2021 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 has been relatively small in recent years. To date, bycatch mortality in the crab (e.g., Tanner crab, snow crab) fisheries that incidentally take PIBKC was 0 t in 2020/21; the average discard mortality over the past five years in these fisheries was 0.0066 t. Most bycatch mortality for PIBKC occurs in the BSAI groundfish fixed gear (pot and hook-and-line) fisheries (5-year average: 0.00421 t) and trawl fisheries (5-year average: 0.291 t). In 2020/21, the estimated PIBKC bycatch mortality was 0 t in the groundfish fixed gear fisheries and 0 t in the groundfish trawl fisheries. Total fishing mortality in 2020/21 was 0 t, while the 5-year average was 0.302 t.

Note, however, that fishery information regarding the current crab fishing year, which ends June 30, is incomplete at the time of this assessment.

3. *Stock biomass:* Based on 5-year running average results from the NMFS EBS Shelf Survey (the time series for PIBKC starts in 1975), stock biomass was largest in the late 1970s (73.4 t), decreased by an order of magnitude by 2000 (to 3.94 t), and decreased by another order of magnitude by 2017 (0.627 t). It continues to fluctuate at low abundances in all size classes; any short-term trends are questionable because the survey estimates exhibit large uncertainties due to the patchiness of catches.

4. *Recruitment:* Recruitment indices are not well understood for Pribilof Islands blue king crab. Pre-recruits may not be well-assessed by the survey due to their use of untrawlable habitat, but abundance in the survey has remained consistently low over at least the past 10 years.

5. *Management performance:* The stock is below MSST and consequently is overfished. Overfishing will be evaluated in September when a complete characterization of bycatch in the crab and groundfish fisheries will be available, but overfishing was not occurring as of April 8, 2021. The following results are based on determining B_{MSY} and MSST by averaging the MMB-at-mating time series based on survey biomass trends smoothed using random effects model; the current (2021/22) MMB-at-mating is also based on the smoothed survey data.

Table 1: Management performance, all units in metric tons. The OFL is a total catch OFL for each year.

year	MSST	MMB at mating	TAC	Retained catch	Total catch mortality	OFL	ABC
2017/18	2,053	230	0	0	0.33	1.16	0.87
2018/19	2,053	230	0	0	0.41	1.16	0.87
2019/20	2,049	180	0	0	0.42	1.16	0.87
2020/21	2,049	181	0	0	0.00	1.16	0.87
2021/22	–	180	–	–	–	1.16	0.87
2022/23	–	180	–	–	–	1.16	0.87

Table 2: Management performance, all units in the table are million pounds.

year	MSST	MMB at mating	TAC	Retained catch	Total catch mortality	OFL	ABC
2017/18	4.526	0.507	0	0	0.0007	0.0026	0.0019
2018/19	4.526	0.507	0	0	0.0009	0.0026	0.0019
2019/20	4.518	0.398	0	0	0.0009	0.0026	0.0019
2020/21	4.518	0.398	0	0	0.0000	0.0026	0.0019
2021/22	–	0.398	–	–	–	0.0026	0.0019
2022/23	–	0.398	–	–	–	0.0026	0.0019

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

6. *Basis for the 2021/22 OFL:* The value of B_{MSY} used to determine stock status is based on Tier 4 considerations. Here, the average estimated MMB-at-mating over a specified time period as a proxy for B_{MSY}. The annual MMB-at-mating time series is estimated using a

random effects model to reduce the inter-annual variability and large uncertainties associated with "raw" estimates of MMB at the time of the survey. Subsequently, the smoothed time series is projected forward to the time at which mating occurs (Feb. 15, by convention) while taking into account intervening natural and fishing mortality. Using this approach, the B_{MSY} proxy was determined to be 4,099 t. The estimated MMB-at-mating for 2021/22 is 180 t, projected from the random effects model-estimate of 2021 survey MMB to time of mating based on natural mortality, assumptions regarding discard mortality in 2021/22, and the F_{OFL} control rule. The ratio of MMB-at-mating for 2021/22 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 2005/06, 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 for 2021/22.

Table 3: Basis for the OFL. All units in metric tons. 'M' is the assumed rate of natural mortality.

year	Tier	MMB at mating	B/B_{MSY}	γ	Years to define B_{MSY}	M yr^{-1}	P*
2017/18	4c	230	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2018/19	4c	230	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2019/20	4c	175	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2020/21	4c	175	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2021/22	4c	180	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2022/23	4c	180	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer

Table 4: Basis for the OFL. All units in millions of lbs. 'M' is the assumed rate of natural mortality.

year	Tier	MMB at mating	B/B_{MSY}	γ	Years to define B_{MSY}	M yr^{-1}	P*
2017/18	4c	0.507	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2018/19	4c	0.507	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2019/20	4c	0.385	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2020/21	4c	0.385	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2021/22	4c	0.398	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2022/23	4c	0.398	0.04	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. *ABC:* The ABC was calculated using a 25% buffer on the OFL, as in the previous assessments since 2015. 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). Although the directed fishery is closed and non-pelagic trawl gear and Oacific cod pot gear are excluded from the Pribilof Islands Habitat Conservation Zone, the stock exhibits no progress towards the rebuilding target.

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 (PIHCZ) 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 has occurred within the PIHCZ since 2015/16.

2. Input data

Retained and discard catch time series were updated with finalized data from the crab and groundfish fisheries for 2018/19 and 2019/20, and with estimates of catch in 2020/21 (data for the latter is incomplete at the time of the assessment in May). Abundance and biomass for PIBKC in the annual summer NMFS EBS bottom trawl survey were added for the 2019 NMFS EBS Shelf Survey. The survey was not conducted in 2020 due to concerns related to the COVID-19 global pandemic. At the time of this assessment, the survey in 2021 had not yet been conducted.

3. Assessment methodology

With the 2017 assessment, PIBKC was moved to a triennial schedule for full assessments following stock prioritization (CPT, 2017). Thus, only a partial assessment was conducted in 2018 (Stockhausen, 2018). However, the NMFS Alaska Regional Office noted that there was a biennial requirement to review the rebuilding status for PIBKC and that it was sensible to have the assessment and report on the same biennial basis. Consequently, the 2019 assessment was a full assessment, as is this (2021) assessment. In addition, the timing for the 2019 full assessment (and subsequent ones) was changed from September to May. This change in timing requires the use of several estimates for quantities used in the assessment model. These include survey MMB in the year of the assessment, as well as retained catch and bycatch quantities in the fishery year prior to the assessment. The NMFS EBS Shelf Survey is typically conducted on an annual basis in June-August, so biomass estimates from the survey in the year of the assessment are no longer available for the assessment, and a value projected by the random effects model used to smooth survey MMB is used as a substitute to calculate MMB-at-mating for the assessment year. As a further complication this year, the 2020 NMFS EBS Shelf Survey was not conducted due to the COVID-19 global pandemic, so the most recent survey data available is from the 2019 NMFS EBS Shelf Survey. Additionally, because the crab fishery year runs (by convention) from July 1 to June 30, estimates of retained catch in the directed fishery and bycatch in the directed and other crab and groundfish fisheries are incomplete at the time of the May assessment. For 2021, the directed fishery was closed and thus there will be no retained catch or bycatch in the directed fishery for 2020/21. As of April 8, 2021, no PIBKC bycatch in the Tanner crab, snow crab, and groundfish fisheries had occurred (based on in-season bycatch records available at that time; snow and Tanner crab: Ben Daly, ADFG, pers. comm.; groundfish fisheries: AKFIN Answers databases). In the 2019 assessment, the values for bycatch obtained prior to the May assessment were used as estimates for the current year-end values to determine MMB-at-mating for the current crab year. This approach was also followed this year, although these values are likely underestimates of the final values. However, given the overall small scale of bycatch in recent years, this approximation is likely to have no effect on the determination of “overfished”" status while the determination of “overfishing” will be revisited by the NPFMC Crab Plan Team and Science and Statistical Committee in September with the end-of-year bycatch numbers for 2020/21.

Otherwise, the methodology is the same as in the 2019 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 in 2015 and used in subsequent assessments (Stockhausen, 2015, 2016, 2017, 2019).

4. Assessment results

Total catch mortality in 2020/21 was 0 t, which did not exceed the OFL (1.16 t). Consequently, overfishing did not occur in 2020/21 (this will be updated in September with a year-end bycatch report). The projected MMB-at-mating for 2021/22 (180 t) decreased slightly from that in 2020/21 (181 t), but remained well below the MSST (2,049 t). Consequently, the stock remains overfished and a directed fishery is prohibited in 2021/22. The OFL, based on average catch, and ABC are identical to last year’s values (1.16 t and 0.87 t, respectively).

B. Responses to SSC and CPT Comments

CPT comments May 2019: *Specific remarks pertinent to this assessment*

Remark: Incorporate information regarding the model used for status determination criteria (now in Appendix C of the document) into the main assessment document.

Response: This information is now incorporated into the main assessment document.

Remark: Include the parameter table in the main assessment document.

Response: The parameter table (Table 25) has now been included in the main assessment document.

Remark: Include an evaluation of progress towards rebuilding.

Response: The status of rebuilding is discussed in Section H. The only source of evidence towards rebuilding for this stock is the NMFS EBS Shelf Survey. This was last conducted in 2019. Based on the lack of a trend in recent MMB, as well as the absence of any recruitment signal in recent survey size compositions, there is no evidence for progress toward rebuilding.

SSC comments June 2019: *Specific remarks pertinent to this assessment Remark*: The SSC noted that the document was very large (in storage) and the authors should consider switching from vector graphics to raster graphics. In addition, much of the critical data and figures are repeated from the main documents into the appendices multiple times. The SSC appreciates the authors’ use of RMarkdown, but would like to see the appendices integrated into the main SAFE for the next full assessment.

Response: The appendices have been incorporated into the main assessment document. The duplication of tables and figures has been eliminated. The size of the complete document (i.e., including the original appendices) has been reduced from ~ 390 MB to ~90 MB. This was not a trivial nor quick exercise. Making major modifications to RMarkdown documents that include results, tables, and figures can (and did) involve a lot more work than simply cutting and pasting text, tables, and figures in a Word document–it can (and did) involve creating an entirely new workflow, although many elements of that workflow were available in one form or another from the previous approach using Appendices. That said, the workflow that has been developed should simplify making changes in the future.

Remark: The SSC also encourages that the stock structure template used for groundfish be considered for either PIBKC specifically or blue king crab in general within the next 2 years.

Response: The author has begun to address this request, and anticipates a draft version will be available for review by the CPT and SSC in September.

CPT comments September 2019: *No specific remarks pertinent to this assessment*

SSC comments October 2019: *No specific remarks pertinent to this assessment*

CPT comments May 2020: *No specific remarks pertinent to this assessment*

SSC comments June 2020: *No specific remarks pertinent to this assessment*

CPT comments September 2020: *No specific remarks pertinent to this assessment*

SSC comments October 2020: *No specific remarks pertinent to this assessment*

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).

3. Stock structure

Stock structure of blue king crab in the North Pacific is largely unknown. Stoutamore (2014) found significant genetic divergence between all sites comparing genetic samples collected from sites in Southeast Alaska, the Pribilof Islands, St. Matthew Island, Little Diomede, Chaunskaya Bay, Shelikhov Gulf, and the western Bering Sea, with Southeast Alaska exhibiting the highest divergence from the other sites. Allele frequencies from the Pribilofs and St. Matthew (and Little Diomede) grouped together more closely than with other sites based on Principal Components Analysis. Temporal changes were significant between samples collected in the Pribilofs and at St. Matthew in the early 1990s and ones collected 2006-2011, although there was no evidence these changes were due to recent population bottlenecks. Stoutamore (2014) suggested that this apparent genetic drift could be a consequence of the large decreases in abundance at these locations since the early 1980s.

The potential for species interactions between blue king crab and red king crab as a cause 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 stations (between 1 and 7) where the species co-occurred in the Pribilof Islands District. Spatially, the stations with co-occurrence were broadly distributed around the Pribilof Islands. In the 1990's, the red king crab population increased substantially as the blue king crab population 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—suggesting 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 population 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 were 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).

During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab (PIBKC) were managed by ADFG under the Bering Sea king crab Registration Area Q Pribilof District (ADF&G 2008; Figure 2). In the Pribilof District, blue king crab occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987). For assessment purposes, the Pribilof District is defined in Figure 2, with the addition of a 20 nm mile strip to the east of the District (bounded by the dotted red line in Figure 2), is considered to define the stock boundary for PIBKC.

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. Stoutamore (2014) found no genetic evidence to support an hypothesis for two genetically-distinct strains extruding and hatching eggs on alternate years. 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). Stoutamore (2014) found strong genetic evidence for a single-paternity mating system.

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 benthic 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 originally adopted in the federal crab fishery management plan for the BSAI areas (Siddeek et al. 2002). This was subsequently revised and a rate of 0.18 yr^{-1} is currently used for PIBKC.

5. Management history

The blue king crab stock in the Pribilof District is currently overfished and the directed fishery has been closed since 1999/2000 (Bowers et al. 2011; NPFMC 2014a; Stockhausen 2019). Bottom trawl gear and pot fishing for Pacific cod are currently excluded from the Pribilof Islands Habitat Conservation Zone (PIHCZ, Figure 3) to minimze bycatch of PIBKC in the groundfish fisheries. Fishing for Tanner crab and snow crab is also prohibited within annual area closures implemented by ADFG that generally incorporate the PIHCZ.

The blue king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (Table 10; Figure 4). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season (Table 10; Figure 4), with an associated increase in effort to 110 vessels (ADFG 2008). The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990; ADFG 2008). The fishery was male only, and legal size was >165 mm carapace width (NPFMC 1994). Guideline harvest levels (GHL) were 10 percent of the estmiated abundance of mature males or 20 percent of the estimated number of legal males (ADFG 2006).

