2015 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Executive Summary

1. Stock: Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been relatively small in recent years, with most bycatch mortality occurring in the BSAI groundfish trawl fisheries (5-year average: 0.09 t [0.0002 million lbs]) and pot fisheries (5-year average: 0.03 t [0.0001 million lbs]). In 2014/15, the estimated crab bycatch mortality was zero in the groundfish trawl fisheries and 0.07 t (< 0.0002 million lbs) in the groundfish pot fisheries. The estimated bycatch mortality for Pribilof Islands blue king crab in other crab fisheries was zero in 2014/15.
3. Stock biomass: Stock biomass decreased between the 1995 and 2008 surveys, and continues to fluctuate at low abundance 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 blue king crab. Pre-recruits have remained consistently low in the past 10 years, although these may not be well assessed with the survey.
5. Management performance: The stock is below MSST and consequently is overfished. Overfishing did not occur during the 2014/2015 fishing year. [Note: MSST changed somewhat 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}].

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
2011/12	2,247 A	365 A	0	0	0.36	1.16	1.04
2012/13	1,994 A	579 A	0	0	0.61	1.16	1.04
2013/14	2,001 A	225 A	0	0	0.03	1.16	1.04
2014/15	2,506 A	320 A	0	0	0.07	1.16	0.87
2015/16	--	318 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
2011/12	4.95 A	0.80 A	0	0	0.0008	0.003	0.002
2012/13	4.39 A	1.09 A	0	0	0.0013	0.003	0.002
2013/14	4.41 A	0.50 A	0	0	0.0001	0.003	0.002
2014/15	5.52 A	0.71 A	0	0	0.0002	0.003	0.002
2015/16	--	0.70 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 2014/2015 OFL: The OFL was determined following Tier 4 considerations. The ratio of the estimate of current (2015/16) 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 a consequence, the OFL is based on a Tier 5 calculation of average bycatch mortalities between 1999/2000 and 2005/2006 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 (0.0003 million lbs) for 2015/16. [Note: MSST changed somewhat 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}].

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*
2011/12	4c	4,209	365	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
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	5,012	318	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*
2011/12	4c	9.28	0.80	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
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	11.05	0.70	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_{max} was calculated using a 25% buffer, as in the 2014 assessment. The ABC_{max} is thus 0.87 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.

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 closes the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod is 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.
2. Input data: Retained and discard catch time series were updated with 2014/2015 data from the crab and groundfish fisheries. Following review by the CPT and approval by the SSC, abundance, biomass and size frequencies estimated from the NMFS crab and groundfish summer bottom trawl survey were recalculated for the entire time series based on a new set of standardized stations and hauls selected to improve sampling design and consistency across the 40-plus year dataset.
3. Assessment methodology: No changes. The Tier 4 approach based on inverse-averaged survey biomass estimates used in this assessment for status determination is identical to that used last year (Stockhausen, 2014). An alternative Tier 4 approach using a random effects/Kalman filter model was developed and is discussed in this chapter. It was not, however, used for status determination because it has not been reviewed and approved by the CPT and SSC.
4. Assessment results: Total catch mortality in 2014/2015 was 0.07 t. The projected MMB for 2015/16 decreased slightly from that in 2013/14 and remained below the MSST. Consequently, the stock remains overfished and a directed fishery is prohibited in 2015/16. 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 May 2014:</u>

Specific remarks pertinent to this assessment

none

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

Specific remarks pertinent to this assessment

none

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

Specific remarks pertinent to this assessment

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.

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

Responses to CPT Comments: These requests will be addressed at the May 2016 CPT meeting.

<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

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 (Somerton 1985; Armstrong et al 1985, 1987).

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab (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 crabs in the North Pacific is largely unknown. Samples were collected in 2009-2011 to support a genetic study on blue king crab population structure by a graduate student at the University of Alaska. 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.

   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 one year later, at six years of age (NPFMC 2003). Female size at 50% maturity for Pribilof blue king crab is estimated at 96-mm carapace length (CL) and size at maturity for males, as estimated from size of chela relative to CL, is estimated at 108-mm CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for those males larger than 100 mm CL (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 for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek et. al 2002).

5. **Management history -** The king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (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).

   Blue king crab in the Pribilof District have occurred as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*) fishery, the eastern 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 are 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 stock after 1995 resulted in a closure of directed fishing from 1999 to the present. The Pribilof Islands blue king crab 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 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 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 is 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 2014/15 from ADFG data (no retained catch, no discard mortality; Tables 1 and 2). The time series of discards in the groundfish pot and trawl fisheries (Tables 2-4) were updated for 2013/14 and calculated for the 2014/15 crab fishery season (July 1-June 30) using the NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (as updated on Aug. 17, 2015).

   Results from the 2015 NMFS EBS bottom trawl survey were added to the assessment (Table 5). The (old) standard NMFS survey time series data, including an additional (as of 2013) 20 nm strip on the eastern portion of the Pribilof District, were recalculated and updated through the 2015 summer bottom trawl survey (Table 6). Additionally, a suite of similar time series was calculated using the newly-standardized set of survey stations and hauls (Table 7). This new standardization improves sampling consistency and strata definitions across the 40-plus years the annual NMFS summer crab and groundfish trawl survey has been conducted and includes data from the 20 nm strip adjacent to the Pribilof District identified in the Environmental Assessment as an area to include in defining the stock area. Time series based on this new standardization will be referred to as "new" survey time series, while those based on the old selection of stations and hauls will be referred to as "old" survey time series. The new standardization primarily affects survey time series values in the early portions of these series. Recent results (e.g., 2013-2015) are based on the same set of hauls and stations in both the "new" and "old" time series.

2. *a. Total catch:*

Crab pot fisheries

Retained pot fishery catches (live and deadloss landings data) are provided for 1973/74 to 2012/13 (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 2014/15 crab fishing season.

b. Bycatch and discards:

Crab pot fisheries

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers 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:

$$w = \alpha \cdot z^{\beta} \quad (1)$$

Values for the length-to-weight conversion parameters α and β were applied across two time periods: 1973-2009 (males: α =0.000329, β =3.175; females: α =0.114389, β =1.9192) and 2010-present (both sexes: α =0.000508, β =3.106). [Note: these coefficients should be updated next year based on the new NMFS EBS trawl survey weight-at-size relationships and catch weights should be recalculated, if possible, for the entire time series.] Average weights ($\overline{W}$) for each category were calculated using the following equation:

$$\overline{W} = \frac{\sum_z W_z \cdot n_z}{\sum_z n_z} \quad (2)$$

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 estimate 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 2014/15, no PIBKC were incidentally caught in the crab fisheries (Table 2).

Groundfish pot, trawl, and hook and line fisheries

AKRO estimates of non-retained catch from all groundfish fisheries in 2014/15, as available through the AKFIN database (updated Aug. 17, 2015), are included in this report (Tables 2-4). Updated estimates for 2009/10-2013/14 were also obtained through the AKFIN database.

Prior to 1991, groundfish bycatch data 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 2014 (see Stockhausen, 2014). The estimates obtained this year are based on the same methods as those used in 2014.

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 fisheries using pot and hook and line gear (Table 2, 3).

In 20114/15, as in 2013/14, bycatch of Pribilof Islands blue king crab occurred almost exclusively in fisheries targeting Pacific cod (*Gadus macrocephalus*; 99.4% by weight, Table 3). In 2012/13, fisheries targeting Pacific cod accounted for 20% of the bycatch while those targeting yellowfin sole (*Limanda aspera*) 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 4). In 2013/14 and 2014/15, hook and line gear accounted for the total bycatch of Pribilof Islands blue king crab. In the previous year, it accounted for only 20% of the bycatch (by weight), whereas non-pelagic trawl gear accounted for 80%. Although this appears to be a large change, 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 2015 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 2015, the survey caught 28 blue king crab in 86 tows/stations across the stock area (Table 5a). Out of the 86 tows, immature males were caught in 2, mature males were caught in 8, immature females were caught in none, and mature females were caught in 4. In 2014, the survey caught only 15 crab in 86 tows across the stock area (Table 5b). Of the crab caught in 2015, 17 were male (4 immature, 13 mature, and 7 legal-sized) while 11 were female (all mature). Swept-area estimates of abundance in the stock area at the time of the 2015 survey, with 95% normal confidence intervals, were 234,000 (± 168,000) mature males, 76,000 (± 113,000) immature males, 125,000 (± 109,000) legal-sized males, 202,000 (± 260,000) mature females, and 0 immature females. Swept-area estimates of biomass were 622 t (± 480 t) for mature males, 82 t (±120 t) for immature males, 428 t (± 325 t) for legal-sized males, 160 t (± 207 t) for mature females, and 0 t for immature females.

The 2015 estimates of survey biomass represent seemingly large increases relative to the 2014 estimates for mature males (166%), legal males (83%), and mature females (76%), while immature males decreased slightly (1%) and immature females decreased substantially (100%, but this results from one less immature female being caught in 2015 than in 2014). However, given the large confidence intervals associated with these estimates, none of the changes are statistically significant. To better determine temporal trends, it is necessary to consider the entire survey time series.

During the two past years, and involving considerable effort, the set of stations and hauls constituting the “standard” dataset for calculating crab-related trends in abundance, biomass and size compositions from the annual NMFS EBS bottom trawl survey was redefined for each crab stock to improve sampling design and consistency across the 40-plus year dataset (R. Foy, verbal report to the CPT, May 2015). The “old” dataset included stations with multiple hauls associated with special projects and “re-tows”, as well as somewhat inconsistent strata definitions across the time series. The new dataset consists of a single haul per station and strata definitions are temporally consistent. In conjunction with this effort, the size-weight regressions used to convert crab abundance to biomass were also revised. As such, new survey biomass and abundance time series have been calculated from the 1975-2015 annual survey results and incorporated into this assessment (Table 7, Fig. 5). For comparison purposes, survey time series based on the “old” survey dataset have also been updated with the results of the 2015 bottom trawl survey (Table 6, Fig.s 6-9).

While the new and old time series exhibit some large differences in the earliest part of the time series (e.g., prior to 1985), they show substantial agreement in the latter part of the time series (e.g., post-1985), although some differences are still apparent (Fig.s 6-9). In both time series, the mature portion of the population was highest in the late 1970’s and early 1980’s, declined in the mid-1980’s into the early 1990’s, recovered somewhat in the mid-1990’s, then declined again through the 2000’s to the present. The uncertainties associated with individual estimates are quite large, due to the patchiness of the stock, and trends can be more easily discerned by smoothing the time series in some fashion (Table 8, Fig. 10). The smoothed time series suggest that the stock reached its minimum size during the 2003-2009 period (~100-200 t) and may have increased slightly since then (to ~300 t).

Size frequencies for males by shell condition from the 3 most recent surveys (2013-2015) are illustrated in Figure 11. Size frequencies for all males across the time series are shown in Fig. 12 for both the new time series and the old time series. Fig. 11 suggests a recent trend toward larger sizes, with little evidence for recruitment in 2014 or 2015. However, given the sampling error associated with this stock, it is hard to draw any firm conclusions regarding such a trend.

Size frequencies for females by shell condition are presented in Fig. 13 for the 3 most recent surveys (2013-2015). Size frequencies for all females are shown in Fig. 14, contrasting the new and old time series.

Spatial patterns found in the 2015 survey are contrasted with those from the 2014 and 2013 surveys in Figures 15 and 16.

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 previous two assessments (Foy, 2013; Stockhausen, 2014), "current" MMB-at-mating has been 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. This approach was also followed in this assessment. An alternative approach to smoothing based on a Random Effects/Kalman Filter model (see Appendix A) is also presented.

2. *Model Description: Not applicable.*

3. *Model Selection and Evaluation: Not applicable*

4. *Results: Not applicable*

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 2008).

   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}^{proxx} 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) (Figure 20).

      2) An estimate of surplus production (ASP = $\mathrm{MMB}_{t+1} - \mathrm{MMB}_t$ + total catch_t) suggested that only meaningful surplus existed 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 and 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 (Figure 21 in Foy, 2013).

B. Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Figure 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 (Figure 22 in Foy, 2013). The current $F_{\mathrm{MSY}}^{proxy} = M$ 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 $F_{\mathrm{MSY}}^{proxy} = M$ 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 "raw" (unsmoothed) estimates for MMB_{survey} from the new survey time series in the formula for MMB_{mating}. B_{MSY}^{proxy} is the average of MMB_{mating} for the years 1980-84 and 1990-97 (see Table 7) and was calculated as 5,012 t.

In this assessment, "current B" is the MMB_{mating} projected for 2015/16. Details of this calculation are provided in Appendix A. For 2015/16, current B = 318 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}) = 5,012 t
- M = 0.18 yr^{-1}
- Current B = 318 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 (Figure 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. $B/B_{\mathrm{MSY}}^{\mathrm{prox}} > 1.0$	$F_{\mathrm{OFL}} = \gamma \cdot M$	(4)
b. $\beta < B/B_{\mathrm{MSY}}^{\mathrm{prox}} \leq 1.0$	$F_{\mathrm{OFL}} = \gamma \cdot M\ [(B/B_{\mathrm{MSY}}^{\mathrm{prox}} - \alpha)/(1 - \alpha)]$	(5)

c. $B/B_{MSY}^{prox} \leq \beta$ $F_{directed} = 0$; $F_{OFL} \leq F_{MSY}$ (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 2008).

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:

The following tables are based on the new survey time series.

