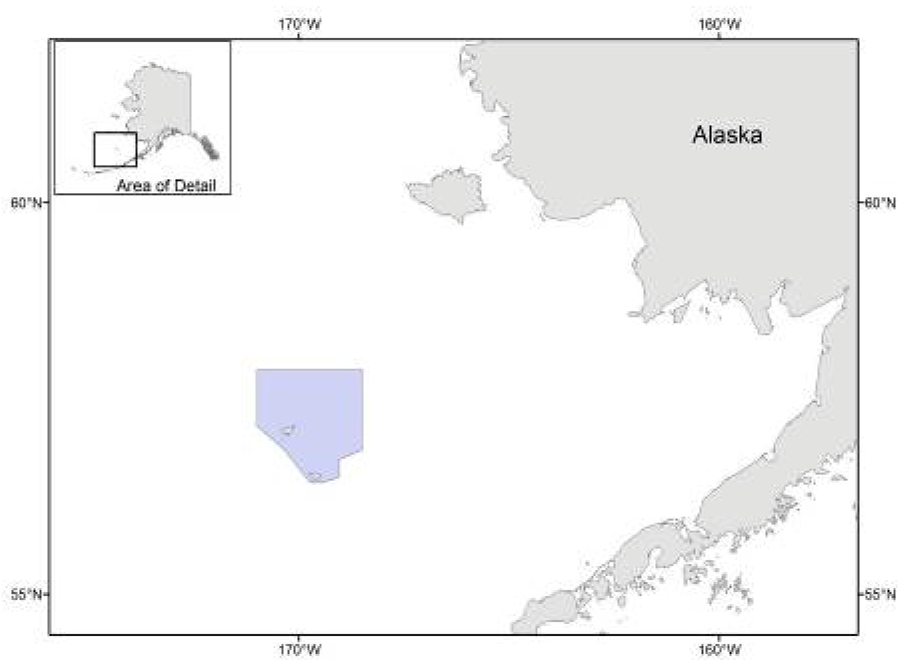

Figure 6. The shaded area shows the Pribilof Islands Habitat Conservation area. Trawl fishing is prohibited year-round in this zone.

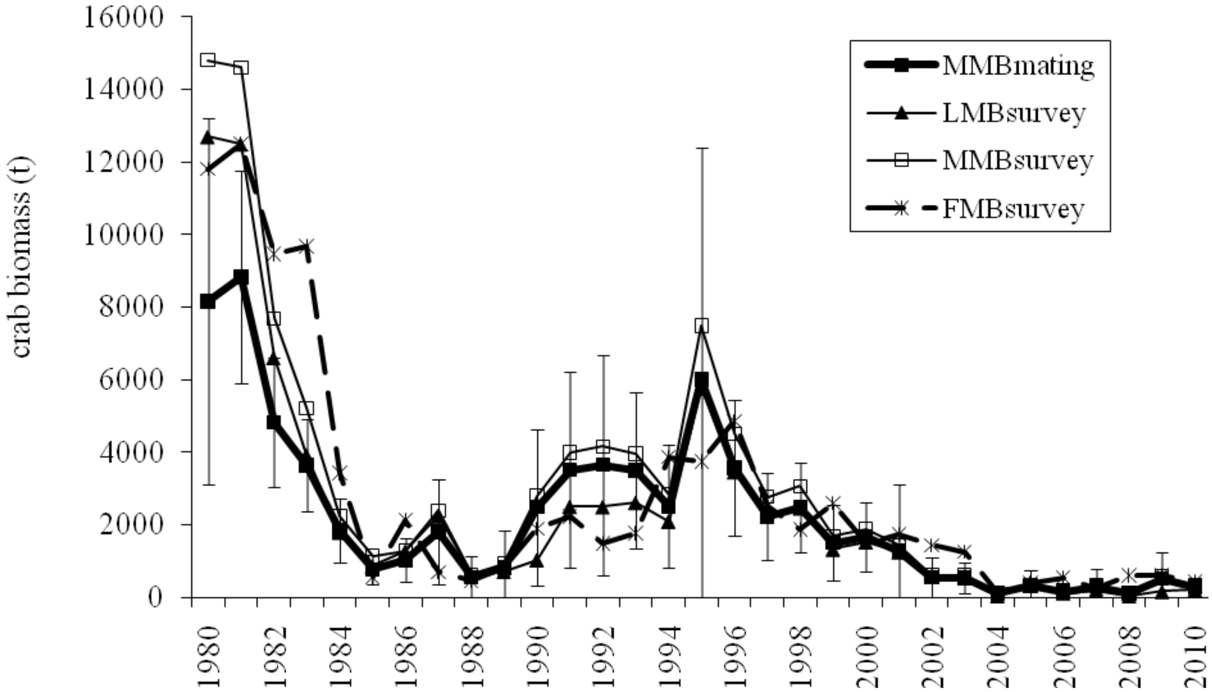

Figure 7. Historical trends of Pribilof Island blue king crab mature male biomass (95% C.I.), mature female biomass, and legal male biomass estimated from the NMFS annual EBS bottom trawl survey.