PIBKC occasionally occur 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 (Tables 11). In addition, blue king crab are taken as bycatch in groundfish fisheries by both fixed and trawl gear, primarily those targeting Pacific cod, flathead sole and yellowfin sole (Tables 12-15).

Amendment 21a to the BSAI Groundfish FMP prohibits the use of non-pelagic trawl gear in the Pribilof Islands Habitat Conservation Area (subsequently renamed the Pribilof Islands Habitat Conservation Zone in Amendment 43; Figure 3), 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 bottom contact 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 (Figure 3) 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 ($>$ 50 years), 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 2020/21 from ADFG data (no retained catch, no bycatch mortality; Tables 10 and 11). The time series of discards in the groundfish pot and trawl fisheries (Tables 12) were updated for 2009/10 -2020/21 using NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (accessed on April 8, 2021). Results from the 2019 NMFS EBS bottom trawl survey were added to the assessment (Tables 17-24).

2. Fishery data

2.a. Retained catch

The directed fishery has been closed since 1999/2000. Historical retention data (including deadloss; Table 10, Figure 4) were obtained from Bowers et al. (2011). Retained catch data start in 1973, reaching a maximum of 4,976 t in 1980/1981 before dropping precipitously. 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 the directed fishery has been set at zero since 1999/2000; there will be no retained catch in the 2020/21 crab fishing season.

2.b. Bycatch and discards:

Crab pot fisheries

Estimated annual bycatch data on PIBKC in the crab fisheries is provided by ADFG for sublegal males ($<$ 138 mm CL), legal males ($\geq$ 138 mm CL), and females based on data collected by onboard observers in the snow crab and Tanner crab fisheries (aggregated across fisheries in Table 11 and Figure 4). 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 time period (males: $\alpha = 0.000508$, $\beta = 3.106409$; females: $\alpha = 0.02065$, $\beta = 2.27$; Daly et al. 2014). Average weights ($\overline{W}$) for each category were calculated using the following equation:

$$\overline{W} = \frac{\sum w_z \cdot n_z}{\sum n_z} \tag{2}$$

where w_z is crab weight-at-size z (i.e., carapace length) using Equation 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 (numbers/observed pot) based on observer data, and total effort (pot lifts) in each crab fishery.

Historical discard catch data are available from 1996/97 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 11), although data may be incomplete for some of these fisheries. Prior to 1998/99, limited observer data exists (only for catcher-processor vessels), so discarded catch before this date is not included here. For this assessment, a 20% handling mortality rate was applied to the bycatch estimates to calculate discard mortality on PIBKC in these pot fisheries (Table 11; Figure 5). In assessments prior to 2017, a handling mortality rate of 50% was applied to bycatch in the pot fisheries. The revised value used here is now consistent with the rates used in other king crab assessments (e.g., Zheng et al., 2016).

As of March 31, 2021, no bycatch mortality in the crab fisheries had been oserved.

Groundfish fisheries

The AKRO estimates of PIBKC bycatch in all groundfish fisheries in 2020/21, as available through the AKFIN database (accessed April 8, 2021), are included in this report (Tables 12-15, Figures 5-6). Updated estimates for 2009/10-2020/21 were obtained through the AKFIN database.

Bycatch data in the groundfish fisheries are available for PIBKC from 1997/98 to present. Between 1997 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 from those used for the “blend.” Starting in January 2008, the groundfish observer program changed the method in which they speciate crab to better reflect their hierarchical 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 using the CAS was at the NMFS statistical area. Beginning in January 2009, ADFG 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. These “Catch-in-Areas” (CIA) bycatch estimates (2009-present) 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). In 2019, the algorithm used by AKFIN to expand observer data was changed from one based on retained groundfish catch weight to the one currently used by AKRO, which is based on total groundfish catch weight. This was applied retroactively to data from calendar year 2017 forward, affecting estimates for crab starting in crab year 2016. As of April 8, 2021, no bycatch of PIBKC had been reported in the groundfish fisheries during 2020/21.

To assess crab mortality in the groundfish fisheries, a 80% discard mortality rate was applied to estimates of bycatch in fisheries using trawl gear while a 20% discard mortality rate was applied to fisheries using fixed gear (pots or hook and line gear; Tables 12 and 15; Figure 5). Since 2009/10, the maximum annual bycatch of PIBKC in the groundfish fisheries was 1.55 t in 2015/16, while the maximum total discard mortality was 0.795 t in 2015/16. In contrast, the average annual bycatch over the past 5 years was 0.4 t, while the average discard mortality was 0.256 t. In general, trawl gear takes more PIBKC than fixed gear, and with higher mortality, although exceptions are fairly common (e.g., 2011/12, 2013/14, 2015/16).

PIBKC is primarily taken as bycatch in fisheries targeting flathead sole, yellowfin sole, northern rock sole, and Pacific cod (Tables 13-15; Figure 6). Although the Pacific cod fishery accounted for the highest bycatch of PIBKC (in 2016) across the time series, it generally ranks below the other fisheries as a source of mortality because its bycatch occurs primarily with fixed gear.

Bycatch taken by fixed gear is typically dispersed along the shelf edge (Figures 7 and 8), although it was concentrated within and near the Habitat Conservation Zone in 2015/16. In contrast, bycatch taken with trawl gear tends to be concentrated along and to the northeast of the eastern boundary of the Habitat Conservation Zone (non-pelagic trawl gear is excluded from the Zone; Figures 9 and 10), although 2012 was an exception in which bycatch was concentrated along the western edge of the Zone.

2.c. Catch-at-length

Not applicable.

3. Survey data

Time series of annual estimates of area-swept abundance and biomass, as well as size composition data, are available for PIBKC from the summer NMFS EBS Shelf Bottom Trawl Survey based on the stock area first defined in the 2013 assessment (Foy, 2013), which includes the Pribilof District and a 20 nm strip adjacent to the eastern edge of the District (Figure 2). The adjacent area was defined as a result of the 2015 rebuilding plan and the concern that crab outside the Pribilof District were not being accounted for in the assessment. The survey has been conducted annually since 1975, with the exception of 2020. In 2020, the survey was not conducted due to issues associated with the global COVID-19 pandemic.

The standardized EBS bottom trawl survey is based on a systematic design with a fixed sampling station at the center of each 37.04 × 37.04 km (20 × 20 nautical mile) grid square (Lauth and Nichol, 2013). In the area surrounding the Pribilof Islands, high-density "corner stations" are sampled to better assess local blue king crab concentrations (Figure 11). Since 1982, the survey has used standard 83-112 Eastern otter trawls, which have 25.3-m (83 ft) headropes and 34.1-m (112 ft) footropes, to sample crab and groundfish species at 77 stations within the Pribilof District, augmented by a column of 9 stations to the east of the District (indicated by the dashed red line in Figure 2) to better encompass the stock limits. The standard tow is nominally 30 minutes on bottom at a tow speed of 3 knots (~1.5 nmi distance), but net mensuration gear is used to more accurately assess time and distance "on bottom" as well as net width to provide a precise estimate of area swept. The net mensuration gear also allows the collection of depth and temperature data.

Details of the NMFS bottom trawl protocols established by the National Oceanic and Atmospheric Administration can be found in Stauffer (2004).

For each tow, all crab were removed from the catch, sorted by species and sex, and a total catch weight was obtained for each species (Zacher et al., 2020). All blue king crab were sampled for biological characteristics, including sex, carapace length (to 0.1 mm), weight, shell condition, and egg color, egg condition, and clutch size for females. Male crab were characterized as immature, mature, sublegal, and legal based on the size categories in Table 16. Females were characterized as immature or mature based on abdominal flap morphology and egg presence (Zacher et al., 2020).

Biomass estimates were calculated using the number of individual male and female crab at each 1 mm size category, using weight-size relationships developed by the AFSC's Kodiak Laboratory (the same as those applied to fishery data, Equation 1; Zacher et al., 2020). Weights were calculated for each 1 mm size bin and summed within the legal male, sublegal male, mature, and immature size categories for each sex caught at a station. Total biomass was estimated by averaging crab density (biomass /area swept) from all stations within the augmented District, and multiplying by its total area (Zacher et al., 2020).

45 stations were included in survey strata for PIBKC in 1975, increasing to 86 by 1983 and remaining essentially constant since then (Tables 2 and 3). In the early 1980s, males were found at up to 38 of these stations and females were found at up to 24. This decreased in the 1990s when males occurred in a maximum of 22 stations, with females occurring at a maximum of 15 stations. Since 2010, the maximum number of stations at which males were caught is 9, with a median of 5, while females were caught at a maximum of 8 stations, with a median of 4. In similar fashion, the number of males caught declined from a maximum of 858 in 1975 to a since-2010 maximum of 22; for females, the corresponding numbers are 343 (in 1981) and 24. In most years, more mature crab were caught than immature, although there were exceptions to this (e.g., 1989 for both sexes). In 2019, a total of 11 males and 11 females were caught at 6 and 2 stations, respectively, all in the high-density sampling area (Tables 17 and 18).

Annual survey abundance and biomass for PIBKC have declined precipitously over the course of the 45 year time series (Tables 19-24 and Figures 12-15). On decadal scales, mean survey abundance and biomass have declined for males from 13.1 million crab and 29.5 thousands t in the 1970s to 0.224 million crab and 0.402 thousands t in the 2010s. Similarly, mean survey abundance and biomass have declined for females from 8.86 million crab and 8.08 thousands t in the 1970s to 0.255 million crab and 0.23 thousands t in the 2010s. Dampened oscillations in survey abundance and biomass have occurred on roughly decadal scales for this stock, with maxima exhibited at the start of the time series for males, followed by a decline to low values in the mid-to-late 1980s, an increase to a relative maximum in the early 1990's, followed by a decline to consistent low values since 1999 (a "blip" with large confidence intervals in 2005 being the exception). Females show a similar pattern, but lagged perhaps 5 years or so (without a large "blip" in 2005). In 2019, apparent increases observed in mature and legal male biomass estimates relative to 2018 were attributed primarily to an abbreviated, but "still valid", tow which may have had the effect of artificially increasing the CPUE calculated for the affected station (Zacher et al., 2020).

One feature that characterizes survey-based estimates of abundance and biomass for PIBKC is the large uncertainty (cv's on the order of 0.5-1) associated with the estimates, which complicates the interpretation of sometimes large interannual swings in estimates of abundance (Tables 21 and 22, Figures 12-13) and biomass ((Tables 23 and 24, Figures 14-15). 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. Following a general decline to a low-point in 1985 (~500,000 males), abundance increased by a factor of 10 in the early 1990s, 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 trends similar to those in abundance.

Size frequencies across the entire time series are shown by sex in Figures 16-18. Based on patterns for crab > 50 mm CL, a single recruitment event starting in 1988 is evident in 17, with a second possible event starting in 2005. However, these plots provide little evidence of recent recruitment.

The small numbers of crab caught in recent surveys make it difficult to draw firm conclusions regarding spatial patterns (Figures 19 and 20). That said, 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.

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. For Tier 4 stocks, it is not possible to determine B_{MSY} and MSST directly. Instead, time-averaged 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} such that the stock is fluctuating around B_{MSY}. However, MMB-at-mating (by convention, MMB on Feb 15) is not directly observed. Instead, estimates of MMB at the time of the NMFS EBS Shelf Survey are available, as are estimates of natural mortality (M), and mortality due to fishing (retained catch mortality, RM and discard catch mortality, MD). The current modeling approach uses M for king crab (0.18), and annual estimates of RM and DM to project estimates of MMB at the time of the survey (July 1, by convention) forward to the time of mating.

Because the interannual variability associated with the annual survey biomass estimates is extremely large, different approaches have been used to provide a "smoothed" version of MMB at the time of the survey from which to project forward to estimate MMB-at-mating. In the 2013 and 2014 assessments (Foy 2013; Stockhausen 2014), inverse-variance (IV) averaging was used to smooth the annual survey biomass estimates. In the 2015 assessment (Stockhausen, 2015), an alternative approach to smoothing based on a random effects (RE) model was presented and subsequently adopted by the CPT and SSC to use in estimating B_{MSY}. One advantage to the RE approach over the IV approach is that it provides an estimate of process error in the MMB time series. Other advantages are that it can handle missing data and it can project uncertainty forward in a consistent fashion. The RE model is used in this assessment to obtain smooth "raw" estimates of annual survey MMB prior to calculating MMB-at-mating.

Since the 2017 assessment, assessments for PIBKC have been moved to an odd-year biennial schedule. The timing of the assessment was also moved from September to May, which has required that several data inputs to the model (assessment year MMB at the time of the survey and retained catch and bycatch values from the crab fishery year prior to the assessment year) be estimated in some fashion. MMB at the time of the survey (July 1) in the year of the assessment can ordinarily be estimated from the observed time series using the RE model to provide a 1-step ahead prediction–(n.b.: it is the same value as that for the previous year, but the uncertainty is larger). Additionally, values for bycatch in the crab and groundfish fisheries are incomplete at the time of the assessment, so these must be estimated as well. Because the directed fishery is closed, retained catch and bycatch in the directed fishery is necessarily be zero.

2. Model Description

MMB at the time of the survey in year y, MMB_{s_y}, is calculated from survey data using:

$$MMB_{s_y} = \sum_z w_z \cdot P_z \cdot n_{z,y}$$

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 PIBKC, P_z is a knife-edge function, with all males larger than 119 mm CL being mature (Table 16).

A random effects (RE) model is used to reduce survey sampling "noise" and obtain more smoothly-varying estimates of MMB at the time of the survey. 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 (or process) 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 from the "raw" survey data, the $< ln(MMB_s) >$'s and ϕ are estimated parameters, and the ϵ's are random effects representing a random walk from one time step to the next (essentially nuisance parameters).

Parameter estimates are obtained by minimizing the joint objective function

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

The current model code is based on code developed by Jim Ianelli (NOAA/NMFS/AFSC). It uses AD Model Builder C++ libraries (Fournier et al., 2012) to minimize the objective function with respect to ϕ while integrating out the random effects.

