2016 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

W.T. Stockhausen
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
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Executive Summary

1. Stock: Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch has been relatively small in recent years, with most bycatch mortality occurring in the BSAI groundfish fixed gear (pot and hook-and-line) fisheries (5-year average: 0.12 t [0.0003 million lbs]) and trawl fisheries (5-year average: 0.24 t [0.0005 million lbs]). In 2015/16, the estimated PIBKC bycatch mortality in the groundfish fixed gear fisheries was 0.372 t (< 0.0008 million lbs) and 0.646 t (< 0.0014 million lbs) in the groundfish trawl fisheries. The estimated bycatch mortality for PIBKC in other crab fisheries in 2015/16 was 0.166 t (0.0004 million lbs). This was the first non-zero bycatch mortality in other crab fisheries since 2010/11.
3. Stock biomass: Stock biomass decreased between the 1995 and 2008 surveys, and continues to fluctuate at low abundances in all size classes. Any short-term trends are questionable given the high uncertainty associated with recent survey results.
4. Recruitment: Recruitment indices are not well understood for Pribilof Islands blue king crab. Pre-recruits may not be well-assessed by the survey, but have remained consistently low in the past 10 years.
5. Management performance: The stock is below MSST and consequently is overfished. Overfishing also occurred during the 2015/2016 fishing year. The following results are based on determining B_{MSY}/MSST by averaging the MMB-at-mating time series estimated using the smoothed survey data from a random effects model; the current (2016/17) MMB-at-mating is also based on the smoothed survey data. [Note: MSST changed substantially between 2013/14 and 2014/15 as a result of changes to the NMFS EBS trawl survey dataset used to calculate the (proxy) B_{MSY}. MSST changed slightly between 2014/15 and 2015/16 due to small differences in the random effects model results with the addition of 2016 survey data.]

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	1,994 A	579 A	closed	0	0.61	1.16	1.04
2013/14	2,001 A	225 A	closed	0	0.03	1.16	1.04
2014/15	2,055 A	344 A	closed	0	0.07	1.16	0.87
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	--	233 B	--	--	--	1.16	0.87

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	4.39 A	1.09 A	closed	0	0.0013	0.003	0.002
2013/14	4.41 A	0.50 A	closed	0	0.0001	0.003	0.002
2014/15	4.53 A	0.76 A	closed	0	0.0002	0.003	0.002
2015/16	4.54 A	0.79 A	closed	0	0.0026	0.003	0.002
2016/17	--	0.51 B	--	--	--	0.003	0.002

Notes:
A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

6. Basis for the 2016/17 OFL: The OFL was based on Tier 4 considerations. The ratio of estimated 2016/17 MMB-at-mating to B_{MSY} is less than β (0.25) for the F_{OFL} Control Rule, so directed fishing is not allowed. As per the rebuilding plan (NPFMC, 2014a), the OFL is based on a Tier 5 calculation of average bycatch mortalities between 1999/2000 and 2005/2006, which is a time period thought to adequately reflect the conservation needs associated with this stock and to acknowledge existing non-directed catch mortality. Using this approach, the OFL was determined to be 1.16 t (0.003 million lbs) for 2016/17. The following results are based on determining B_{MSY}/MSST by averaging the MMB-at-mating time series estimated using the smoothed survey data from a random effects model; the current (2016/17) MMB-at-mating is also based on the smoothed survey data.

All weights in t:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	4,109	361	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	4,116	233	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

All weights in million lbs:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	9.06	0.79	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	9.07	0.51	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

7. Probability density function for the OFL: Not applicable for this stock.
8. The ABC was calculated using a 25% buffer on the OFL, as in the 2015 assessment. The ABC is thus 0.87 t (= 0.25*x*1.16 t).
9. Rebuilding analyses results summary: In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet a rebuilding horizon of 2014. A preliminary assessment model developed by NMFS (not used in this assessment) suggested that rebuilding could occur within 50 years due to random recruitment (NPFMC, 2014a). Subsequently, Amendment 43 to the King and Tanner Crab Fishery Management Plan (Crab FMP) and Amendment 103 to the Bering Sea and Aleutian Islands Groundfish FMP (BSAI Groundfish FMP) to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. The function of these amendments is to promote bycatch reduction on PIBKC by closing the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod. No pot fishing for Pacific cod occurred within the Pribilof Islands Habitat Conservation Zone in 2015/16.

A. Summary of Major Changes:

1. Management: In 2002, NMFS notified the NPFMC that the PIBKC stock was overfished. A rebuilding plan was implemented in 2003 that included the closure of the stock to directed fishing until the stock was rebuilt. In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. Subsequently, Amendment 43 to the Crab FMP and Amendment 103 to the BSAI Groundfish FMP to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. Amendment 103 closed the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod to promote bycatch reduction on PIBKC. Amendment 43 amended the prior rebuilding plan to incorporate new information on the likely rebuilding timeframe for the stock, taking into account environmental conditions and the status and population biology of the stock. No pot fishing for Pacific cod occurred within the Pribilof Islands Habitat Conservation Zone in 2015/16.
2. Input data: Retained and discard catch time series were updated with 2015/2016 data from the crab and groundfish fisheries. Abundance and biomass for PIBKC in the annual summer NMFS EBS bottom trawl survey were updated for the 2016 survey.
3. Assessment methodology: No changes from the 2015 assessment. The Tier 4 approach used in this assessment for status determination, based on smoothing the raw survey biomass time series using a random effects model, is identical to that adopted by the CPT and SSC last year (Stockhausen, 2015).
4. Assessment results: Total catch mortality in 2015/16 was 1.18 t, which exceeded the OFL (1.16 t). Consequently, overfishing occurred in 2015/16. The projected MMB-at-mating for 2016/17 decreased somewhat from that in 2015/16 and remained below the MSST. Consequently, the stock remains overfished and a directed fishery is prohibited in 2016/17. The OFL, based on average catch, and ABC are identical to last year's values.

B. Responses to SSC and CPT Comments

<u>CPT comments September 2014:</u>

Specific remarks pertinent to this assessment

1. The CPT expressed interest in seeing information about whether the amount of observer coverage has changed since the new groundfish observer program was implemented in 2013.

2. The CPT would like to see the spatial distribution of bycatch by State statistical area.

Responses to CPT Comments:

1. The amount of observer coverage since the new groundfish observer program was implemented has been similar each year (unofficial estimates for all BSAI vessels: 65% in 2013, 75% in 2014, 73% in 2015; C. Faunce, NMFS, pers. comm.).

2. Maps of the spatial distribution of bycatch in the groundfish fisheries are included in Appendix B.

<u>SSC comments October 2014:</u>

Specific remarks pertinent to this assessment

none

<u>CPT comments May 2015:</u>

Specific remarks pertinent to this assessment

none

<u>SSC comments June 2015:</u>

Specific remarks pertinent to this assessment

none

<u>CPT comments September 2015:</u>

Specific remarks pertinent to this assessment

Use results from the random effects smoothing model to calculate both B_{MSY} and current B for status determination.

Responses to CPT Comments:

Done.

<u>SSC comments October 2015:</u>

Specific remarks pertinent to this assessment

none

<u>CPT comments May 2016:</u>

Specific remarks pertinent to this assessment

none

<u>SSC comments June 2016:</u>

Specific remarks pertinent to this assessment

none

C. Introduction

1. **Stock -** Pribilof Islands blue king crab (PIBKC), *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 are found in widely-separated populations across the North Pacific (Figure 1). In the western Pacific, blue king crabs occur off Hokkaido in Japan and isolated populations have been observed in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are found in 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, blue king crabs are found in the Gulf of Alaska in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). The 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 (Armstrong et al 1985, 1987; Somerton, 1985).

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab (PIBKC) were managed under the Bering Sea king crab Registration Area Q Pribilof District. The southern boundary of this district is formed by 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., while its northern boundary is a line at the latitude of Cape Newenham (58° 39' N lat.), its eastern boundary is 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 its western boundary is the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupied the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

3. **Stock structure** - Stock structure of blue king crab in the North Pacific is largely unknown. Samples were collected in 2009-2011 by a graduate student at the University of Alaska to support a genetic study on blue king crab population structure. Aspects of blue king crab harvest and abundance trends, phenotypic characteristics, behavior, movement, and genetics will be evaluated by the author following the guidelines in the AFSC report entitled "Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans" by P. Spencer (unpublished report).

   The potential for species interactions between blue king crab and red king crab as a potential reason for PIBKC shifts in abundance and distribution were addressed in a previous assessment (Foy, 2013). Foy (2013) compared the spatial extent of both speices in the Pribilof Islands from 1975 to 2009 and found that, 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. Spatially, the stations with co-occurance were all dominated by blue king crab and broadly distributed around the Pribilof Islands. 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 maximum of 8, but they were equally dominated by both blue king crab and red king crab—sugggesting a direct overlap in distribution at the scale of a survey station. During this time period, the stations dominated by red king crab were dispersed around the Pribilof Islands. Between 2001 and 2009 the blue king crab population decreased dramatically while the red king crab fluctuated. The number of stations dominated by blue king crab in 2001-2009 was similar to that for stations dominated by red king crab for both males and females, suggesting continued competition for similar habitat. The only stations dominated by blue king crab in the latter period are to the north and east of St. Paul Island. Although blue king crab protection measures also afford protection for the red king crab in this region, red king crab stocks continue to fluctuate (more so than simply accounted for by 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). 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. 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, upon 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 at six years of age (NPFMC 2003). Female size at 50% maturity for Pribilof blue king crab is estimated to be 96-mm carapace length (CL) and size at maturity for males, estimated from chela height relative to CL, is estimated to be 108-mm CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for those males larger than 100 mm CL (NMFS 2005).

   Longevity is unknown for this 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 yr^{-1} for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek et al. 2002). A rate of 0.18 yr^{-1} is currently used for PIBKC.

5. **Management history -** The blue king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (Fig. 3). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season (Fig. 3), with an associated increase in effort to 110 vessels (ADF&G 2008). 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 (NPFMC 1994). Guideline harvest levels (GHL) were 10 percent of the abundance of mature males or 20 percent of the number of legal males (ADF&G 2006).

   PIBKC have occurred as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*) fishery, the western Bering Sea Tanner crab (*Chionoecetes bairdi*) fishery, the Bering Sea hair crab (*Erimacrus isenbeckii*) fishery, and the Pribilof red and blue king crab fisheries. In addition, blue king crab have been taken as bycatch in flatfish, sablefish, halibut, pollock, and Pacific cod fisheries.

   Amendment 21a to the BSAI Groundfish FMP prohibits the use of trawl gear in the Pribilof Islands Habitat Conservation Area (Fig. 4; subsequently renamed the Pribilof Islands Habitat Conservation Zone in Amendment 43), which the amendment also established (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from the impact from trawl gear.

   Declines in the PIBKC stock after 1995 resulted in a closure of directed fishing from 1999 to the present. The stock was declared overfished in September 2002, and ADFG developed a rebuilding harvest strategy as part of the NPFMC comprehensive rebuilding plan for the stock. The rebuilding plan also included the closure of the stock to directed fishing until it was rebuilt. In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. Subsequently, Amendment 43 to the King and Tanner Crab Fishery Management Plan (FMP) and Amendment 103 to the BSAI Groundfish FMP to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. Amendment 103 closes the Pribilof Islands Habitat Conservation Zone (Fig. 4) to pot fishing for Pacific cod to promote bycatch reduction on PIBKC. Amendment 43 amends the prior rebuilding plan to incorporate new information on the likely rebuilding timeframe for the stock, taking into account environmental conditions and the status and population biology of the stock (NPFMC 2014a).

D. Data

1. *Summary of new information:* The time series of retained and discarded catch in the crab fisheries was updated for 2015/16 from ADFG data (no retained catch, 0.166 t bycatch mortality; Tables 1 and 2). The time series of discards in the groundfish pot and trawl fisheries (Tables 2-4) were updated for 2014/15 and calculated for the 2015/16 crab fishery season (July 1-June 30) using NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (as updated on Aug. 15, 2016). Results from the 2016 NMFS EBS bottom trawl survey were added to the assessment (Table 5), based on the "new" standardization described in the 2015 assessment (Stockhausen, 2015).

2. *a. Total catch:*

<u>Crab pot fisheries</u>

Retained pot fishery catches (live and deadloss landings data) are provided for 1973/74 to 2015/16 (Table 1, Fig. 3), including the 1973/74 to 1987/88 and 1995/96 to 1998/99 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/96 to 1998/99 seasons, blue king crab and red king crab were fished under the same Guideline Harvest Level (GHL). Total allowable catch (TAC) for a directed fishery has been set at zero since 1999/2000; there was no retained catch in the 2015/16 crab fishing season.

b. Bycatch and discards:

<u>Crab pot fisheries</u>

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 in the crab fisheries (Table 2). Catch weight was calculated by first determining the mean weight (in grams) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was then calculated from length frequency tables, where the carapace length (*z*; in mm) was converted to weight (*w*; in g) using the following equation:

$$w = \alpha \cdot z^{\beta} \tag{1}$$

Values for the length-to-weight conversion parameters α and β were applied across the 1975-2016 time period: males) α =0.000508, β =3.106409; females) α =0.02065, β =2.27 (Daly et al. 2014). Average weights ($\overline{W}$) for each category were calculated using the following equation:

$$\overline{W} = \frac{\sum_z W_z \cdot n_z}{\sum_z n_z} \tag{2}$$

where w_z is crab weight-at-size *z* (i.e., carapace length) using Eq. 1, and n_z is the number of crabs observed at that size in the category.

Finally, estimated total non-retained weights for each crab fishery were the product of average weight ($\overline{W}$), CPUE based on observer data, and total effort (pot lifts) in each fishery. A 50% handling mortality rate was applied to the bycatch estimates to calculate non-retained crab mortality in these pot fisheries.

Historical non-retained catch data are available from 1996/97 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 2, Bowers et al. 2011), although data may be incomplete for some of these fisheries. Prior to 1998/99, limited observer data exists (for catcher-processor vessels only), so non-retained catch before this date is not included here.

In 2015/16, several PIBKC were incidentally caught in the crab fisheries, yielding an expanded estimate of 0.166 t bycatch mortality (Table 2). The expanded estimates were obtained by multiplying the biomass of the observed fishery-specific bycatch by the ratio of unobserved to observed effort in the relevant crab fishery, then applying an assumed handling mortality rate of 50%. Bycatch mortality during 2015/16 was the first non-zero bycatch mortality in the crab fisheries since 2010/11.

<u>Groundfish pot, trawl, and hook and line fisheries</u>

The AKRO estimates of non-retained catch from all groundfish fisheries in 2015/16, as available through the AKFIN database (accessed Aug. 15, 2016), are included in this report (Tables 2-4). Updated estimates for 2009/10-2014/15 were also obtained through the AKFIN database.

Groundfish bycatch data from before 1999 are available only in INPFC reports and are not included in this assessment. Non-retained crab catch data in the groundfish fisheries are available from 1991/92 to present. Between 1991 and December 2001, bycatch was estimated using the "blend method." From January 2003 to December 2007, bycatch was estimated using the Catch Accounting System (CAS), based on substantially different methods than the "blend." Starting in January 2008, the groundfish observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, the haul-level weights collected by observers were used to estimate the crab weights through CAS instead of applying an annual (global) weight factor to convert numbers to biomass. Spatial resolution was at the NMFS statistical area. Beginning in January 2009, ADF&G statistical areas (1^{o} longitude *x* 0.5^{o} latitude) were included in groundfish production reports and allowed an increase in the spatial resolution of bycatch estimates from the NMFS statistical areas to the state statistical areas. Bycatch estimates (2009-present) based on the state statistical areas were first provided in the 2013 assessment, and improved methods for aggregating observer data were used in the 2014 and 2015 assessments (see Stockhausen, 2015). The estimates obtained this year are based on the same methods as those used in 2014 and 2015.

To assess crab mortalities in the groundfish fisheries, an 80% handling mortality rate was applied to estimates of bycatch in trawl fisheries, and a 50% handling mortality rate was applied to fixed gear fisheries using pot and hook and line gear (Tables 2 and 3).

In 2015/16, fisheries targeting Pacific cod (*Gadus microcephalus*) accounted for 48% of the estimated total PIBKC bycatch (by weight) in the groundfish fisheries, with fisheries targeting yellowfin sole (*Limanda aspera*) accounting for another 43% (Table 4). In contrast, in 2014/15 and 2013/14 bycatch of PIBKC occurred almost exclusively in the Pacific cod fisheries (99.4% by weight, Table 4). However, in 2012/13 the Pacific cod fisheries accounted for only 20% of the bycatch while those targeting yellowfin sole accounted for 77.2%. The flathead sole (*Hippoglossoides elasodon*) fishery also accounted for a substantial fraction of the bycatch in 2010/11 (59%).

Since the 2009/10 crab fishing season, Pribilof Islands blue king crab have been taken as bycatch in the groundfish fisheries only by hook and line and non-pelagic trawl gear (Table 5). Starting in 2015, as a consequence of Amendment 43 to the BSAI Groundfish FMP, the Pribilof Islands Habitat Conservation Area was formally closed to pot fishing for Pacific cod in order to promote recovery of the PIBKC stock. In 2015/16, non-pelagic trawl gear accounted for 52% (by weight) of bycatch of PIBKC in the groundfish fisheries. In 2013/14 and 2014/15, hook and line gear accounted for the total bycatch of PIBKC. In 2012/13, it accounted for only 20% of the bycatch (by weight), whereas non-pelagic trawl gear accounted for 80%. Although these appear to be large interannual changes, the actual bycatch amounts involved are small and interannual variability is consequently expected to be rather high.

c. Catch-at-length: NA

d. Survey biomass:

The 2016 NMFS EBS bottom trawl survey was conducted between May and August of this year. Survey results for PIBKC are based on the stock area first defined in the 2013 assessment (Foy, 2013), which includes the Pribilof District (Fig. 2) and a 20 nm strip adjacent to the eastern edge of the District (not shown in Fig. 2). This new area was defined as a result of the new rebuilding plan and the concern that crab outside the Pribilof District were not being accounted for in the assessment.

In 2016, the survey caught 33 blue king crab in 86 stations across the stock area, while 20 and 28 crab were caught across the same stations in 2014 and 2015, respectively (Table 6). Five immature males were caught in 2016, similar to numbers caught in 2014 and 2015 (5 and 4, respectively). Only three mature males (one of which was legal size) were caught in 2016, compared with 5 and 13 in 2014 and 2015, respectively. Five immature females were caught in 2016; only one was caught in 2014 and none in 2015. Finally, 19 mature females were caught in 2016, compared with only 4 in 2014 and 11 in 2015.

The area-swept estimate of mature male abundance in the stock area at the time of the survey was 56,000 (±62,000) in 2016, representing a substantial (but not statistically significant) decline from 234,000 (± 168,000) in 2015 and 92,000 (±128,000) in 2014. The abundance estimate for immature males in 2016 was 94,000 (±95,000), not substantially (or significantly) different from those in 2015 (76,000) or 2014 (91,000). The area-swept estimate for immature female abundance in 2016 was 132,000 (±130,000), while that for mature females was 323,000 (±328,000). These were both larger than (but not significantly different from) abundance estimates in 2015 (0 and 202,000, respectively) and 2014 (28,000 and 74,000, respectively).

The area-swept estimate of mature male biomass in the stock area at the time of the survey was 129 t (±154 t) in 2016, representing a substantial (but not statistically significant) decline from 622 t (± 480 t) in 2015 and 233 t (±320 t) in 2014. The biomass estimate for immature males in 2016 was 70 t (±67 t), not substantially (or significantly) different from those in 2015 (82 t) or 2014 (83 t). The area-swept estimate for immature female biomass in 2016 was 49 t (±48 t), while that for mature females was 352 t (±340 t). These were both larger than (but not significantly different from) abundance estimates in 2015 (0 and 160 t, respectively) and 2014 (16 t and 91 t, respectively).

One feature that characterizes survey-based estimates of abundance and biomass for PIBKC is the large uncertainty (cv's on the order of 0.5) associated with the estimates, which complicates the interpretation of sometimes large interannual swings in estimates (Tables 7 and 8; Fig.s 5 and 6). Estimated total abundance of male PIBKC from the NMFS EBS bottom trawl survey declined from ~24 million crab in 1975, the first year of the "standardized" survey, to ~150,000 in 2016 (the lowest estimated abundance since 2004, which was the minimum for the time series; Table 7). Following a general decline to a low-point in 1985 (~500,000 males), abundance increased by a factor of 10 in the early1990s, then generally declined (with small amplitude oscillations superimposed) to the present. Estimated female abundance generally followed a similar trend. It spiked at 180 million crab in 1980, from ~13 million crab in 1975 and only ~1 million in 1979, then returned to more typical levels in 1981 (~6 million crab). More recently, abundance has fluctuated around 200,000 females. Estimated biomass for both males and females have followed similar trends similar to those in abundance (Table 8, Fig.s 5 and 6).