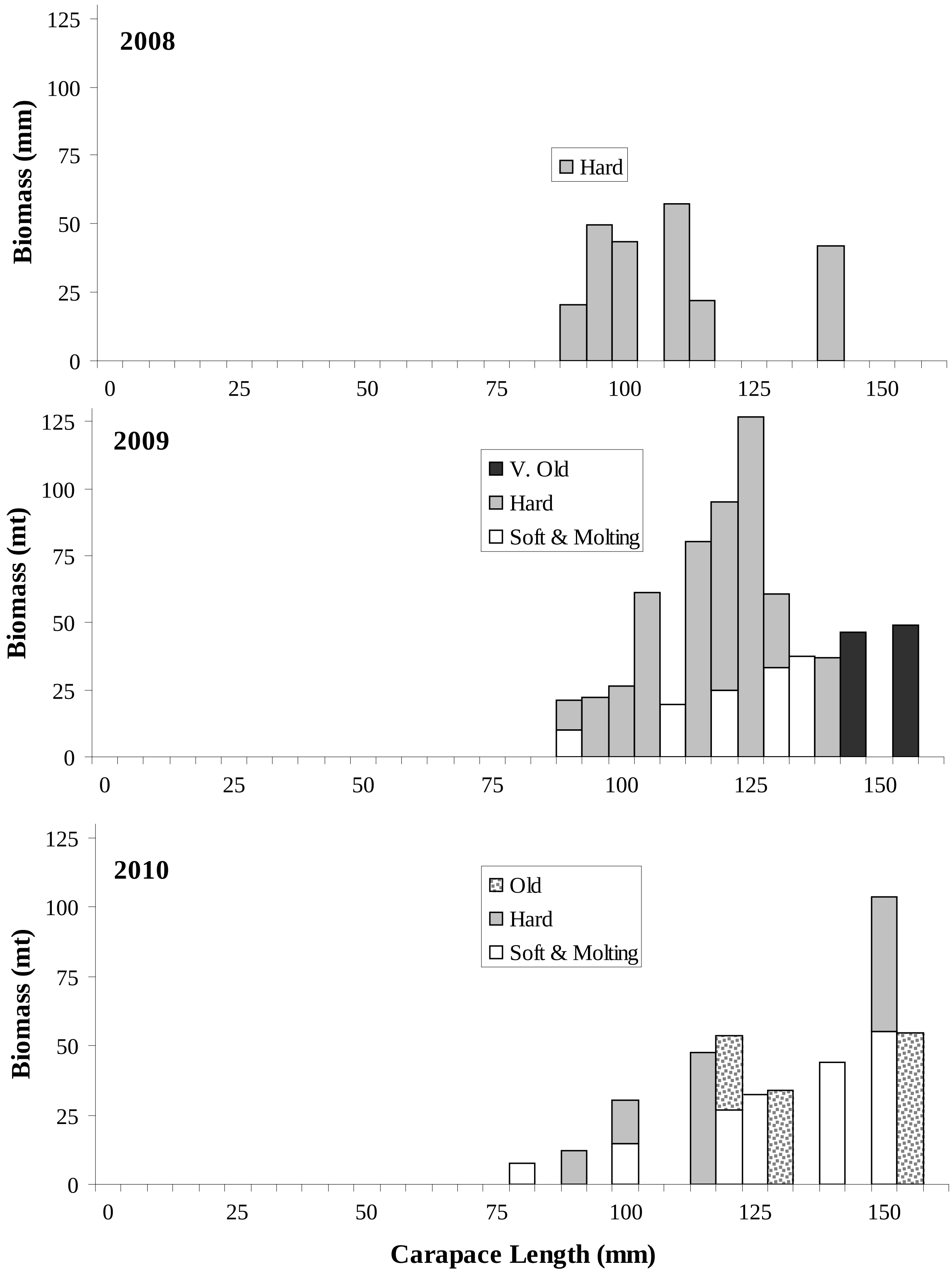

Figure 8. Distribution of Pribilof Island blue king crab in 5 mm length bins by shell condition for the last 3 surveys.