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*
2011/12	4c	4,209	365	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
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	5,012	318	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*
2011/12	4c	9.28	0.80	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
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	11.05	0.70	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 2015/2016, B_{MSY}^{proxy} *= 5,012 t, derived as the mean* MMB_{mating} *from 1980 to 1984 and 1990 to 1997 using the new 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 2015/16 was estimated at 318 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 2008). 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 2015/16, 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 $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$. For the PIBKC stock, the CPT has recommended, and the SSC has approved, using a constant buffer of 25% is applied 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 0.70 and has ranged between 0.17 and 0.80 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 2015/2016, $F_{\text{directed}} = 0$ 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
2011/12	2,247 [A]	365 [A]	0	0	0.36	1.16	1.04
2012/13	1,994 [A]	579 [A]	0	0	0.61	1.16	1.04
2013/14	2,001 [A]	225 [A]	0	0	0.03	1.16	1.04
2014/15	2,506 [A]	320 [A]	0	0	0.07	1.16	0.87
2015/16	--	318 [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
2011/12	4.95 [A]	0.80 [A]	0	0	0.0008	0.003	0.002
2012/13	4.39 [A]	1.09 [A]	0	0	0.0013	0.003	0.002
2013/14	4.41 [A]	0.50 [A]	0	0	0.0001	0.003	0.002
2014/15	5.52 [A]	0.71 [A]	0	0	0.0002	0.003	0.002
2015/16	--	0.70 [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 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 will 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 a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District.

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Figure 16. Size class distribution of blue king crab in the Pribilof District during the 2013 (upper), 2014 (center), and 2015 (lower) EBS bottom trawl surveys.

Figure 17. 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).

Tables

Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly, 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	3224	20
1975/1976	314,931	1104	19
1976/1977	855,505	2999	12
1977/1978	807,092	2929	8
1978/1979	797,364	2901	8
1979/1980	815,557	2719	10
1980/1981	1,497,101	4976	9
1981/1982	1,202,499	4119	7
1982/1983	587,908	1998	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 - 2014/2015	0	0	--

Table 2. Total non-retained catch (bycatch/discard) mortalities from directed and non-directed fisheries for Pribilof Islands District blue king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to estimates of non-retained catch based on observer data in the crab and groundfish fisheries. Crab 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).

Year	Crab pot fisheries			Groundfish fisheries	
	Non-retained legal male (t)	Sublegal male (t)	Female (t)	Fixed gear (t)	Trawl gear (t)
1991/1992	NA	NA	NA	0.03	4.96
1992/1993	NA	NA	NA	0.44	48.63
1993/1994	NA	NA	NA	0.00	27.39
1994/1995	NA	NA	NA	0.02	5.48
1995/1996	NA	NA	NA	0.05	1.03
1996/1997	0	0.4	0	0.02	0.05
1997/1998	0	0	0	0.73	0.10
1998/1999	1.15	0.23	1.86	9.90	0.06
1999/2000	1.75	2.15	0.99	0.40	0.02
2000/2001	0	0	0	0.06	0.02
2001/2002	0	0	0	0.42	0.02
2002/2003	0	0	0	0.04	0.24
2003/2004	0	0	0	0.17	0.18
2004/2005	0	0	0	0.41	0.00
2005/2006	0	0	--	0.18	1.07
2006/2007	0	0	--	0.07	0.06
2007/2008	0	0	--	2.00	0.11
2008/2009	0	0	--	0.07	0.38
2009/2010	0	0	--	0.11	0.17
2010/2011	0	0.09	--	0.02	0.05
2011/2012	0	0	--	0.06	0.01
2012/2013	0	0	0	0.08	0.54
2013/2014	0	0	0	0.03	0.00
2014/2015	0	0	0	0.07	0.00

Table 3. Proportion by weight of the 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 2009/10-2014/15, 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 1% of the blue king crab bycatch across all years are not shown in the table. These include pollock-bottom trawl, pollock-midwater trawl, halibut, Greenland turbot, and arrowtooth flounder.

Crab Fishery Year	% bycatch (biomass) by trip target					total bycatch (# crabs)
	yellowfin sole %	Pacific cod %	flathead sole %	rocksole %	sablefish %	
2003/2004	47.0	22.0	31.0	< 1	< 1	252
2004/2005	< 1	100.0	< 1	< 1	< 1	259
2005/2006	< 1	97.0	3.0	< 1	< 1	757
2006/2007	54.0	20.0	< 1	26.0	< 1	96
2007/2008	3.0	96.0	1.0	< 1	< 1	2,950
2008/2009	77.0	23.0	< 1	< 1	< 1	295
2009/2010	30.5	51.1	16.8	< 1	< 1	281
2010/2011	< 1	38.5	59.0	< 1	< 1	48
2011/2012	< 1	99.8	< 1	< 1	< 1	62
2012/2013	77.2	20.0	2.9	< 1	< 1	410
2013/2014	< 1	99.4	< 1	< 1	< 1	39
2014/2015	< 1	99.4	< 1	< 1	< 1	64

Table 4. Proportion by weight of the 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 2009/10-2014/15, 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.

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

Table 5. Summaries of the a) 2015 and b) 2014 NMFS annual EBS bottom trawl surveys for Pribilof Islands District blue king crab by stock component.

a) 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

b) 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 6. Time series for Pribilof Islands blue king crab abundance and biomass based on the old standardization for the NMFS annual EBS bottom trawl survey.

Year	@ time of survey					@ mating time
	Mature male abundance	Mature male biomass (t)	Legal male biomass (t)	Total male biomass (t)	Total female biomass (t)	Mature male biomass (t)
1975/76	14,955,818	33,862	24,037	41,292	12,172	29,449
1976/77	3,568,103	9,573	8,585	13,333	5,770	5,795
1977/78	13,043,983	38,756	36,706	42,137	13,573	32,133
1978/79	6,140,638	15,798	12,291	18,315	6,492	11,489
1979/80	5,232,918	12,974	10,843	14,275	4,097	9,118
1980/81	5,432,065	14,253	12,163	16,050	63,713	8,146
1981/82	3,921,734	10,744	9,686	13,014	9,911	5,794
1982/83	2,344,203	6,691	6,241	7,740	9,376	4,140
1983/84	1,851,301	4,919	4,069	5,795	10,248	3,493
1984/85	674,376	1,761	1,446	1,860	2,580	1,453
1985/86	428,076	959	687	995	523	637
1986/87	480,198	1,368	1,340	1,372	2,431	1,121
1987/88	903,180	2,659	2,529	2,833	913	2,095
1988/89	237,868	766	766	921	717	690
1989/90	239,948	752	752	1,914	1,745	677
1990/91	1,738,237	3,259	1,549	5,376	3,811	2,934
1991/92	2,014,086	4,266	3,025	5,521	2,776	3,838
1992/93	1,935,278	3,995	2,761	5,635	2,649	3,574
1993/94	1,875,500	4,144	2,913	5,136	2,092	3,718
1994/95	1,263,447	3,028	2,491	3,578	4,858	2,724
1995/96	3,139,328	7,753	6,365	8,616	4,844	6,390
1996/97	1,712,015	4,221	3,522	4,899	5,585	3,399
1997/98	1,201,296	2,940	2,515	3,288	3,028	2,429
1998/99	967,097	2,545	2,283	3,175	2,182	2,063
1999/00	617,258	1,573	1,297	1,719	2,868	1,414
2000/01	725,050	1,902	1,588	2,005	1,462	1,712
2001/02	522,239	1,454	1,329	1,533	1,817	1,309
2002/03	225,476	618	588	618	1,401	556
2003/04	228,897	638	610	656	1,307	574
2004/05	47,905	97	44	130	123	87
2005/06	91,932	313	313	610	847	281
2006/07	50,638	137	115	210	558	123
2007/08	100,295	254	170	417	257	228
2008/09	18,256	42	42	235	672	38
2009/10	248,626	452	170	684	625	407
2010/11	138,787	322	202	420	440	290
2011/12	165,525	461	399	461	37	415
2012/13	272,233	644	459	809	237	580
2013/14	104,361	250	190	265	166	225
2014/15	91,856	233	233	317	108	210
2015/16	233,630	622	428	703	160	--

Table 7. Time series for Pribilof Islands blue king crab abundance and biomass based on the new standardization for the NMFS annual EBS bottom trawl survey.

Year	@ time of survey					@ mating time
	Mature male abundance	Mature male biomass (t)	Legal male biomass (t)	Total male biomass (t)	Total female biomass (t)	Mature male biomass (t)
1975/76	15,288,169	38,054	27,016	46,395	12,442	33,223
1976/77	4,782,105	14,059	12,649	18,188	5,792	9,834
1977/78	13,043,983	42,618	40,366	46,332	13,572	35,611
1978/79	6,140,638	17,370	13,517	20,135	6,492	12,904
1979/80	4,107,868	10,959	9,040	11,021	1,189	7,304
1980/81	7,842,342	23,553	20,679	25,637	212,303	16,519
1981/82	3,834,431	11,628	10,554	13,332	6,484	6,590
1982/83	2,353,813	7,389	6,893	8,541	9,377	4,769
1983/84	1,851,301	5,409	4,474	6,371	10,248	3,934
1984/85	770,643	2,216	1,824	2,345	3,085	1,862
1985/86	428,076	1,055	756	1,094	525	723
1986/87	480,198	1,505	1,473	1,508	2,431	1,244
1987/88	903,180	2,923	2,781	3,115	913	2,333
1988/89	237,868	842	842	1,012	718	758
1989/90	239,948	828	828	2,102	1,746	745
1990/91	1,470,419	3,078	1,514	5,082	2,929	2,771
1991/92	2,014,086	4,690	3,326	6,067	2,776	4,220
1992/93	1,935,278	4,391	3,035	6,192	2,649	3,930
1993/94	1,875,500	4,556	3,203	5,644	2,092	4,089
1994/95	1,294,263	3,410	2,806	4,029	4,893	3,068
1995/96	3,101,712	8,360	6,787	9,328	4,279	6,937
1996/97	1,712,015	4,641	3,873	5,386	5,585	3,776
1997/98	1,201,296	3,233	2,765	3,614	3,028	2,692
1998/99	967,098	2,798	2,510	3,490	2,182	2,291
1999/00	617,258	1,729	1,426	1,890	2,868	1,555
2000/01	725,051	2,091	1,746	2,205	1,462	1,883
2001/02	522,239	1,599	1,461	1,686	1,817	1,439
2002/03	225,476	680	647	680	1,401	612
2003/04	228,897	702	671	721	1,307	632
2004/05	47,905	107	48	143	123	96
2005/06	91,932	344	344	670	847	309
2006/07	55,579	166	139	253	576	149
2007/08	110,080	306	206	503	282	275
2008/09	18,256	46	46	258	672	41
2009/10	248,626	497	187	751	625	447
2010/11	130,465	303	190	395	394	273
2011/12	165,525	461	399	461	37	415
2012/13	272,233	644	459	809	237	579
2013/14	104,361	250	190	265	166	225
2014/15	91,856	233	233	317	108	210
2015/16	233,630	622	428	703	160	--

Table 8. Estimates of mature male biomass (MMB) at the time of mating for Pribilof Islands blue king crab using three methods for smoothing MMB at the time of the survey to reduce estimation error: 1) Unaveraged (no smoothing); 2) smoothing using a three-year centered Inverse Variance Average, and 3) , smoothing using a Random Effects Model.

year	Unaveraged (t)		Inverse-Variance Averaging (t)		Random Effects Model (t)	
	old time series	new time series	old time series	new time series	old time series	new time series
1975/76	29,449	33,223	--	--	18,718	23,196
1976/77	5,795	9,834	7,317	12,755	10,656	15,114
1977/78	32,133	35,611	7,142	11,425	13,440	16,395
1978/79	11,489	12,904	9,522	8,057	11,344	12,551
1979/80	9,118	7,304	9,732	8,956	9,581	9,435
1980/81	8,146	16,519	5,776	5,944	7,089	9,372
1981/82	5,794	6,590	3,652	4,158	5,507	6,407
1982/83	4,140	4,769	3,711	4,228	4,189	4,822
1983/84	3,493	3,934	1,448	2,068	3,173	3,640
1984/85	1,453	1,862	1,133	1,289	1,617	1,980
1985/86	637	723	881	1,005	858	988
1986/87	1,121	1,244	912	1,010	1,158	1,289
1987/88	2,095	2,333	753	854	1,293	1,437
1988/89	690	758	813	892	1,192	1,284
1989/90	677	745	794	819	1,377	1,438
1990/91	2,934	2,771	1,127	1,140	2,391	2,343
1991/92	3,838	4,220	3,382	3,653	3,239	3,431
1992/93	3,574	3,930	3,702	4,073	3,447	3,742
1993/94	3,718	4,089	3,209	3,571	3,544	3,885
1994/95	2,724	3,068	3,272	3,619	3,289	3,614
1995/96	6,390	6,937	2,759	3,112	3,607	3,862
1996/97	3,399	3,776	2,738	3,023	3,218	3,547
1997/98	2,429	2,692	2,431	2,695	2,508	2,773
1998/99	2,063	2,291	1,723	1,916	1,989	2,208
1999/00	1,414	1,555	1,754	1,926	1,617	1,777
2000/01	1,712	1,883	1,525	1,679	1,503	1,654
2001/02	1,309	1,439	857	945	1,036	1,139
2002/03	556	612	592	651	641	706
2003/04	574	632	123	136	447	494
2004/05	87	96	120	132	224	250
2005/06	281	309	106	119	212	239
2006/07	123	149	153	185	176	202
2007/08	228	275	60	65	181	206
2008/09	38	41	51	56	173	189
2009/10	407	447	62	70	252	266
2010/11	290	273	322	308	292	291
2011/12	415	415	327	310	342	341
2012/13	580	579	303	303	371	371
2013/14	225	225	240	240	331	331
2014/15	210	210	288	288	344	344
2015/16	--	--	--	--	--	--