Given a smoothed estimate, {MMB}_{s_y}, of MMB at the time of the survey in year y, MMB-at-mating (MMB_{m_y}) is calculated using

1. $MMB_{f_y} = MMB_{s_y} \cdot e^{-M \cdot t_{sf}}$

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

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** on 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. The fisheries (directed and bycatch) are assumed to act as "pulse" fisheries just prior to mating.

3. Model Selection and Evaluation

No other models were considered. Based on Table 25 and Figure 22, the RE model appears to have satisfactorily converged to a (presumably) global minimum. The only non-RE parameter estimated is *phi*, the ln-scale estimate of the process error. The maximum gradient at the final model iteration is acceptably small ($< 10^{-7}$; theoretically, it should be 0 but this is numerically unrealistic). In addition, the model hessian was invertible and the standard deviation of the estimated ln-scale process error (0.17984) appears reasonable. Results from Markov Chain Monte Carlo (MCMC) sampling of the posterior distribution using the R package adnuts (Monahan, 2018; Monahan and Kristiensen, 2018) also do not indicate any problems with the model: the histogram and density plots (lower two plots in Figure 22) are approximately normal and the mode of each agrees with the estimated value for *phi* (referred to as "logSdLam" in the Figure).

4. Results

The estimate for the ln-scale process error, ϕ, is -0.836474 ± 0.17984. The RE model appears to have satisfactorily reduced the interannual variability and uncertainty in the "raw" survey MMB time series (Table 26 and Figure 23). The estimated current (2021) MMB *at the time of the survey* from the RE-smoothed results is 201 t.

F. Calculation of the OFL

1. Tier Level:

Based on available data, the CPT and SSC determined in 2013 that this stock is in Tier 4 for status determination as defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008a). The assessment author has no recommendation to change this classification.

2. Parameters and stock sizes

- $M = 0.18\ yr^{-1}$
- ϕ = -0.836474 ± 0.17984
- $MMB_{s,2021}$ = 206 ± 124.4 t

3. OFL specification

3.a. Stock status level

For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as $0.5 \cdot B_{MSY}$ (or a proxy thereof, $B_{MSY_{proxy}}$). If B drops below the MSST, the stock is considered to be overfished. The stock status level is based on the ratio of "current" spawning stock biomass (B) to B_{MSY}. 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 ($B_{MSY_{proxy}}$ 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 previously endorsed using the time periods 1980-84 and 1990-97 to calculate $B_{MSY_{proxy}}$ for PIBKC 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 the following:

A. Production potential

1) Between 2006 and 2013 the stock appeared 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 in Foy 2013).

2) An estimate of surplus production using the equation

$$ASP_t = MMB_{t+1} - MMB_t + C_t$$

where C_t denotes total catch mortality in year t suggested that meaningful surplus production 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 climate regime shifts where temperature and current patterns change 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 indicate a production shift.

B. Exploitation rates

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, then decreased until the fishery was closed in 1987 (Figure 3). Following the re-opening of the fishery in 1995, total catch declined annually until the fishery was closed again in 1999 (Figure 3). The current $F_{MSY_{proxy}} = M$ is 0.18 yr^{-1}, so time periods with greater exploitation rates should not be considered to represent periods with average rates of fishery removals.

C. Recruitment

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 $F_{MSY_{proxy}} =$

M were not sustainable.

In Tier 4, 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 legal portion of the stock (retained catch OFL). The stock status level (a, b or c) is based on the ratio of B to $B_{MSY_{proxy}}$, and determines the F_{OFL} based on the Tier 4 F_{OFL} Control Rule (Figure 25) as described in the following table:

Level	$B/B_{MSY_{proxy}}$	F_{OFL}
a.	$B/B_{MSY_{proxy}} > 1.0$	$F_{OFL} = \gamma \cdot M$
b.	$\beta < B/B_{MSY_{proxy}} \leq 1.0$	$F_{OFL} = \gamma \cdot M[(B/B_{MSY_{proxy}} - \alpha)/(1-\alpha)]$
c.	$B/B_{MSY_{proxy}} \leq \beta$	$F_{directed} = 0$, $F_{OFL} \leq F_{MSY}$

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 $F_{OFL_{proxy}}$. When the ratio $B/B_{MSY_{proxy}}$ drops below β (Stock Status Level c), directed fishing mortality is set to zero. Values for α and β (0.1 and 0.25, respectively) are based on a sensitivity analysis of the effects on $B/B_{MSY_{proxy}}$ (NPFMC 2008a). Thus, $B/B_{MSY_{proxy}} \leq \beta$ corresponds to $B <$ MSST and the stock is considered overfished.

In this assessment, $B_{MSY_{proxy}}$ is the average of MMB_{mating} for the years 1980/81-1984/85 and 1990/91-1997/98 (Table 27), i.e. 4,099 t. "current B" (B) is MMB_{mating} for the assessment year, taking into account projected natural and fishing mortality to the time of mating (Feb. 15, by convention). For the assessment year, the fishery has not yet 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. 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:
   - $MMB_f = MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $RM_{OFL} = \left(1 - e^{-F_{OFL}}\right) \cdot MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $DM_{OFL} = \theta \cdot \frac{MMB_f}{p_{male}}$
   - $OFL = RM_{OFL} + DM_{OFL}$
3. project MMB-at-mating from the "current" survey MMB and the OFL:
   - $MMB_m = \left[MMB_{f_y} - \left(RM_{OFL} + p_{male} \cdot DM_{OFL}\right)\right] \cdot e^{-M \cdot t_{fm}}$
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 B.

In this procedure, p_{male} is the fraction of discard mortality on males (taken to be 0.5). Note that this procedure determines the OFL for the assessment year as well as the current MMB-at-mating, B. 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. The value for θ used for this assessment is 6.946244×10^{-4}, based on averaging over the last three years (Table 29).

Calculating the OFL for the upcoming 2021/22 fishing year requires a value of survey biomass for 2021. The annual NMFS EBS Bottom Trawl Survey is conducted June-August but, starting in 2019, the timing of this assessment was moved from September (after the NMFS EBS Bottom Trawl Survey) to May (before the survey) so the value for the current-year survey biomass is now generally based on a 1-step projection from the RE-smoothed time series. For the random-walk random effects model used here, the best 1-step projection for the current-year survey biomass is simply the RE-estimated survey biomass for the previous year, although the uncertainty of the predicted current-year value is inflated over that for the previous year–reflecting the accumulated process error associated with projecting the estimate forward in time without additional data. The 2020 NMFS EBS Shelf Survey, however, was not conducted due to complications associated with the COVID-19 global pandemic. Consequently, a 2-step projection is required for the 2021 (current year) survey biomass, because the last year in which the survey was conducted is 2019. This estimate will also be the RE-estimated 2019 survey biomass (because no information exists to update the model) with uncertainty further inflated for the two-year projection interval.

The results of the Tier 4 OFL calculation are given in Table 30. "Current" B for crab fishery year 2021/22 is 180 t. Because B/B_{MSY} is 0.044 $< \beta$, the stock is in Tier 4c and directed fishing is prohibited. Furthermore, the stock is overfished because $B \leq$ MSST.

3.b. Basis for MMB-at-mating

The basis for projecting MMB from the survey to the time of mating for years prior to the assessment year is discussed in detail the Model Description section above.

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

The following tables summarize the basis for the OFL (repeating Tables 3 and 4).

Table 6: Basis for the OFL. All units in t. 'M' is the assumed rate of natural mortality.

year	Tier	MMB at mating	B/B_{MSY}	γ	Years to define B_{MSY}	M yr^{-1}	P*
2017/18	4c	230	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2018/19	4c	230	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2019/20	4c	175	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2020/21	4c	175	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2021/22	4c	180	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2022/23	4c	180	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer

Table 7: Basis for the OFL. All units in millions of lbs. 'M' is the assumed rate of natural mortality.

year	Tier	MMB at mating	B/B_{MSY}	γ	Years to define B_{MSY}	M yr^{-1}	P*
2017/18	4c	0.507	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2018/19	4c	0.507	0.06	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2019/20	4c	0.385	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2020/21	4c	0.385	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2021/22	4c	0.398	0.04	1	1980/81-1984/85 & 1990/91-1997/98	0.18	25% buffer
2022/23	4c	0.398	0.04	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

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

5. Recommendations:

For 2021/22, $B_{MSY_{proxy}}$ = 4,099 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 2021/22 was estimated at 180 t. The $B/B_{MSY_{proxy}}$ ratio corresponding to the biomass reference is 0.044. $B/B_{MSY_{proxy}}$ is $< \beta$, therefore the stock status level is c, $F_{directed} = 0$, and $F_{OFL} \leq F_{MSY}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 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 2021/22, based on average catch mortality over the period specified, is 1.16 t.

Based on fishery data available at the time of the assessment, total fishing mortality on PIBKC in 2020/21 was 0 t, below the OFL of 1.16 t, suggesting that overfishing is not occurring in 2020/21. This will be revisited in September.

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 $\sigma_{total} = \sqrt{\sigma_w^2 + \sigma_b^2}$. 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 (2019) is 0.6039959, 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 $\gamma \cdot M$ 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 2021/22, $F_{directed} = 0$ 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 based on a 25% buffer of the average catch between 1999/2000 and 2005/2006 would be 0.87 t. The following tables repeat the information in Tables 1 and 2.

Table 8: Management performance, all units in the table are in metric tons.

year	MSST	MMB at mating	TAC	Retained catch	Total catch mortality	OFL	ABC
2017/18	2,053	230	0	0	0.33	1.16	0.87
2018/19	2,053	230	0	0	0.41	1.16	0.87
2019/20	2,049	180	0	0	0.42	1.16	0.87
2020/21	2,049	181	0	0	0.00	1.16	0.87
2021/22	–	180	–	–	–	1.16	0.87
2022/23	–	180	–	–	–	1.16	0.87

Table 9: Management performance, all units in the table are in millions of lbs.

year	MSST	MMB at mating	TAC	Retained catch	Total catch mortality	OFL	ABC
2017/18	4.526	0.507	0	0	0.0007	0.0026	0.0019
2018/19	4.526	0.507	0	0	0.0009	0.0026	0.0019
2019/20	4.518	0.398	0	0	0.0009	0.0026	0.0019
2020/21	4.518	0.398	0	0	0.0000	0.0026	0.0019
2021/22	–	0.398	–	–	–	0.0026	0.0019
2022/23	–	0.398	–	–	–	0.0026	0.0019

Notes: 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.

Jonathan Reum (AFSC) and colleagues have developed a qualitative network model that describes important biological interactions that may influence the productivity of PIBKC (Reum et al., 2019). The purpose was to explore the potential efficacy of different management interventions in the context of predicted future climate change, including new policies on fisheries that target the predators/competitors of PIBKC, as well as out-stocking of benthic PIBKC juveniles assuming implementation of a hatchery program,. Under a scenario of no climate change, predicted increases in BKC were reliable only when stock enhancement was implemented in a BKC hatchery-program scenario. However, when climate change was accounted for, stock enhancement could not counteract the adverse impacts of climate, which had an overall negative effect on BKC. Thus, a stock enhancement program for PIBKC may be a necessary, but not sufficient, requirement for rebuilding to occur.

The recent trajectory of the time series of MMB-at-survey time does not show evidence of an increasing trend. Further, survey size compositions provide no evidence for recent recruitment to the stock. Based on the available data, it appears there has been no real progress towards rebuilding the stock.

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. Other data gaps include stock-specific natural mortality rates and a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District.

Jared Weems, a PhD student at University of Alaska, Fairbanks, has conducted research on alternative survey designs, including visual censuses, drop camera, and collector traps to better quantify PIBKC in a study funded by NPRB. He presented results from his study to the CPT in September 2020. The objectives of the project were to 1) quantify supply and abundance of early juvenile stages of blue king crab and red king crab, 2) assess habitat availability in nearshore St. Paul Island areas relative to historical survey sites, and 3) identify juvenile king crab predators and predation potential. To assess abundance, Weems compared historical (a 1980s habitat study) bottom trawl and rock dredge young-of-the-year (YOY) crab abundance data to current abundance levels via settlement collector bags and scuba diver visual surveys. Historical results showed YOY BKC occurred at relatively high abundance levels in St Paul Island nearshore areas (N=514 YOY), whereas current abundance levels were low (N=8 YOY). Historical bottom trawl and rock dredge benthic habitat data were compared to current habitat assessed via scuba diver and drop camera surveys. Benthic habitat complexity matched in 87% of the locations that were sampled in both time periods, so there was little suggestion of habitat degradation with time. In the current study, though, no PIBKC were found in shellhash substrate, an important settlement and nursery habitat for juvenile PIBKC, which occurred in relatively high density on the east and southern sides of St. Paul Island. Overall, with respect to PIBKC recruitment limitation in the Pribilof Islands, this study suggested that 1) BKC abundance is limiting but that 2) benthic habitat is non-limiting and relatively unchanged over time.

Jonathan Reum (AFSC) and colleagues have developed a qualitative network model that describes important biological interactions that may influence the productivity of PIBKC (Reum et al., 2019). The purpose was to explore the potential efficacy of different management interventions that include new policies on fisheries that target the predators/competitors of PIBKC, as well as out-stocking of benthic PIBKC juveniles assuming implementation of a hatchery program, in the context of predicted future climate change. Under a scenario of no climate change, predicted increases in BKC were reliable only when stock enhancement was implemented in a BKC hatchery-program scenario. However, when climate change was accounted for, stock enhancement could not counteract the adverse impacts of climate, which had an overall negative effect on BKC. Other management scenarios considered related to changes in fishing effort on BKC predators. For those scenarios, BKC outcomes were unreliable, but climate change further decreased the probability of observing recovery. The study concluded that the largest gains in prediction precision would be made by reducing uncertainty associated with ecological interactions between adult blue and red king crab.