Size frequencies for males by shell condition from the five most recent surveys (2012-2016) are illustrated in Figure 7. Size frequencies for all males across the time series are shown in Fig. 8 for both the new time series and the old time series. While Fig. 7 suggested a recent trend toward larger sizes in 2014-15, this does not appear to have continued in 2016. These plots provide little evidence of recent recruitment.

Size frequencies for females by shell condition are presented in Fig. 9 for the five most recent surveys (2012-2016). Size frequencies for all females are shown in Fig. 10. These also provide little indication of recent recruitment.

The spatial pattern of PIBKC abundance in recent surveys is generally centered fairly compactly within the Pribilof District to the east of St. Paul Island (although 2015 is an exception) and north of St. George Island, within a 60 nm radius of St. Paul (Figures 11-13). There is some suggestion that PIBKC may segregate by sex and maturity state (at least during the early summer time period when the survey is conducted; Fig. 12), but its validity is questionable given the overall sampling variability associated with this stock.

E. Analytic Approach

1. *History of modeling approaches*

   A catch survey analysis has been used for assessing the stock in the past, although it is not currently in use. In October 2013, the SSC concurred with the CPT that the PIBKC stock falls under Tier 4 for status determination but it recommended that the OFL be calculated using a Tier 5 approach, with ABC based on a 10% buffer.

   In the 2013 and 2014 assessments (Foy 2013; Stockhausen 2014), "current" MMB-at-mating was projected from the time of the latest survey using an inverse-variance averaging approach to smoothing annual survey biomass estimates because the uncertainties associated with the annual estimates are extremely large. In the 2015 assessment, an alternative approach to smoothing based on a Random Effects model was presented and subsequently adopted by the CPT and SSC to use in estimating B_{MSY} and "current" MMB-at-mating. The Random Effects model (Appendix A) is used in this assessment.

2. *Model Description:* See Appendix A.

3. *Model Selection and Evaluation: Not applicable*

4. *Results:* See Appendix A.

F. Calculation of the OFL

1. *Tier Level:*

   Based on available data, the ***author recommended classification for this stock is Tier 4*** 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 2008a).

   In Tier 4, stock status is based on the ratio of "current" spawning stock biomass (B) to B_{MSY} (or a proxy thereof, B_{MSY}^{proxy}, also referred to as B_{REF}). MSY (maximum sustained yield) 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. The fishing mortality that, if applied over the long-term, would result in MSY is F_{MSY}. B_{MSY} is the long-term average stock size when fished at F_{MSY}, and is based on mature male biomass at the time of 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. Although B_{MSY} cannot be calculated for a Tier 4 stock, a proxy value (B_{MSY}^{proyx} or B_{REF}) is defined as the average biomass over a specified time period that satisfies the conditions under which B_{MSY} would occur (i.e., equilibrium biomass yielding MSY under an applied F_{MSY}).

   The time period for establishing B_{MSY}^{proxy} is assumed to be representative of the stock being fished at an average rate near F_{MSY} and fluctuating around B_{MSY}. The SSC has endorsed using the time periods 1980-84 and 1990-97 to calculate B_{MSY}^{proxy} for Pribilof Islands blue king crab to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected (Foy 2013). Considerations for choosing the current time periods included:

   A. Production potential

      1) Between 2006 and 2013 the stock does appears to be below a threshold for responding to increased production based on the lack of response of the adult stock biomass to slight fluctuations in recruitment (male crab 120-134 mm) (Fig. 20).

2) An estimate of surplus production (ASP = MMB_{t+1} – MMB_t + total catch_t) suggested that only meaningful surplus existed only in the late 1970s and early 1980s while minor surplus production in the early 1990s may have led to the increases in biomass observed in the late 1990s.

3) Although a climate regime shift where temperature and current structure changes are likely to impact blue king crab larval dispersal and subsequent juvenile crab distribution, no apparent trends in production before or after 1978 were observed (Foy 2013). There are few empirical data to identify trends that may allude to a production shift. However, further analysis is warranted given the paucity of surplus production and recruitment subsequent to 1981 and the spikes in recruits (male crab 120-134 mm) /spawner (MMB) observed in the early 1990s and 2009 (Fig. 21 in Foy 2013).

B. Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Fig. 20 in Foy 2013) while total catch increased until 1980, before the fishery was closed in 1987, and increased again in 1995 before closing again in 1999 (Fig. 22 in Foy 2013). The current $F_{\text{MSY}}^{proxy} = M$ is 0.18, so time periods with greater exploitation rates should not be considered to represent a period with an average rate of fishery removals.

C. Subsequent to increases in exploitation rates in the late 1980s and 1990s, the quantity ln(recruits/MMB) dropped, suggesting that exploitation rates at the levels of $F_{\text{MSY}}^{proxy} = M$ were not sustainable.

Thus, MMB_{mating} is the basis for calculating B_{MSY}^{proxy}. The formulas used to calculate MMB_{mating} from MMB at the time of the survey (MMB_{survey}) are documented in Appendix A. For this stock, B_{MSY}^{proxy} was calculated using the random effects model-smoothed estimates for MMB_{survey} from the survey time series in the formula for MMB_{mating}. B_{MSY}^{proxy} is the average of MMB_{mating} for the years 1980/81-1984/85 and 1990/91-1997/98 (see Table 7) and was calculated as 4,116 t.

In this assessment, "current *B*" is the MMB_{mating} projected for 2016/17. Details of this calculation are also provided in Appendix A. For 2016/17, current *B* = 233 t.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, F_{OFL}, which would result 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}^{proxy} and if current *B* drops below the MSST, the stock is considered to be overfished.

2. *List of parameter and stock sizes:*

- B_{MSY}^{proxy} (B_{REF}) = 4,116 t
- M = 0.18 yr^{-1}
- Current *B* = 233 t

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 Tier 4 F_{OFL} is derived using the F_{OFL} Control Rule (Fig. 17), where the Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current *B* to B_{MSY}^{proxy}.

Stock Status Level:	F_{OFL}:	
a. $B/B_{\text{MSY}}^{\text{prox}} > 1.0$	$F_{\text{OFL}} = \gamma \cdot M$	(4)

b. $\beta < B/B_{MSY}^{prox} \leq 1.0$ $\quad F_{OFL} = \gamma \cdot M\,[(B/B_{MSY}^{prox} - \alpha)/(1 - \alpha)]$ (5)

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

When B/B_{MSY}^{proxy} is greater than 1 (Stock Status Level a), F_{OFL}^{proxy} is given by the product of a scalar (γ=1.0, nominally**)** and M. When B/B_{MSY}^{proxy} is less than 1 and greater than the critical threshold β (= 0.25) (Stock Status Level b), the scalar α (= 0.1) determines the slope of the non-constant portion of the control rule for F_{OFL}^{proxy}. Directed fishing mortality is set to zero when the ratio B/B_{MSY}^{proxy} drops below β (Stock Status Level c). Values for α and β are based on a sensitivity analysis of the effects on B/B_{MSY}^{proxy} (NPFMC 2008a).

b. The basis for projecting MMB from the survey to the time of mating is discussed in detail in Appendix A.

c. Specification of F_{OFL}, OFL and other applicable measures:

All weights in t:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	4,109	361	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	4,116	233	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

All weights in million lbs:

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	9.06	0.79	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	9.07	0.51	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

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

   a. The retained portion of the catch for this stock is zero (0 t).

5. *Recommendations:*

For 2016/2017, B_{MSY}^{proxy} = *4,116 t, derived as the mean MMB_{mating} from 1980/81 to 1984/85 and 1990/91 to 1997/98 using the random effects model-smoothed survey time series*. The stock demonstrated highly variable levels of MMB during both of these periods, likely leading to uncertain approximations for B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to limited numbers of tows with crab catches.

MMB_{mating} for 2016/17 was estimated at 233 t for B_{MSY}^{proxy}. The B/B_{MSY}^{proxy} ratio corresponding to the biomass reference is 0.06. B/B_{MSY}^{proxy} is < β, 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 2008a). The preferred method was a total catch OFL equivalent to the average catch mortalities between 1999/2000 and 2005/06. This period was after the targeted fishery was closed and did not include recent changes to the groundfish fishery that led to increased blue king crab bycatch. ***The OFL for 2016/17, based on an average catch mortality, is 1.16 t***.

G. Calculation of the ABC

To calculate an Annual Catch Limit (ACL) to account for scientific uncertainty in the OFL, an acceptable biological catch (ABC) control rule was developed such that ACL=ABC. For Tier 3 and 4 stocks, the ABC is set below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL (P*). Currently, P* is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty (σ_w) in the OFL to establish the maximum permissible ABC (ABC_{max}). Any additional uncertainty to account for uncertainty outside of the assessment methods (σ_b) is considered as a recommended ABC below ABC_{max}. Additional uncertainty is included in the application of the ABC by adding the uncertainty components as $\sigma_{total} = \sqrt{\sigma_b^2 + \sigma_w^2}$. For the PIBKC stock, the CPT has recommended, and the SSC has approved, a constant buffer of 25% to the OFL (NPFMC, 2014b).

1. *Specification of the probability distribution of the OFL used in the ABC:* The OFL was set based on a Tier 5 calculation of average catch mortalities between 1999/2000 and 2005/06 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality. As such, the OFL does not have an associated probability distribution.

2. *List of variables related to scientific uncertainty considered in the OFL probability distribution:* None. The OFL is based on a Tier 5 calculation and does not have an associated probability distribution. However, 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 spatial extent 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 0.61, and has ranged between 0.17 and 1.00 since the 1980 peak in biomass.

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 rather are pre-specified.

   - F_{MSY} is assumed to be equal to γM when applying the OFL control rule, where the proportionality constant γ is assumed to be equal to 1 and M is assumed to be known.

   - 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. 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}.

4. *Recommendations:*

   For 2016/17, $F_{directed}$ = 0 and the total catch OFL is based on catch biomass would maintain the conservation needs with this stock and acknowledge the existing non-directed catch mortality. In this case, the ***ABC_{max} based on a 25% buffer of the average catch between 1999/2000 and 2005/2006 would be 0.87 t.***

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	1,994 A	579 A	closed	0	0.61	1.16	1.04
2013/14	2,001 A	225 A	closed	0	0.03	1.16	1.04
2014/15	2,055 A	344 A	closed	0	0.07	1.16	0.87
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	--	233 B	--	--	--	1.16	0.87

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2012/13	4.39 A	1.09 A	closed	0	0.0013	0.003	0.002
2013/14	4.41 A	0.50 A	closed	0	0.0001	0.003	0.002
2014/15	4.53 A	0.76 A	closed	0	0.0002	0.003	0.002
2015/16	4.54 A	0.79 A	closed	0	0.0026	0.003	0.002
2016/17	--	0.51 B	--	--	--	0.003	0.002

Notes:
A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

H. Rebuilding Analyses

Rebuilding analyses results summary: A revised rebuilding plan analysis was submitted to the U.S. Secretary of Commerce in 2014 because NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. The Secretary approved the plan in 2015, as well as the two amendments that implement it (Amendment 43 to the King and Tanner Crab Fishery Management Plan and Amendment 103 to the BSAI Groundfish Fishery Management Plan). These amendments impose a closure to all fishing for Pacific cod with pot gear in the Pribilof Islands Habitat Conservation Zone. This measure was designed to protect the main concentration of the stock from the fishery with the highest observed rates of bycatch (NPFMC, 2014a). The area has been closed to trawling since 1995.

I. Data Gaps and Research Priorities

Given the large CVs associated with the survey abundance and biomass estimates for the Pribilof Islands blue king crab stock, assessment of this species might benefit from additional surveys using alternative gear at finer spatial resolution. Further data gaps include stock-specific natural mortality rates and a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District.

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Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly and J. Webb, ADF&G, personal communications).

Year	Retained Catch		Avg. CPUE
	Abundance	Biomass (t)	legal crabs/pot
1973/1974	174,420	579	26
1974/1975	908,072	3,224	20
1975/1976	314,931	1,104	19
1976/1977	855,505	2,999	12
1977/1978	807,092	2,929	8
1978/1979	797,364	2,901	8
1979/1980	815,557	2,719	10
1980/1981	1,497,101	4,976	9
1981/1982	1,202,499	4,119	7
1982/1983	587,908	1,998	5
1983/1984	276,364	995	3
1984/1985	40,427	139	3
1985/1986	76,945	240	3
1986/1987	36,988	117	2
1987/1988	95,130	318	2
1988/1989	0	0	--
1989/1990	0	0	--
1990/1991	0	0	--
1991/1992	0	0	--
1992/1993	0	0	--
1993/1994	0	0	--
1994/1995	0	0	--
1995/1996	190,951	628	5
1996/1997	127,712	425	4
1997/1998	68,603	232	3
1998/1999	68,419	234	3
1999/2000 - 2015/2016	0	0	--

Table 2. Total bycatch (non-retained catch) from the directed and non-directed fisheries for Pribilof Islands District blue king crab. Crab fishery bycatch data is not available prior to 1996/1997 (Bowers et al. 2011; D. Pengilly ADF&G). Gear-specific groundfish fishery data is not available prior to 1991/1992 (J. Mondragon, NMFS).

fishery year	crab (pot) fisheries (t)			groundfish fisheries (t)	
	females	legal males	sublegal males	fixed gear	trawl gear
1991/92	--	--	--	0.067	6.199
1992/93	--	--	--	0.879	60.791
1993/94	--	--	--	0.000	34.232
1994/95	--	--	--	0.035	6.856
1995/96	--	--	--	0.108	1.284
1996/97	0.000	0.000	0.807	0.031	0.067
1997/98	0.000	0.000	0.000	1.462	0.130
1998/99	3.715	2.295	0.467	19.800	0.079
1999/00	1.969	3.493	4.291	0.795	0.020
2000/01	0.000	0.000	0.000	0.116	0.023
2001/02	0.000	0.000	0.000	0.833	0.029
2002/03	0.000	0.000	0.000	0.071	0.297
2003/04	0.000	0.000	0.000	0.345	0.227
2004/05	0.000	0.000	0.000	0.816	0.002
2005/06	0.050	0.000	0.000	0.353	1.339
2006/07	0.104	0.000	0.000	0.138	0.074
2007/08	0.136	0.000	0.000	3.993	0.132
2008/09	0.000	0.000	0.000	0.141	0.473
2009/10	0.000	0.000	0.000	0.216	0.207
2010/11	0.000	0.000	0.186	0.039	0.056
2011/12	0.000	0.000	0.000	0.112	0.007
2012/13	0.000	0.000	0.000	0.167	0.669
2013/14	0.000	0.000	0.000	0.064	0.000
2014/15	0.000	0.000	0.000	0.142	0.000
2015/16	0.103	0.000	0.230	0.745	0.808

Table 3. Total bycatch (discard) *mortality* from directed and non-directed fisheries for Pribilof Islands District blue king crab. Gear-specific handling mortalities were applied to estimates of non-retained catch from Table 2 for fixed gear (i.e., pot and hook/line; 0.5) and trawl gear (0.8).

fishery year	crab (pot) fisheries (t)			groundfish fisheries (t)		total bycatch mortality (t)
	females	legal males	sublegal males	fixed gear	trawl gear	
1991/92	--	--	--	0.034	4.959	4.993
1992/93	--	--	--	0.440	48.633	49.072
1993/94	--	--	--	0.000	27.386	27.386
1994/95	--	--	--	0.018	5.485	5.502
1995/96	--	--	--	0.054	1.027	1.081
1996/97	0.000	0.000	0.404	0.016	0.054	0.473
1997/98	0.000	0.000	0.000	0.731	0.104	0.835
1998/99	1.857	1.148	0.234	9.900	0.063	13.202
1999/00	0.984	1.746	2.145	0.398	0.016	5.290
2000/01	0.000	0.000	0.000	0.058	0.018	0.076
2001/02	0.000	0.000	0.000	0.417	0.023	0.440
2002/03	0.000	0.000	0.000	0.036	0.238	0.273
2003/04	0.000	0.000	0.000	0.173	0.182	0.354
2004/05	0.000	0.000	0.000	0.408	0.002	0.410
2005/06	0.025	0.000	0.000	0.177	1.071	1.273
2006/07	0.052	0.000	0.000	0.069	0.059	0.180
2007/08	0.068	0.000	0.000	1.997	0.106	2.170
2008/09	0.000	0.000	0.000	0.071	0.378	0.449
2009/10	0.000	0.000	0.000	0.108	0.165	0.273
2010/11	0.000	0.000	0.093	0.020	0.045	0.158
2011/12	0.000	0.000	0.000	0.056	0.006	0.062
2012/13	0.000	0.000	0.000	0.084	0.535	0.619
2013/14	0.000	0.000	0.000	0.032	0.000	0.032
2014/15	0.000	0.000	0.000	0.071	0.000	0.071
2015/16	0.051	0.000	0.115	0.372	0.646	1.185

Table 4. Proportion by weight of the estimated total Pribilof Islands blue king crab bycatch in the groundfish fisheries among trip targets. For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-2015/16, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the Pribilof Islands Blue King Crab District. Groundfish fishery target species that caught blue king crab but made up less than 2% of the blue king crab bycatch across all years are not shown in the table. The estimated total bycatch of Pribilof Islands blue king crab in numbers across all groundfish fisheries is also shown.

Crab Fishery Year	% bycatch (biomass) by trip target				total bycatch (# crabs)
	yellowfin sole %	Pacific cod %	flathead sole %	rocksole %	
2003/04	47	22	31	< 1	252
2004/05	< 1	100	< 1	< 1	259
2005/06	< 1	97	3	< 1	757
2006/07	54	20	< 1	26	96
2007/08	3	96	1	< 1	2,950
2008/09	77	23	< 1	< 1	295
2009/10	31	51	17	< 1	281
2010/11	< 1	39	59	< 1	48
2011/12	< 1	100	< 1	< 1	62
2012/13	77	20	3	< 1	410
2013/14	< 1	99	< 1	< 1	39
2014/15	< 1	99	< 1	< 1	64
2015/16	43	48	9	< 1	609

Table 5. Proportion by weight of the estimated total Pribilof Islands blue king crab bycatch in the groundfish fisheries among gear types. For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-2015/16, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the Pribilof Islands Blue King Crab District. The estimated total bycatch of Pribilof Islands blue king crab in numbers across all groundfish fisheries is also shown.