Figures

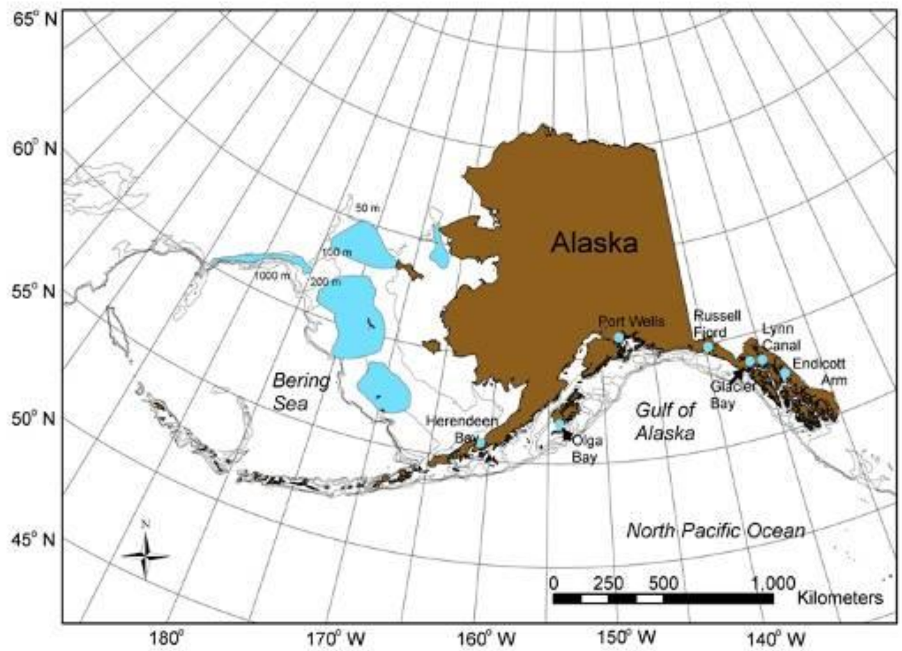


Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

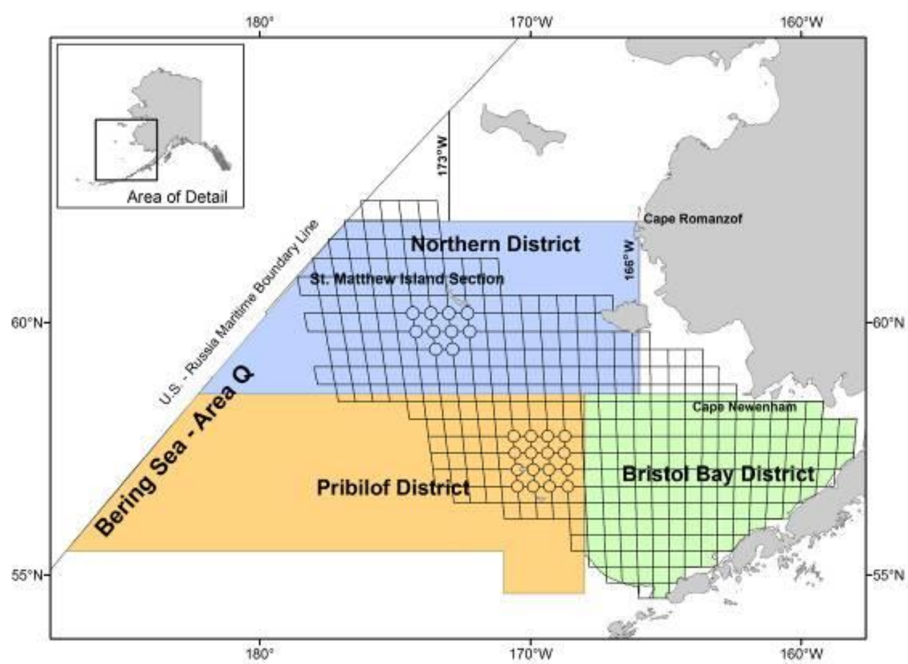


Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District. This figure does not show the additional 20 nm strip considered starting in 2013 year for biomass and catch data in the Pribilof District.

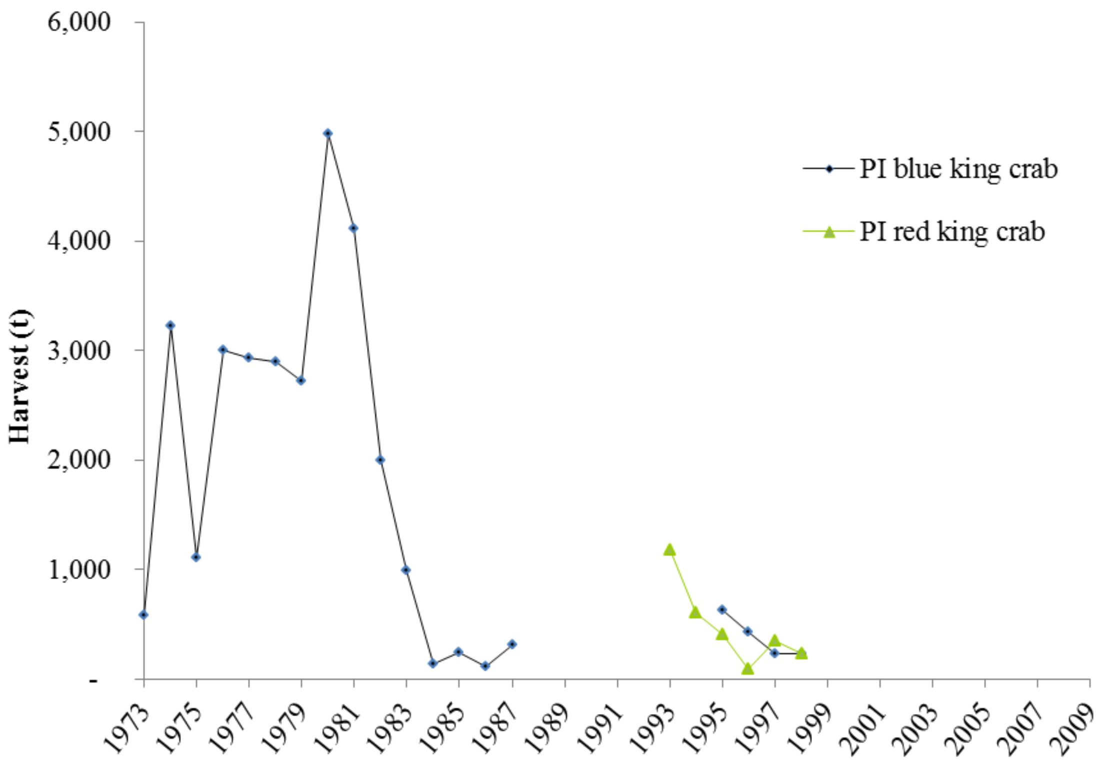


Figure 3. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

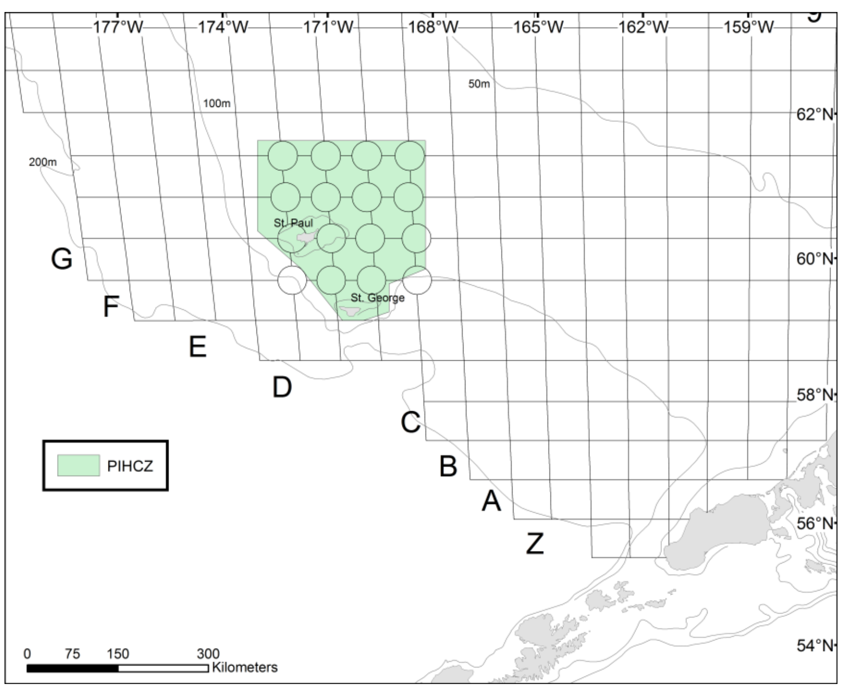
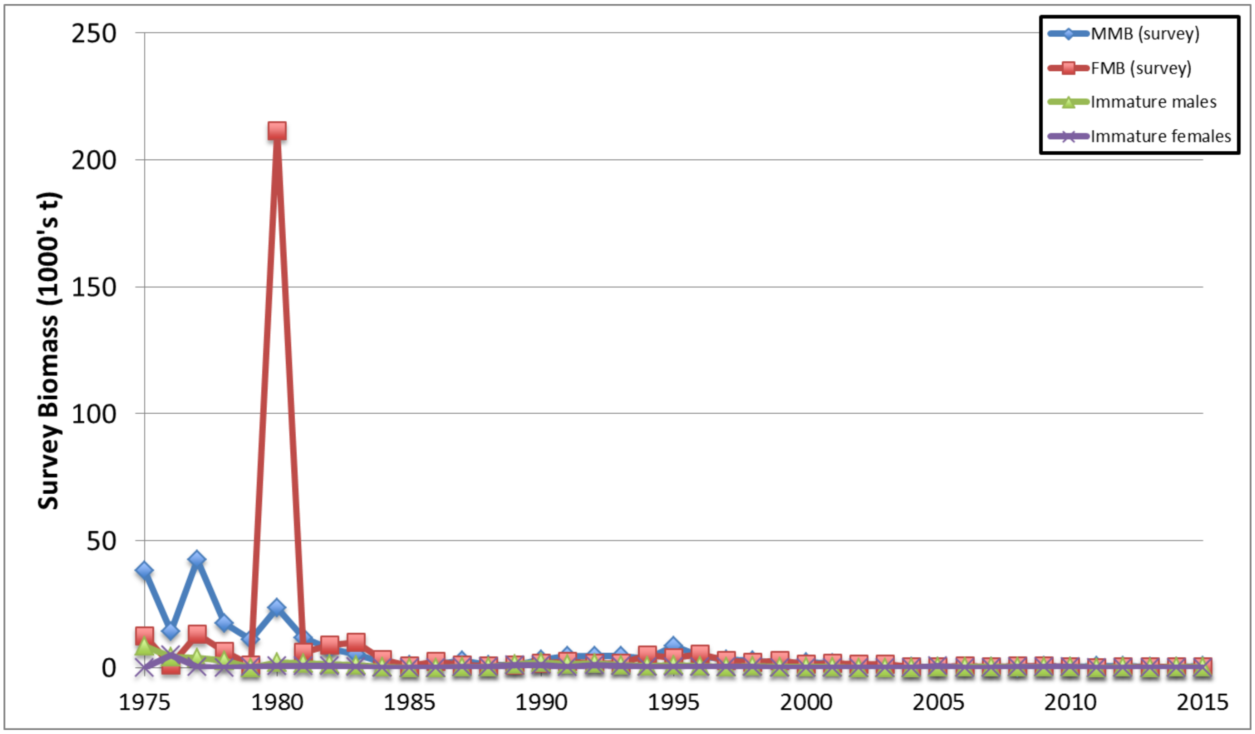


Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.



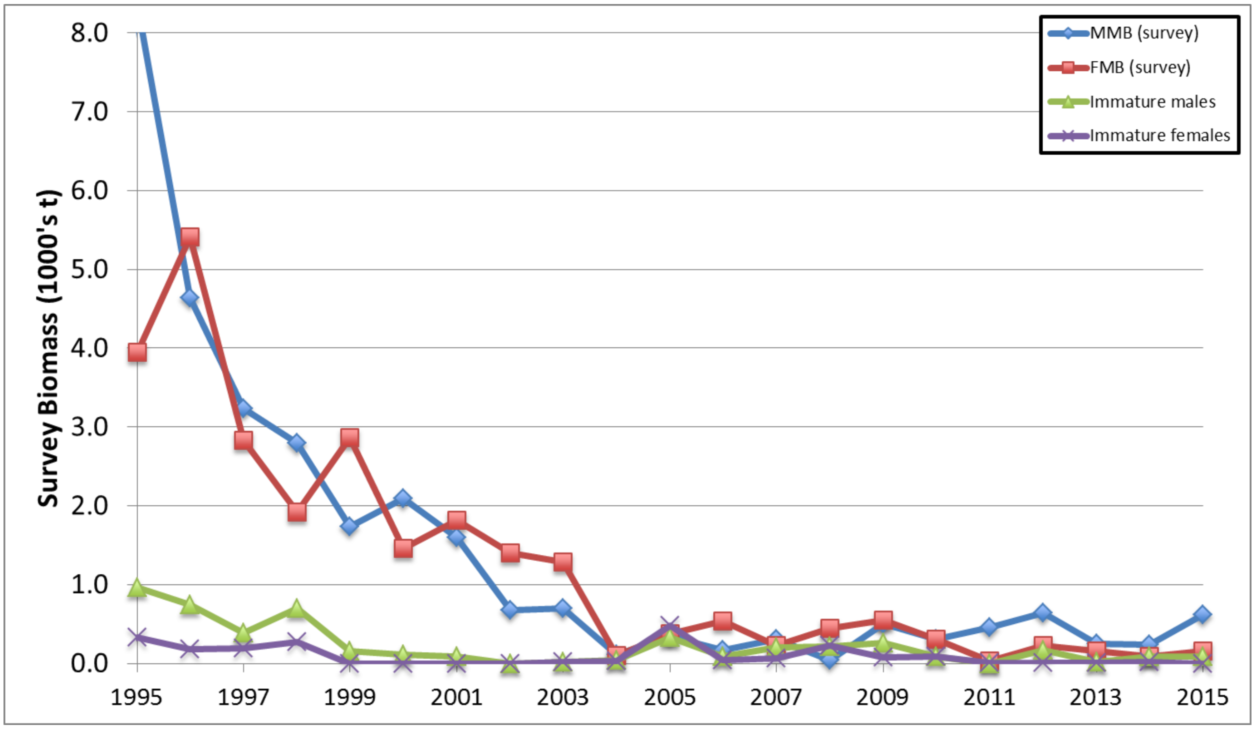


Figure 5. Time series for various stock components of Pribilof Islands blue king crab estimated using the new standardization for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015.