Given these studies, it may be worthwhile to: 1) develop a program to better identify critical nursery habitat within the Pribilof Islands and to characterize postlarval supply to, and settlemnt abundance in, these areas for both blue and red king crab, and 2) better characterize ecological interactions between adult blue and red king crab.

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Tables

Table 10: Retained catch and average CPUE (number of legal males/pot lift) of PIBKC in the directed pot fishery, 1973-1998/99. The directed fishery has been closed since the 1999/2000 fishing season. NA: not applicable (no directed fishery)

crab year	number	biomass (t)	avg. cpue (num. legal crab/pot lift)
1973/74	174,420	579	26
1974/75	908,072	3,224	20
1975/76	314,931	1,104	19
1976/77	855,505	2,999	12
1977/78	807,092	2,929	8
1978/79	797,364	2,901	8
1979/80	815,557	2,719	10
1980/81	1,497,101	4,976	9
1981/82	1,202,499	4,119	7
1982/83	587,908	1,998	5
1983/84	276,364	995	3
1984/85	40,427	139	3
1985/86	76,945	240	3
1986/87	36,988	117	2
1987/88	95,130	318	2
1988/89	0	0	*NA*
1989/90	0	0	*NA*
1990/91	0	0	*NA*
1991/92	0	0	*NA*
1992/93	0	0	*NA*
1993/94	0	0	*NA*
1994/95	0	0	*NA*
1995/96	190,951	628	5
1996/97	127,712	425	4
1997/98	68,603	232	3
1998/99	68,419	234	3
1999/00	0	0	*NA*

Table 11: Bycatch catch of PIBKC in the directed and other crab fisheries, as estimated from crab observer data. A discard mortality rate of 0.2 was applied to obtain discard mortalities. Units are t.

		catch			discard
crab year	females	sublegal males	legal males	total catch	mortality
1996/97	0.000	0.807	0.000	0.807	0.161
1997/98	0.000	0.000	0.000	0.000	0.000
1998/99	3.715	0.467	2.295	6.477	1.295
1999/00	1.969	4.291	3.493	9.752	1.950
2000/01	0.000	0.000	0.000	0.000	0.000
2001/02	0.000	0.000	0.000	0.000	0.000
2002/03	0.000	0.000	0.000	0.000	0.000
2003/04	0.000	0.000	0.000	0.000	0.000
2004/05	0.000	0.000	0.000	0.000	0.000
2005/06	0.050	0.000	0.000	0.050	0.010
2006/07	0.104	0.000	0.000	0.104	0.021
2007/08	0.136	0.000	0.000	0.136	0.027
2008/09	0.000	0.000	0.000	0.000	0.000
2009/10	0.000	0.000	0.000	0.000	0.000
2010/11	0.000	0.186	0.000	0.186	0.037
2011/12	0.000	0.000	0.000	0.000	0.000
2012/13	0.000	0.000	0.000	0.000	0.000
2013/14	0.000	0.000	0.000	0.000	0.000
2014/15	0.000	0.000	0.000	0.000	0.000
2015/16	0.102	0.230	0.000	0.333	0.067
2016/17	0.000	0.000	0.000	0.000	0.000
2017/18	0.064	0.000	0.000	0.064	0.013
2018/19	0.000	0.101	0.000	0.101	0.020
2019/20	0.000	0.000	0.000	0.000	0.000
2020/21	0.000	0.000	0.000	0.000	0.000

Table 12: Bycatch of PIBKC in the groundfish fisheries, by gear type. Biomass and (discard) mortality are in kilograms.Discard mortality rates of 0.2 and 0.8 for fixed and trawl gear, respectively, were applied to obtain discard mortalities.

		fixed			trawl	
year	number	biomass	mortality	number	biomass	mortality
2009/10	87	216	43	193	207	165
2010/11	16	44	9	35	56	45
2011/12	54	112	22	8	7	6
2012/13	72	170	34	340	669	535
2013/14	41	65	13	0	0	0
2014/15	65	144	29	0	0	0
2015/16	352	744	149	257	808	646
2016/17	49	77	15	524	455	364
2017/18	0	0	0	265	378	303
2018/19	14	20	4	398	466	373
2019/20	5	9	2	226	518	415
2020/21	0	0	0	0	0	0

Table 13: Bycatch in numbers of PIBKC in the groundfish fisheries, by target type.

year	Flathead Sole number	Pacific Cod number	Pollock - bottom number	Rock Sole - BSAI number	Yellowfin Sole - BSAI number
2009/10	54	87	20	0	119
2010/11	35	14	0	0	0
2011/12	0	62	0	0	0
2012/13	12	72	0	0	328
2013/14	0	41	0	0	0
2014/15	0	64	0	0	0
2015/16	58	351	0	0	199
2016/17	0	48	0	432	92
2017/18	95	0	0	0	170
2018/19	0	14	97	0	300
2019/20	0	5	0	55	170
2020/21	0	0	0	0	0

Table 14: Bycatch in biomass (kg) of PIBKC in the groundfish fisheries, by target type.

year	Flathead Sole biomass	Pacific Cod biomass	Pollock - bottom biomass	Rock Sole - BSAI biomass	Yellowfin Sole - BSAI biomass
2009/10	71	216	7	0	129
2010/11	56	42	0	0	0
2011/12	0	119	0	0	0
2012/13	24	170	0	0	645
2013/14	0	64	0	0	0
2014/15	0	143	0	0	0
2015/16	147	742	0	0	661
2016/17	0	75	0	368	87
2017/18	227	0	0	0	151
2018/19	0	20	23	0	442
2019/20	0	9	0	188	330
2020/21	0	0	0	0	0

Table 15: Discard mortality, in kg, of PIBKC in the groundfish fisheries, by target type.Discard mortality rates of 0.2 and 0.8 for fixed and trawl gear, respectively, were applied to obtain discard mortalities.

year	Flathead Sole mortality	Pacific Cod mortality	Pollock - bottom mortality	Rock Sole - BSAI mortality	Yellowfin Sole - BSAI mortality
2009/10	57	43	5	0	103
2010/11	45	8	0	0	0
2011/12	0	28	0	0	0
2012/13	19	34	0	0	516
2013/14	0	13	0	0	0
2014/15	0	29	0	0	0
2015/16	117	148	0	0	529
2016/17	0	15	0	294	70
2017/18	182	0	0	0	121
2018/19	0	4	19	0	354
2019/20	0	2	0	151	264
2020/21	0	0	0	0	0

Table 16: Size groups for various male components of the PIBKC stock used here. Female maturity is based on abdominal flap morphology and egg presence.

sex	size.range	category
male	$<$ 120 mm CL	immature male
male	$>$ 119 mm CL	mature male
male	$<$ 135 mm CL	sublegal male
male	$>$ 134 mm CL	legal male

Table 17: Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for male population components in the NMFS EBS trawl survey in the Pribilof District.

	survey	immature males		mature males		sublegal males		legal males		all males	
	number	non-0	no.	non-0	no.	non-0	no.	non-0	no.	non-0	no.
year	of hauls	hauls	crab	hauls	crab	hauls	crab	hauls	crab	hauls	crab
1975	45	11	305	13	553	11	530	13	328	13	858
1976	59	3	105	11	91	9	122	10	74	12	196
1977	58	7	56	10	129	9	73	9	112	10	185
1978	58	8	60	11	130	10	112	10	78	12	190
1979	33	2	2	9	77	6	23	9	56	9	79
1980	70	10	41	21	133	12	64	21	110	21	174
1981	84	19	99	36	184	23	128	36	155	38	283
1982	84	19	70	35	114	21	84	31	100	38	184
1983	86	15	47	32	93	18	74	29	66	35	140
1984	86	10	27	20	37	17	37	16	27	25	64
1985	86	3	4	14	24	8	13	11	15	14	28
1986	86	1	1	13	26	2	2	13	25	13	27
1987	86	5	34	15	50	6	38	14	46	16	84
1988	85	5	52	5	12	5	52	5	12	9	64
1989	86	8	160	4	11	8	160	4	11	10	171
1990	86	8	90	10	59	11	126	7	23	14	149
1991	85	16	92	19	103	20	129	14	66	22	195
1992	86	12	89	14	73	13	119	12	43	17	162
1993	85	12	75	19	96	15	115	17	56	21	171
1994	86	8	32	18	68	12	51	18	49	19	100
1995	86	7	66	18	177	15	118	14	125	19	243
1996	86	7	32	19	87	11	54	19	65	20	119
1997	86	7	25	17	65	10	39	16	51	19	90
1998	85	12	56	20	56	15	66	17	46	21	112
1999	86	7	9	13	34	9	18	11	25	15	43
2000	85	4	9	16	40	9	20	13	29	16	49
2001	86	3	5	6	28	4	9	5	24	7	33
2002	86	0	0	6	12	1	1	6	11	6	12
2003	86	2	2	7	14	3	3	7	13	9	16
2004	85	3	5	3	3	5	7	1	1	6	8
2005	84	3	54	2	5	3	54	2	5	4	59
2006	86	4	7	3	3	4	8	2	2	6	10
2007	86	4	14	2	6	4	17	2	3	4	20
2008	86	2	13	1	1	2	13	1	1	3	14
2009	86	5	16	3	15	5	27	3	4	5	31
2010	86	2	6	5	8	3	10	4	4	5	14
2011	86	0	0	3	9	2	2	2	7	3	9
2012	86	1	9	4	13	1	14	4	8	4	22
2013	86	1	3	2	6	2	5	2	4	3	9
2014	86	3	5	2	5	3	5	2	5	4	10
2015	86	2	4	8	13	6	10	5	7	9	17

2016	86	4	5	3	3	5	7	1	1	5	8
2017	86	2	4	4	4	3	5	3	3	5	8
2018	86	4	6	3	3	4	6	3	3	5	9
2019	86	5	8	3	3	5	8	3	3	6	11

Table 18: Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for female population components in the NMFS EBS trawl survey in the Pribilof District.

	survey	immature females		mature females		all females	
	number	non-0	no.	non-0	no.	non-0	no.
year	of hauls	hauls	crab	hauls	crab	hauls	crab
1975	45	0	0	9	265	9	265
1976	59	3	81	4	11	5	92
1977	58	2	9	5	136	5	145
1978	58	1	1	8	107	8	108
1979	33	2	3	4	22	5	25
1980	70	3	6	11	337	11	343
1981	84	13	31	20	202	23	233
1982	84	5	35	23	264	24	299
1983	86	6	15	17	288	18	303
1984	86	6	24	14	145	15	169
1985	86	7	15	8	28	12	43
1986	86	2	2	8	106	10	108
1987	86	5	22	7	36	11	58
1988	85	5	38	8	20	9	58
1989	86	8	131	9	40	13	171
1990	86	5	75	9	90	10	165
1991	85	9	36	11	126	15	162
1992	86	4	66	9	76	11	142
1993	85	5	45	13	89	15	134
1994	86	3	8	12	271	13	279
1995	86	3	38	11	220	12	258
1996	86	7	13	10	213	12	226
1997	86	4	17	11	137	13	154
1998	85	8	29	11	107	15	136
1999	86	0	0	10	155	10	155
2000	85	0	0	13	74	13	74
2001	86	1	1	9	93	10	94
2002	86	1	1	6	66	7	67
2003	86	4	4	7	69	9	73
2004	85	3	5	3	4	5	9
2005	84	1	43	5	15	6	58
2006	86	4	6	3	22	6	28
2007	86	3	7	2	9	5	16
2008	86	3	19	4	24	6	43
2009	86	3	9	3	29	4	38
2010	86	5	9	4	15	7	24
2011	86	1	1	2	2	3	3
2012	86	1	1	5	15	6	16
2013	86	2	2	4	8	5	10
2014	86	1	1	3	4	4	5
2015	86	0	0	4	11	4	11

2016	86	4	5	7	19	8	24
2017	86	4	5	4	10	6	15
2018	86	1	1	3	6	4	7
2019	86	0	0	2	11	2	11

Table 19: Summary statistics for trawl survey abundance by decade, in millions.

	decade									
	1970		1980		1990		2000		2010	
category	mean	max	mean	max	mean	max	mean	max	mean	max
immature females	1.706	7.369	0.7645	2.636	0.756	2.177	0.3201	2.2681	0.05116	0.1656
mature females	7.156	13.880	21.3116	182.903	3.008	5.047	0.7272	1.6975	0.20400	0.3594
all females	8.862	14.732	22.0762	183.684	3.764	5.322	1.0472	2.5573	0.25516	0.4544
immature males	4.042	8.476	1.3213	3.515	1.237	2.450	0.3257	1.9813	0.09662	0.1945
mature males	9.099	15.288	1.8942	7.842	1.619	3.102	0.2274	0.7251	0.12712	0.2722
sublegal males	6.497	14.712	1.6675	4.331	1.791	3.349	0.3850	1.9813	0.13763	0.3026
legal males	6.644	11.769	1.5480	6.244	1.065	2.186	0.1681	0.5276	0.08610	0.1642
all males	13.141	23.764	3.2155	10.575	2.856	4.371	0.5531	2.0733	0.22373	0.4668

Table 20: Summary statistics for trawl survey biomass by decade, in 1,000's t.

	decade									
	1970		1980		1990		2000		2010	
category	mean	max	mean	max	mean	max	mean	max	mean	max
immature females	1.125	4.968	0.3149	0.8008	0.3763	1.118	0.09232	0.4773	0.02422	0.08408
mature females	6.953	13.154	24.4680	211.6037	2.9518	5.408	0.81884	1.8163	0.20584	0.41163
all females	8.078	13.572	24.7829	212.3032	3.3281	5.585	0.91115	1.8167	0.23006	0.41163
immature males	3.811	8.341	0.7711	2.0838	0.9836	2.004	0.13309	0.3258	0.07633	0.16471
mature males	25.721	42.618	5.7347	23.5529	4.0885	8.360	0.65383	2.0913	0.32571	0.64394
sublegal males	8.148	19.378	1.3954	4.9581	1.9477	3.567	0.23745	0.5649	0.14687	0.34967
legal males	21.383	40.366	5.1104	20.6786	3.1245	6.787	0.54947	1.7457	0.25518	0.45898
all males	29.532	46.395	6.5058	25.6367	5.0721	9.328	0.78692	2.2047	0.40204	0.80865