Crab Fishery Year	% bycatch (biomass) by gear type				total bycatch (# crabs)
	non-pelagic trawl %	pelagic trawl %	hook and line %	pot %	
2003/04	79	0	21	0	252
2004/05	1	0	99	0	259
2005/06	3	0	18	79	757
2006/07	20	0	20	0	96
2007/08	3	0	1	95	2,950
2008/09	77	0	23	0	295
2009/10	49	0	7	44	281
2010/11	59	0	41	0	48
2011/12	6	0	94	0	62
2012/13	80	0	20	0	410
2013/14	0	0	100	0	39
2014/15	0	0	100	0	64
2015/16	52	0	48	0	609

Table 6. Summaries of the a) 2016, b) 2015, and c) 2014 NMFS annual EBS bottom trawl surveys for the Pribilof Islands District blue king crab by stock component.

a) 2016 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	4	5	5	0.094	0.095	70	67
Mature male	86	3	3	3	0.056	0.062	129	154
Legal male	86	1	1	1	0.019	0.038	68	133
Immature female	86	4	5	5	0.132	0.130	49	48
Mature female	86	7	19	19	0.323	0.328	352	340

b) 2015 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	2	4	4	0.076	0.113	82	120
Mature male	86	8	13	13	0.234	0.168	622	480
Legal male	86	5	7	7	0.125	0.109	428	385
Immature female	86	0	0	0	0.000	0.000	0	0
Mature female	86	4	11	11	0.202	0.260	160	207

c) 2014 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	3	5	5	0.091	0.105	83	102
Mature male	86	2	5	5	0.092	0.128	233	320
Legal male	86	2	5	5	0.092	0.128	233	320
Immature female	86	1	1	1	0.028	0.054	16	32
Mature female	86	3	4	4	0.074	0.088	91	108

Table 7. Abundance time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

Year	Males								Females	
	immature		mature		legal		total		total	
	abundance	cv	abundance	cv	abundance	cv	abundance	cv	abundance	cv
1975	8,475,781	0.57	15,288,169	0.50	9,051,486	0.50	23,763,950	0.47	13,147,587	0.61
1976	4,959,559	0.95	4,782,105	0.45	4,012,289	0.47	9,741,664	0.59	8,138,538	0.91
1977	4,215,865	0.46	13,043,983	0.74	11,768,927	0.77	17,259,848	0.63	14,731,651	0.86
1978	2,421,458	0.50	6,140,638	0.50	3,922,874	0.62	8,562,096	0.43	5,987,437	0.66
1979	79,355	0.70	4,107,868	0.33	3,017,119	0.31	4,187,222	0.32	1,311,351	0.77
1980	2,732,728	0.47	7,842,342	0.41	6,244,058	0.42	10,575,070	0.40	183,684,143	0.98
1981	2,099,475	0.32	3,834,431	0.18	3,245,951	0.18	5,933,906	0.21	6,260,015	0.42
1982	1,371,283	0.28	2,353,813	0.18	2,071,468	0.19	3,725,096	0.17	8,713,260	0.63
1983	1,030,732	0.36	1,851,301	0.19	1,321,395	0.17	2,882,033	0.22	9,771,695	0.76
1984	517,574	0.40	770,643	0.22	558,226	0.25	1,288,217	0.21	3,234,663	0.37
1985	67,765	0.60	428,076	0.28	270,242	0.29	495,841	0.27	746,266	0.36
1986	18,904	1.00	480,198	0.31	460,311	0.31	499,102	0.30	2,138,616	0.88
1987	621,541	0.83	903,180	0.41	830,151	0.42	1,524,721	0.43	1,072,008	0.48
1988	1,238,053	0.84	237,868	0.51	237,868	0.51	1,475,921	0.71	1,363,093	0.64
1989	3,514,764	0.59	239,948	0.62	239,948	0.62	3,754,712	0.58	3,777,855	0.58
1990	2,449,864	0.60	1,470,419	0.63	571,708	0.54	3,920,283	0.58	4,223,169	0.56
1991	1,920,443	0.37	2,014,086	0.36	1,237,558	0.44	3,934,529	0.34	3,572,899	0.35
1992	2,435,796	0.59	1,935,278	0.42	1,154,465	0.45	4,371,074	0.48	3,946,863	0.52
1993	1,483,524	0.52	1,875,500	0.31	1,114,301	0.30	3,359,024	0.34	2,663,329	0.38
1994	638,520	0.37	1,294,263	0.34	935,269	0.34	1,932,783	0.33	5,191,978	0.44
1995	1,146,803	0.89	3,101,712	0.60	2,186,409	0.62	4,248,514	0.67	4,697,035	0.49
1996	719,430	0.63	1,712,015	0.28	1,269,275	0.26	2,431,445	0.33	5,321,557	0.46
1997	467,234	0.53	1,201,296	0.29	932,852	0.28	1,668,530	0.34	2,934,717	0.39
1998	949,447	0.46	967,098	0.25	797,187	0.25	1,916,545	0.31	2,329,750	0.37
1999	159,536	0.37	617,258	0.33	452,740	0.34	776,794	0.33	2,755,976	0.49
2000	163,835	0.56	725,051	0.30	527,589	0.30	888,885	0.31	1,363,070	0.46
2001	92,918	0.65	522,239	0.71	445,863	0.74	615,157	0.69	1,715,981	0.74
2002	0	0.00	225,476	0.47	207,146	0.49	225,476	0.47	1,240,582	0.78
2003	45,271	0.72	228,897	0.39	213,572	0.40	274,168	0.34	1,187,583	0.72
2004	87,651	0.59	47,905	0.56	15,584	1.00	135,556	0.42	168,094	0.51
2005	1,981,338	0.96	91,932	0.71	91,932	0.71	2,073,270	0.92	2,557,310	0.89
2006	138,118	0.49	55,579	0.56	38,242	0.70	193,697	0.42	542,588	0.62
2007	246,165	0.72	110,080	0.85	54,403	0.75	356,245	0.64	288,245	0.59
2008	233,919	0.93	18,256	1.00	18,256	1.00	252,174	0.86	779,488	0.75
2009	267,717	0.63	248,626	0.73	68,117	0.59	516,343	0.68	629,385	0.76
2010	101,151	0.84	130,465	0.49	64,703	0.48	231,616	0.61	414,660	0.62
2011	0	0.00	165,525	0.79	129,098	0.87	165,525	0.79	54,601	0.56
2012	194,522	1.00	272,233	0.80	164,165	0.68	466,755	0.88	346,777	0.70
2013	76,351	1.00	104,361	0.86	68,726	0.80	180,712	0.64	195,644	0.53
2014	90,990	0.59	91,856	0.71	91,856	0.71	182,846	0.57	102,088	0.51
2015	75,575	0.77	233,630	0.37	124,592	0.45	309,205	0.41	202,464	0.65
2016	94,022	0.52	55,852	0.56	19,345	1.00	149,874	0.49	454,449	0.50

Table 8. Biomass time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

Year	Males								Females	
	immature		mature		legal		total		total	
	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv
1975	8,341	0.52	38,054	0.50	27,016	0.50	46,395	0.47	12,442	0.64
1976	4,129	0.94	14,059	0.45	12,649	0.47	18,188	0.45	5,792	0.89
1977	3,713	0.44	42,618	0.77	40,366	0.78	46,332	0.73	13,572	0.87
1978	2,765	0.51	17,370	0.56	13,517	0.64	20,135	0.51	6,492	0.72
1979	61	0.79	10,959	0.32	9,040	0.31	11,021	0.31	1,189	0.76
1980	2,084	0.49	23,553	0.43	20,679	0.45	25,637	0.42	212,303	0.98
1981	1,704	0.30	11,628	0.17	10,554	0.17	13,332	0.18	6,484	0.46
1982	1,152	0.23	7,389	0.19	6,893	0.19	8,541	0.17	9,377	0.67
1983	962	0.36	5,409	0.18	4,474	0.17	6,371	0.19	10,248	0.78
1984	130	0.36	2,216	0.23	1,824	0.25	2,345	0.22	3,085	0.38
1985	39	0.73	1,055	0.27	755	0.28	1,094	0.26	525	0.44
1986	4	1.00	1,505	0.30	1,473	0.31	1,508	0.30	2,431	0.90
1987	191	0.78	2,923	0.41	2,781	0.41	3,115	0.40	913	0.53
1988	170	0.71	842	0.53	842	0.53	1,012	0.46	718	0.47
1989	1,275	0.62	827	0.64	827	0.64	2,102	0.55	1,746	0.50
1990	2,004	0.66	3,078	0.60	1,514	0.52	5,082	0.61	2,929	0.49
1991	1,377	0.39	4,690	0.39	3,326	0.45	6,067	0.37	2,776	0.38
1992	1,801	0.51	4,391	0.42	3,035	0.45	6,192	0.43	2,649	0.46
1993	1,088	0.54	4,556	0.31	3,203	0.30	5,644	0.30	2,092	0.40
1994	619	0.39	3,410	0.34	2,806	0.35	4,029	0.34	4,893	0.44
1995	968	0.86	8,360	0.60	6,787	0.62	9,328	0.63	4,279	0.50
1996	745	0.61	4,641	0.27	3,873	0.27	5,386	0.28	5,585	0.49
1997	381	0.55	3,233	0.28	2,765	0.27	3,614	0.29	3,028	0.41
1998	692	0.41	2,798	0.25	2,510	0.25	3,490	0.25	2,182	0.39
1999	161	0.40	1,729	0.34	1,426	0.35	1,890	0.33	2,868	0.47
2000	113	0.68	2,091	0.30	1,746	0.31	2,205	0.30	1,462	0.46
2001	87	0.76	1,599	0.73	1,461	0.76	1,686	0.73	1,817	0.72
2002	0	0.00	680	0.51	647	0.52	680	0.51	1,401	0.78
2003	19	0.98	702	0.40	671	0.41	721	0.39	1,307	0.73
2004	36	0.65	107	0.58	48	1.00	143	0.46	123	0.50
2005	326	0.94	344	0.71	344	0.71	670	0.59	847	0.61
2006	87	0.58	166	0.60	139	0.70	253	0.46	576	0.71
2007	197	0.74	306	0.80	206	0.73	503	0.66	282	0.71
2008	212	0.95	46	1.00	46	1.00	258	0.80	672	0.70
2009	254	0.68	497	0.71	187	0.60	751	0.70	625	0.82
2010	92	0.85	303	0.46	190	0.48	395	0.52	394	0.63
2011	0	0.00	461	0.84	399	0.89	461	0.84	37	0.67
2012	165	1.00	644	0.74	459	0.64	809	0.79	237	0.64
2013	15	1.00	250	0.80	190	0.75	265	0.75	166	0.65
2014	83	0.62	233	0.70	233	0.70	317	0.57	108	0.53
2015	82	0.75	622	0.39	428	0.46	703	0.39	160	0.66
2016	70	0.49	129	0.61	68	1.00	199	0.52	401	0.48

Table 9. Estimates of mature male biomass (MMB) at the time of mating for Pribilof Islands blue king crab using: (1) the "raw" survey biomass time series and (2) the survey biomass time series smoothed using the Random Effects Model. Shaded rows signify averaging time period for B_{MSY}/MSST. The 2016/17 estimates are projected values (see Appendix A).

year	"Raw" Survey Biomass (t)	Random Effects Model (t)
1975/76	33,223	23,279
1976/77	9,834	15,099
1977/78	35,611	16,450
1978/79	12,904	12,561
1979/80	7,304	9,418
1980/81	16,519	9,420
1981/82	6,590	6,414
1982/83	4,769	4,823
1983/84	3,934	3,644
1984/85	1,862	1,977
1985/86	723	983
1986/87	1,244	1,288
1987/88	2,333	1,441
1988/89	758	1,278
1989/90	745	1,430
1990/91	2,771	2,343
1991/92	4,220	3,440
1992/93	3,930	3,748
1993/94	4,089	3,888
1994/95	3,068	3,611
1995/96	6,937	3,877
1996/97	3,776	3,553
1997/98	2,692	2,773
1998/99	2,291	2,208
1999/00	1,555	1,775
2000/01	1,883	1,657
2001/02	1,439	1,141
2002/03	612	705
2003/04	632	494
2004/05	96	248
2005/06	309	238
2006/07	149	202
2007/08	275	206
2008/09	41	188
2009/10	447	265
2010/11	273	289
2011/12	415	336
2012/13	579	360
2013/14	225	311
2014/15	210	305
2015/16	559	361
2016/17*	116	233

Figures

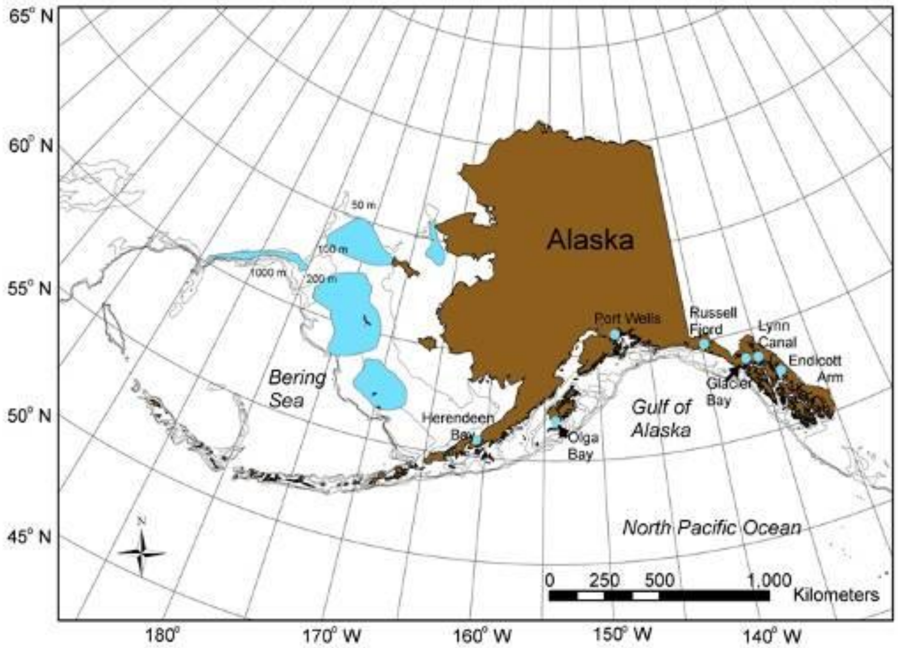


Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

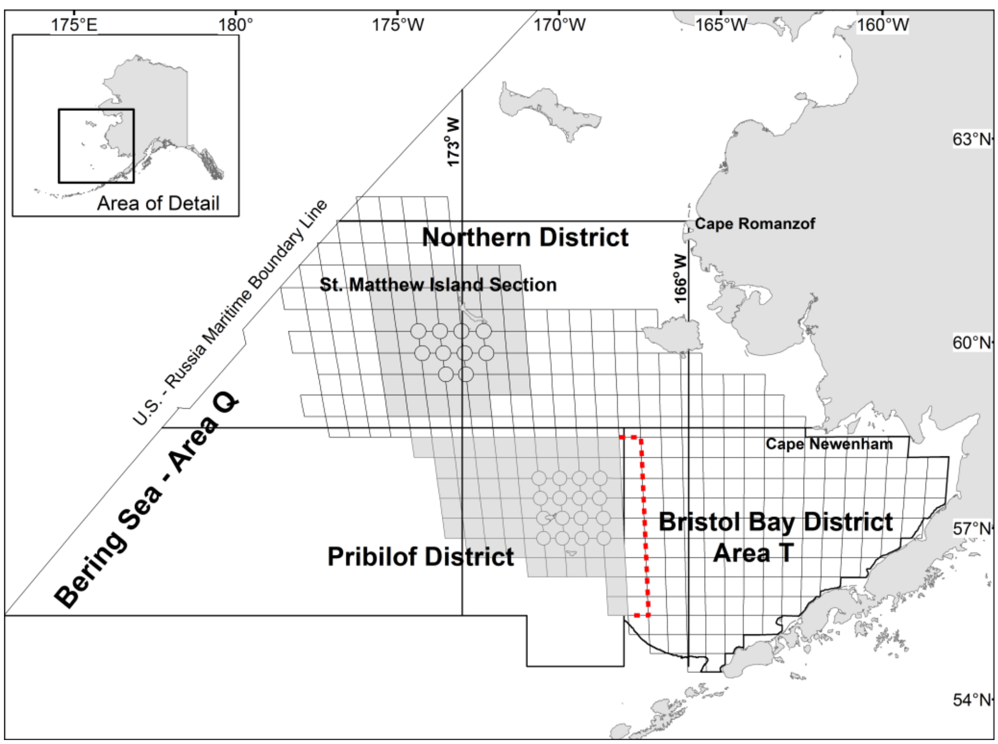


Figure 2. King crab Registration Area Q (Bering Sea) showing, among others, the Pribilof District. This figure also indicates the additional 20 nm strip (red dotted line) considered starting in 2013 year for biomass and catch data in the Pribilof District.

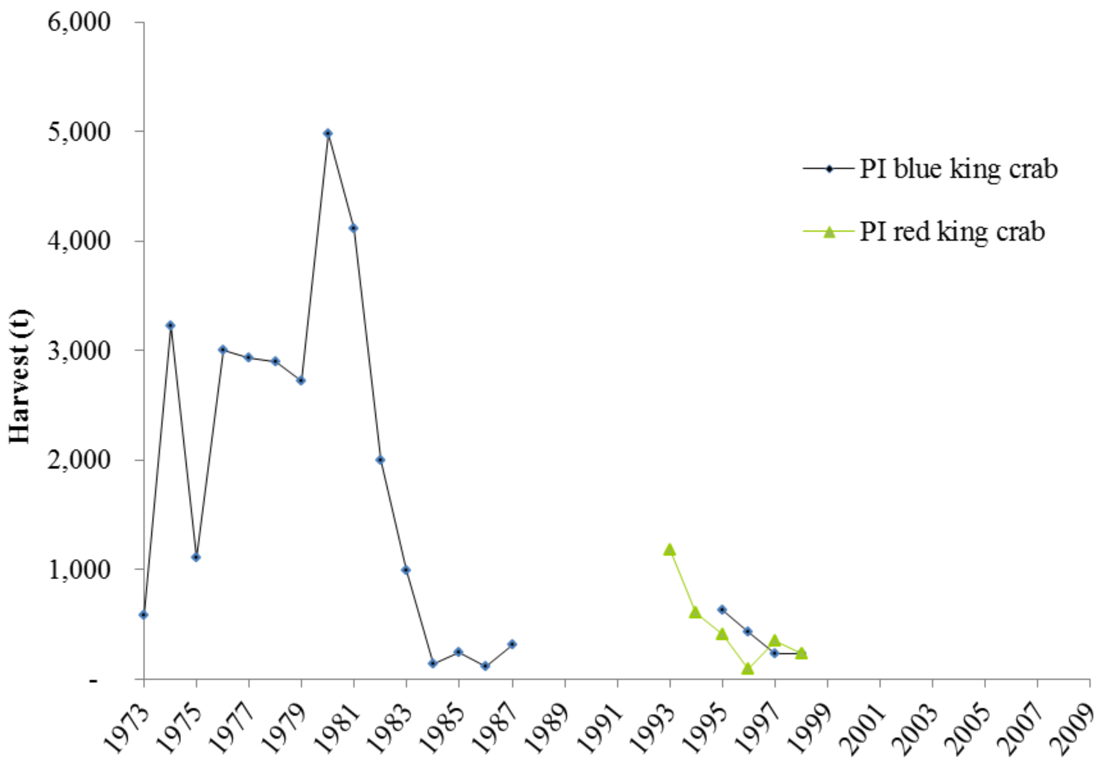


Figure 3. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

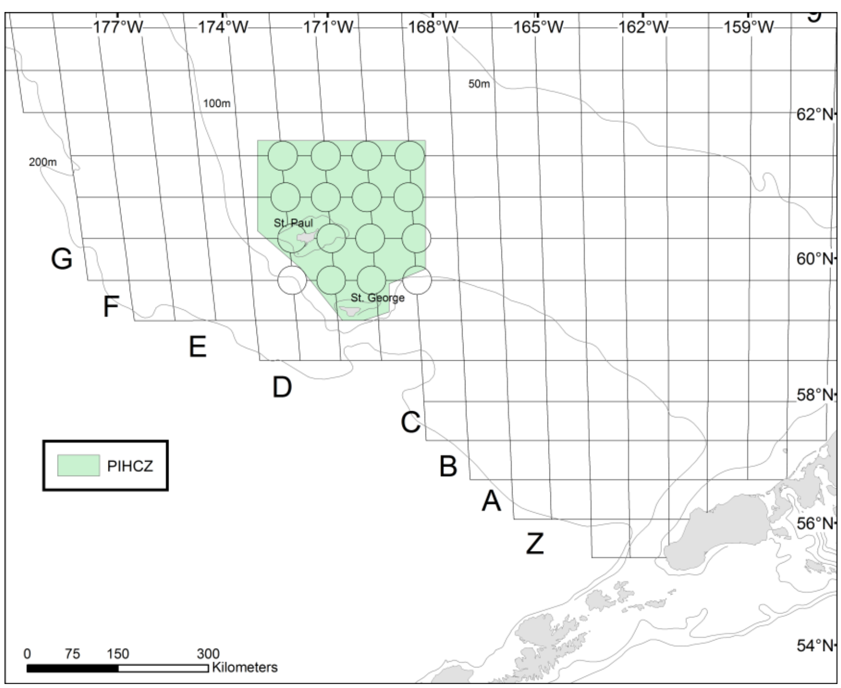


Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.