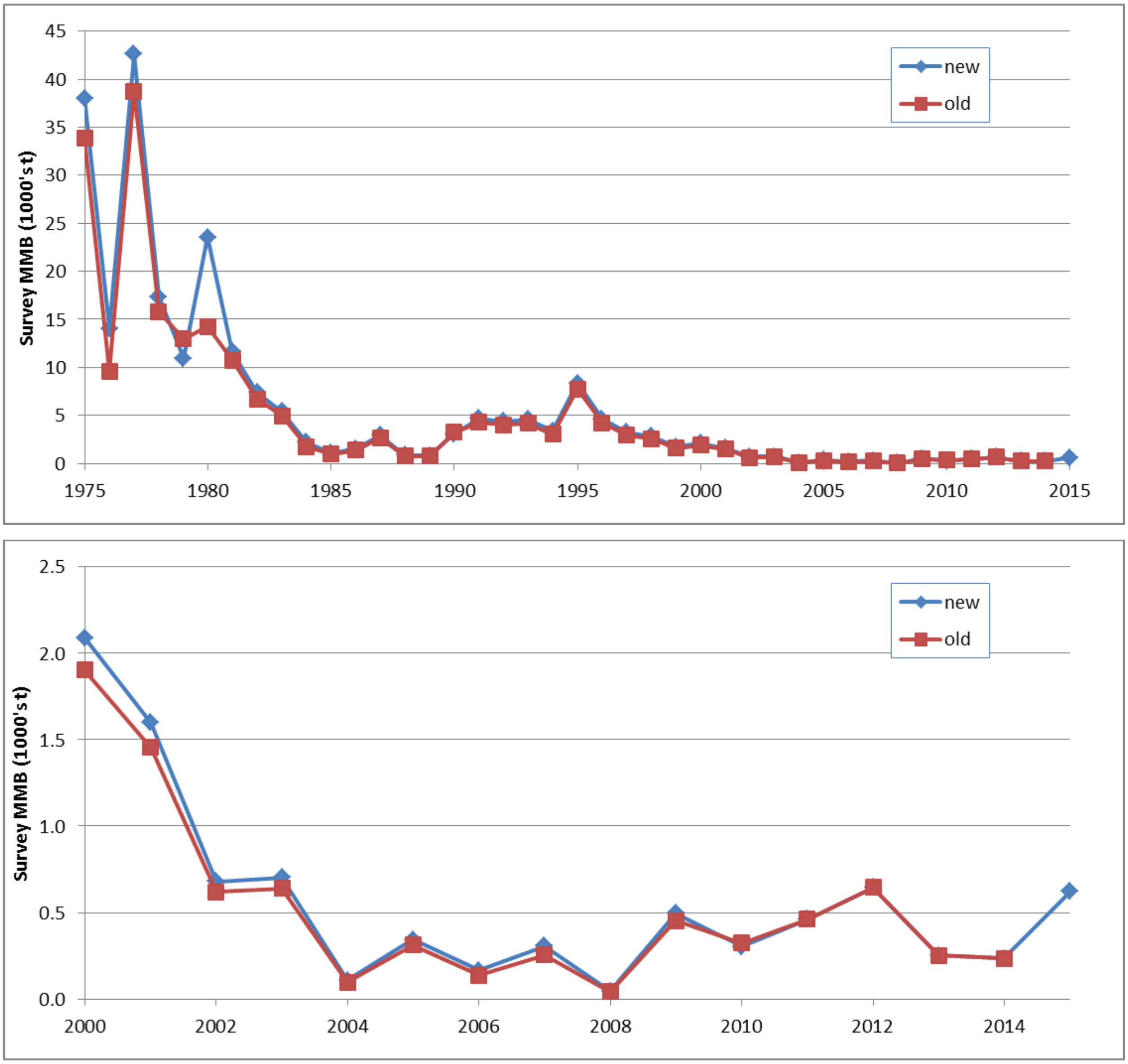


Figure 6. Comparison of time series for survey mature male biomass (MMB) estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.

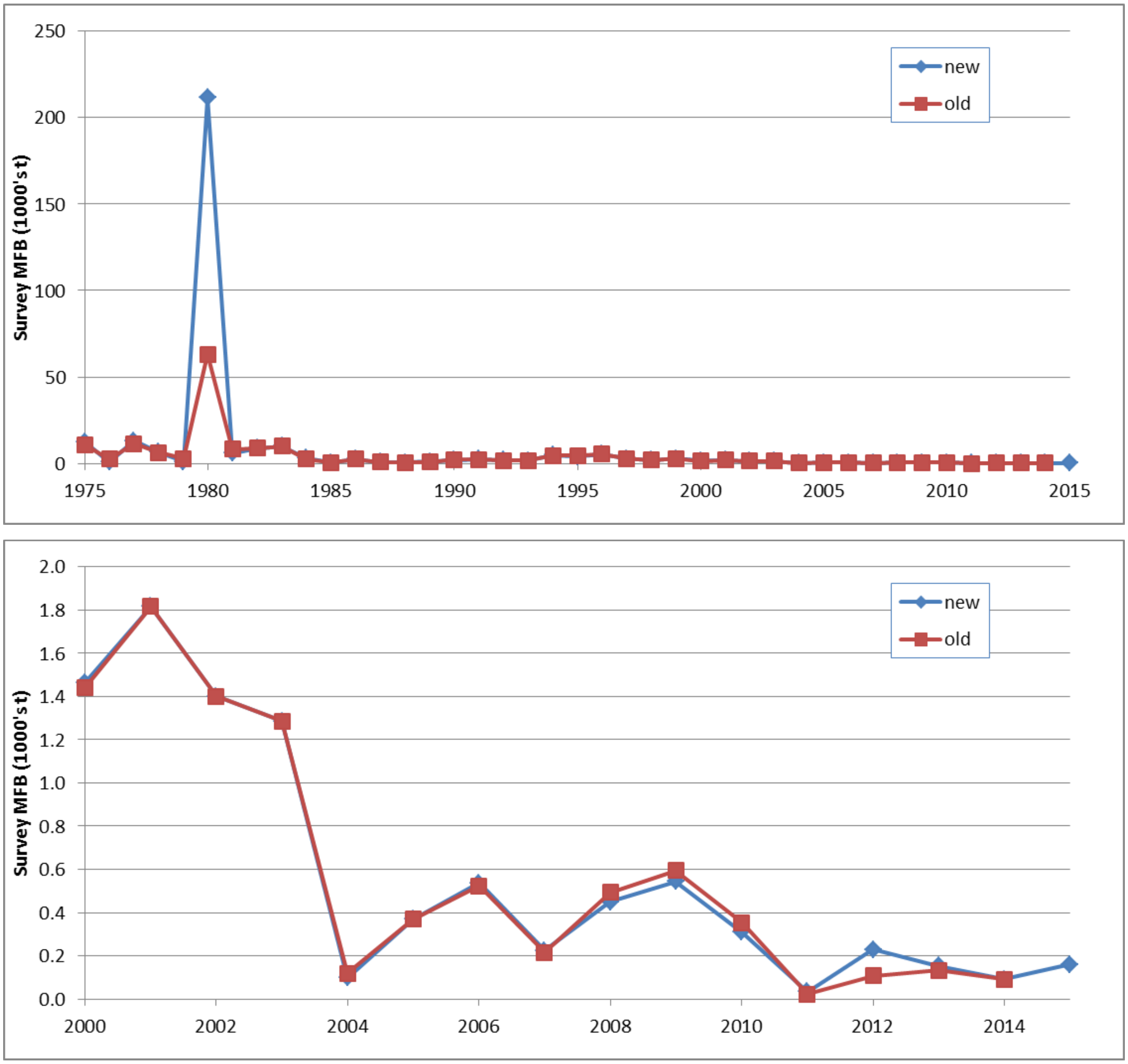
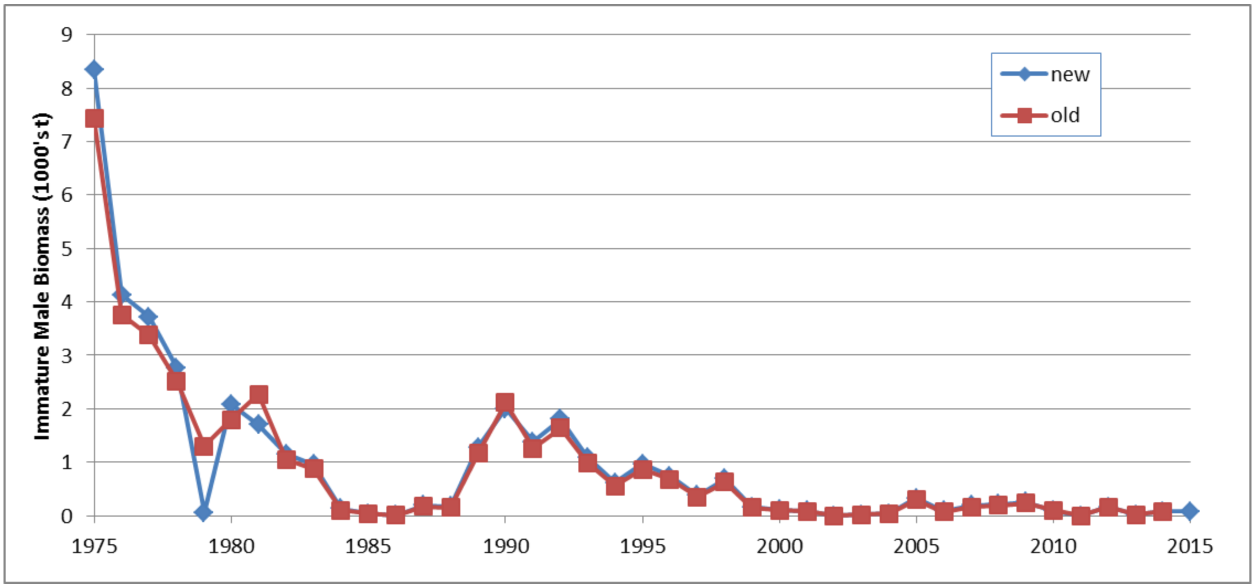


Figure 7. Comparison of time series for survey maturefe male biomass (MFB) estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.



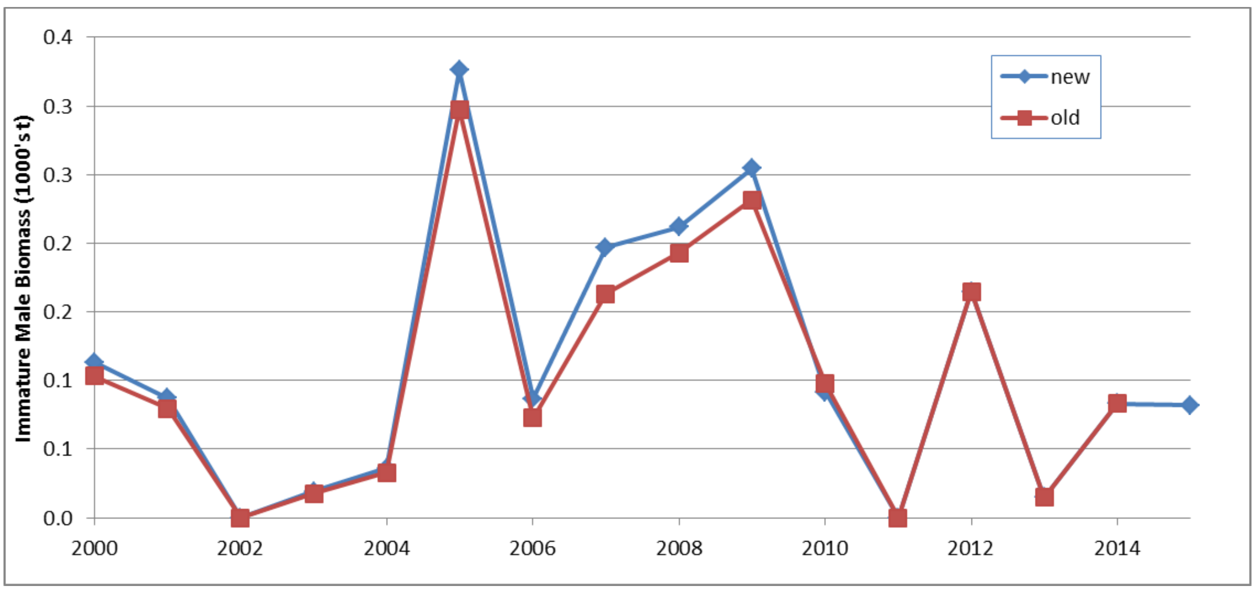


Figure 8. Comparison of time series for immature male biomass at the time of the survey estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.