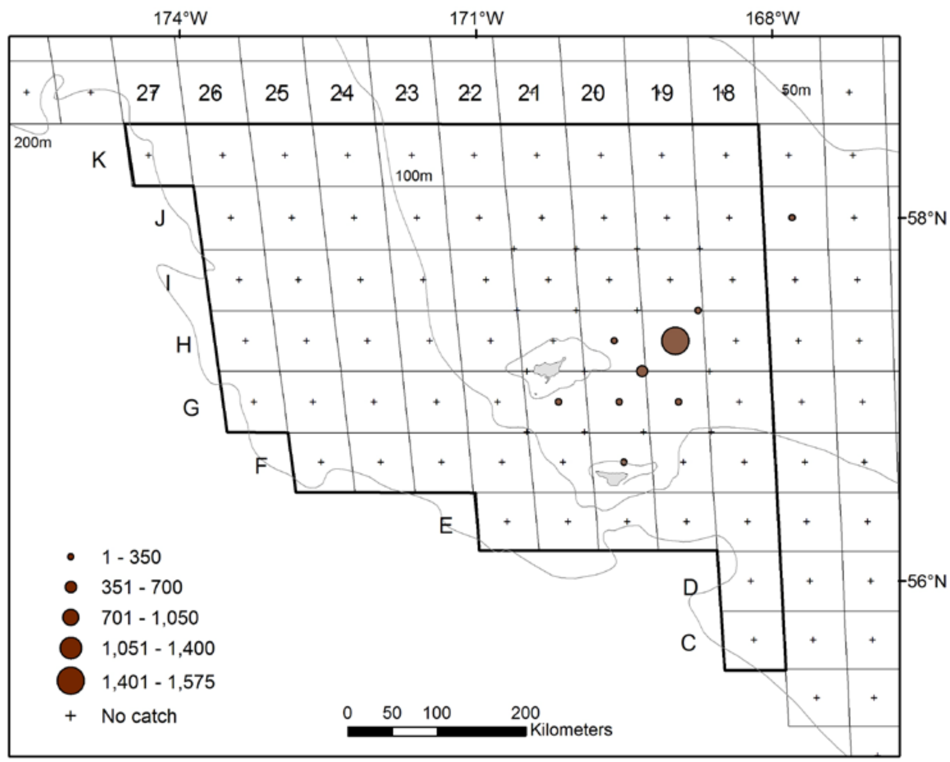

Figure 9. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2010 EBS bottom trawl survey.

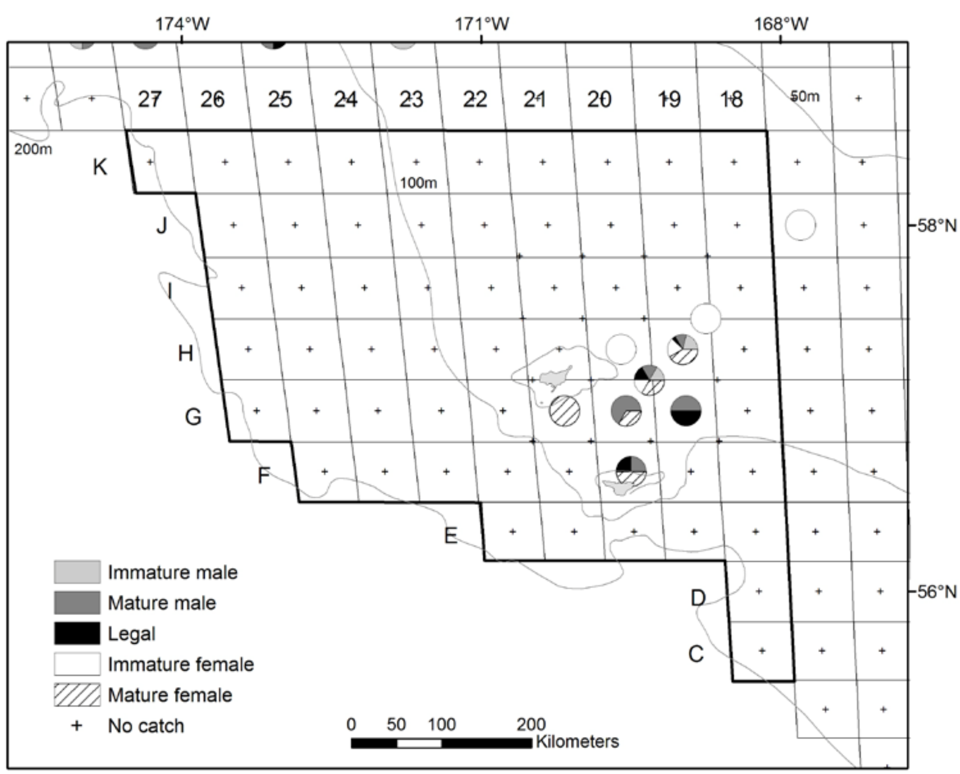

Figure 10. 2010 EBS bottom trawl survey size class distribution of blue king crab in the Pribilof District.