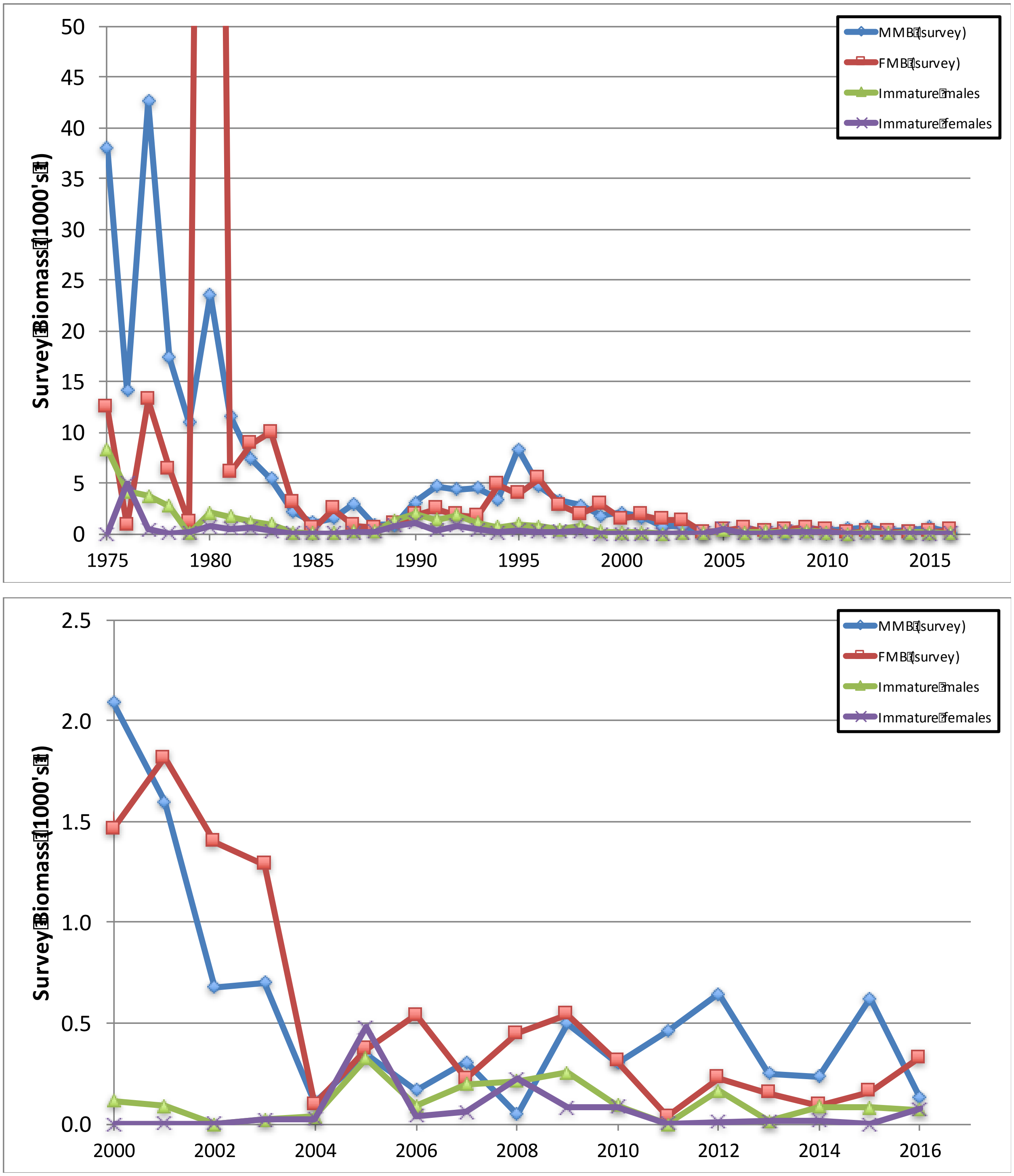


Figure 5. Time series of area-swept biomass estimates for various stock components of Pribilof Islands blue king crab estimated using the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2016. Lower graph: 2000-2015. MMB (blue): mature male biomass at survey time; FMB (red): female mature biomass at survey time. The estimate for FMB in 1980 (off the upper chart) is 212,000 t. To facilitate comparison confidence intervals are not shown.

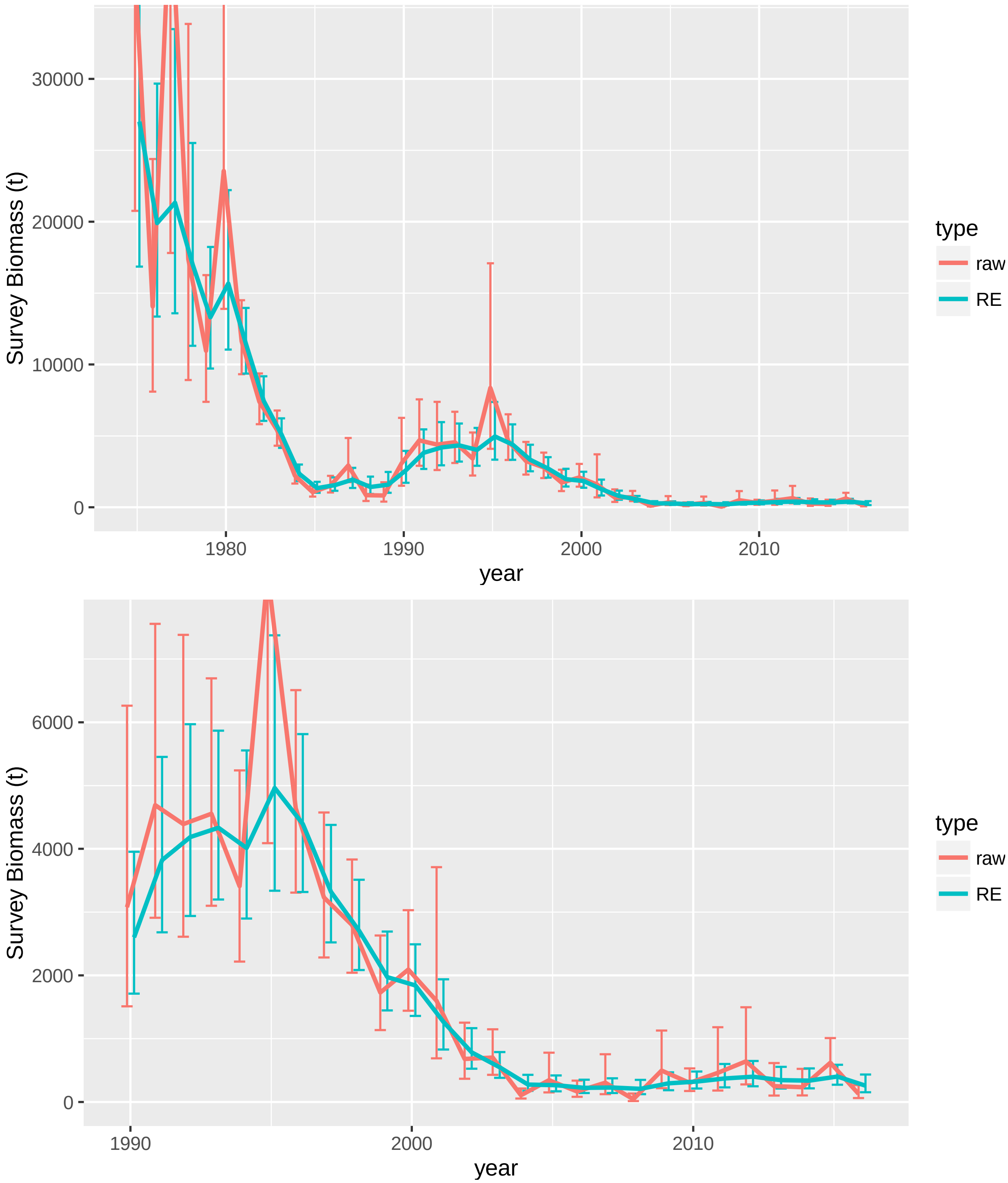


Figure 6. Time series for MMB at the time of the survey estimated from the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 1990-2015. Red line: “raw” time series. Green line: random effects (RE) model-smoothed time series. Error bars show 80% CIs.

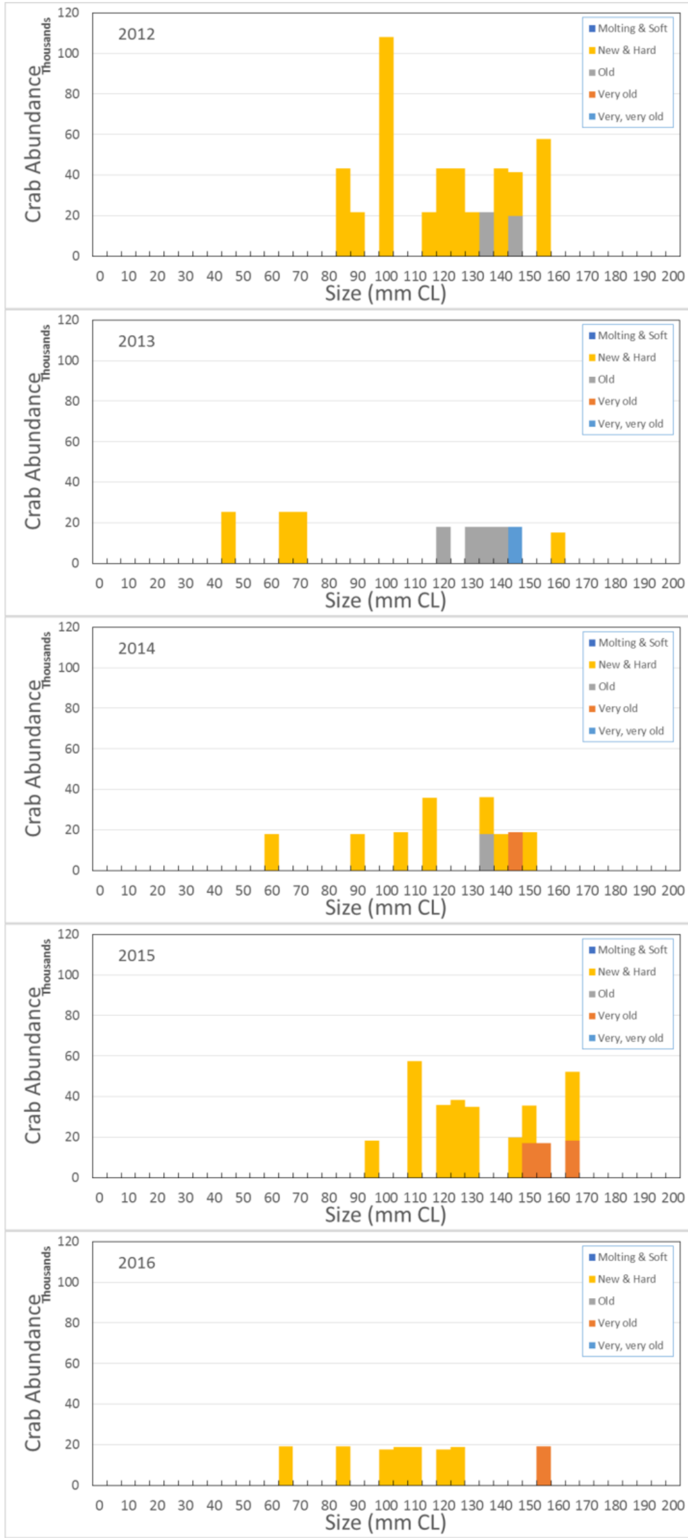


Figure 7. Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from the last five NMFS EBS bottom trawl surveys.

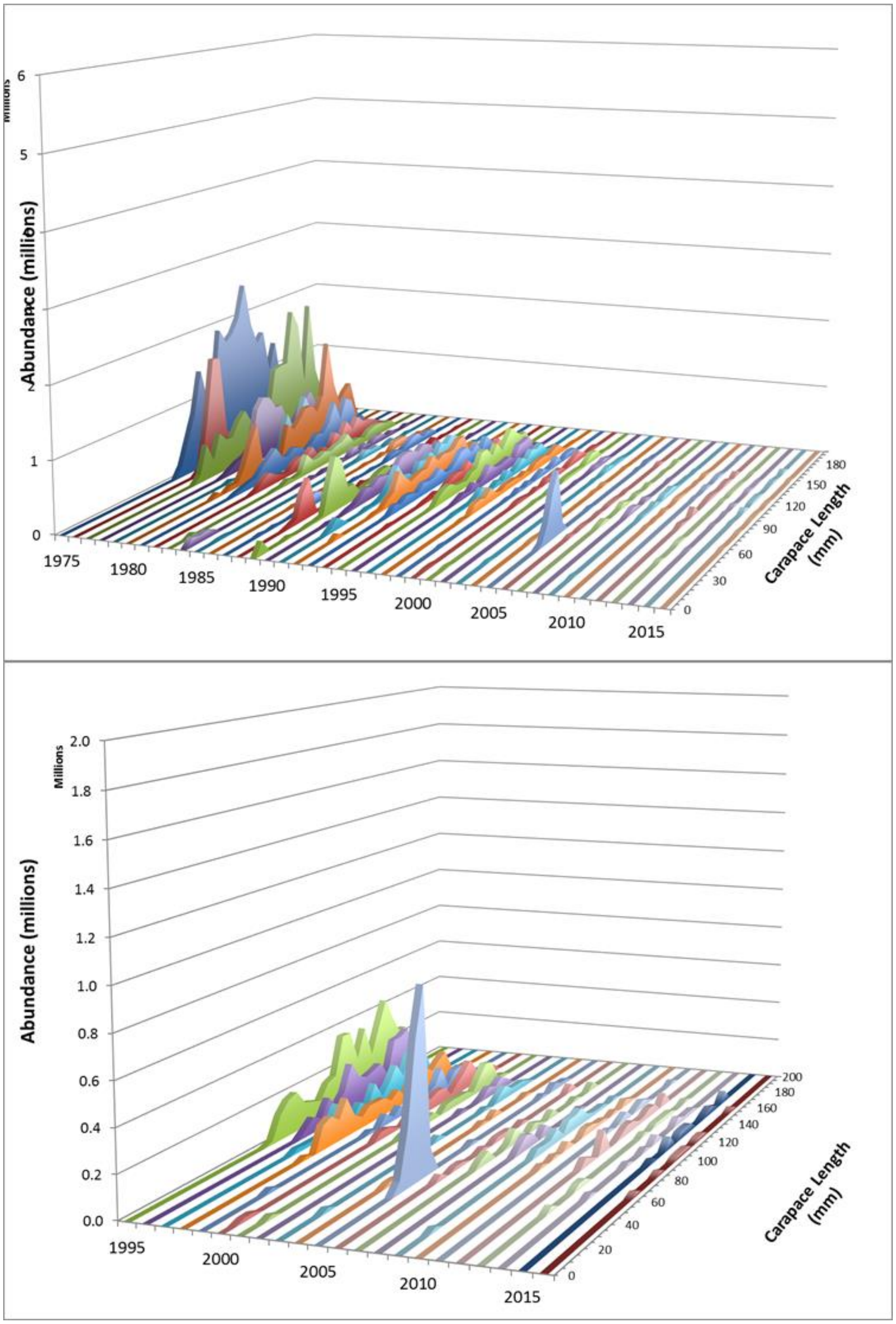


Figure 8. Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

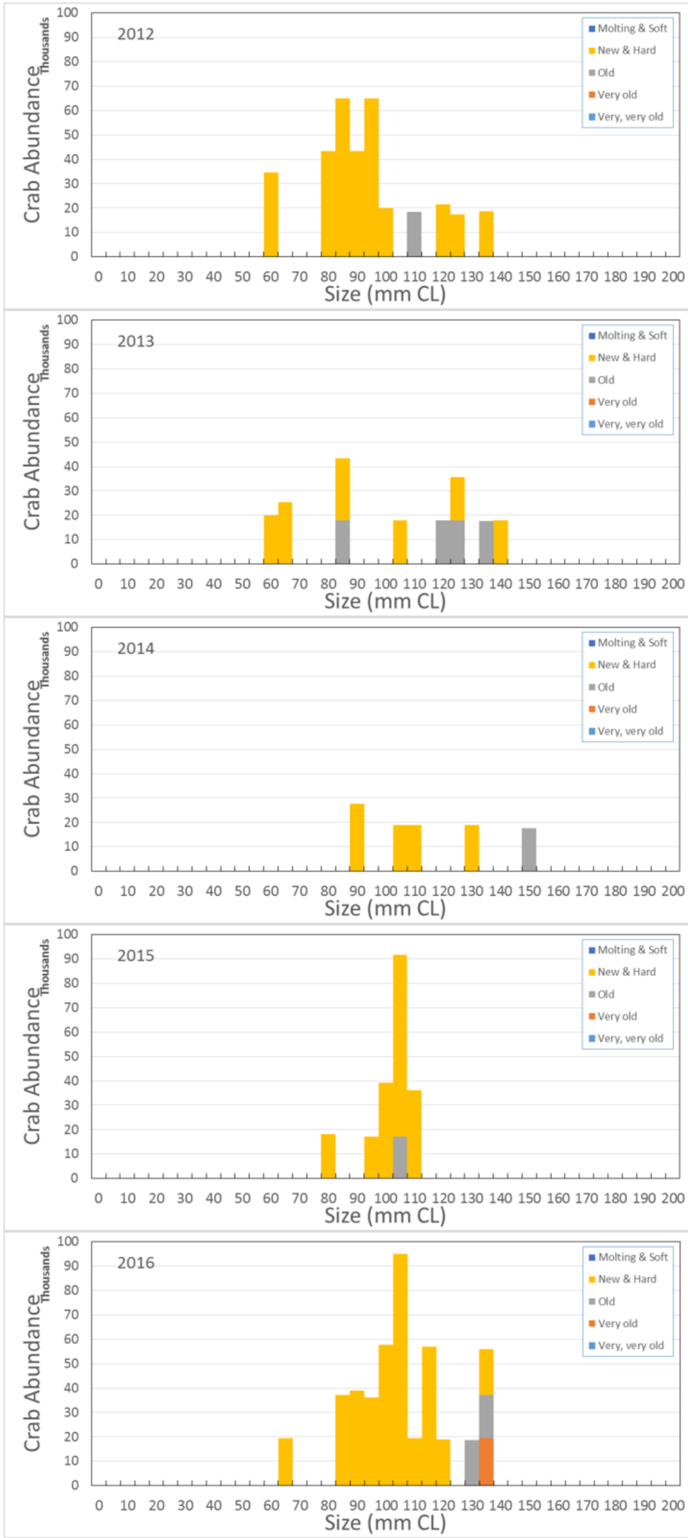
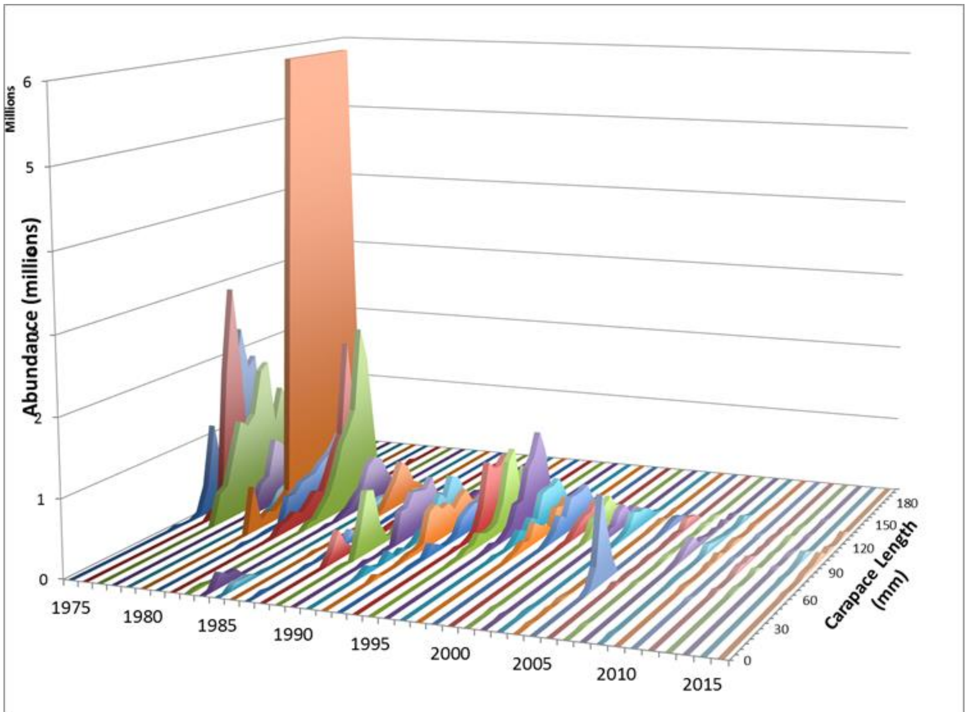


Figure 9. Size-frequencies by shell condition for female Pribilof Island blue king crab by 5 mm length bins from the last five NMFS bottom trawl surveys.