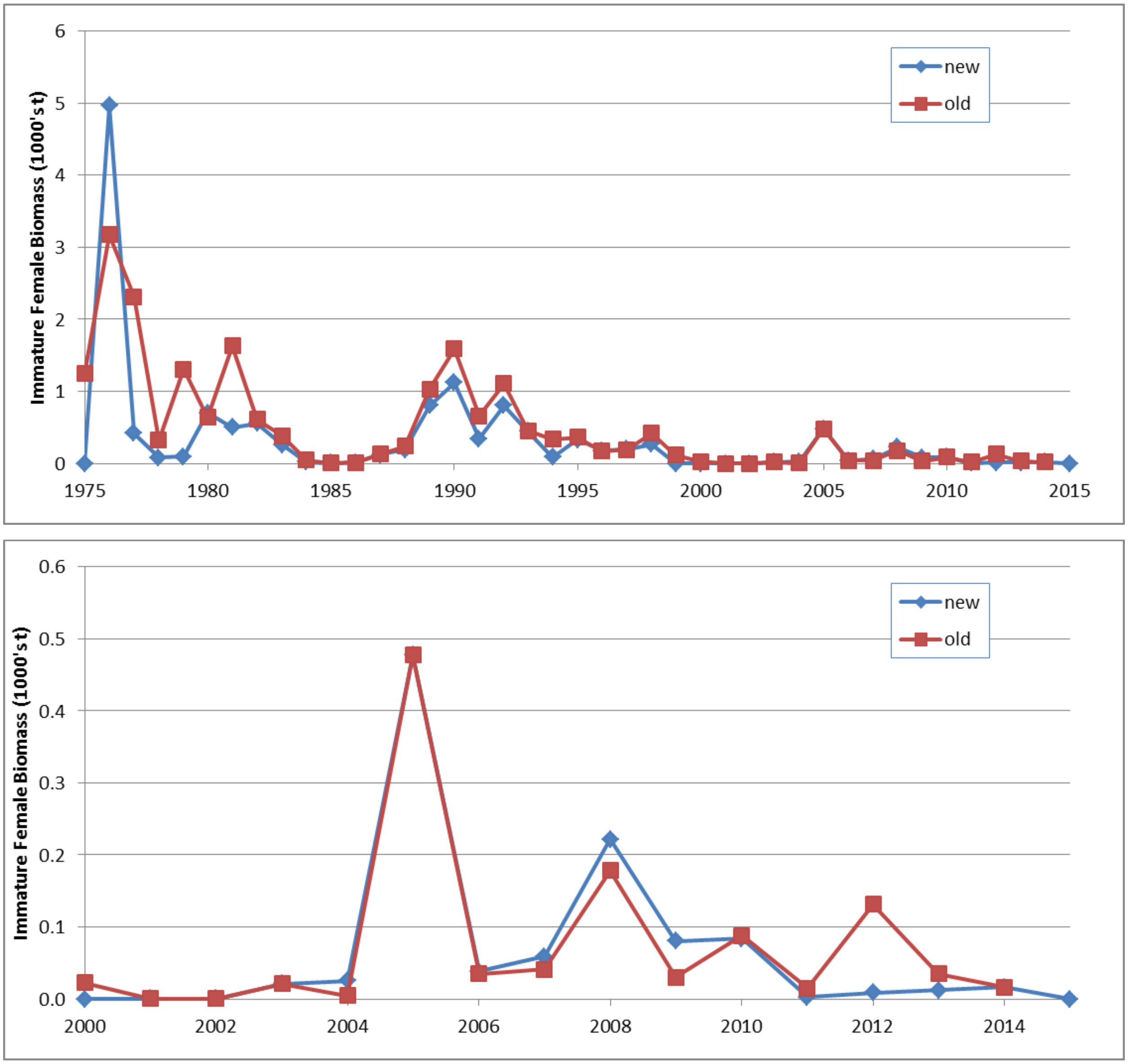
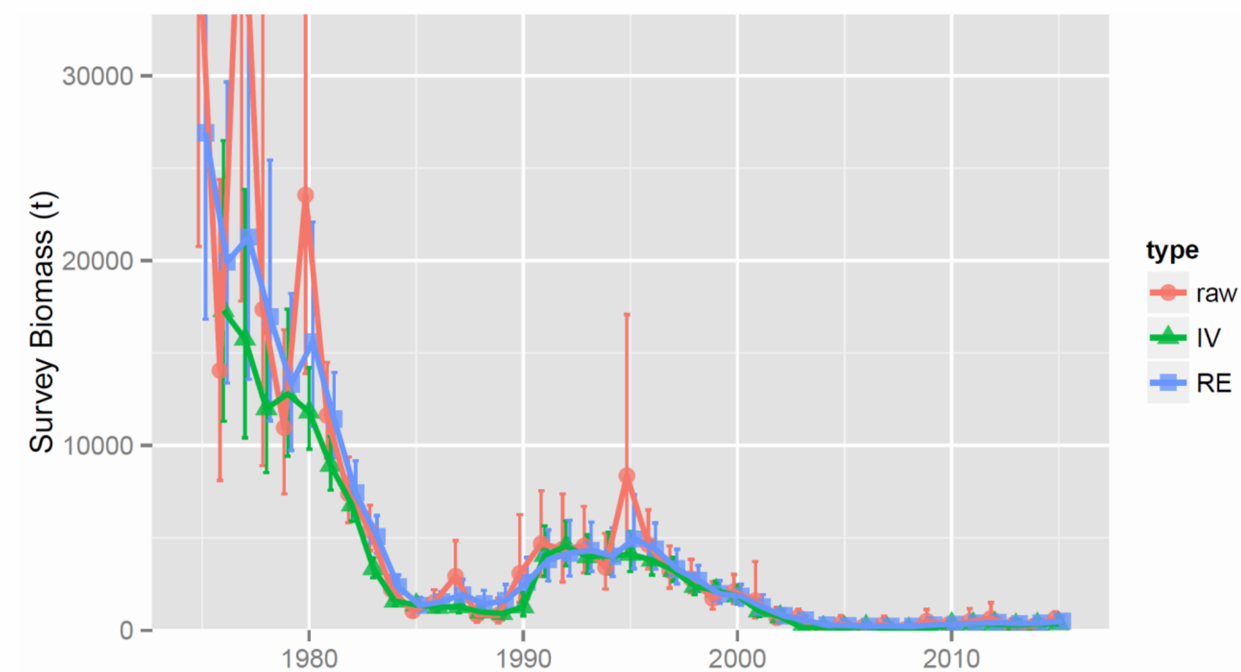


Figure 9. Comparison of time series for survey mature male biomass (MMB) estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.



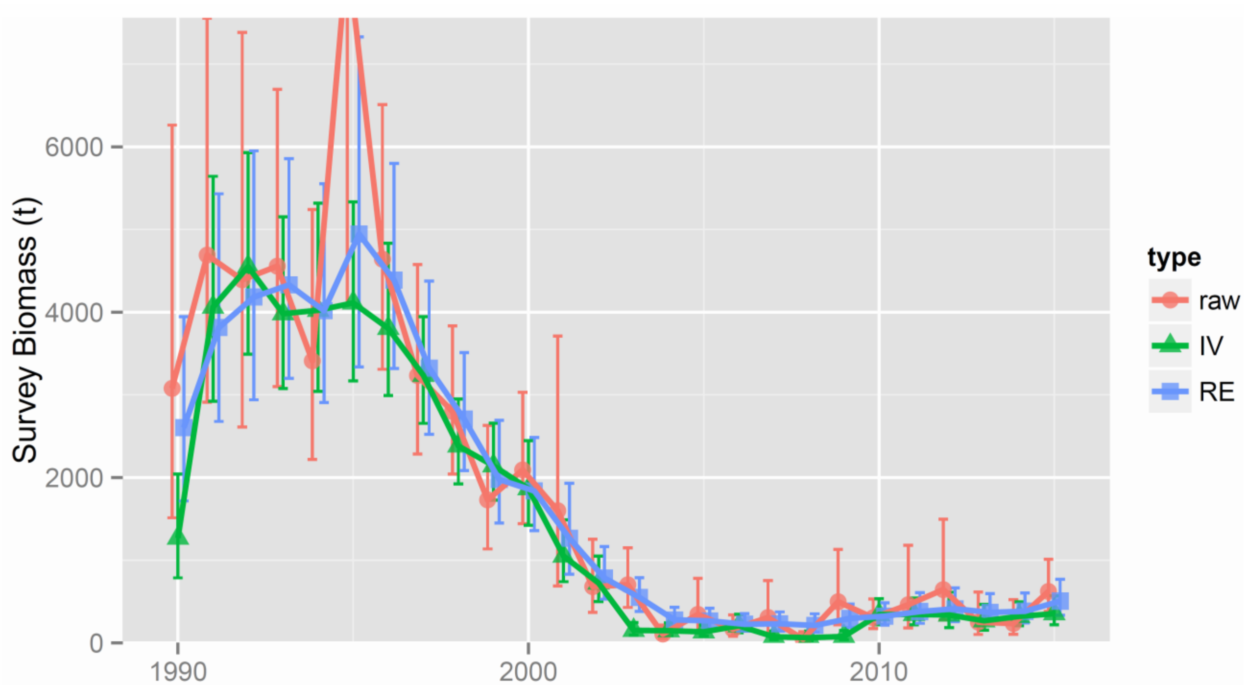


Figure 10. Time series for MMB at the time of the survey estimated from the NMFS annual EBS bottom trawl survey using the new standardization. Upper graph: 1975-2015. Lower graph: 1990-2015. Red line: "raw" time series. Green line: 3-year center-averaged smoothed series using inverse-variance (IV) weighting. Blue line: random effects (RE) model results. Error bars show 80% CIs.

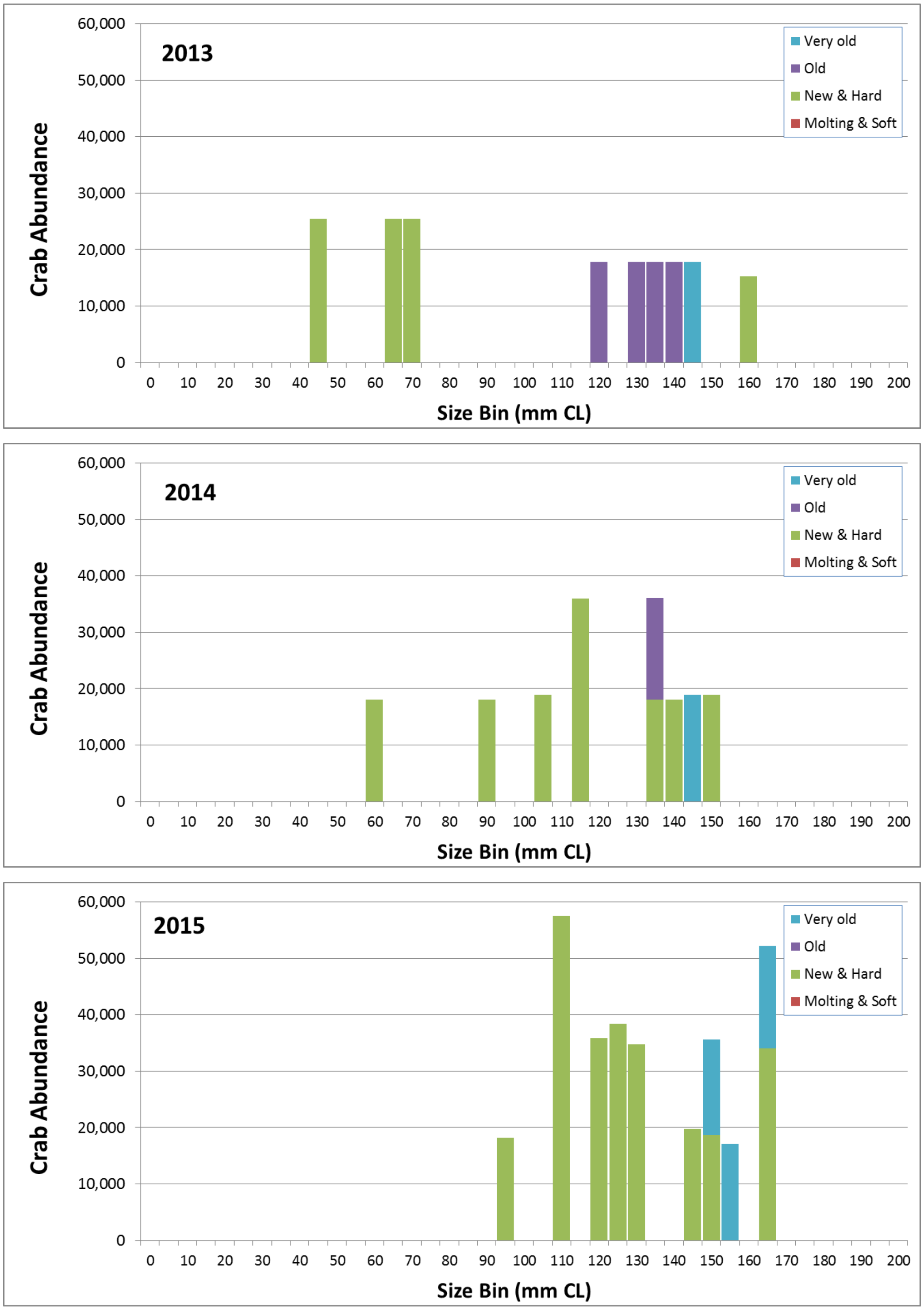


Figure 11. Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from the last 3 surveys.