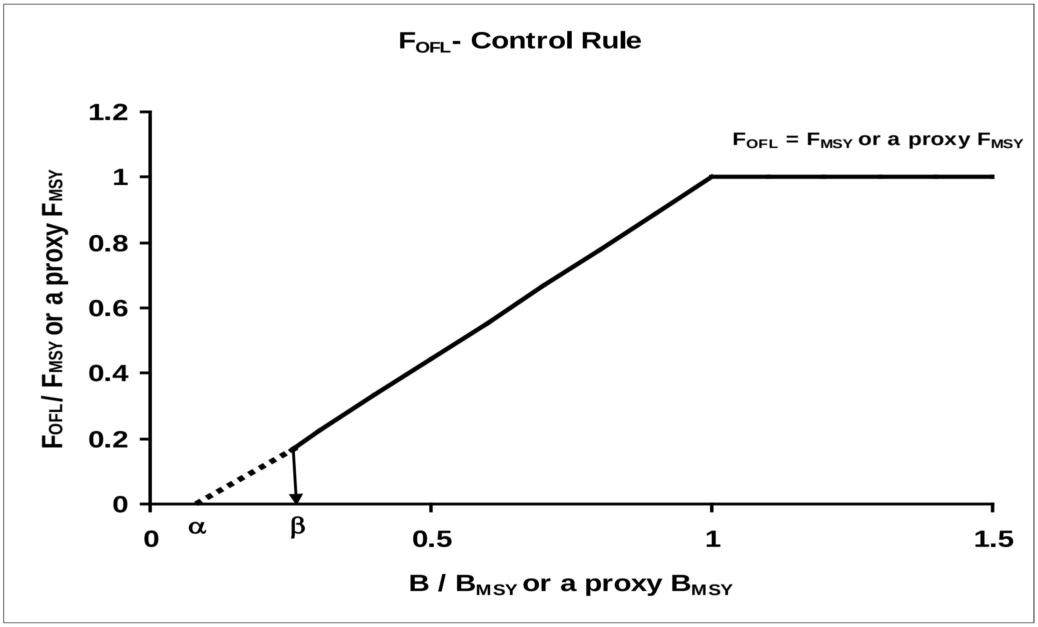

Figure 11. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β.

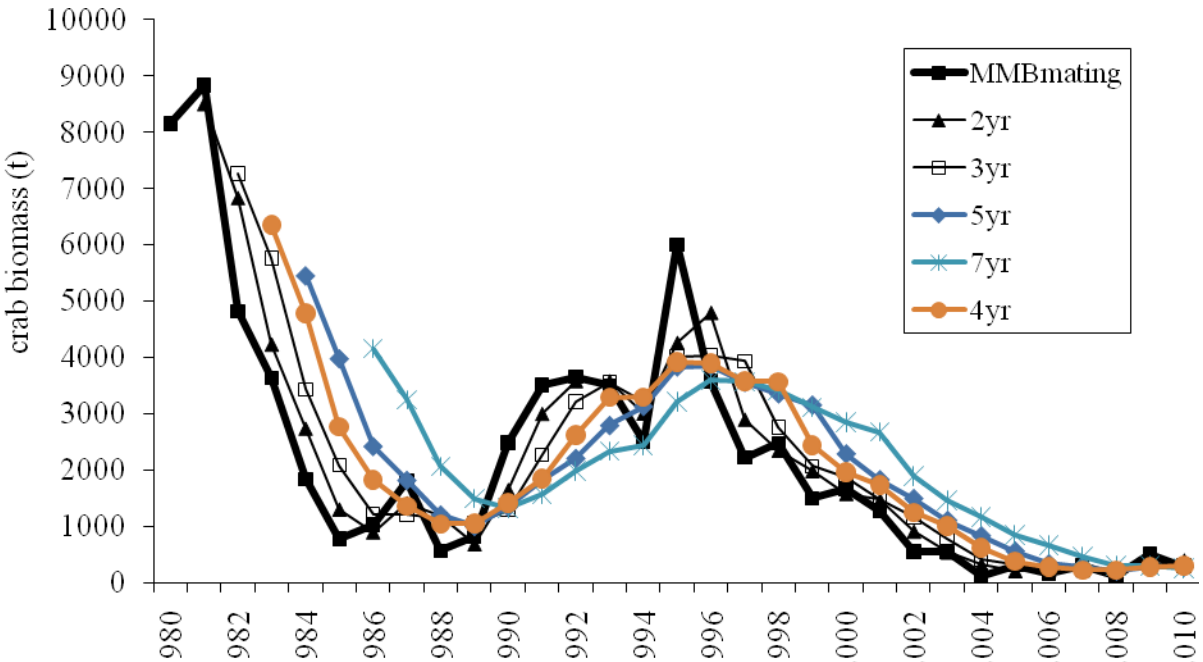

Figure 12. Alternative average biomass options ranging from 2 to 7 year for calculating MMB in the most recent year.