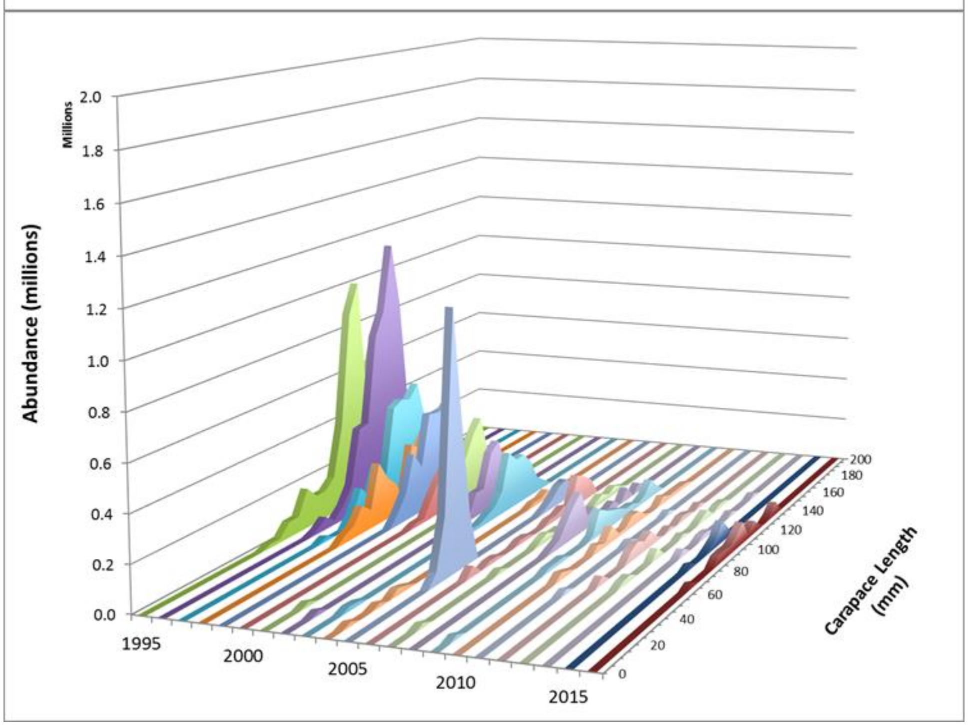


Figure 10. Size frequencies from the annual NMSF bottom trawl survey for female Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

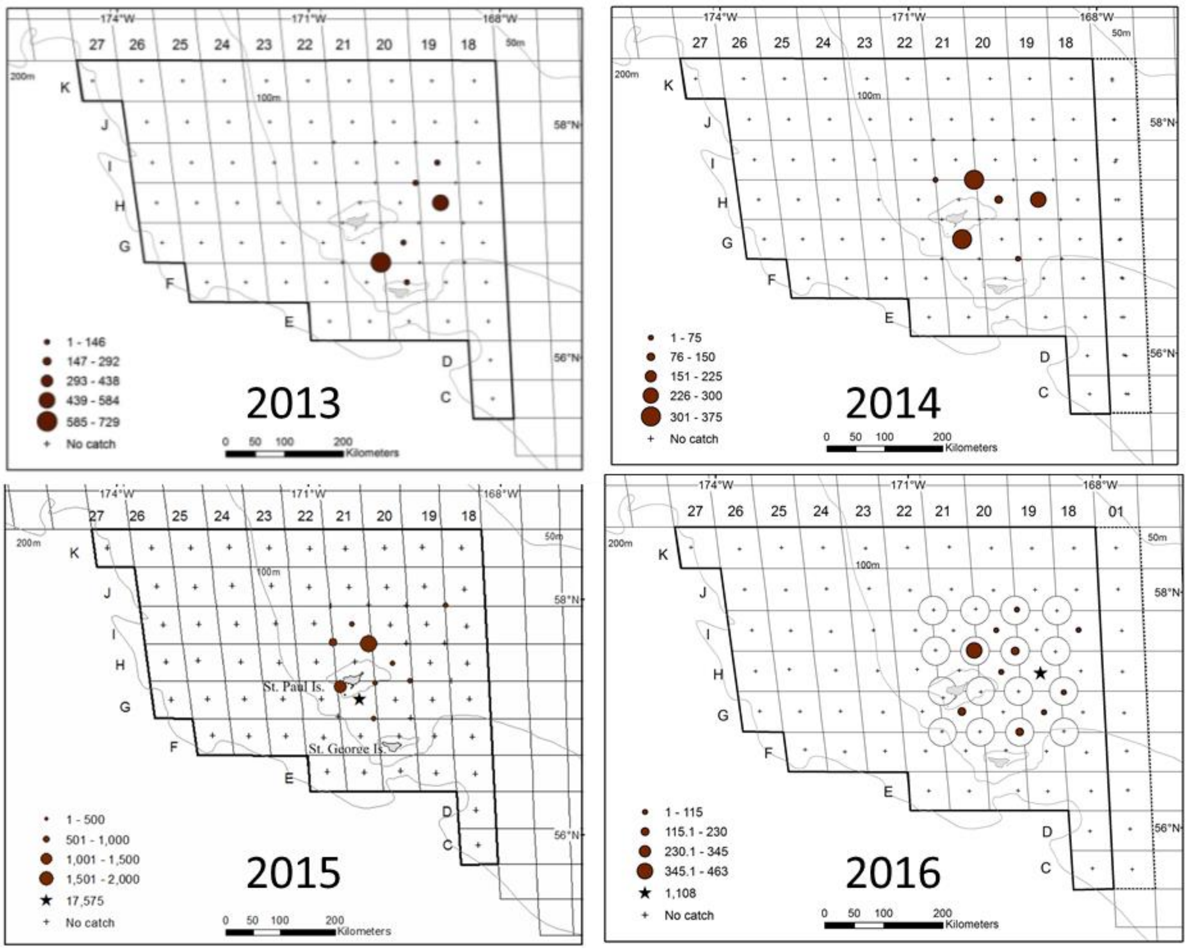


Figure 11. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2013-2016 NMFS EBS bottom trawl surveys. Note that each ma uses a different scale.

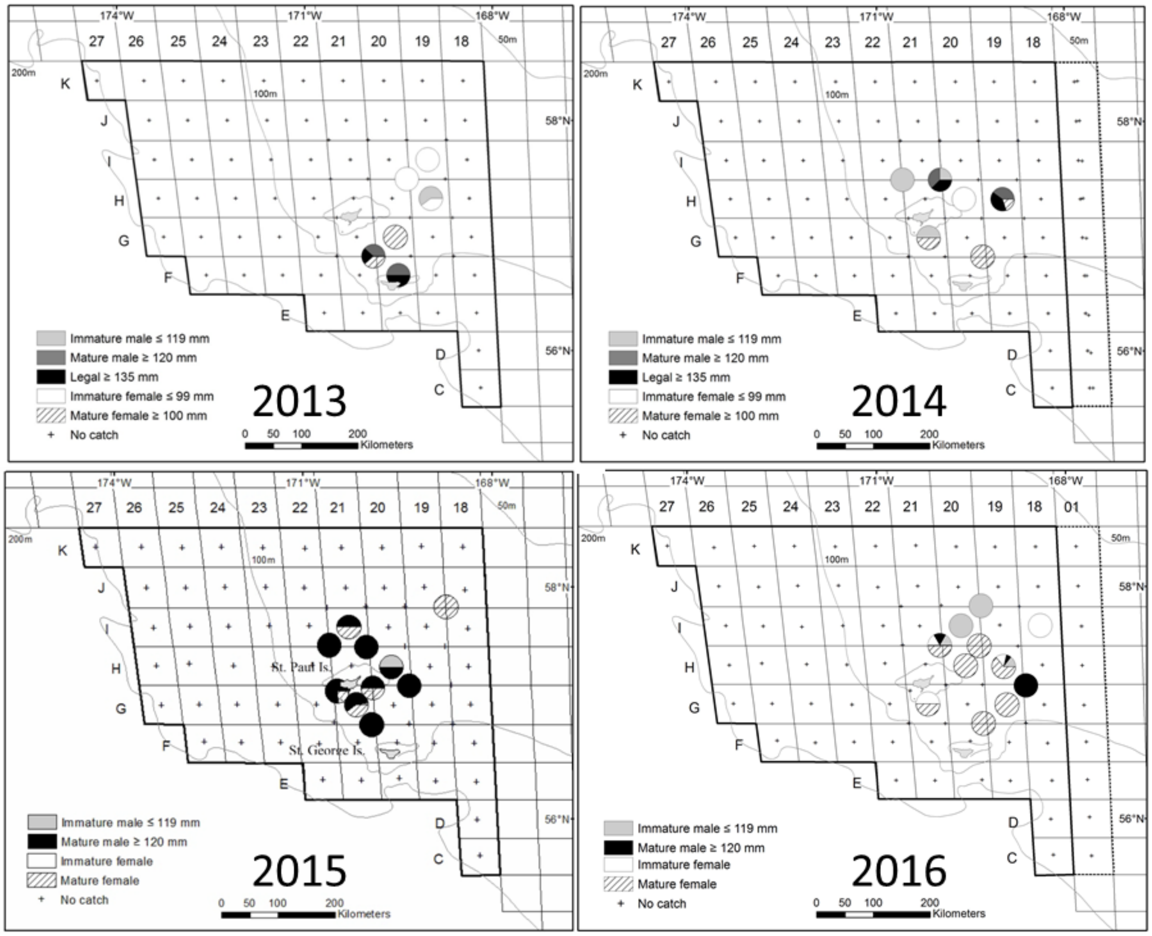


Figure 12. Size class distribution of blue king crab in the Pribilof District during the 2013-2016 NMFS EBS bottom trawl surveys.

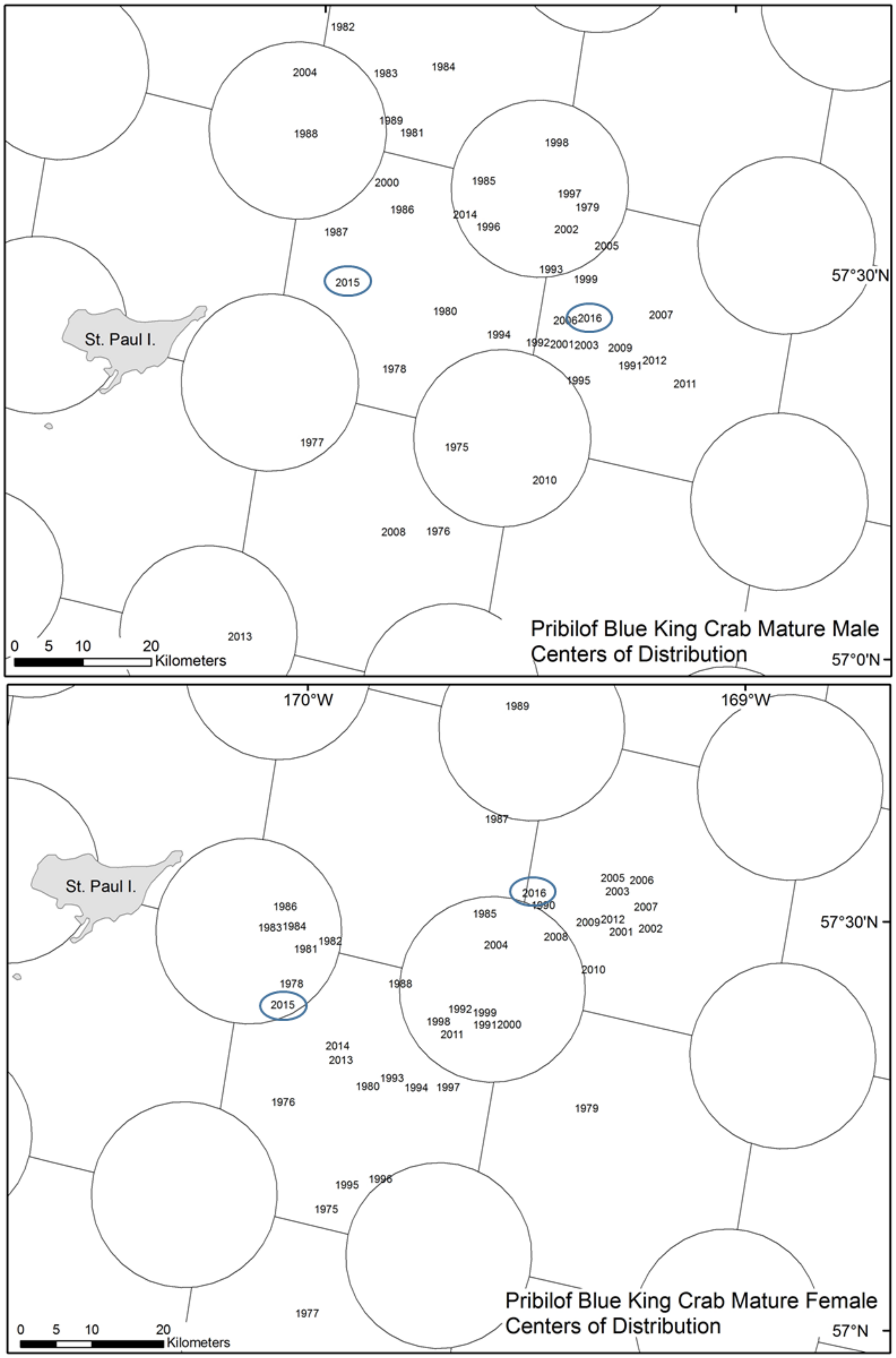


Figure 13. Centers of distribution for mature male (upper) and mature female (lower) blue king crab in the Pribilof District during the 1975-2016 NMFS EBS bottom trawl surveys. Positions for 2015 and 2016 are circled.

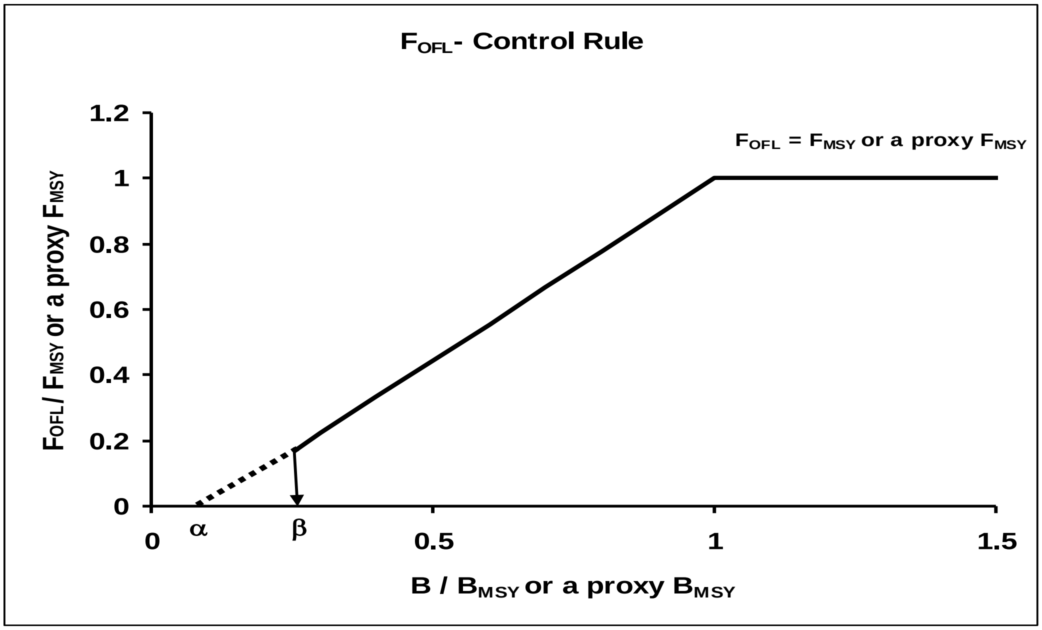


Figure 14. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Appendix A: PIBKC 2016 Status Determination

William Stockhausen

02 September, 2016

Introduction

This is an appendix to the 2016 stock assessment chapter for the Pribilof Islands blue king crab stock (PIBKC). It presents results for current status determination (is overfishing occurring?, is the stock overfished?) for the current year using the "rPIBKC"" R package developed by the assessment author. The rPIBKC package (source code and R package) is available under version control at https://github.com/wStockhausen/rPIBKC.git.

This appendix is the result of processing an R Markdown document to create a Word document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents that can encapsulate R code. Following changes to the fishery and/or survey data used for this assessment, the R Markdown document can be re-evaluated to produce an updated version of this appendix using one mouse click. For more details on using R Markdown see http://rmarkdown.rstudio.com.

Status Determination and OFL calculations

For all crab stocks managed by the NPFMC, overfishing is evaluated by comparing the previous year's catch mortality (retained + discard mortality) to the previous year's OFL: if the former is greater than the latter, then overfishing is occurring. Overfished status is assessed with respect to MSST, the Minimum Stock Size Threshold. If stock biomass drops below the MSST, the stock is considered to be overfished. For crab stocks, MSST is one-half B_{MSY}, where B_{MSY} is the resulting spawning stock biomass when the stock is fished at maximum sustainable yield. Thus, the stock is overfished if $B/B_{MSY} < 0.5$, where B is "current"" spawning stock biomass. In general, the overfishing limit (OFL) for the subsequent year is based on B/B_{MSY} and an "F_{OFL}" harvest control rule, where F_{OFL} is the fishing mortality rate that yields the OFL. Furthermore, if $B/B_{MSY} < \beta(= 0.25)$, directed fishing on the stock is prohibited. For PIBKC, OFL is based on average historic catch mortality over a specified time period (a Tier 5 approach) and is consequently fixed at 1.16 t.

PIBKC falls into Tier 4 for status determination. For Tier 4 stocks, it is not possible to determine B_{MSY} and MSST directly. Instead, average mature male biomass (MMB) at the time of mating ("MMB at mating"") is used as a proxy for B_{MSY}, where the averaging is over some time period assumed to be representative of the stock being fished at an average rate near F_{MSY} and is thus fluctuating around B_{MSY}. For PIBKC, the NPFMC's Science and Statistical Committee (SSC) has endorsed using the disjoint time periods [1980-84, 1990-97] to calculate $B_{MSY_{proxy}}$ to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected. Once $B_{MSY_{proxy}}$ has been calculated, overfished status is then determined by the ratio $B/B_{MSY_{proxy}}$: the stock is overfished if the ratio is less than 0.5, where B is taken as "current" MMB-at-mating.

MMB-at-mating

MMB-at-mating (MMB_m) is calculated from MMB at the time of the annual NMFS EBS bottom traw survey (MMB_s) by accounting for natural and fishing mortality from the time of the survey to mating. MMB at the time of the survey in year y is calculated from survey data using:

$$MMB_{s_y} = \sum zw_z \cdot P_z \cdot n_{z,y}$$

where w_z is male weight at size z (mm CL), P_z is the probability of maturity at size z, and $n_{z,y}$ is survey-estimated male abundance at size z in year y.

For a year y prior to the assessment year, MMB_{m_y} is given by

1. $MMB_{f_y} = MMB_{s_y} \cdot e^{-M \cdot t_{sf}}$
2. $MMB_{m_y} = [MMB_{f_y} - RM_y - DM_y] \cdot e^{-M \cdot t_{fm}}$

where MMB_{f_y} is the MMB in year y just prior to the fishery, M is natural mortality, RM_y is retained mortality on MMB in the directed fishery in year y, DM_y is discard mortality on MMB (NOT all crab) in all fisheries in year y, t_{sf} is the time between the survey and the fishery, and t_{fm} is the time between the fishery and mating.

For the assessment year, the fishery has not occurred so RM and DM are unknown. The amount of fishing mortality presumably depends on the (as yet-to-be-determined) overfishing limit, so an iterative procedure is used to estimate MMB-at-mating for the fishery year. This procedure involves:

1. "guess" a value for F_{OFL}, the directed fishing mortality rate that yields OFL ($F_{OFL_{max}} = \gamma \cdot M$ is used)
2. determine the OFL corresponding to fishing at F_{OFL} using the following equations:
   - $MMB_f = MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $RM_{OFL} = (1 - e^{-F_{OFL}}) \cdot MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $DM_{OFL} = \theta \cdot \frac{MMB_f}{p_{male}}$
   - $OFL = RM_{OFL} + DM_{OFL}$
3. project MMB-at-mating from the "current" survey MMB and the OFL:
   - $MMB_m = [MMB_{f_y} - (RM_{OFL} + p_{male} \cdot DM_{OFL})] \cdot e^{-M \cdot t_{fm}}$

4. use the harvest control rule to determine the F_{OFL} corresponding to the projected MMB-at-mating.
5. update the "guess" in 1. for the result in 4.
6. repeat steps 2-5 until the process has converged, yielding self-consistent values for F_{OFL} and MMB-at-mating.

where p_{male} is the assumed fraction of discard mortality on males. Note that this procedure determines the OFL for the assessment year as well as the current MMB-at-mating. Also note that, while the retained mortality RM_{OFL} is based on the F_{OFL}, the discard mortality DM_{OFL} is assumed to be proportional to the MMB at the time of the fishery, with proportionality constant $\frac{\theta}{p_{male}}$. The constant θ is determined by the average ratio of discard mortality on MMB (DM_{MMB}) to MMB at the time of the fishery (MMB_f) over a recent time interval:

$$\theta = \frac{1}{N} \sum y \frac{DM_{MMB_y}}{MMB_{f_y}}$$

where the sum is over the last N years. In addition, DM_{MMB} is assumed to be proprtional to total discard mortality, with that proportionality given by the percenatge of males in the stock.

Data

Data from the following files were used in this assessment:

- fishery data: ./Data2016AM.Fisheries.csv
- survey data : ./Data2016AM.Surveys.csv

The following figures illustrate the time series of retained PIBKC in the directed fishery and PIBKC incidentally taken in the crab and groundfish fisheries (i.e., bycatch):

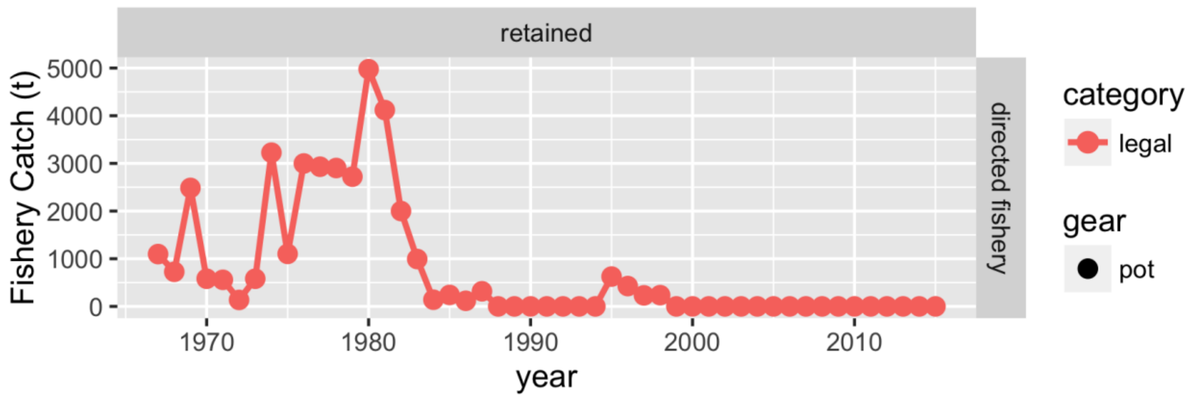


Figure 1. Time series of retained PIBKC catch in the directed fishery.