old standardization new standardization

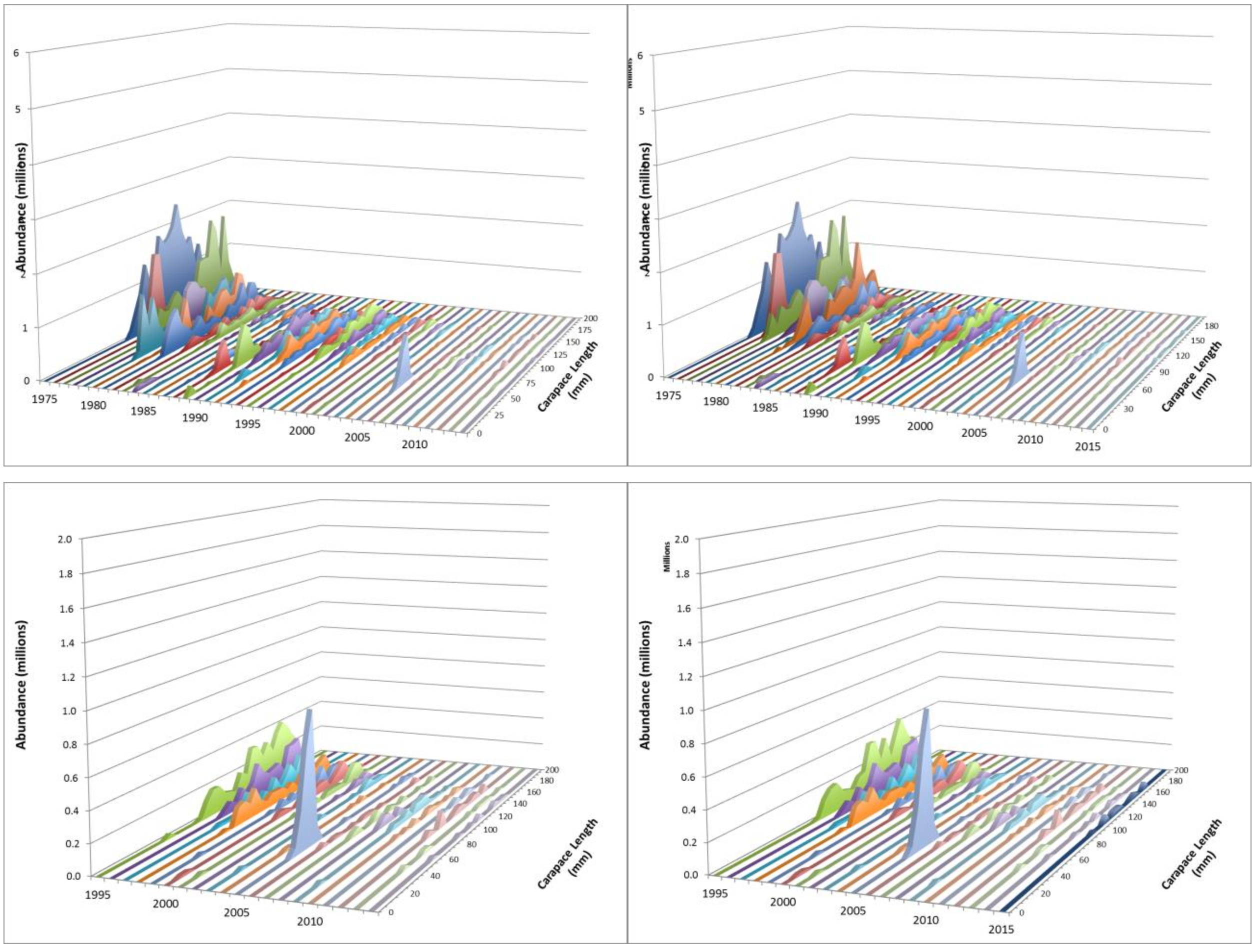


Figure 12. Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. Results using the old standardization are shown in the lefthand column for comparison with those from the new standardization. The top row shows the entire time series, the bottom shows the size compositions since 1995.

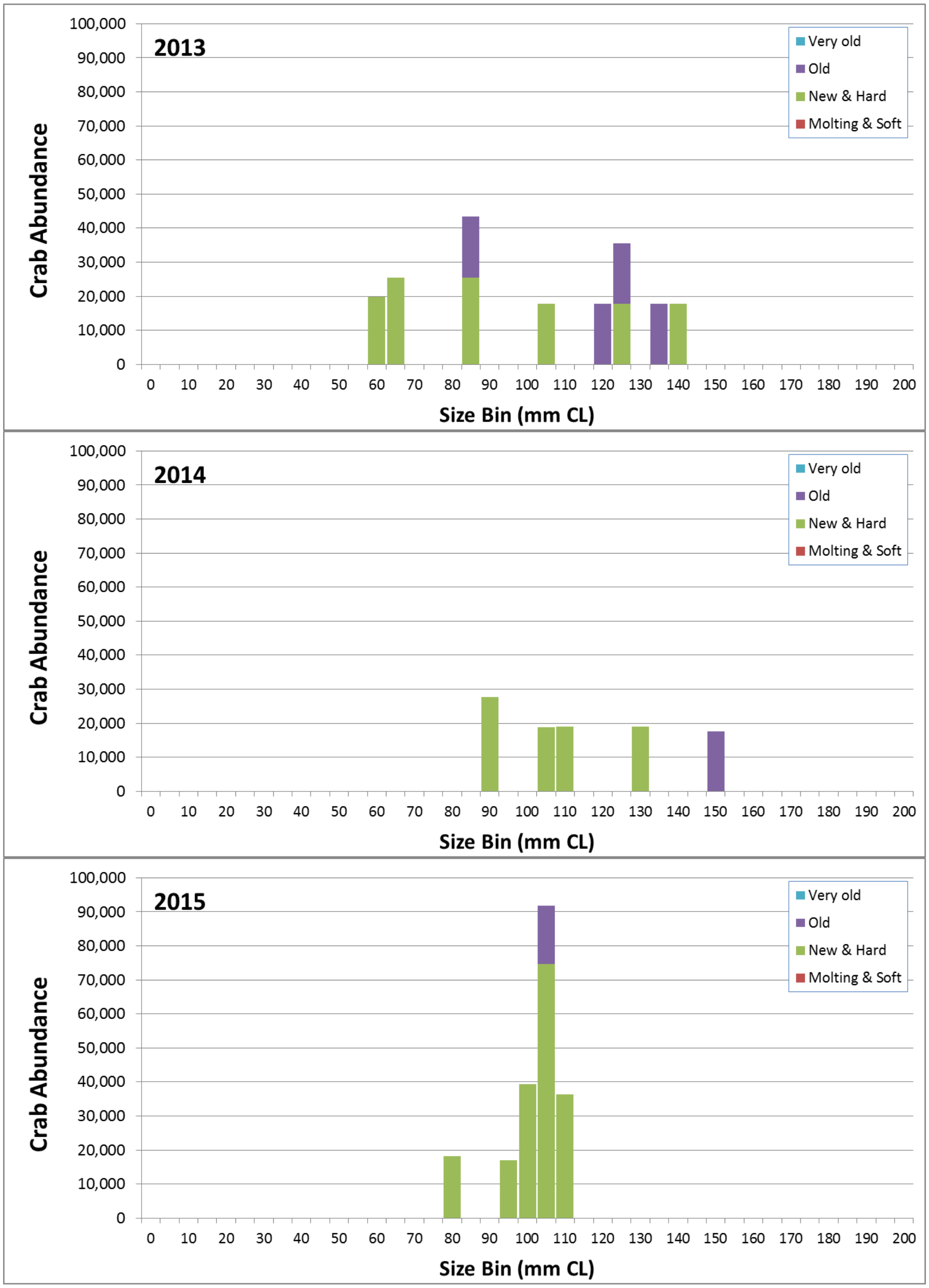


Figure 13. Size-frequencies by shell condition for female Pribilof Island blue king crab by 5 mm length bins from the last three NMFS bottom trawl surveys.

old standardization new standardization

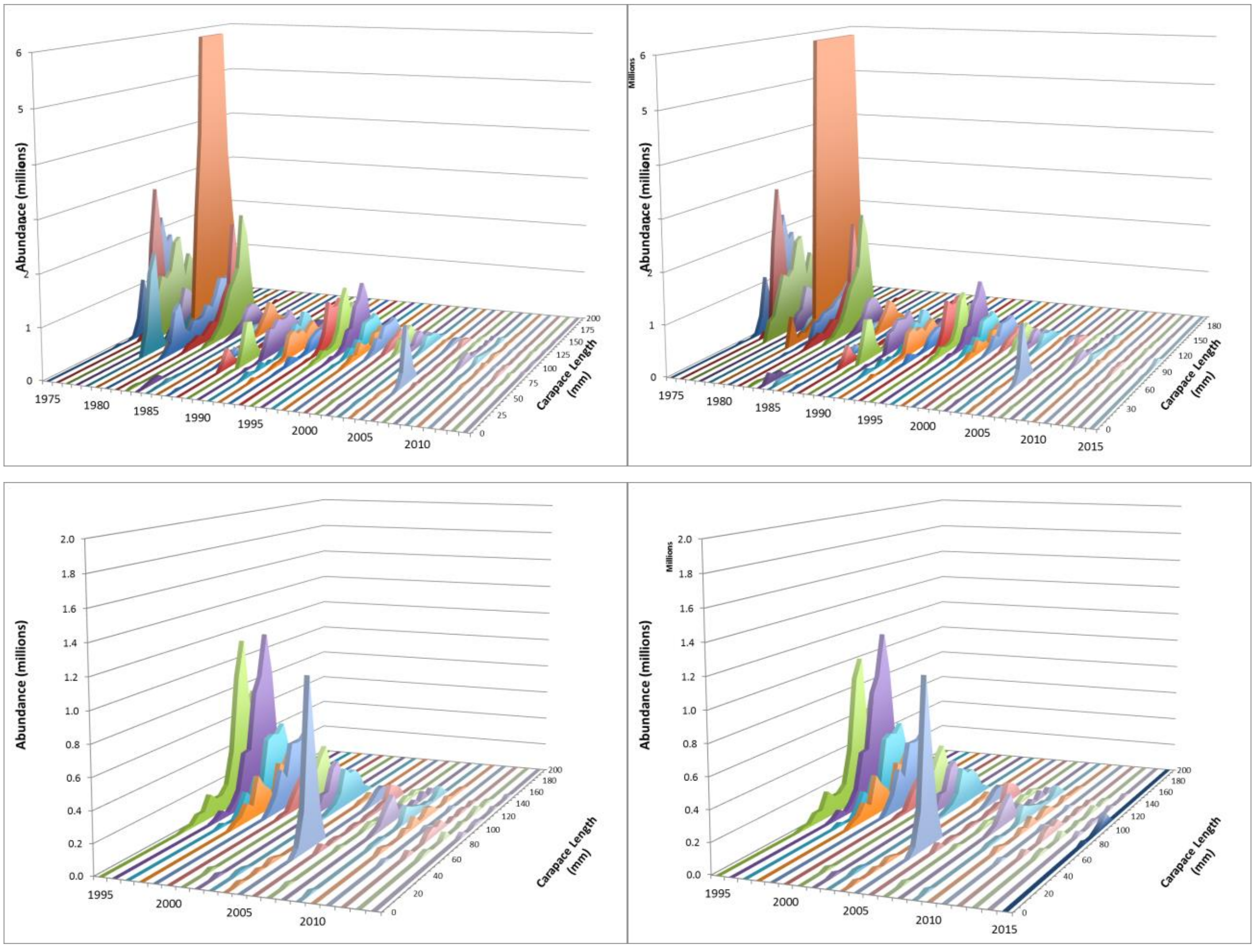
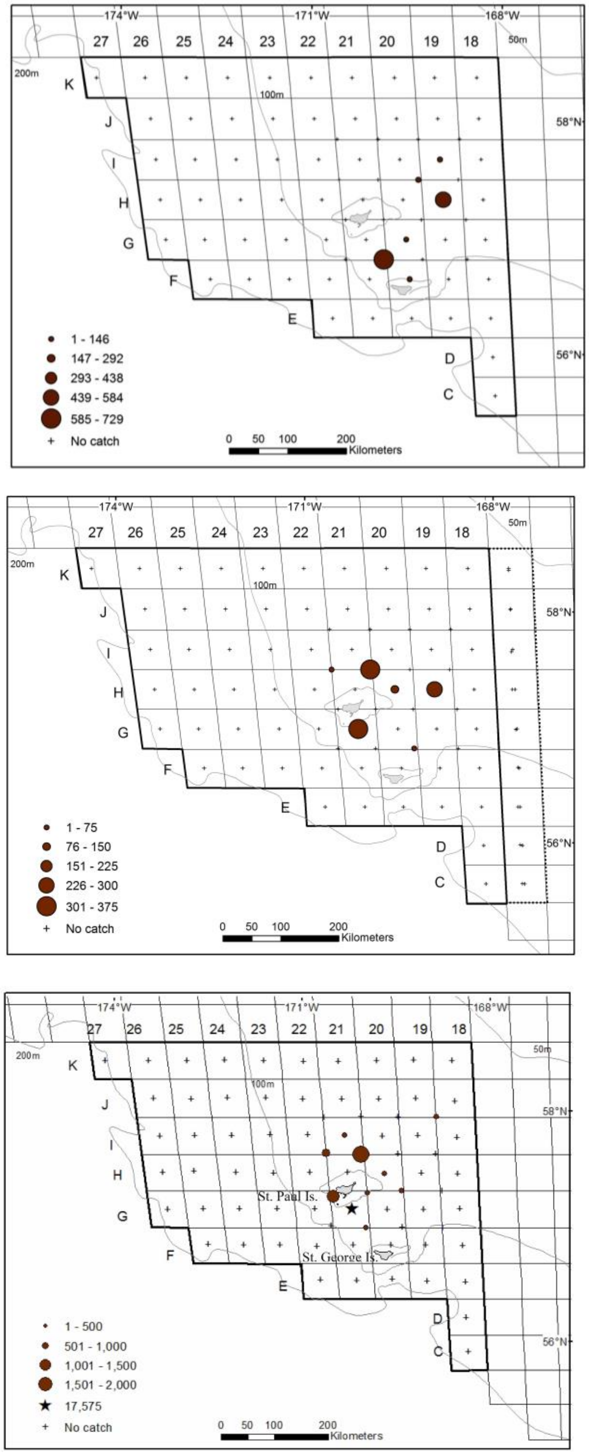


Figure 14. Size frequencies from the annual NMSF bottom trawl survey for female Pribilof Islands blue king crab by 5 mm length bins. Results using the old standardization are shown in the lefthand column for comparison with those from the new standardization. The top row shows the entire time series, the bottom shows the size compositions since 1995.