Table 21: Estimated annual abundance (millions of crab) of male PIBKC population components from the NMFS EBS trawl survey.

	immature males		mature males		sublegal males		legal males		all males	
year	abundance	cv	abundance	cv	abundance	cv	abundance	cv	abundance	cv
1975	8.476	0.567	15.288	0.502	14.712	0.479	9.051	0.501	23.764	0.466
1976	4.960	0.954	4.782	0.445	5.729	0.882	4.012	0.471	9.742	0.589
1977	4.216	0.457	13.044	0.743	5.491	0.440	11.769	0.771	17.260	0.625
1978	2.421	0.502	6.141	0.496	4.639	0.419	3.923	0.616	8.562	0.428
1979	0.139	0.699	6.240	0.360	1.913	0.472	4.467	0.347	6.380	0.357
1980	2.733	0.466	7.842	0.408	4.331	0.458	6.244	0.420	10.575	0.400
1981	2.099	0.324	3.834	0.180	2.688	0.317	3.246	0.177	5.934	0.207
1982	1.371	0.281	2.354	0.181	1.654	0.255	2.071	0.188	3.725	0.172
1983	1.031	0.357	1.851	0.186	1.561	0.309	1.321	0.170	2.882	0.220
1984	0.518	0.397	0.771	0.225	0.730	0.290	0.558	0.247	1.288	0.212
1985	0.068	0.598	0.428	0.281	0.226	0.340	0.270	0.294	0.496	0.269
1986	0.019	1.000	0.480	0.305	0.039	0.698	0.460	0.313	0.499	0.298
1987	0.622	0.834	0.903	0.414	0.695	0.748	0.830	0.416	1.525	0.434
1988	1.238	0.842	0.238	0.509	1.238	0.842	0.238	0.509	1.476	0.708
1989	3.515	0.588	0.240	0.624	3.515	0.588	0.240	0.624	3.755	0.585
1990	2.450	0.596	1.470	0.626	3.349	0.596	0.572	0.538	3.920	0.578
1991	1.920	0.373	2.014	0.363	2.697	0.332	1.238	0.444	3.935	0.343
1992	2.436	0.588	1.935	0.420	3.217	0.520	1.154	0.453	4.371	0.475
1993	1.484	0.520	1.876	0.310	2.245	0.432	1.114	0.300	3.359	0.339
1994	0.639	0.374	1.294	0.341	0.998	0.343	0.935	0.345	1.933	0.332
1995	1.147	0.889	3.102	0.600	2.062	0.744	2.186	0.615	4.249	0.675
1996	0.719	0.625	1.712	0.281	1.162	0.547	1.269	0.263	2.431	0.334
1997	0.467	0.525	1.201	0.294	0.736	0.464	0.933	0.284	1.669	0.342
1998	0.949	0.458	0.967	0.246	1.119	0.414	0.797	0.253	1.917	0.309
1999	0.160	0.373	0.617	0.334	0.324	0.388	0.453	0.345	0.777	0.327
2000	0.164	0.563	0.725	0.296	0.361	0.385	0.528	0.297	0.889	0.312
2001	0.093	0.645	0.522	0.710	0.169	0.595	0.446	0.744	0.615	0.690
2002	0.000	0.000	0.225	0.473	0.018	1.000	0.207	0.495	0.225	0.473
2003	0.045	0.717	0.229	0.389	0.061	0.589	0.214	0.402	0.274	0.341
2004	0.088	0.590	0.048	0.563	0.120	0.460	0.016	1.000	0.136	0.417
2005	1.981	0.964	0.092	0.712	1.981	0.964	0.092	0.712	2.073	0.921
2006	0.138	0.495	0.056	0.564	0.155	0.503	0.038	0.699	0.194	0.419
2007	0.246	0.717	0.110	0.854	0.302	0.644	0.054	0.745	0.356	0.639
2008	0.234	0.928	0.018	1.000	0.234	0.928	0.018	1.000	0.252	0.862
2009	0.268	0.631	0.249	0.732	0.448	0.697	0.068	0.588	0.516	0.676
2010	0.101	0.841	0.130	0.486	0.167	0.728	0.065	0.482	0.232	0.608
2011	0.000	0.000	0.166	0.792	0.036	0.698	0.129	0.868	0.166	0.792
2012	0.195	1.000	0.272	0.797	0.303	1.000	0.164	0.678	0.467	0.879
2013	0.076	1.000	0.104	0.862	0.112	0.745	0.069	0.804	0.181	0.644
2014	0.091	0.591	0.092	0.710	0.091	0.591	0.092	0.710	0.183	0.566
2015	0.076	0.766	0.234	0.367	0.185	0.525	0.125	0.446	0.309	0.408
2016	0.094	0.517	0.056	0.563	0.131	0.458	0.019	1.000	0.150	0.488
2017	0.068	0.773	0.091	0.503	0.087	0.637	0.072	0.589	0.159	0.456

2018	0.110	0.572	0.056	0.563	0.110	0.572	0.056	0.563	0.166	0.521
2019	0.155	0.485	0.071	0.575	0.155	0.485	0.071	0.575	0.226	0.462

Table 22: Estimated annual abundance (millions of crab) of female PIBKC population components from the NMFS EBS trawl survey.

	immature females		mature females		all females	
year	abundance	cv	abundance	cv	abundance	cv
1975	0.000	0.000	13.148	0.608	13.148	0.608
1976	7.369	0.966	0.769	0.513	8.139	0.910
1977	0.852	0.825	13.880	0.860	14.732	0.857
1978	0.061	1.000	5.927	0.662	5.987	0.656
1979	0.250	0.714	2.054	0.809	2.305	0.763
1980	0.781	0.774	182.903	0.977	183.684	0.976
1981	0.827	0.408	5.433	0.437	6.260	0.423
1982	0.876	0.514	7.837	0.648	8.713	0.626
1983	0.464	0.545	9.308	0.780	9.772	0.763
1984	0.465	0.516	2.769	0.380	3.235	0.366
1985	0.260	0.541	0.486	0.437	0.746	0.360
1986	0.037	0.698	2.102	0.898	2.139	0.882
1987	0.402	0.743	0.670	0.584	1.072	0.478
1988	0.898	0.869	0.465	0.479	1.363	0.642
1989	2.636	0.738	1.142	0.659	3.778	0.576
1990	2.177	0.910	2.046	0.547	4.223	0.555
1991	0.805	0.463	2.767	0.416	3.573	0.353
1992	1.797	0.927	2.150	0.494	3.947	0.521
1993	0.881	0.606	1.783	0.445	2.663	0.378
1994	0.145	0.574	5.047	0.443	5.192	0.437
1995	0.658	0.920	4.039	0.521	4.697	0.491
1996	0.276	0.418	5.046	0.484	5.322	0.463
1997	0.320	0.669	2.614	0.423	2.935	0.388
1998	0.500	0.431	1.830	0.443	2.330	0.365
1999	0.000	0.000	2.756	0.490	2.756	0.490
2000	0.000	0.000	1.363	0.463	1.363	0.463
2001	0.019	1.000	1.697	0.753	1.716	0.745
2002	0.019	1.000	1.222	0.794	1.241	0.782
2003	0.067	0.483	1.120	0.764	1.188	0.721
2004	0.098	0.634	0.070	0.603	0.168	0.510
2005	2.268	1.000	0.289	0.565	2.557	0.886
2006	0.113	0.548	0.430	0.766	0.543	0.617
2007	0.122	0.728	0.166	0.899	0.288	0.592
2008	0.342	0.898	0.437	0.658	0.779	0.748
2009	0.152	0.612	0.477	0.818	0.629	0.755
2010	0.166	0.558	0.249	0.691	0.415	0.622
2011	0.018	1.000	0.037	0.698	0.055	0.563
2012	0.035	1.000	0.312	0.764	0.347	0.695
2013	0.045	0.704	0.150	0.627	0.196	0.534
2014	0.028	1.000	0.074	0.604	0.102	0.507
2015	0.000	0.000	0.202	0.655	0.202	0.655
2016	0.095	0.515	0.359	0.520	0.454	0.504
2017	0.105	0.501	0.244	0.624	0.350	0.535

2018	0.020	1.000	0.114	0.614	0.134	0.537
2019	0.000	0.000	0.297	0.828	0.297	0.828

Table 23: Estimated annual biomass (1000's t) of male PIBKC population components from the NMFS EBS trawl survey.

	immature males		mature males		sublegal males		legal males		all males	
year	biomass	cv	biomass	cv	biomass	cv	biomass	cv	biomass	cv
1975	8.341	0.525	38.054	0.501	19.378	0.466	27.016	0.499	46.395	0.475
1976	4.129	0.944	14.059	0.451	5.539	0.811	12.649	0.468	18.188	0.452
1977	3.713	0.443	42.618	0.768	5.966	0.463	40.366	0.784	46.332	0.729
1978	2.765	0.509	17.370	0.558	6.618	0.412	13.517	0.642	20.135	0.506
1979	0.108	0.782	16.502	0.350	3.241	0.474	13.369	0.349	16.610	0.349
1980	2.084	0.492	23.553	0.430	4.958	0.464	20.679	0.446	25.637	0.417
1981	1.704	0.299	11.628	0.174	2.779	0.297	10.554	0.175	13.332	0.175
1982	1.152	0.232	7.389	0.187	1.647	0.217	6.893	0.192	8.541	0.175
1983	0.962	0.357	5.409	0.178	1.897	0.297	4.474	0.175	6.371	0.187
1984	0.130	0.362	2.216	0.229	0.521	0.268	1.824	0.247	2.345	0.222
1985	0.039	0.733	1.055	0.267	0.338	0.374	0.755	0.283	1.094	0.263
1986	0.004	1.000	1.505	0.303	0.035	0.897	1.473	0.307	1.508	0.302
1987	0.191	0.783	2.923	0.411	0.334	0.536	2.781	0.414	3.115	0.397
1988	0.170	0.707	0.842	0.529	0.170	0.707	0.842	0.529	1.012	0.457
1989	1.275	0.620	0.827	0.637	1.275	0.620	0.827	0.637	2.102	0.551
1990	2.004	0.661	3.078	0.600	3.567	0.665	1.514	0.515	5.082	0.610
1991	1.377	0.386	4.690	0.386	2.741	0.336	3.326	0.450	6.067	0.373
1992	1.801	0.512	4.391	0.423	3.157	0.446	3.035	0.446	6.192	0.432
1993	1.088	0.545	4.556	0.307	2.442	0.409	3.203	0.301	5.644	0.305
1994	0.619	0.388	3.410	0.345	1.224	0.350	2.806	0.351	4.029	0.343
1995	0.968	0.863	8.360	0.604	2.541	0.673	6.787	0.615	9.328	0.629
1996	0.745	0.605	4.641	0.269	1.512	0.524	3.873	0.265	5.386	0.279
1997	0.381	0.545	3.233	0.276	0.849	0.451	2.765	0.271	3.614	0.294
1998	0.692	0.413	2.798	0.249	0.980	0.354	2.510	0.255	3.490	0.252
1999	0.161	0.402	1.729	0.337	0.464	0.414	1.426	0.347	1.890	0.333
2000	0.113	0.679	2.091	0.296	0.459	0.373	1.746	0.305	2.205	0.304
2001	0.087	0.764	1.599	0.735	0.225	0.628	1.461	0.759	1.686	0.733
2002	0.000	0.000	0.680	0.506	0.033	1.000	0.647	0.525	0.680	0.506
2003	0.019	0.984	0.702	0.400	0.050	0.723	0.671	0.411	0.721	0.390
2004	0.036	0.649	0.107	0.583	0.094	0.487	0.048	1.000	0.143	0.455
2005	0.326	0.942	0.344	0.710	0.326	0.942	0.344	0.710	0.670	0.589
2006	0.087	0.585	0.166	0.603	0.114	0.616	0.139	0.699	0.253	0.462
2007	0.197	0.737	0.306	0.798	0.298	0.632	0.206	0.734	0.503	0.661
2008	0.212	0.952	0.046	1.000	0.212	0.952	0.046	1.000	0.258	0.797
2009	0.254	0.680	0.497	0.713	0.565	0.740	0.187	0.604	0.751	0.698
2010	0.092	0.853	0.303	0.461	0.205	0.702	0.190	0.483	0.395	0.522
2011	0.000	0.000	0.461	0.843	0.062	0.705	0.399	0.886	0.461	0.843
2012	0.165	1.000	0.644	0.735	0.350	1.000	0.459	0.643	0.809	0.786
2013	0.015	1.000	0.250	0.797	0.075	0.824	0.190	0.752	0.265	0.754
2014	0.083	0.623	0.233	0.699	0.083	0.623	0.233	0.699	0.317	0.567
2015	0.082	0.747	0.622	0.394	0.275	0.494	0.428	0.458	0.703	0.395
2016	0.071	0.486	0.130	0.613	0.133	0.495	0.068	1.000	0.201	0.515
2017	0.046	0.767	0.255	0.514	0.076	0.599	0.224	0.573	0.300	0.470

2018	0.096	0.540	0.154	0.571	0.096	0.540	0.154	0.571	0.249	0.522
2019	0.115	0.542	0.206	0.604	0.115	0.542	0.206	0.604	0.321	0.504

Table 24: Estimated annual biomass (1000's t) of female PIBKC population components from the NMFS EBS trawl survey.