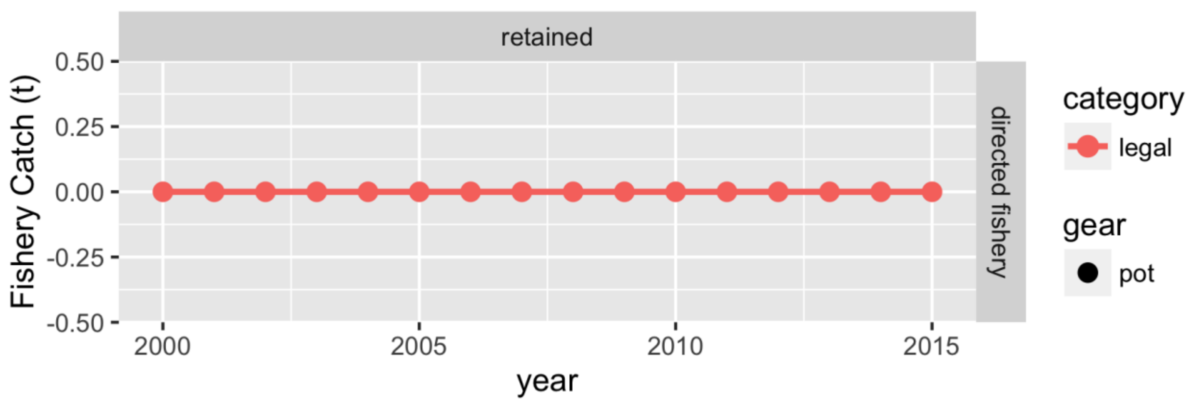


Figure 2. Time series of retained PIBKC catch in the directed fishery (recent time period).

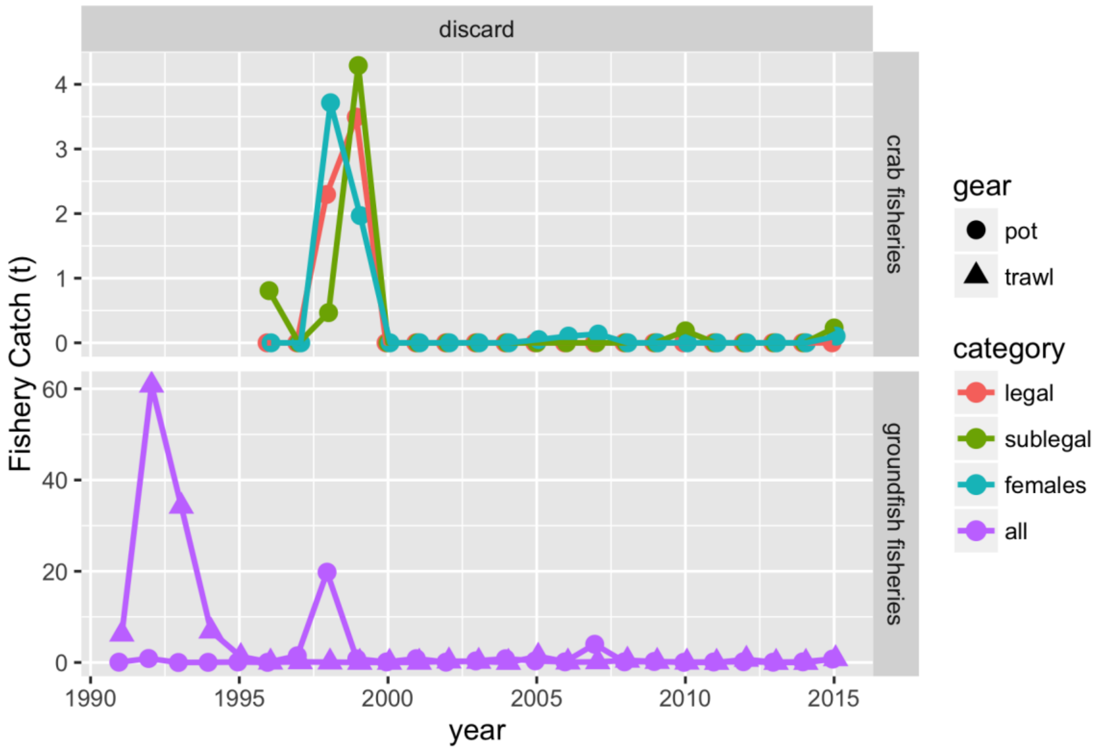


Figure 3. Time series of PIBKC bycatch in the crab and groundfish fisheries.

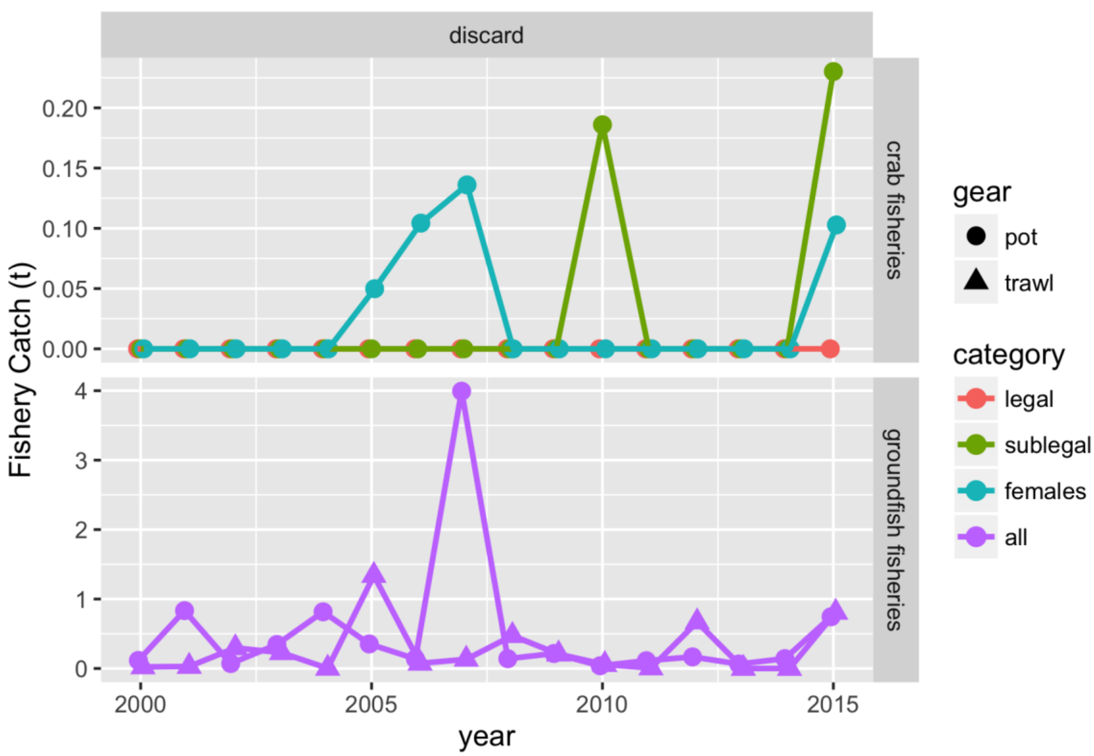


Figure 4. Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period).

The following figures illustrate the time series of PIBKC survey biomass in the NMFS EBS bottom trawl survey:

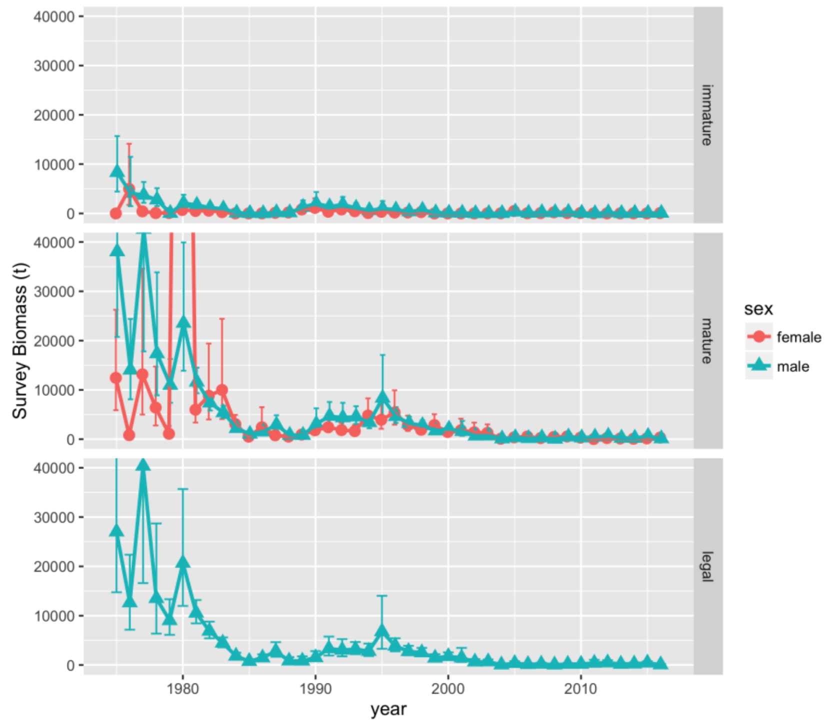


Figure 5. Time series of NMFS EBS bottom trawl survey biomass for PIKC. Confidence intervals shown are 80 CI's, assuming lognormal error distributions.

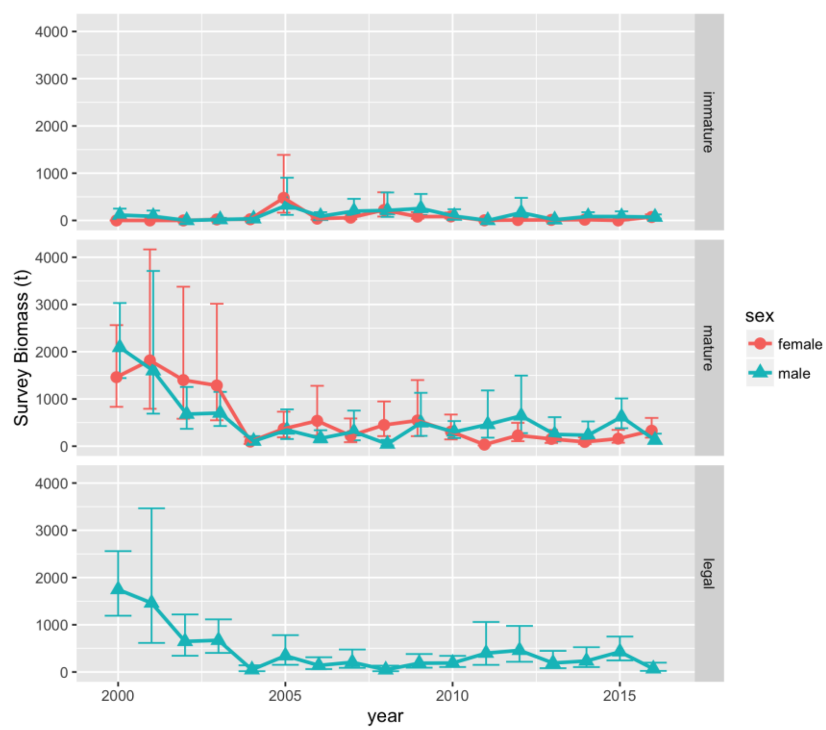


Figure 6. Time series of NMFS EBS bottom trawl survey biomass for PIKC (recent time period). Confidence intervals shown are 80 CI's, assuming lognormal error distributions.

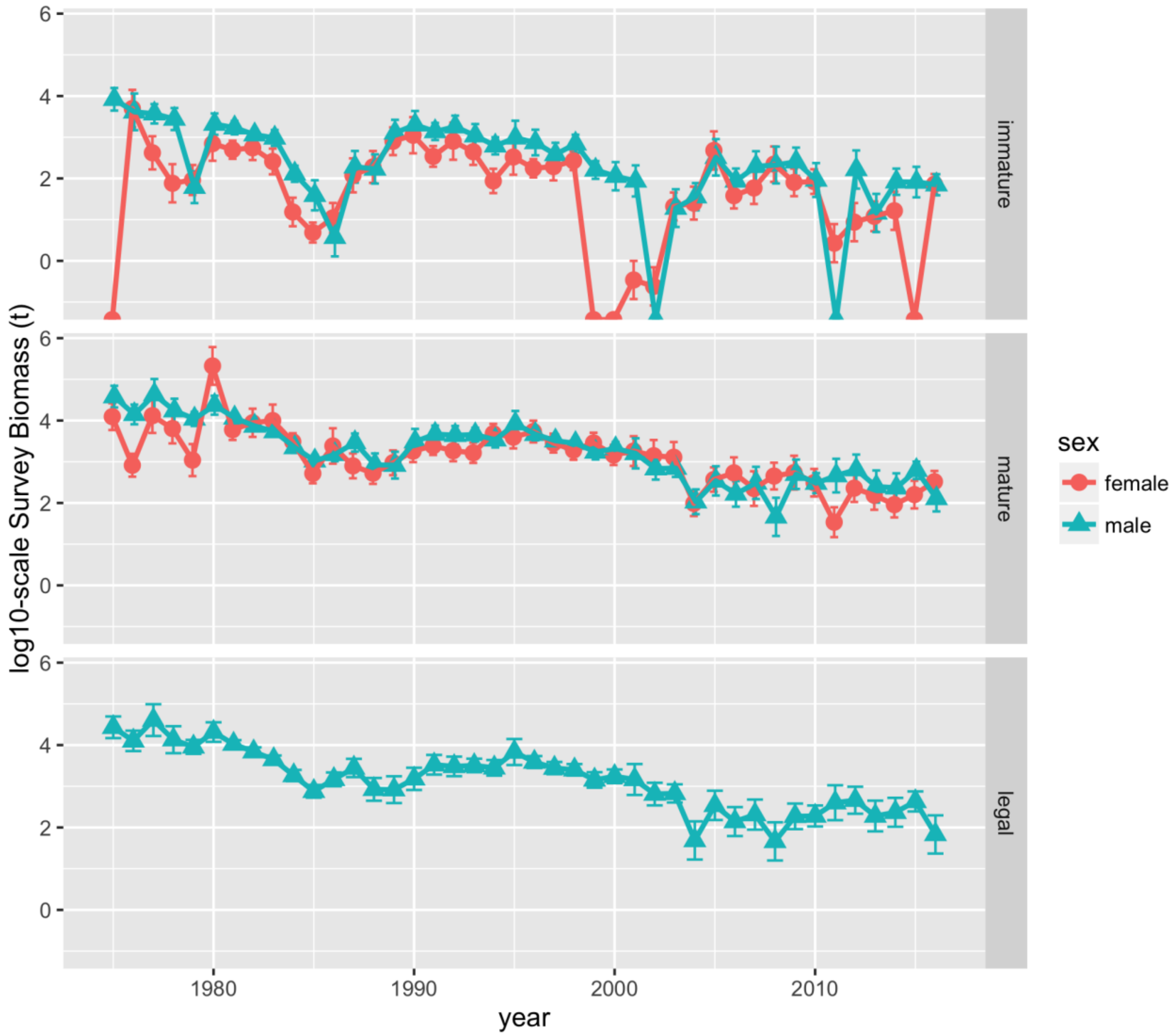


Figure 7. Log10-scale time series of NMFS EBS bottom trawl survey biomass for PIKC. Confidence intervals shown are 80 CI's, assuming lognormal error distributions.

Survey smoothing

For PIBKC, the variances associated with annual survey estimates of MMB are so large that, prior to estimating B_{MSY} and "current" MMB-at-mating, the survey MMB time series is first smoothed to reduce overall variability. Starting with the 2015 assessment (Stockhausen, 2015), a random effects (RE) model based on code developed by Jim Ianelli (NOAA/NMFS/AFSC) has been used to perform the smoothing. This is a statistical approach which models annual log-scale changes in "true" survey MMB as a random walk process using

$$< ln(MMB_s) >_y = < ln(MMB_s) >_{y-1} + \epsilon_y, \text{where } \epsilon_y \sim N(0, \phi^2)$$

as the state equation and

$$ln(MMB_{s_y}) = < ln(MMB_s) >_y + \eta_y, \text{where } \eta_y \sim N(0, \sigma_{s_y}^2)$$

as the observation equation, where $< ln(MMB_s) >_y$ is the estimated "true" log-scale survey MMB in year y, ϵ_y represents normally-distributed process error in year y with standard deviation ϕ, MMB_{s_y} is the observed survey MMB in year y, η_y represents normally-distributed ln-scale observation error, and σ_{s_y} is the log-scale survey MMB standard deviation in year y. The MMB_s's and σ_s's are observed quantities, the $< ln(MMB_s) >$'s and ϕ are estimated parameters, and the ϵ's are random effects (essentially nuisance parameters) that are integrated out in the solution.

Parameter estimates are obtained by minimizing the objective function

$$\Lambda = \sum y[\, ln(2\pi\phi) + (\frac{< ln(MMB_s) \underset{y}{>} -< ln(MMB_s) \underset{y-1}{>}}{\phi})^2] + \sum y(\frac{ln(MMB_{s_y}) -< ln(MMB_s) \underset{y}{>}}{\sigma_{s_y}})^2$$

The model is coded in C++ and uses AD Model Builder (Fournier et al., 2012) to minimize the objective function.