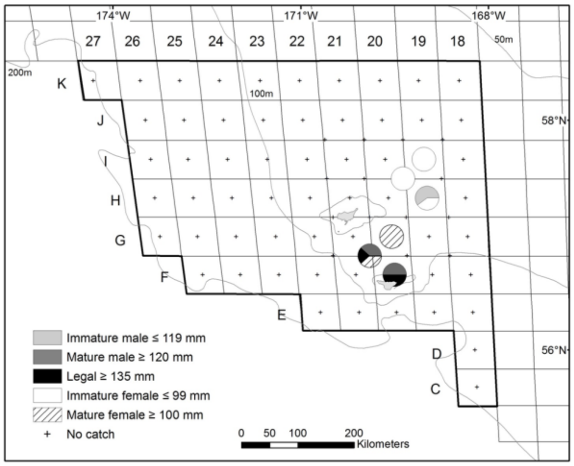


2013

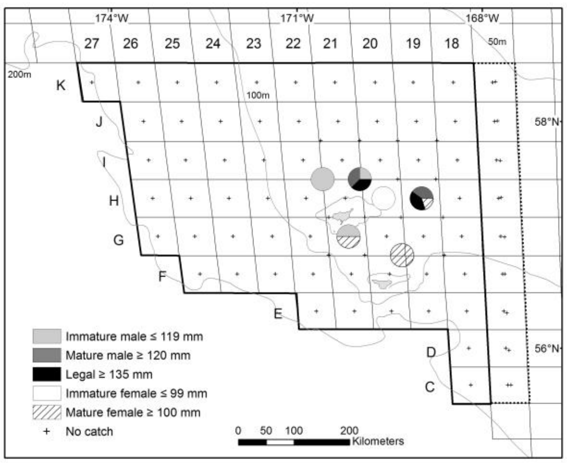
2014

2015

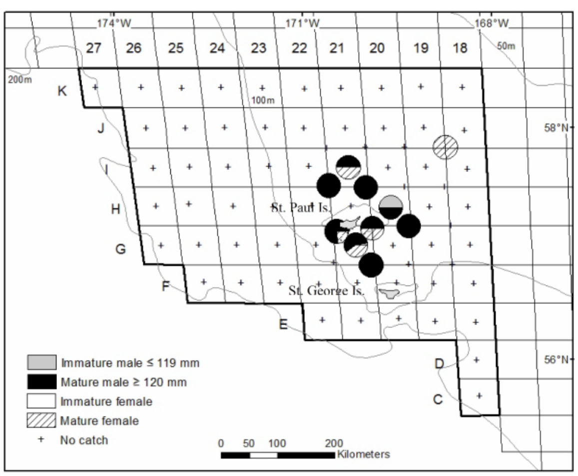
Figure 15. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2013 (upper), 2014 (center), and 2015 (lower) EBS bottom trawl surveys.



2013



2014



2015

Figure 16. Size class distribution of blue king crab in the Pribilof District during the 2013 (upper), 2014 (center), and 2015 (lower) EBS bottom trawl surveys.

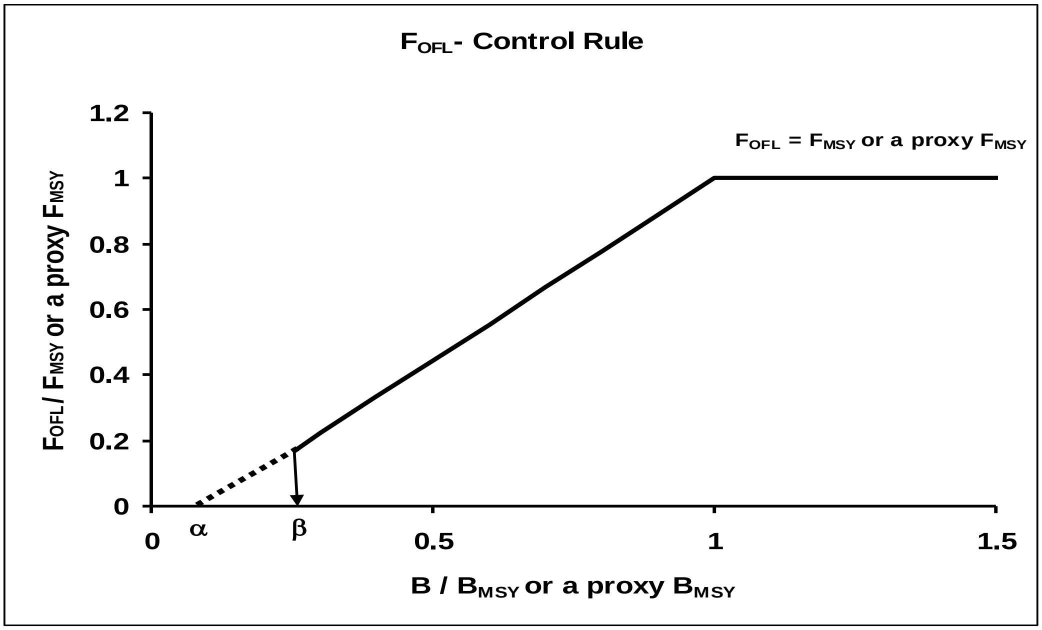


Figure 17. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Appendix A: PIBKC 2015 Status Determination and OFL Setting (using the new survey time series)

William Stockhausen

August 23, 2015

Introduction

This is an appendix to the 2015 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 and the overfishing limit (OFL) for the upcoming year using the rPIBKC R package developed by the assessment author. The rPIBKC package (source code and R package) is available under source 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 B_{MSY}, i.e. spawning stock biomass fished at maximum sustainable yield (MSY), such that the stock is overfished if $B/B_{MSY} <$ 0.5, where B is "current"" spawning stock biomass. 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.

PIBKC falls into Tier 4 for status determination and OFL setting. For Tier 4 stocks, it is not possible to determine B_{MSY} directly. Instead, average mature male biomass (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 $B_{MSY_{proxy}}$ 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. 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

In order to determine overfished status for PIBKC, one needs to determine "current" B and $B_{MSY_{proxy}}$, both of which are based on MMB.

Survey MMB

MMB at the time of the annual NMFS trawl survey is calculated from annual survey data using:

$$MMB_s = \sum_z w_z \cdot P_z \cdot n_z$$

where w_z is weight at size z (CL), P_z is the probability of maturity at size z, and n_z is survey-estimated male abundance at size z.

MMB-at-mating

MMB-at-mating (MMB_m) is calculated from survey MMB (MMB_s) by accounting for natural and fishing mortality from the time of the survey to mating. 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 is retained mortality on MMB in the directed fishery, DM is discard mortality on MMB (NOT all crab) in all fisheries, 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.
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 overall discard mortality represented by 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 ${}^{\theta}/_{p_{male}}$. 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_y}) 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.

Survey smoothing

For PIBKC, the variances associated with annual survey estimates of MMB are so large that, prior to estiamting "current" MMB-at-mating, the survey MMB time series is first smoothed in some fashion to reduce overall variability.

Inverse-variance averaging

In recent assessments, inverse-variance (IV) averaging using a centered, 3-year window has been used to smooth the survey MMB time series using:

$$< MMB_s >_y = \frac{[\sum_{-1 \le i \le 1} w_{y+i} \cdot MMB_{s_{y+i}}]}{\sum_{-1 \le i \le 1} w_{y+i}}$$

where $w_y = \frac{1}{\sigma_{s_y}^2}$ and $\sigma_{s_y}^2$ is the variance associated with MMB_{s_y}. One should note, however, that it is not possible to use a centered, 3-year averaging window to obtain a smoothed value for the "current" survey MMB because the survey subsequent to the assessment year has not been conducted yet. Instead, a non-centered 2-year window is used to obtain a smoothed estimate of "current' survey MMB.

Random effects/Kalman filter smoothing

As an alternative to IV averaging, I implemented a random effects/kalman filter (RE) model in ADMB, based on code developed by Jim Ianelli (NOAA/NMFS/AFSC). This is a statistical approach which models annual log-scale changes in "true" survey MMB as a random walk process using

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

as the state equation and

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

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

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

Averaging Results

For comparison, the raw, IV-averaged, and RE-smoothed survey MMB time series are shown in Fig.s A.1-A.3 on both arithmetic and natural log scales.

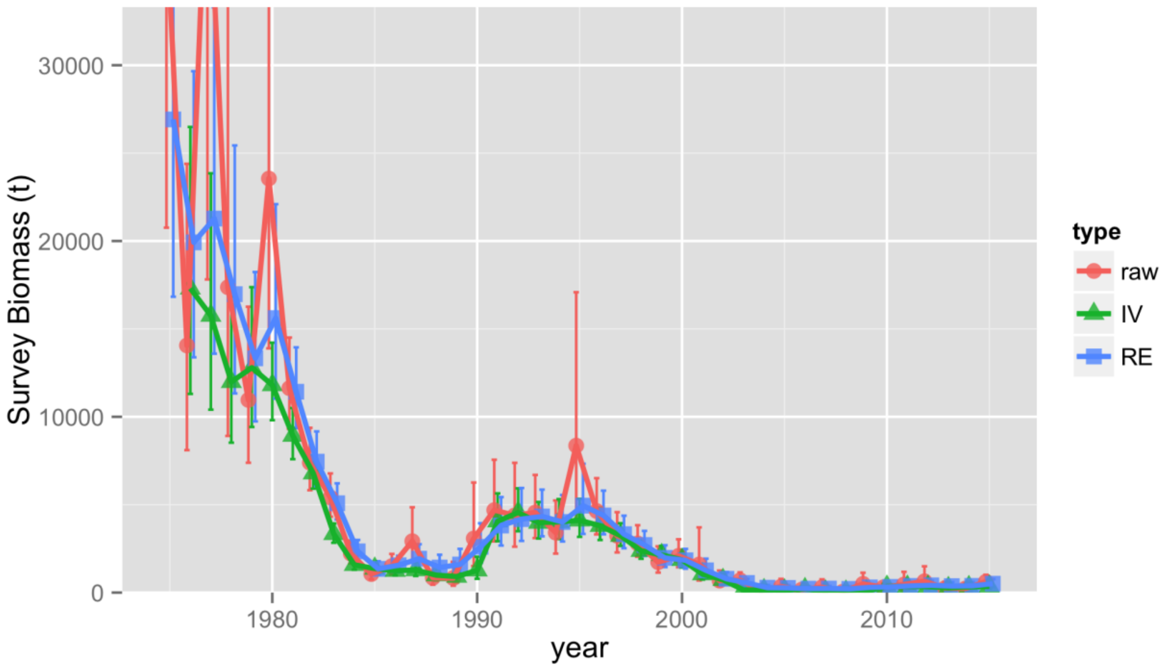


Fig. A.1. Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

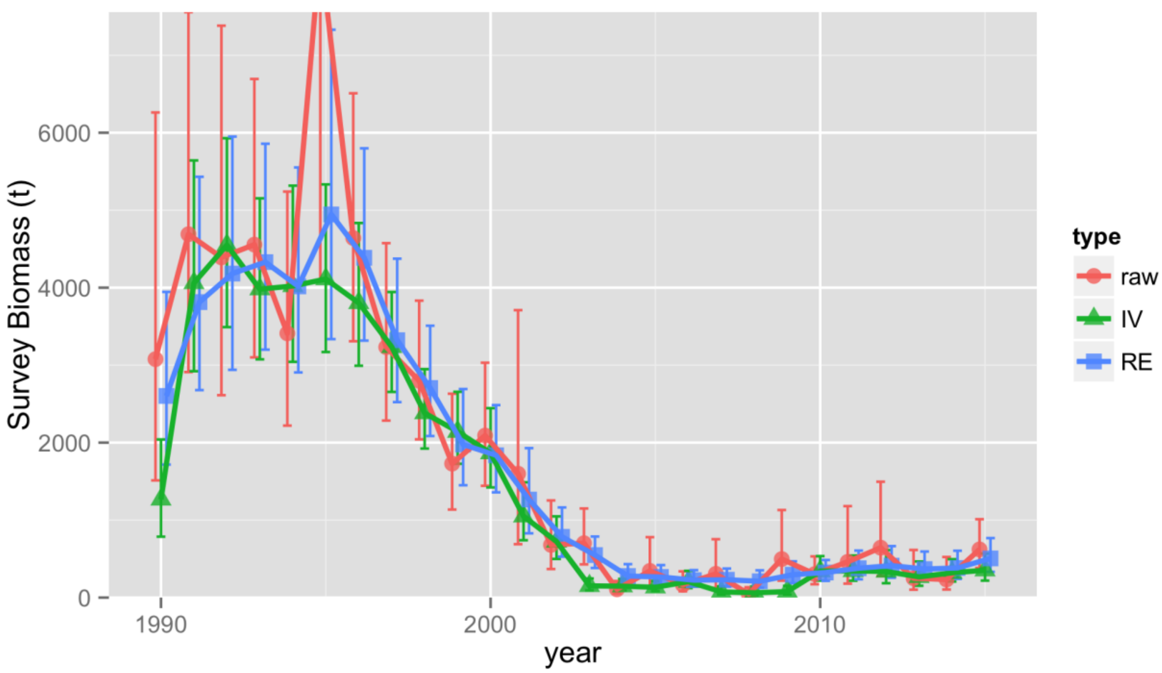


Fig. A.2. Arithmetic-scale raw and smoothed survey MMB time series, since 1990. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