	immature females		mature females		all females	
year	biomass	cv	biomass	cv	biomass	cv
1975	0.000	0.000	12.442	0.636	12.442	0.636
1976	4.968	0.972	0.824	0.532	5.792	0.891
1977	0.419	0.829	13.154	0.875	13.572	0.874
1978	0.076	1.000	6.416	0.725	6.492	0.717
1979	0.161	0.725	1.929	0.790	2.090	0.756
1980	0.699	0.865	211.604	0.984	212.303	0.983
1981	0.497	0.413	5.987	0.469	6.484	0.458
1982	0.553	0.572	8.824	0.678	9.377	0.669
1983	0.258	0.607	9.990	0.791	10.248	0.781
1984	0.015	0.688	3.070	0.381	3.085	0.380
1985	0.005	0.457	0.520	0.448	0.525	0.445
1986	0.011	0.727	2.420	0.901	2.431	0.896
1987	0.119	0.855	0.795	0.583	0.913	0.526
1988	0.190	0.788	0.528	0.491	0.718	0.473
1989	0.801	0.666	0.945	0.581	1.746	0.497
1990	1.118	0.928	1.810	0.508	2.929	0.491
1991	0.343	0.475	2.433	0.414	2.776	0.376
1992	0.802	0.961	1.848	0.480	2.649	0.463
1993	0.444	0.624	1.647	0.461	2.092	0.399
1994	0.087	0.570	4.806	0.447	4.893	0.443
1995	0.331	0.904	3.948	0.519	4.279	0.496
1996	0.177	0.415	5.408	0.502	5.585	0.491
1997	0.194	0.659	2.835	0.429	3.028	0.407
1998	0.267	0.425	1.914	0.441	2.182	0.392
1999	0.000	0.000	2.868	0.467	2.868	0.467
2000	0.000	0.000	1.462	0.460	1.462	0.460
2001	0.000	1.000	1.816	0.722	1.817	0.722
2002	0.000	1.000	1.401	0.776	1.401	0.775
2003	0.021	0.667	1.286	0.745	1.307	0.734
2004	0.025	0.821	0.098	0.597	0.123	0.504
2005	0.477	1.000	0.370	0.570	0.847	0.606
2006	0.038	0.602	0.538	0.760	0.576	0.712
2007	0.059	0.792	0.223	0.876	0.282	0.707
2008	0.222	0.901	0.450	0.635	0.672	0.705
2009	0.080	0.660	0.545	0.849	0.625	0.818
2010	0.084	0.578	0.310	0.660	0.394	0.634
2011	0.003	1.000	0.034	0.725	0.037	0.674
2012	0.009	1.000	0.229	0.660	0.237	0.637
2013	0.012	0.722	0.154	0.700	0.166	0.654
2014	0.016	1.000	0.091	0.605	0.108	0.529
2015	0.000	0.000	0.160	0.662	0.160	0.662
2016	0.050	0.490	0.354	0.493	0.405	0.478
2017	0.055	0.501	0.206	0.591	0.262	0.533

2018	0.013	1.000	0.108	0.725	0.121	0.654
2019	0.000	0.000	0.412	0.859	0.412	0.859

Table 25: Results from fitting random effects model to male survey MMB data.

quantity	value
objective function value	$2.838e+01$
max gradient	$4.549e-08$
estimated ln-scale process error	$-8.365e-01$
sd(ln-scale process error)	$1.798e-01$
estimated process error	$4.332e-01$
sd(estimated process error)	$7.791e-02$

Table 26: A comparison of estimates for MMB (in t) at the time of the survey. Note that the survey was not conducted in 2020 and has not yet been conducted in 2021 so the 'raw' values are unavailable and the smoothed values are 1-step and 2-step ahead predictions.

		raw			RE	
year	value	lci	uci	value	lci	uci
1975	38,053.59	20,759.61	69,754.48	26,784.90	17,034.71	42,115.83
1976	14,058.93	8,103.53	24,391.05	19,946.70	13,547.47	29,368.65
1977	42,618.32	17,814.39	101,958.08	21,189.60	13,764.47	32,620.15
1978	17,369.71	8,912.49	33,852.16	16,960.00	11,462.90	25,093.26
1979	10,959.38	7,385.67	16,262.32	13,352.10	9,817.39	18,159.47
1980	23,552.92	13,894.39	39,925.46	15,538.70	11,082.00	21,787.69
1981	11,628.25	9,320.75	14,507.00	11,412.30	9,362.15	13,911.40
1982	7,388.96	5,824.58	9,373.50	7,447.72	6,063.18	9,148.42
1983	5,408.73	4,315.80	6,778.45	5,074.75	4,157.49	6,194.38
1984	2,215.66	1,659.01	2,959.08	2,351.50	1,849.90	2,989.11
1985	1,054.79	753.94	1,475.68	1,356.55	1,029.82	1,786.94
1986	1,504.69	1,029.62	2,198.96	1,556.99	1,163.92	2,082.81
1987	2,923.38	1,761.10	4,852.75	1,922.68	1,360.00	2,718.16
1988	842.43	445.93	1,591.49	1,435.90	964.21	2,138.35
1989	827.50	391.56	1,748.76	1,609.75	1,051.08	2,465.37
1990	3,077.51	1,512.59	6,261.49	2,603.20	1,740.69	3,893.08
1991	4,689.67	2,910.49	7,556.46	3,800.49	2,691.45	5,366.52
1992	4,391.01	2,612.05	7,381.55	4,173.43	2,959.22	5,885.85
1993	4,555.60	3,100.43	6,693.73	4,324.43	3,213.99	5,818.52
1994	3,410.36	2,219.61	5,239.91	4,020.55	2,928.76	5,519.34
1995	8,360.23	4,090.73	17,085.84	4,921.59	3,362.53	7,203.53
1996	4,640.62	3,308.54	6,509.03	4,376.01	3,324.26	5,760.51
1997	3,232.58	2,284.30	4,574.53	3,321.94	2,534.27	4,354.42
1998	2,797.93	2,042.57	3,832.65	2,703.85	2,092.13	3,494.43
1999	1,729.24	1,136.48	2,631.17	1,978.47	1,461.46	2,678.39
2000	2,091.34	1,442.89	3,031.19	1,832.25	1,362.25	2,464.40
2001	1,598.74	688.93	3,710.05	1,262.12	840.00	1,896.36
2002	679.80	368.60	1,253.75	784.43	534.71	1,150.78
2003	702.01	428.47	1,150.19	548.48	385.14	781.09
2004	106.88	53.46	213.67	280.69	183.64	429.04
2005	344.06	151.76	780.00	267.08	172.14	414.36
2006	165.89	81.25	338.67	226.16	145.90	350.59
2007	306.46	124.64	753.49	231.03	144.95	368.26
2008	45.98	15.82	133.66	211.94	130.04	345.41
2009	497.11	218.63	1,130.34	294.05	188.63	458.37
2010	302.93	172.57	531.78	320.96	216.47	475.88
2011	461.36	180.34	1,180.27	370.62	235.44	583.40
2012	643.94	277.26	1,495.58	396.44	250.68	626.93
2013	250.14	101.79	614.66	343.53	217.66	542.17
2014	233.39	103.97	523.89	335.97	218.74	516.03
2015	621.71	382.23	1,011.25	390.15	271.33	560.99
2016	128.55	62.34	265.09	246.93	164.41	370.87

2017	252.78	135.99	469.85	229.48	154.21	341.49
2018	153.55	77.73	303.35	197.35	128.77	302.46
2019	205.96	100.78	420.90	200.55	121.96	329.78
2020	0.00	0.00	0.00	200.55	99.37	404.75
2021	0.00	0.00	0.00	200.55	86.52	464.88

Table 27: A comparison of estimates for MMB (in t) at the time of the survey, fishery, and mating. Note that, for the 2021 assessment year, the survey has not yet been conducted since 2019, so the value of MMB at the time of the survey for 2021 is a 2-step ahead prediction. The value of MMB-at-mating for the assessment year cannot be determined until $B_{MSY_{proxy}}$ has been determined.

year	survey time	fishery time	mating time
1975	26,785	25,606	23,077
1976	19,947	19,069	15,135
1977	21,190	20,257	16,318
1978	16,960	16,214	12,536
1979	13,352	12,765	9,458
1980	15,539	14,855	9,304
1981	11,412	10,910	6,396
1982	7,448	7,120	4,822
1983	5,075	4,851	3,633
1984	2,352	2,248	1,985
1985	1,357	1,297	995
1986	1,557	1,488	1,291
1987	1,923	1,838	1,432
1988	1,436	1,373	1,293
1989	1,610	1,539	1,449
1990	2,603	2,489	2,344
1991	3,800	3,633	3,419
1992	4,173	3,990	3,734
1993	4,324	4,134	3,880
1994	4,021	3,844	3,617
1995	4,922	4,705	3,841
1996	4,376	4,183	3,538
1997	3,322	3,176	2,773
1998	2,704	2,585	2,210
1999	1,978	1,891	1,781
2000	1,832	1,752	1,650
2001	1,262	1,207	1,136
2002	784	750	706
2003	548	524	494
2004	281	268	253
2005	267	255	240
2006	226	216	204
2007	231	221	208
2008	212	203	191
2009	294	281	265
2010	321	307	289
2011	371	354	334
2012	396	379	357
2013	344	328	309
2014	336	321	302
2015	390	373	351

2016	247	236	222
2017	229	219	206
2018	197	189	178
2019	201	192	180
2020	201	192	181
2021	201	192	NA

Table 28: Estimated current MMB at the time of the survey and $B_{MSY_{proxy}}$ using the RE-smoothed survey data.

	Current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
RE-smoothed	201	$4,099$

Table 29: Estimated value for the θ coefficient.

	Estimation Type	theta
1	RE-smoothed	0.0006946

Table 30: Results from the OFL determination. RM_{OFL} = retained catch portion of the OFL, DM_{OFL} = discard mortality portion of the OFL used to determine B ('current' MMB-at-mating for 2021/22)

	quantity	units	RE.smoothed
1	B ("current" MMB)	t	180.44
2	B_{MSY}	t	4,098.97
3	stock status	–	overfished
4	F_{OFL}	$year^{-1}$	0.00
5	RM_{OFL}	t	0.00
6	DM_{OFL}	t	0.27
7	OFL	t	0.27

Figures

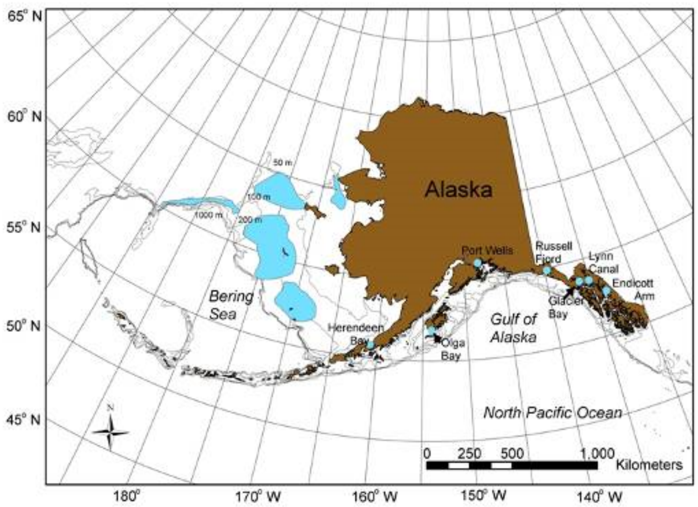

Figure 1: Distribution of blue king crab, *Paralithodesplatypus*, in Alaskan waters.

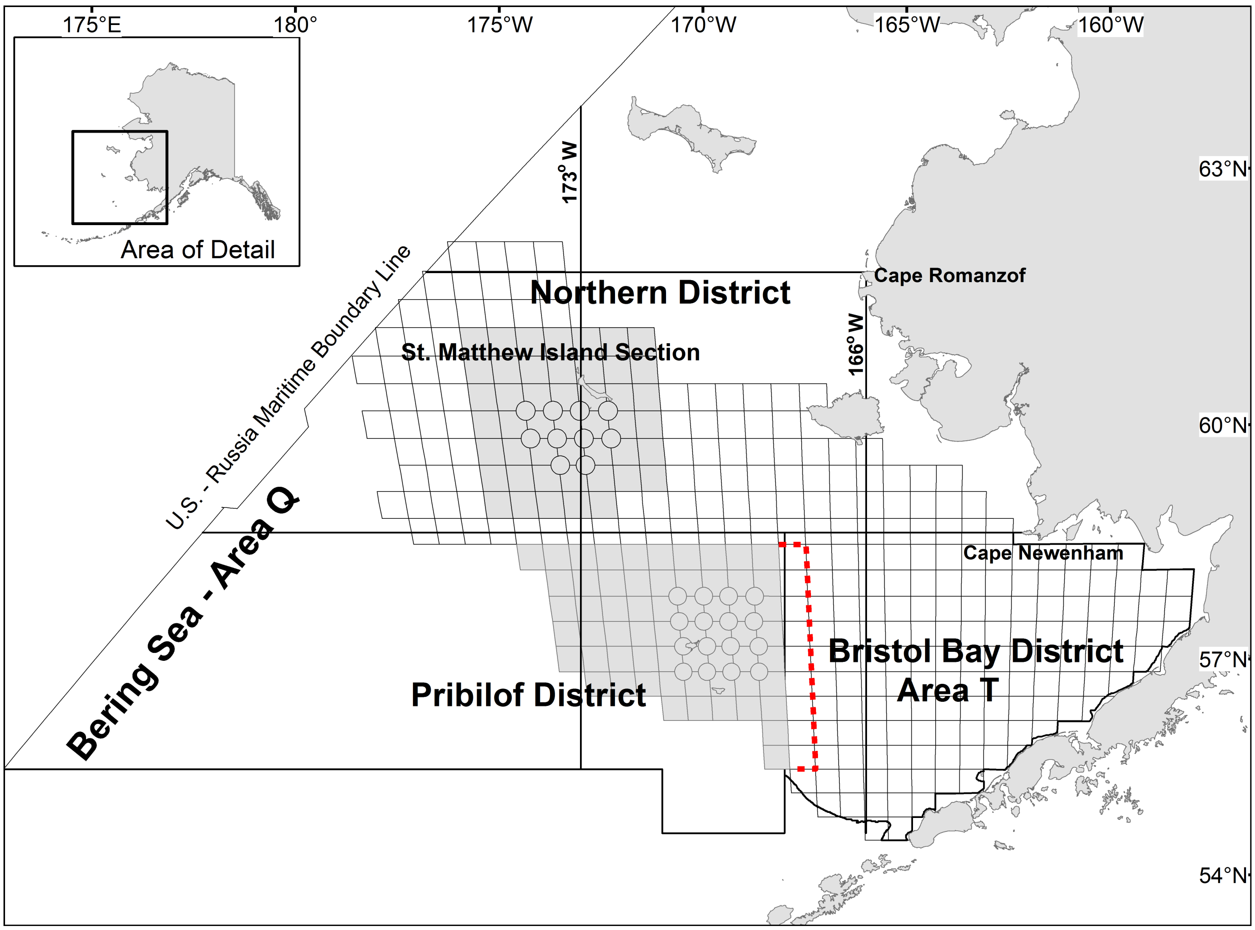

Figure 2: Map of the ADFG King Crab Registration Area Q (Bering Sea), showing (among others) the Pribilof District, which constitutes the stock boundary for PIBKC. The figure also indicates NMFS EBS Shelf survey grid (squares and circles), the original area used to calculate survey biomass and fishery catch data (shded in grey) in the Pribilof District, and the additional 20nm strip (red dotted line) added in 2013 .