Smoothing results

For comparison, the raw and RE-smoothed survey MMB time series are shown in Figures 8-10, on both arithmetic and natural log scales:

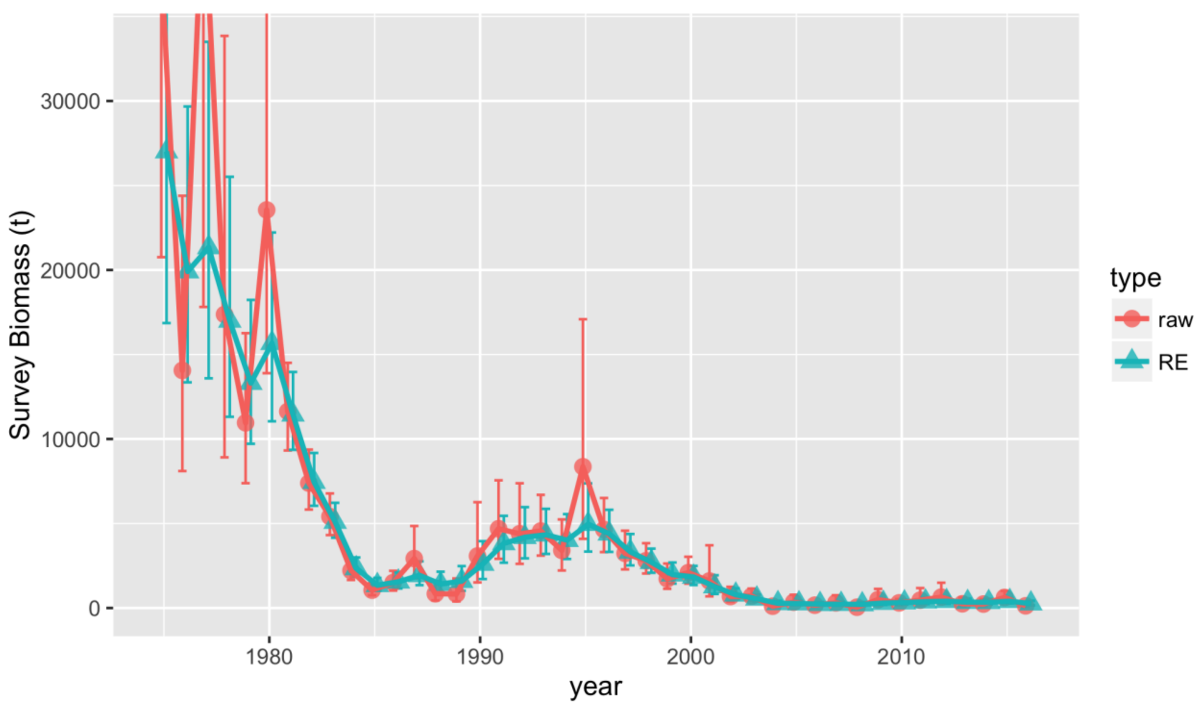


Figure. 8. Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

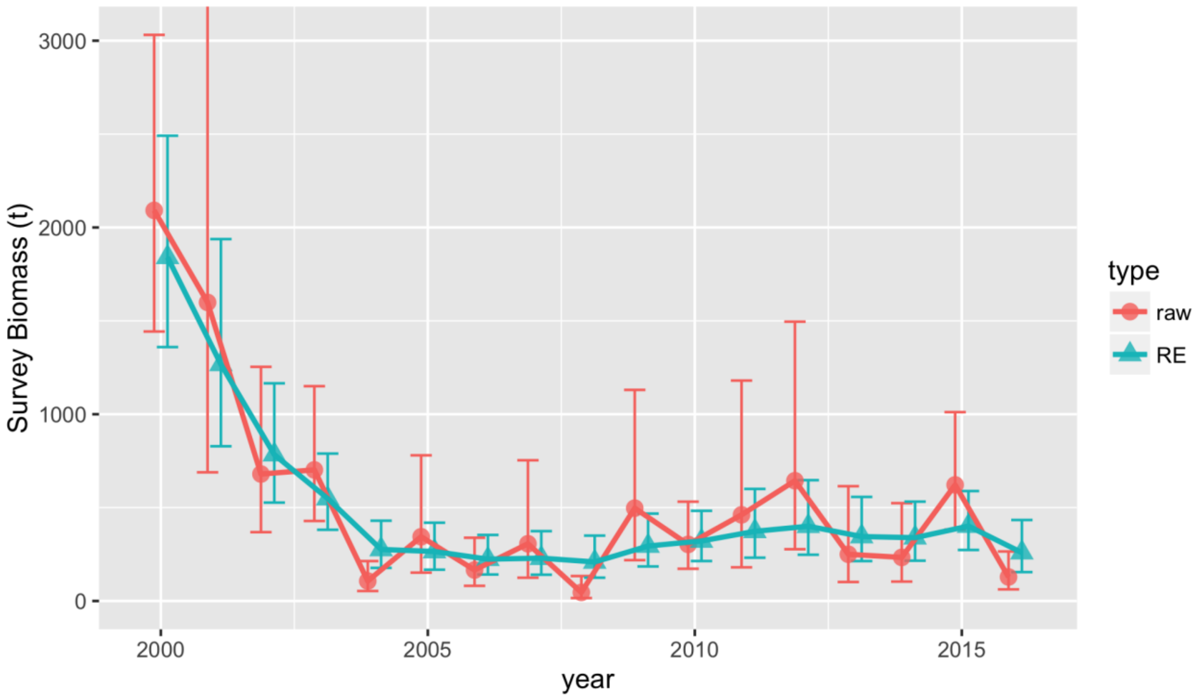


Figure. 9. Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

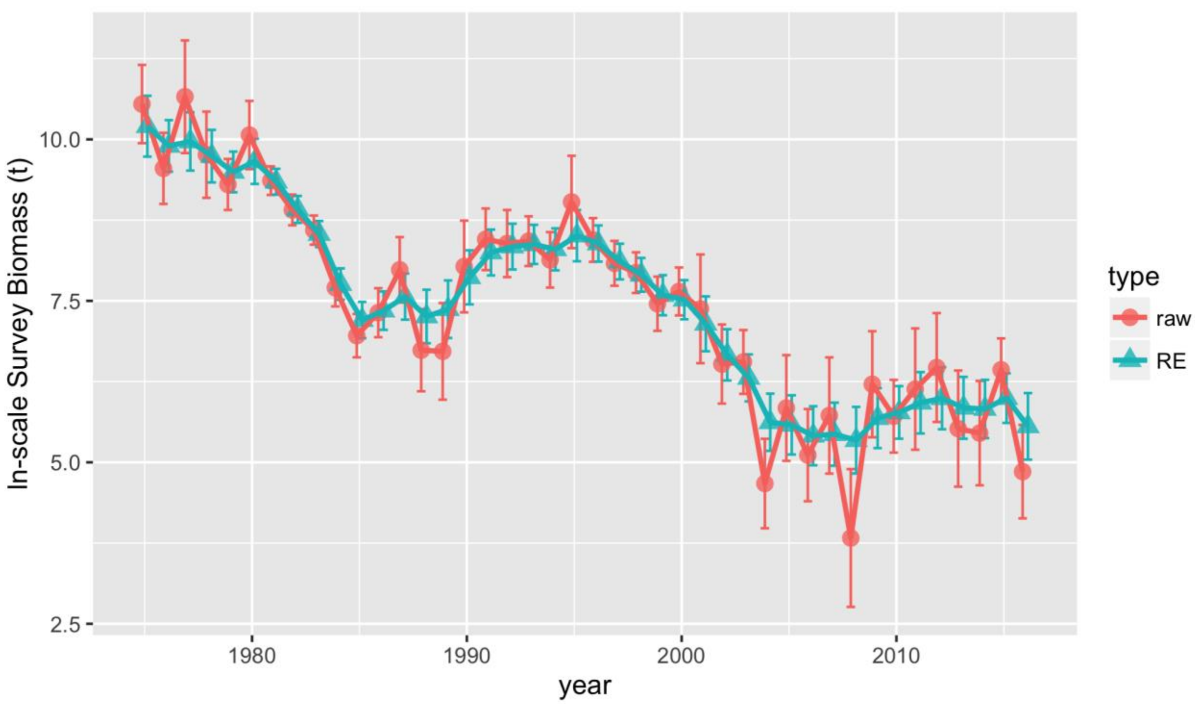


Fig. 10. Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

Status determination

Overfishing status

For PIBKC, the total fishing mortality in 2015/16 was 1.1848941 t while the OFL was 1.16 t. Thus, overfishing occurred in 2015/16.

Overfished status

As discussed previously, overfished status is determined by the ratio $B/B_{MSY_{proxy}}$: the stock is overfished if the ratio is less than 0.5, where B is taken as "current" MMB-at-mating. For PIBKC, $B_{MSY_{proxy}}$ is obtained by averaging estimated MMB-at-mating over the period [1980/81-1984/85,1990/91-1997/98]. Following recommendations made by the CPT and SSC in 2015 (CPT, 2015; SSC, 2015), B and $B_{MSY_{proxy}}$ are based on MMB-at-mating calculated using the RE-smoothed time series of survey biomass projected forward to mating time.

MMB-at-mating

For comparison, time series for MMB-at-mating using both the raw (unsmoothed) survey MMB time series and the RE-smoothed survey MMB time series were calculated. The results are shown below in Figures 11 and 12:

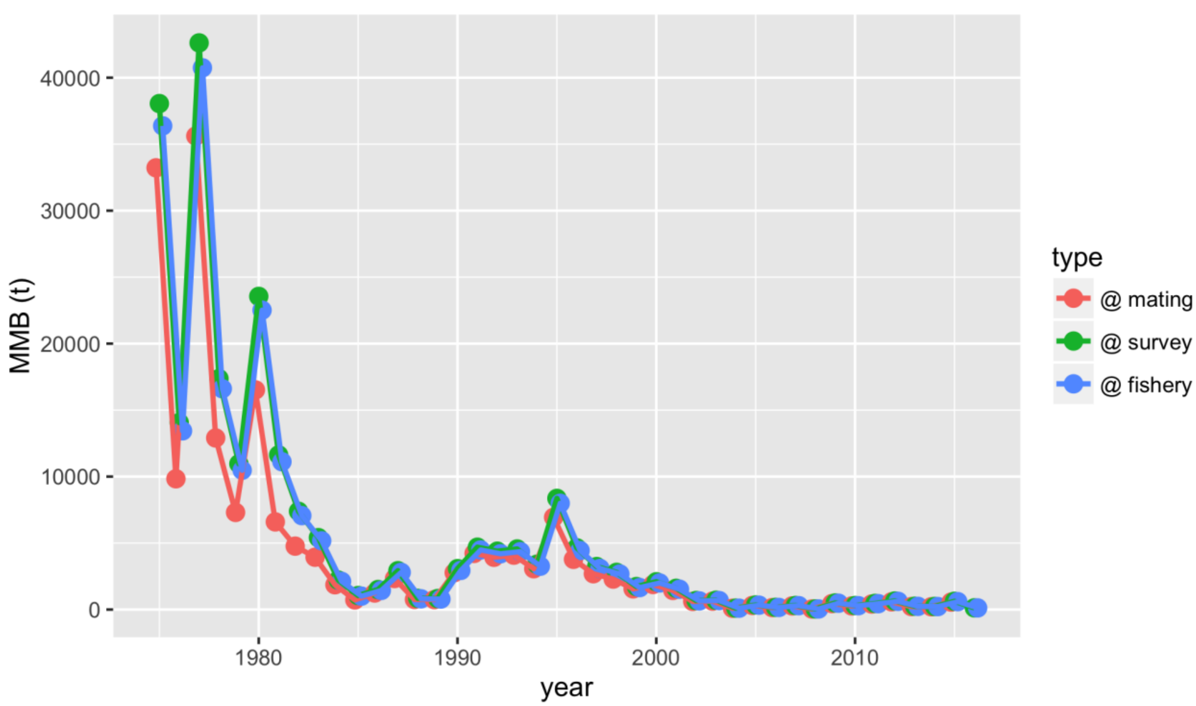


Fig. 11. Estimated time series for MMB at the time of the survey (no smoothing), at the time of the fishery, and at the time of mating.

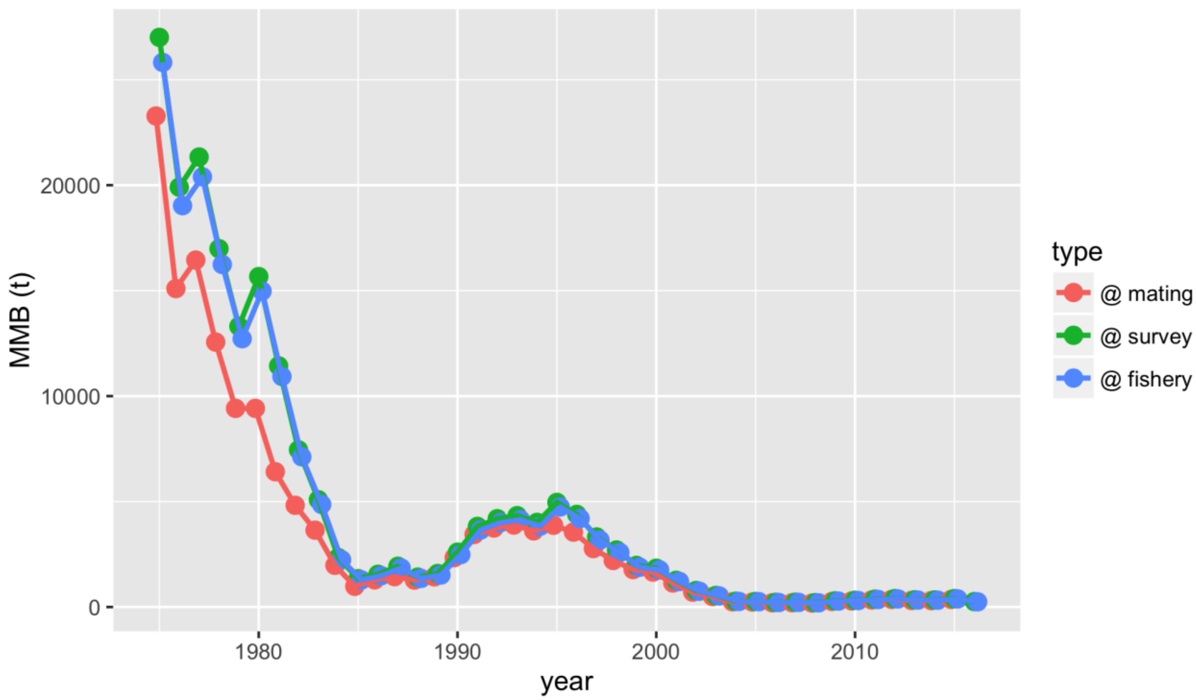


Fig. 12. Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating.

Values for $B_{MSY_{proxy}}$ and the estimated current (2016) MMB *at the time of the survey* from the raw survey data and the RE-smoothed results are:

Estimation Type	Current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
raw data	128.5542681	5012.1154242
RE-smoothed	259.016	4116.1607184

The value above for $B_{MSY_{proxy}}$ using the raw data is shown for illustration only. As noted previously, $B_{MSY_{proxy}}$ for this assessment is based on averaging the MMB-at-mating calculated from the RE-smoothed survey MMB (i.e., 4116.1607184 t).

Values for θ, used in the projected MMB calculations, based on averaging over the last three years, are:

Estimation Type	θ
raw data	3.6101753×10^{-4}
RE-smoothed	4.954664×10^{-4}

Results from the calculations for B ("current" MMB), overfished status, and an illustrative Tier 4-based OFL for 2016/17 (not used for PIBKC) are:

quantity	units	raw data	RE-smoothed
B ("current" MMB)	t	115.6987757	233.0829145
B_{MSY}	t	5012.1154242	4116.1607184
stock status	–	overfished	overfished
F_{OFL}	$year^{-1}$	0	0
RM_{OFL}	t	0	0
DM_{OFL}	t	0.0887363	0.2453734
OFL	t	0.0887363	0.2453734

Because B/B_{MSY} using RE-smoothed MMB-at-mating from the table above is 0.0566 < 0.5, the stock is overfished.

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CPT. 2015. Introduction. In: Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2015 Final Crab SAFE. North Pacific Fishery Management Council, 605 W. 4th Avenue, #306, Anchorage, AK 99501. 35 pp.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

SSC. 2015. SCIENTIFIC AND STATISTICAL COMMITTEE to the NORTH PACIFIC FISHERY MANAGEMENT COUNCIL. October 5th – 7th, 2015. 33 pp. http://npfmc.legistar.com/gateway.aspx?M=F&ID=acaba646-c746-4ad5-acb4-f6d70d72b06f.pdf

Stockhausen, W. 2015. 2015 stock assessment for the Pribilof Islands blue king crab fishereis of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2015 Final Crab SAFE. North Pacific Fishery Management Council, 605 W. 4th Avenue, #306, Anchorage, AK 99501. p. 511-561.

Appendix B: Bycatch Estimation

W.T. Stockhausen
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA

J. Gasper, J. Keating
Alaska Regional Office
National Marine Fisheries Service, NOAA

September 1, 2016

Introduction

For the Pribilof Islands blue king crab (PIBKC) stock, because the directed fishery is closed, estimated bycatch mortality of incidentally-taken blue king crab in the groundfish and (other) crab fisheries is the only source of fishery-related mortality included in the assessment. This Appendix outlines how observer data on incidentally-taken (bycatch) PIBKC in the groundfish and crab fisheries is used to estimate total bycatch of PIBKC in these fisheries for determining whether or not overfishing has occurred.

Bycatch Estimation in the Groundfish Fisheries

Data collected by at-sea observers are used to estimate total bycatch of blue king crab in the groundfish fisheries in the Pribilof Islands blue king crab (PIBKC) stock area; total bycatch estimates (weight and numbers) are provided by the Alaska Fisheries Information Network (AKFIN). In the 2015/16 crab year, all bycatch of blue king crab in the PIBCK stock area occurred on vessels that used either trawl or longline gear; these vessels had at least one groundfish fishery observer onboard (many vessels had two observers onboard), with the result that all trawl haul and longline sets were sampled by observers. Vessels fishing pot gear were only partially observed (i.e., not all trips had observers on board); however, very little pot effort occurred in the stock area. A brief description of the estimation methods follows, and readers are directed to Cahalan et al. (2010 and 2014) for more detail on estimation. In addition, detailed descriptions of the observer sampling methods can be found in the Observer Sampling Manual, prepared each year by AFSC (http://www.afsc.noaa.gov/FMA/default.htm).

AKFIN estimation methods for BSAI crab incidentally caught in the groundfish fisheries are a modification of the estimation methods used in the Alaska Region's Catch Accounting System (CAS). CAS was designed for the management of groundfish and Prohibited Species Catch (PSC) by the NMFS Alaska Region. It provides estimates of crab bycatch by federal reporting area and Groundfish Fishery Management Plan (FMP) area as numbers of crab, which is how crab PSC is managed. The AKFIN methods modify how observer data are aggregated across space and also provide estimates in weight, as well as in numbers. Most importantly, the AKFIN method restricts estimates of crab bycatch to their respective stock area as defined in each crab stock assessment.

The sampling design on trawl vessels follows a hierarchical random sampling scheme. Observers randomly sample hauls within a trip. Within each haul, a random sample of catch is taken. Generally, observers will sample all hauls on a trip, and the amount of catch sampled depends on the size of the haul and species diversity in the haul. All catch on trawl vessels fishing in the PIBKC stock area is weighed on motion-compensated flow scales, and observers divert catch from the flow scale to take species composition. The species-specific weight is expanded by the sampling fraction to estimate the total catch of that species. In some situations, crab cannot be identified beyond the genus level (e.g., carapace is crushed); in these situations, unidentified crab are speciated using identified species from sampled hauls within a federal reporting area.

Catch estimation on hook-and-line vessels also uses a hierarchical sampling design. Observers select multiple random subsets of hooks from all hooks fished on a set. Within each sampled set of hooks, observers record the species and disposition for each hook sampled. This tally of fish is expanded by the sampling fraction (the fraction of total hooks sampled) to estimate the total number of fish caught. Observers collect species-specific weight data from a random subset of hooks. An average weight per crab (by species) is applied to the total estimated number of crab (by species) per set to obtain the total estimated weight of crab on a set. Unsampled sets are factored in by calculating an average discard ratio (discarded crab divided by total groundfish and halibut) for observed hauls on a trip (based on week for catcher-processor vessels) and within the stock area. Total catch is then obtained as the product of the ratio estimator and the total groundfish weight by ADFG area for a trip.

Blue king crab bycatch in the groundfish fishery is estimated by ADFG statistical areas within the Pribilof island stock area. Haul-specific information is assigned to an ADFG statistical area based on its retrieval location. Total groundfish and halibut catch is assigned to ADFG statistical areas based on haul retrieval locations for catcher-processors and as reported on ADFG fish tickets for catcher vessels. The ADFG statistical area is the smallest spatial scale that is estimated since this is finest resolution that landed catch is reported on trips.

In 2015/16, nearly all catch in the hook-and-line fishery occurred on trips with onboard observers, thus expansion to unsampled trips was unnecessary. The total estimated PIBKC bycatch by the groundfish fishery was simply the sum of the estimated incidental catch on observed trips for all ADFG areas within the stock area. Unfortunately, the stock area boundaries do not follow ADFG area boundaries on the eastern and northern sides of the stock area. This may result in a small underestimate of catch on the northern boundary, and an overestimate of catch on the eastern boundary for trawl. However, the extent of this uncertainty is unknown since trawl vessels regularly bisect the boundary when making tows, complicating estimation in a way that does not occur for hook-and-line (since that effort generally occurs entirely within the PIBKC boundary).

Figures 1 and 2 show the spatial distribution of blue king crab incidentally caught in the groundfish non-pelagic trawl fisheries by ADFG statistical area for the 2015/16 crab year and the average bycatch for the five-year period 2010/11-2014/15. Also shown is the corresponding groundfish catch. Note that fishing with non-pelagic trawl gear is not allowed with the Pribilof Islands Habitat Conservation Area. In 2015/16, most PIBKC bycatch in the trawl fisheries occurred in the northeast corner of the Pribilof blue king crab stock boundary (i.e., the Pribilof Island District), as did most groundfish catch (Figure 1). This was a much different spatial pattern than occurred during 2010/11-2014/15, when most PIBKC bycatch occurred to the northwest of St. Paul and none occurred in the northeast corner of the Pribilof Island District (Figure 2).

Figures 3 and 4 show the spatial distribution of blue king crab incidentally caught in the groundfish hook-and-line fisheries by ADFG statistical area for the 2015/16 crab year and the average bycatch for the five-year period 2010/11-2014/15. Also shown is the corresponding groundfish catch. In contrast to trawl gear, fishing with hook-and-line gear is allowed with the Pribilof Islands Habitat Conservation Area. Most PIBKC bycatch in the hook-and-line fisheries in 2015/16 occurred in the statistical area centered on St. Paul Island and eastward, as well as north of St. George Island, whereas the majority of groundfish catch in the hook-and-line fisheries occurred more to the south of St. Paul and west and south of St. George (Figure 3). These patterns are broadly consistent with the 5-year average spatial patterns (Figure 4), although the color scales are fairly coarse and may somewhat obscure finer-scale variation.

Bycatch Estimation in the Crab Fisheries

Beginning in 1988, ADFG has required varying levels of observer coverage aboard vessels participating in crab fisheries in the Bering Sea and Aleutian Islands for fishery management and data-gathering needs

(Gaeuman, 2014). Regulations (5 AAC 39.645) require deployment of observers on all vessels that process snow crab *Chionoecetes opilio*, Tanner crab *C. bairdi*, grooved Tanner crab *C. tanneri*, triangle Tanner crab *C. angulatus*, red king crab *Paralithodes camtschaticus*, blue king crab *P. platypus* or golden king crab *Lithodes aequispinus*. Those regulations additionally charge ADFG with deploying observers as needed on catcher vessels participating in commercial BSAI king and Tanner crab fisheries, excluding those of Norton Sound and St. Lawrence Island Sections.