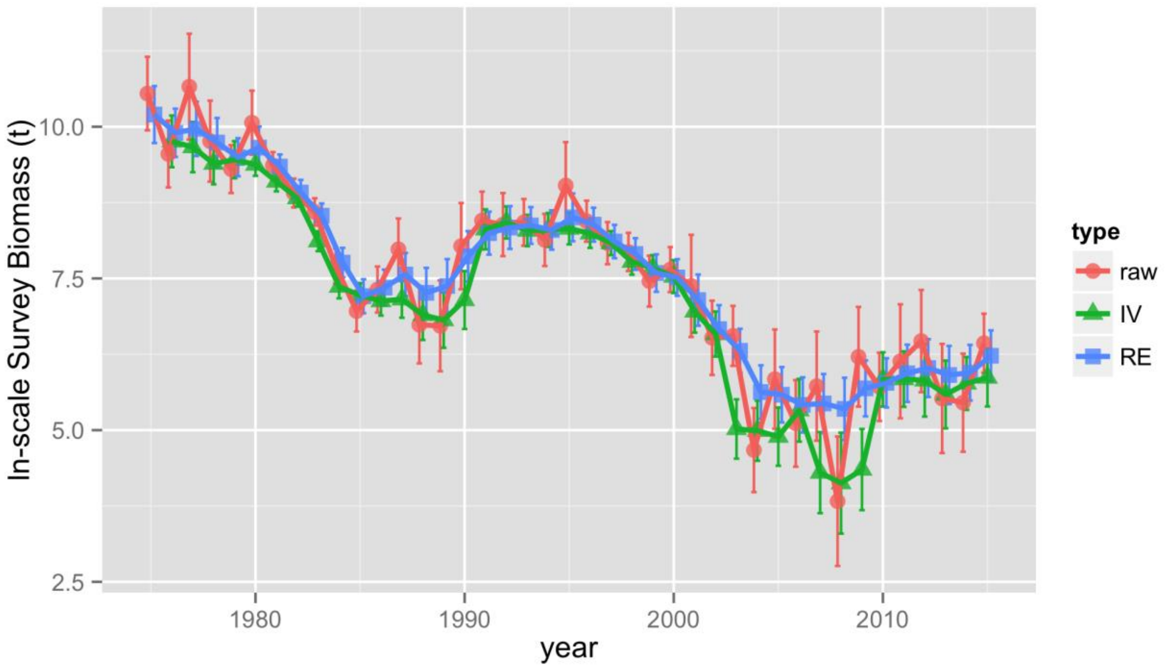


Fig. A.3. Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

Status determination and OFL calculations

Overfishing status

For PIBKC, the total fishing mortality in 2014/15 was 0.071 t while the OFL was 1.16 t. Thus, overfishing did not occur in 2014/15.

OFL calculations and overfished status

MMB-at-mating

For comparison, I calculated time series of MMB-at-mating using the raw (unsmoothed) survey MMB time series, the IV-averaged survey MMB time series, and the RE-smoothed survey MMB time series (Fig.s A.4-6).

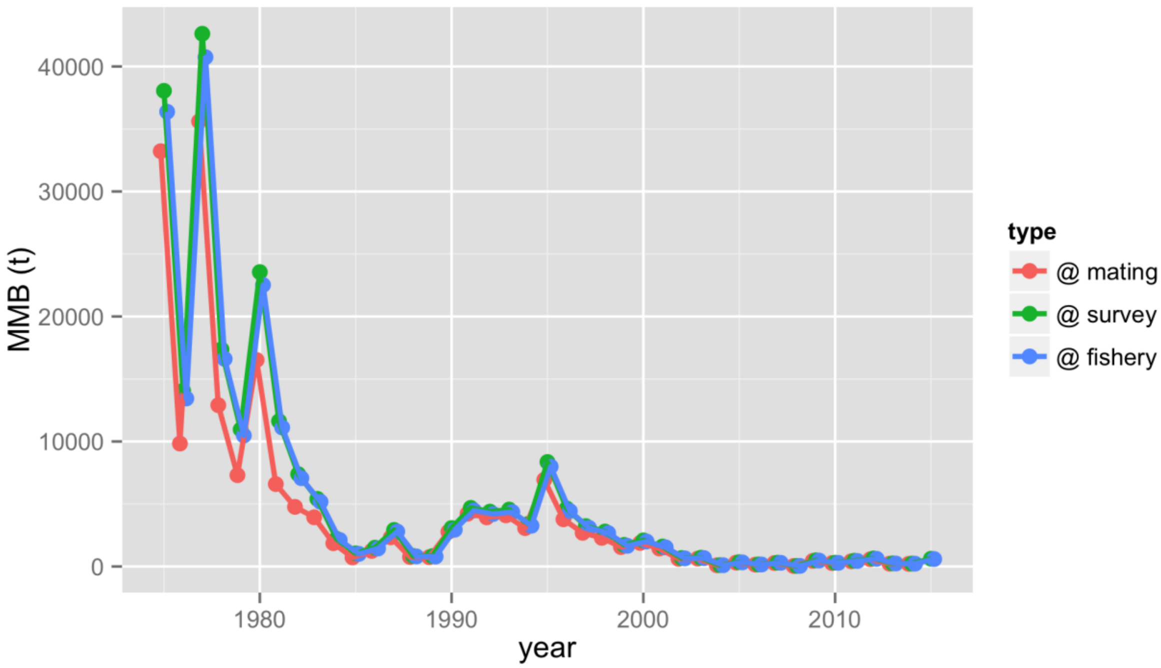


Fig. A.4. Estimated time series for MMB at the time of the survey (no smoothing), at the time of the fishery, and at the time of mating.

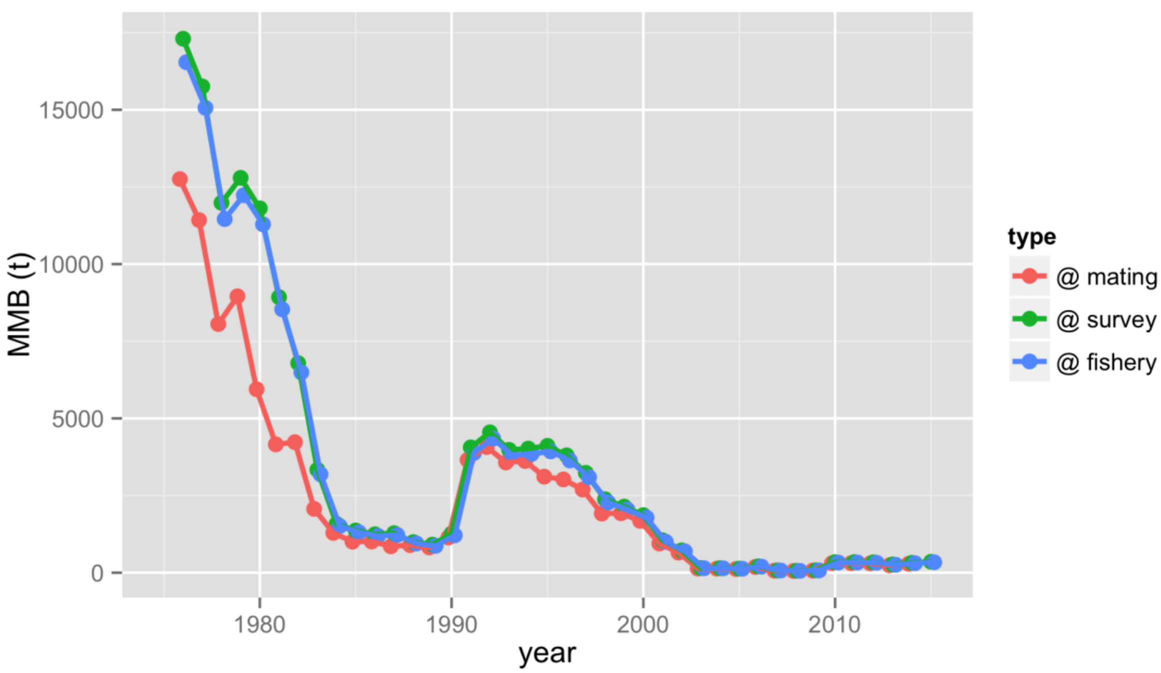


Fig. A.5. Estimated time series for MMB using IV method at the time of the survey (the inverse-averaged time series), at the time of the fishery, and at the time of mating.

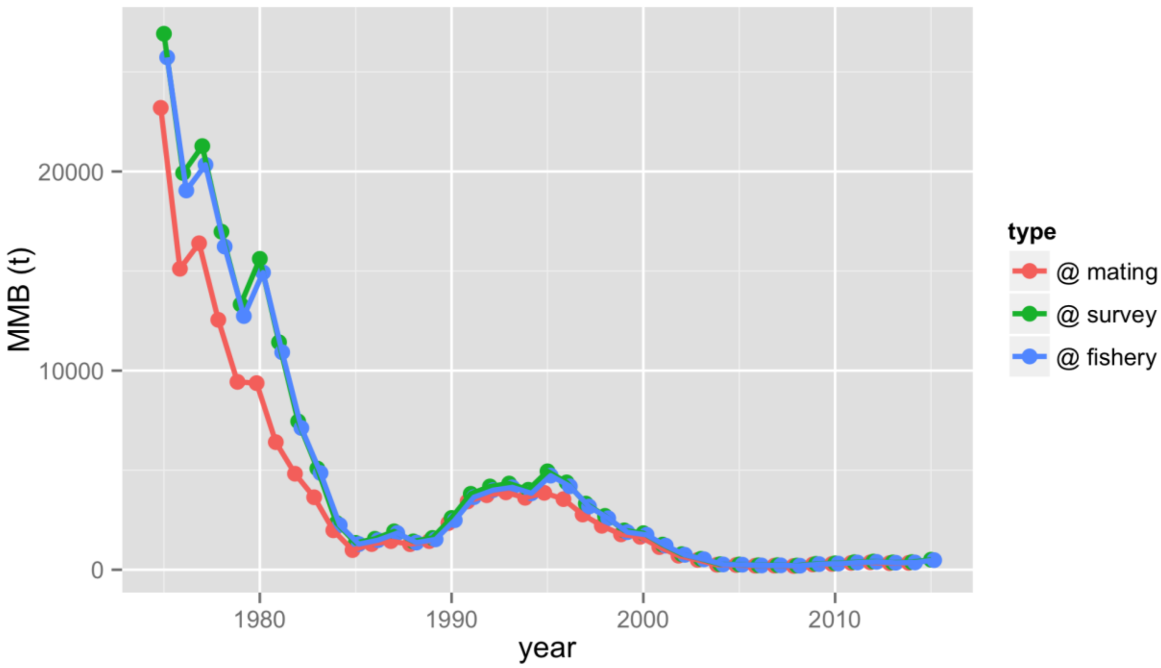


Fig. A.6. Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating.

Values for $B_{MSY_{proxy}}$, obtained by averaging estimated MMB-at-mating over the period [1980-1984,1990-1997], as well as the estimated current (2015/16) MMB at the time of the survey from the raw survey data, the IV-averaged results, and the RE-smoothed results, are:

Type	current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
Raw	621.7	5012.1
IV	352.9	3274.9
RE	505.5	4109.1

The values above for $B_{MSY_{proxy}}$ using the IV and RE methods are shown for illustration only. The $B_{MSY_{proxy}}$ used to determine overfished status and calculate the OFL is based on averaging the MMB-at-mating calculated from the raw survey MMB (i.e., 5,012.1 t).

Values for θ, used in the projected MMB calculations, representing the average value from the previous 3 years as calculated from the IV and RE methods are:

Type	θ
IV	3.7943658×10^{-4}
RE	3.0898071×10^{-4}

The results of the iterative status determination and OFL setting procedure described above, for the new NMFS EBS trawl survey standardization, are:

quantity	units	Raw	IV	RE
Projected MMB	t	missing1	317.6040582	454.940123
B_{MSY}	t	missing2	5012.1154242	5012.1154242
stock status			overfished	overfished
F_{OFL}	$year^{-1}$	missing3	0	0
RM_{OFL}	t	missing4	0	0
DM_{OFL}	t	missing5	0.2560223	0.2986122
OFL	t	missing6	0.1280111	0.1493061

Results were not calculated for the "raw" data, hence "missing" in the table above. Because the PIBKC stock is under a rebuilding plan, the OFL(s) calculated above are illustrative and will not be used for management this stock. As discussed in Section F5 of the main chapter, the OFL is based on historical average catch levels.

For comparison purposes, these procedures were also applied using survey time series calculated using the old standardization approach. The results are summarized in the following table (results were not calculated for the "raw" data, hence "missing" in the table):

quantity	units	Raw	IV	RE
Projected MMB	t	missing1	317.2714406	455.3479237
B_{MSY}	t	missing2	4002.4982102	4002.4982102
stock status			overfished	overfished
F_{OFL}	$year^{-1}$	missing3	0	0
RM_{OFL}	t	missing4	0	0
DM_{OFL}	t	missing5	0.2558485	0.2987104
OFL	t	missing6	0.1279243	0.1493552

Using the new survey standardization results in a 25% higher estimate for B_{MSY} with respect to the old standardization, while the projected MMB and OFL are quite similar (when the same survey smoothing method is used) because the old and new survey standardization methods yield almost identical results for the most recent surveys.