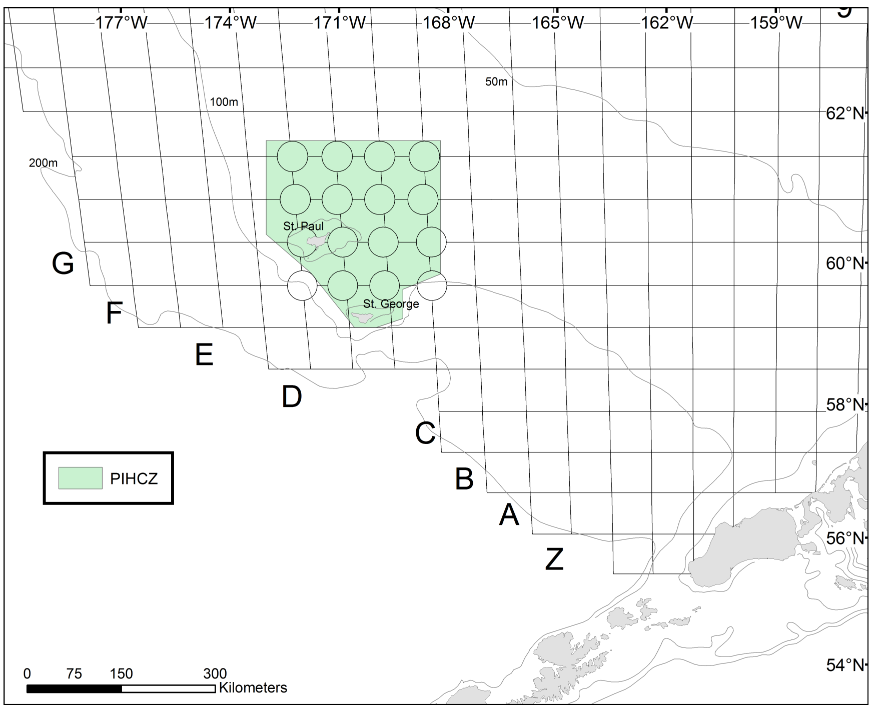

Figure 3: The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid (squares and circles).

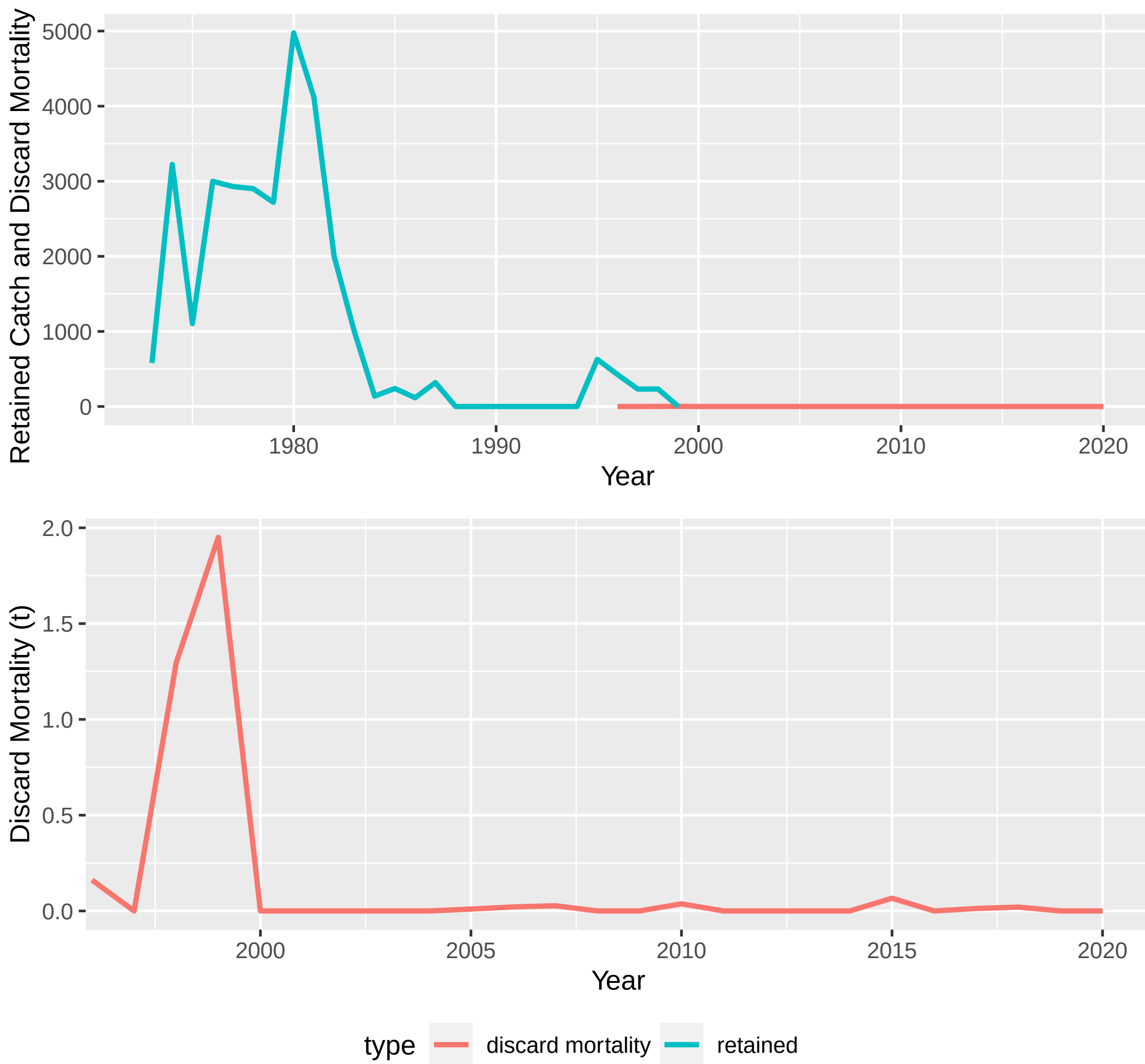

Figure 4: Retained catch and discard mortality, in t, for PIBKC in the crab fisheries. A discard mortality rate of 0.2 was used to convert bycatch biomass to mortality. The lower plot shows discard mortality in the crab fiheries on an expanded y scale to show annual details.

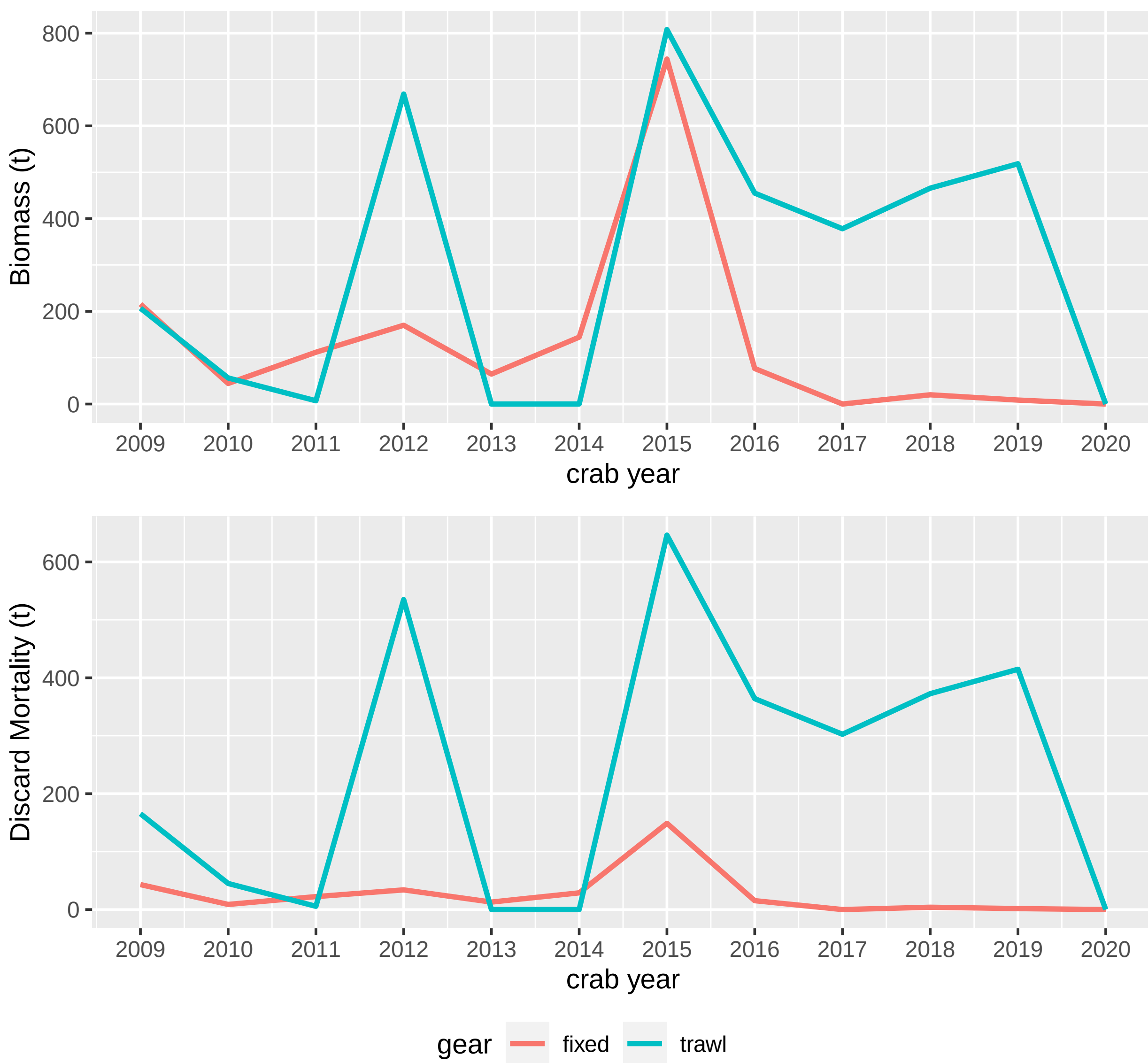

Figure 5: Upper plot: Bycatch of PIBKC in the groundfish fisheries since 2009 by gear type (no mortality applied). Lower plot: Discard mortality of PIBKC in the groundfish fisheries since 2009 by gear type. Gear-specific discard mortality rates of 0.2 and 0.8 were applied to bycatch from fixed and trawl gear, respectively