Per Gaeuman (2014):

> ADFG observers deployed on fishing vessels in the BSAI crab fisheries record the gear type, location, depth and soak time of a daily random sample of pot lifts, the species composition of their contents, and the sex and legal status of commercially important captured crabs. For a subset of sampled pot lifts, a range of biological measurements and assessments of commercially important crabs and other species of interest is also obtained. In addition, ADFG onboard observers and dockside samplers document overall vessel catch and effort, take size-frequency samples, conduct legal tallies and estimate the average weight of delivered catch. ADFG Westward Region staff maintain the information collected by observers and dockside samplers in a database that is used in research and management of Alaska's BSAI crab stocks.

Observers are deployed on three types of vessels: floating-processor vessels, catcher-processor vessels, and catcher vessels (Gaeuman, 2014). Duties vary somewhat depending on vessel type. Observers deployed on floating-processor vessels primarily monitor deliveries from catcher vessels. Sampling duties during each delivery include obtaining a size-frequency sample, conducting a legal tally and determining average weight of retained crabs. For observers deployed on catch-processor vessels, sampling duties include pot lift sampling, size-frequency sampling, legal-tally sampling and determination of average weight of retained crab for each day the vessel retained catch. Occasionally, catcher vessels delivered to a catcher-processor vessel. In those situations, the observer samples the catcher-vessel catch as if deployed on a floating processor. On rare occasions, a catcher-processor vessel will deliver to a shore side processor, in which case the observer assumes the responsibilities of an observer deployed on a catcher vessel. Observers deployed on catcher vessels are tasked with pot lift sampling on each day a vessel fishes. When the vessel delivers to a processing facility, whether at sea or on shore, the observer obtains a size-frequency sample, conducts a legal tally and determines average weight of retained crab. If deliveries are made at sea to a floating-processor vessel, all sampling is completed by the observer deployed on the catcher vessel. Observers are assigned to all participating catcher-processor vessels and by simple random sampling to a subset of all participating catcher vessels. Sampled pot lifts are selected by simple random sampling from all pot lifts on each vessel fishing day, independently across days.

For this assessment, estimation of PIBKC bycatch in the other crab fisheries by ADFG was based on a simple expansion of incidentally-taken PIBKC in "observed" pots enumerated, sexed and sized by ADFG observers onboard catcher vessels (pers. comm., J. Webb, ADFG). Total bycatch biomass is estimated by: 1) estimating CPUE by bycatch class (female , sublegal male, legal non-retained male) per observer sampled potlift for each directed crab fishery in which bycatch is observed; then 2) expanding CPUE to total bycatch (numbers) by total directed fishery effort. 3) The weighted mean size of crab in each bycatch class in each directed fishery is estimated from the size-frequency distribution and converted to mean weight using the NMFS published weight-length relationship; then 4) total bycatch in numbers is converted to biomass by bycatch class in each directed fishery using average crab weight. Finally, 5) the sum of the biomasses by bycatch class in each directed fishery, converted to metric tons, is the overall estimate of annual bycatch biomass for the species.

For PIBKC, the size-weight regressions developed from the NMFS EBS bottom trawl survey (Foy et al., 2016) were used to convert measured size to weight in grams using $w_{x,z} = a \cdot z^{b}$:

sex	a	b

males	0.000508	3.106409
females	0.02065	2.27

For 2015/16, numbers/weights of observed PIBKC bycatch were expanded to estimated total bycatch numbers/weight using:

Fishery	Sampled Pots	Total Effort (Pot lifts)	% Pots Observed	Expansion Factor
EBS snow	1,857	201,650	0.921	108.589
Tanner-West	898	85,244	1.053	94.927

where $\left(\frac{N_f^T}{N_f^O}\right)$ is the expansion factor (and % observed pots is the inverse, multiplied by 100).

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Figures

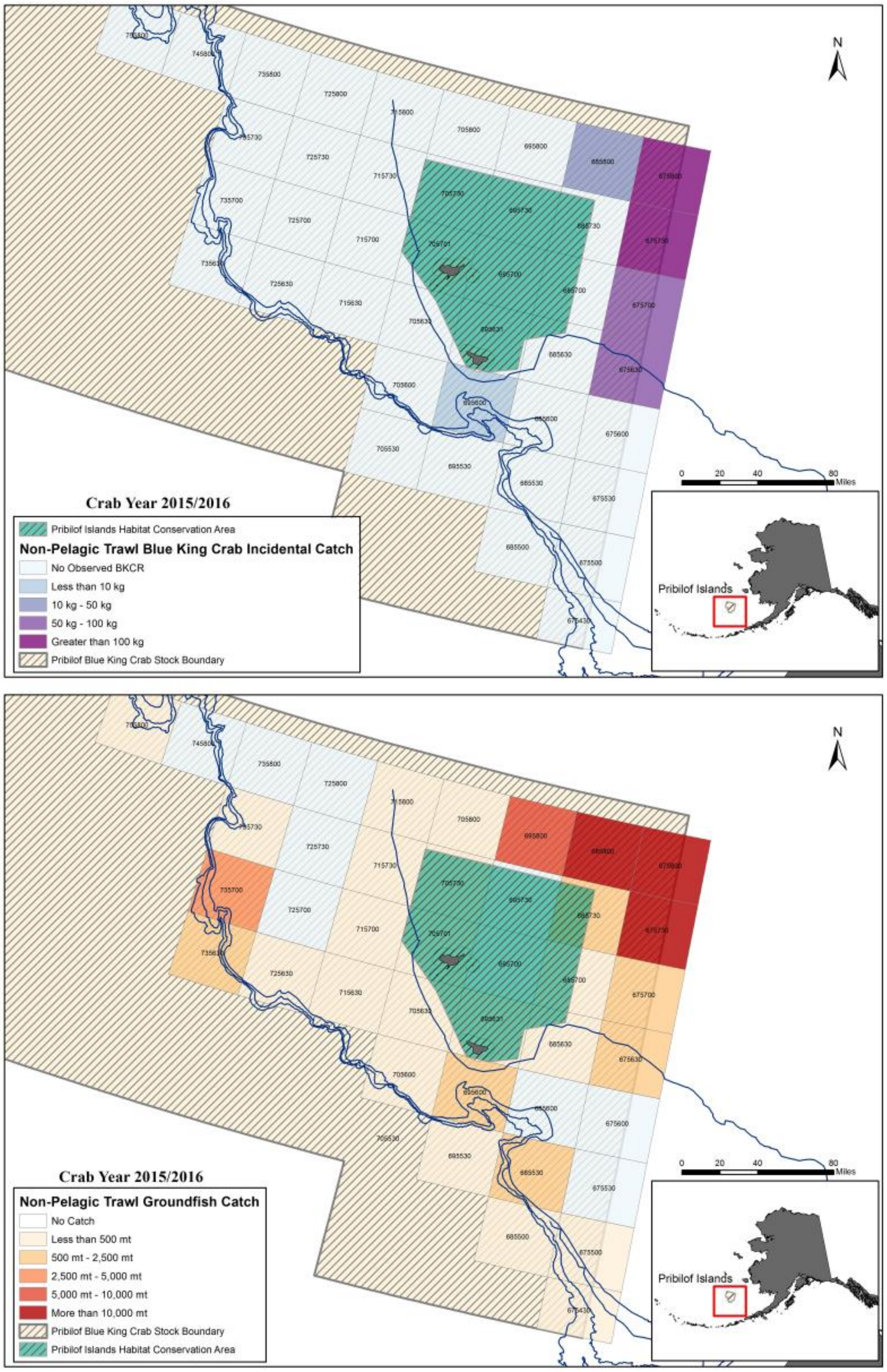


Figure 1. Spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using non-pelagic trawl gear in the 2015/16 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat (1^{o} long. x 0.5^{o} lat.) areas, the yellow hatched area denotes the PIBKC stock boundary, and the hatched green area represents the Pribilof Islands Habitat Conservation Area closed to non-pelagic trawl gear.

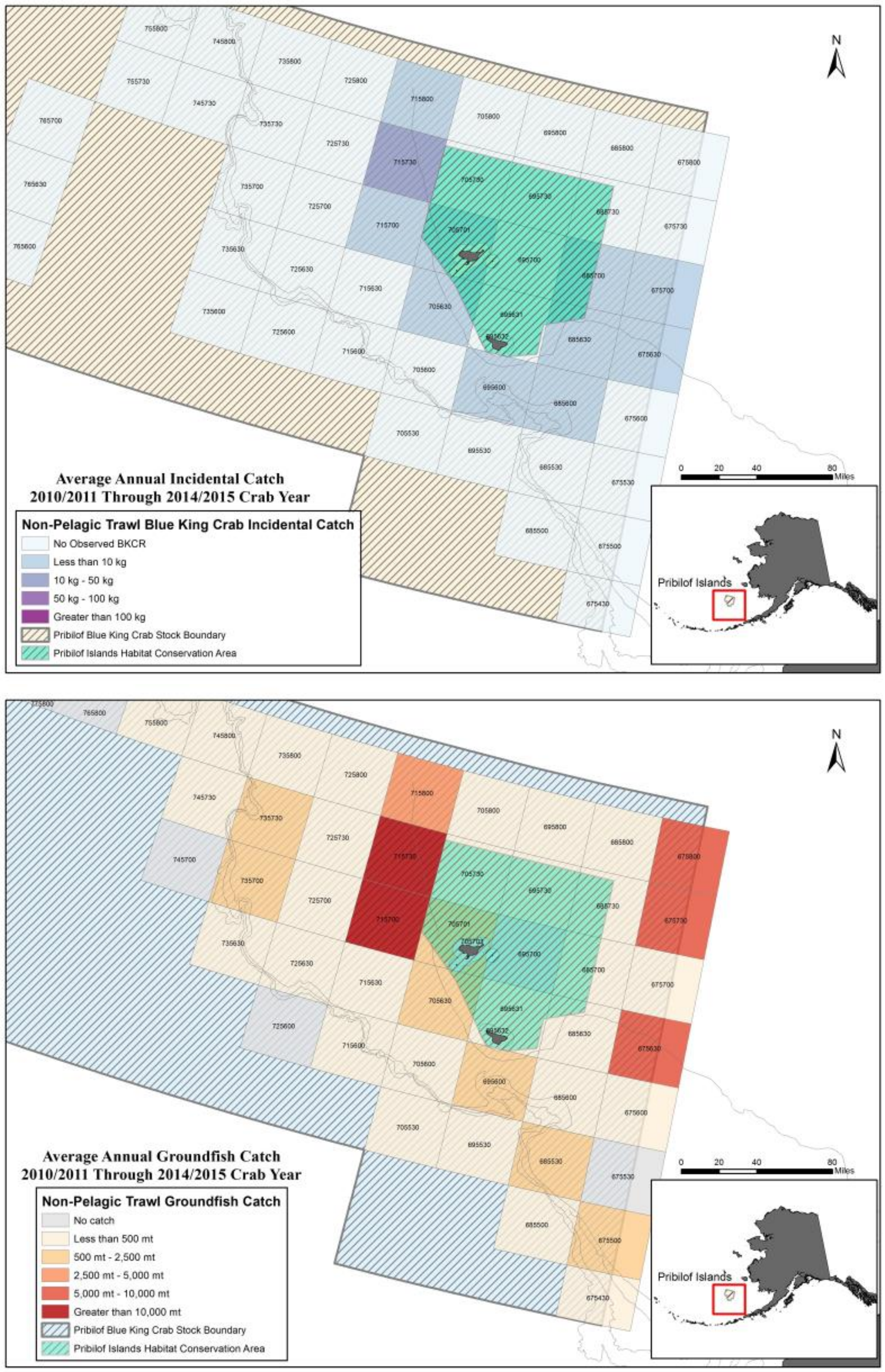
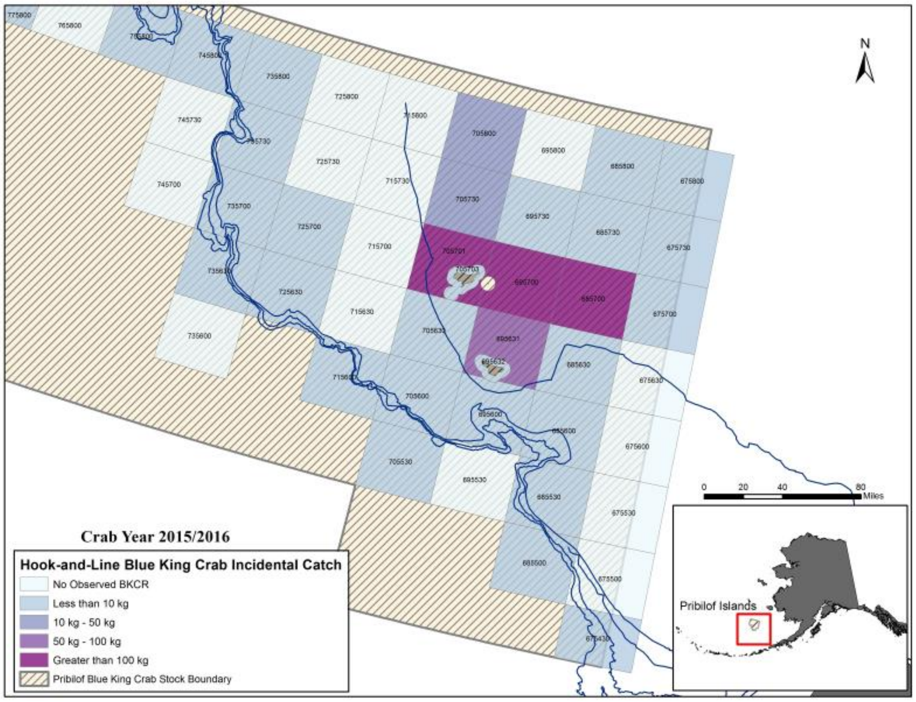


Figure 2. Average spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using non-pelagic trawl gear in the 2010/11-2014/15 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat (1º long. x 0.5º lat.) areas, the yellow hatched area denotes the PIBKC stock boundary, and the hatched green area represents the Pribilof Islands Habitat Conservation Area closed to non-pelagic trawl gear.



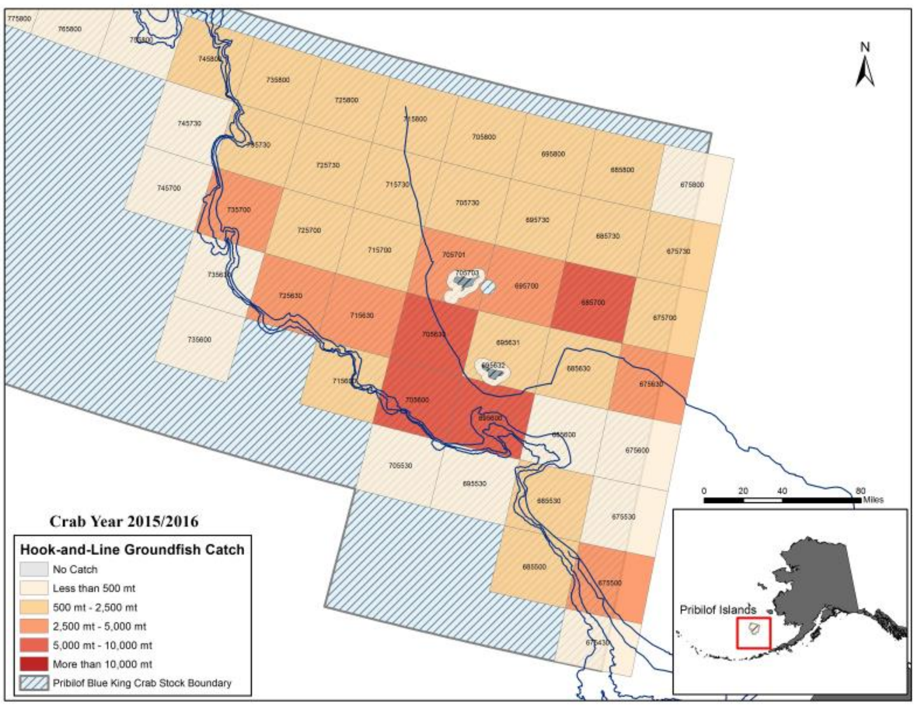
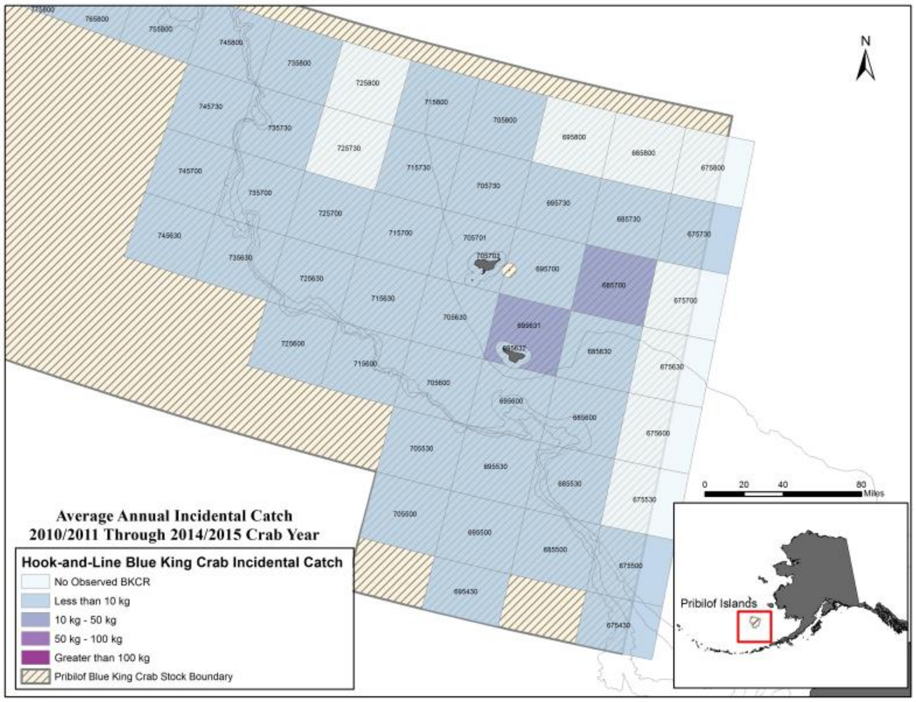


Figure 3. Spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using hook-and-line trawl gear in the 2015/16 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat areas (1° long. x 0.5° lat.); the yellow hatched area denotes the PIBKC stock boundary.



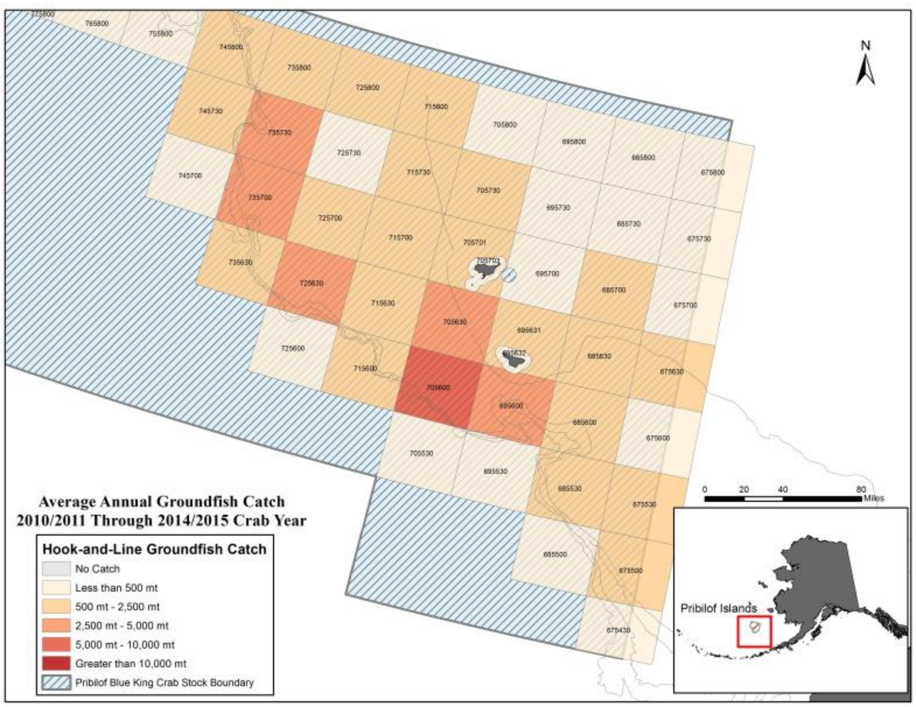


Figure 4. Average spatial distribution of estimated total PIBKC bycatch (upper) and groundfish catch using hook-and-line trawl gear in the 2010/11-2014/15 BSAI groundfish fisheries, by ADFG stat area. Squares denote ADFG stat areas (1º long. x 0.5º lat.); the yellow hatched area denotes the PIBKC stock boundary.