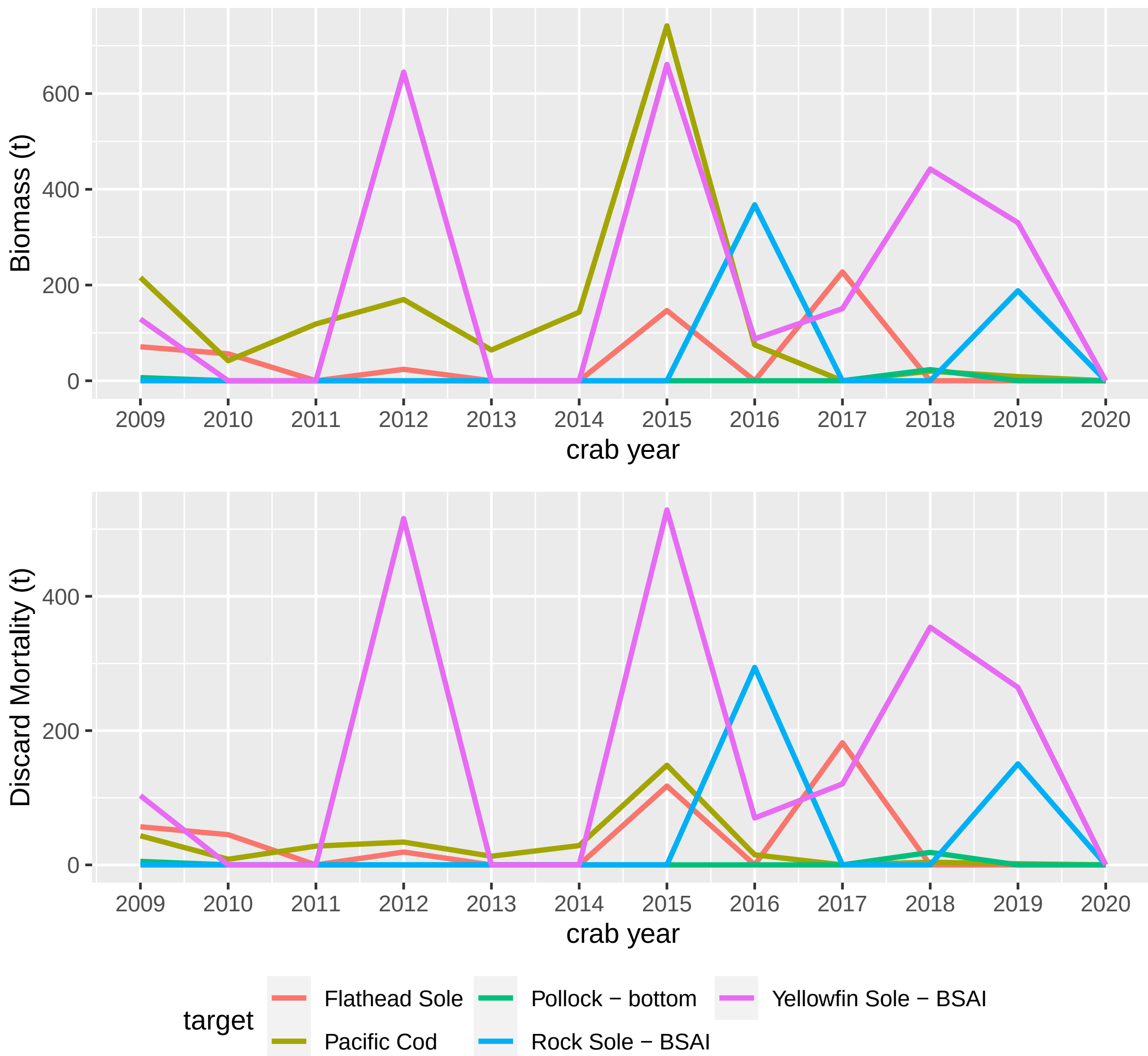

Figure 6: Upper plot: Bycatch of PIBKC in the groundfish fisheries, by target type since 2009. Lower plot: Discard mortality of PIBKC in the groundfish fisheries, by target type since 2009.Gear-specific discard mortality rates of 0.2 and 0.8 were applied to bycatch from fixed and trawl gear, respectively

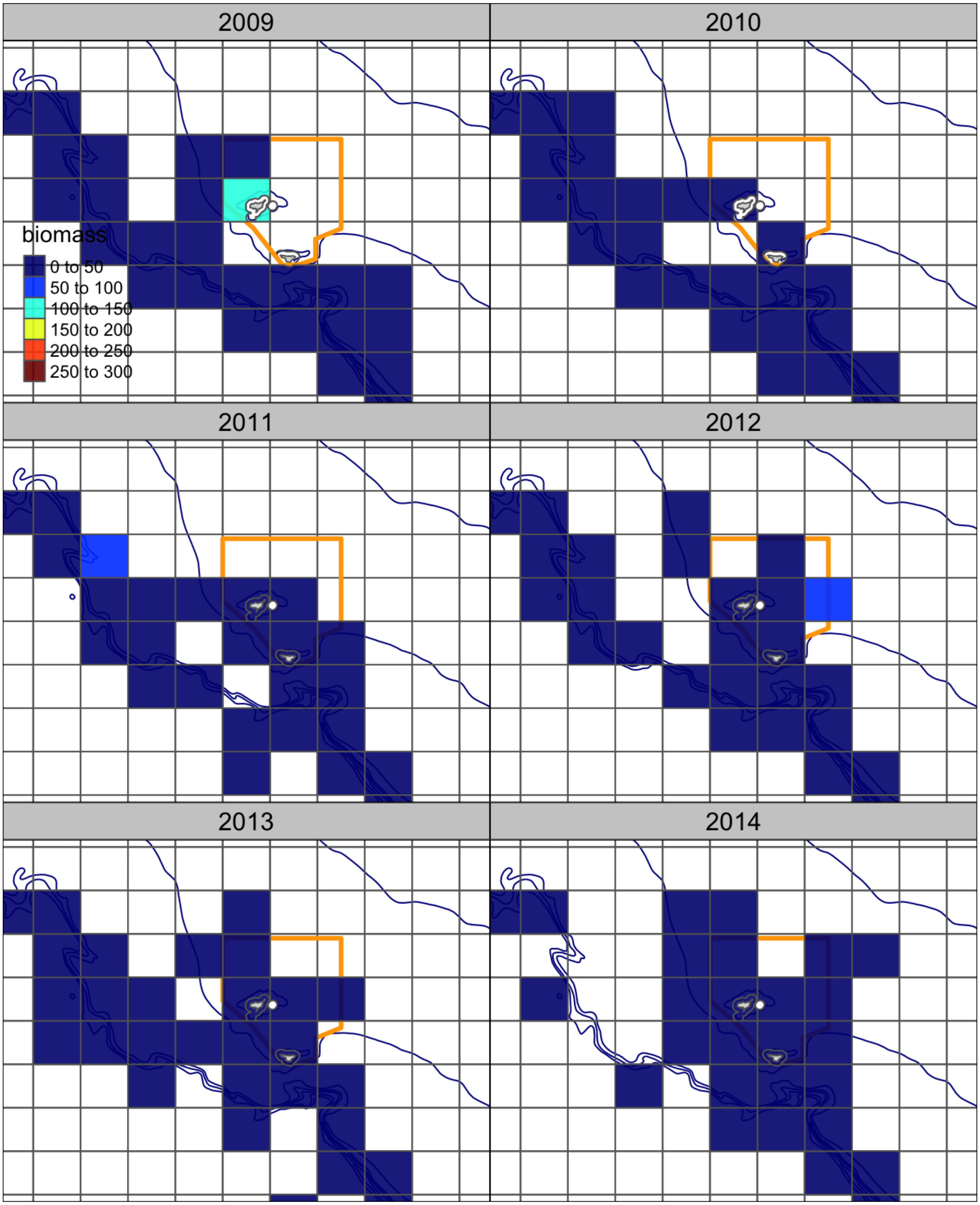

Figure 7: Estimated bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries, expanded from groundfish observer reports. (1 of 2).

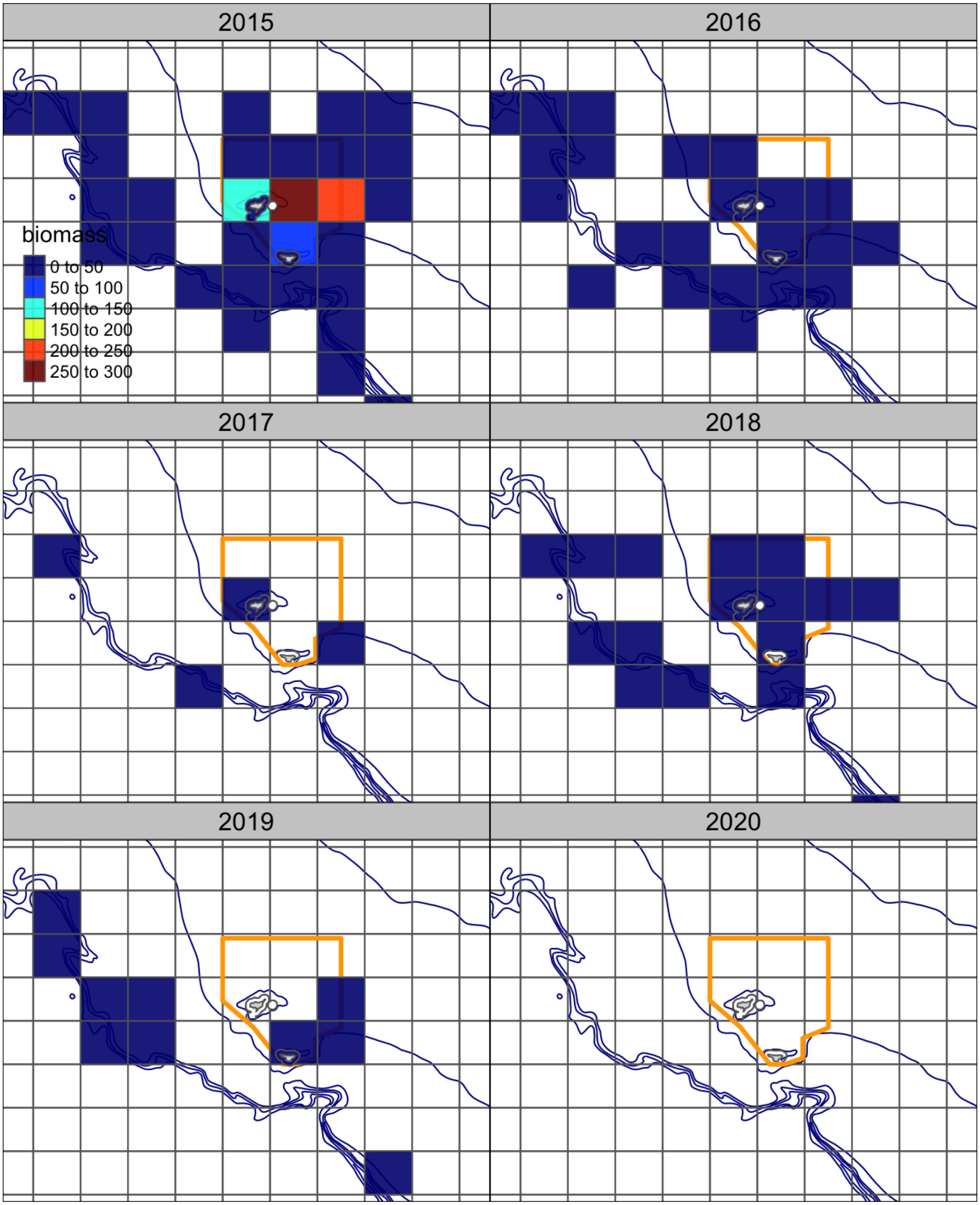

Figure 8: Estimated bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries, expanded from groundfish observer reports. (2 of 2).

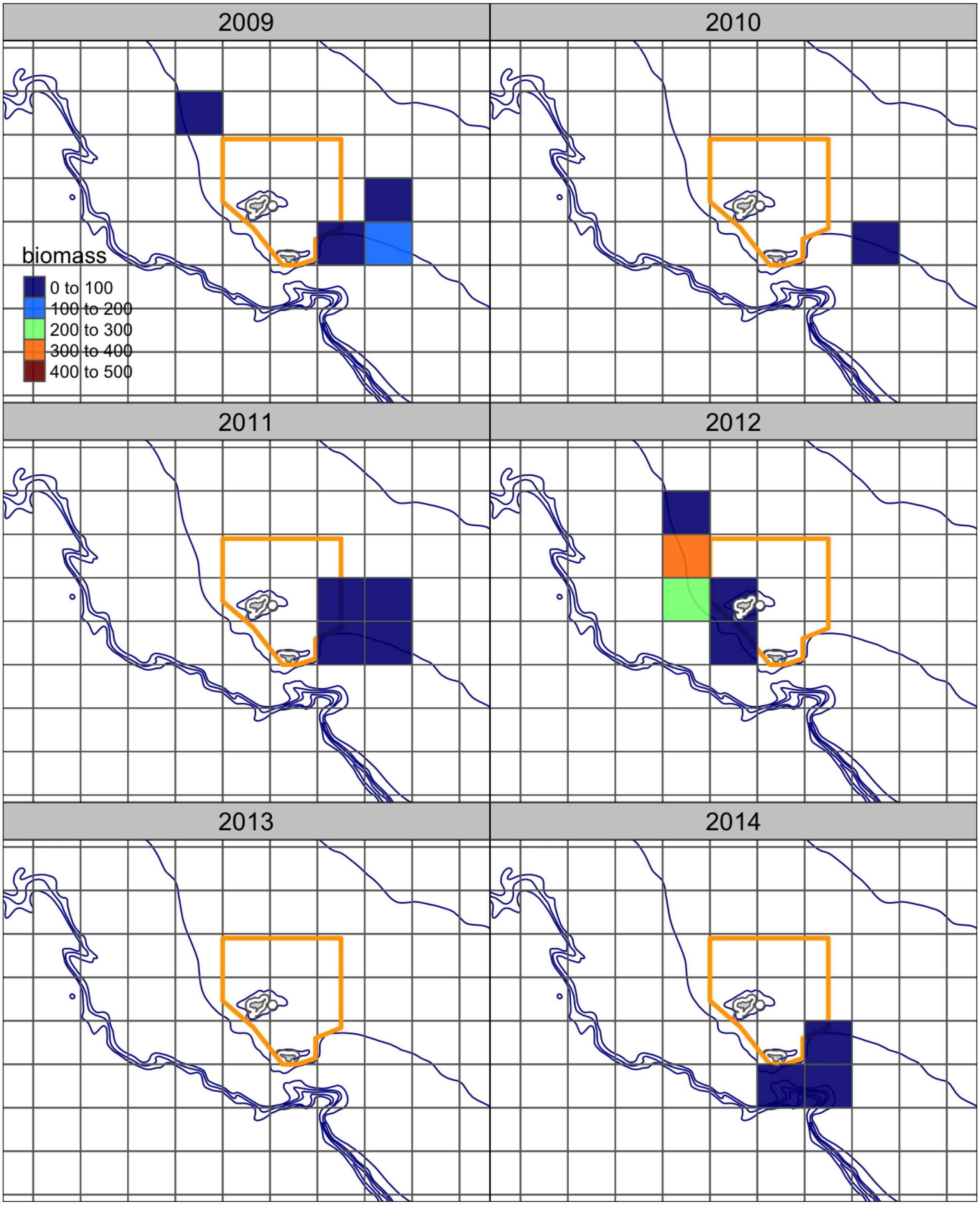

Figure 9: Estimated bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries, expanded from groundfish observer reports. (1 of 2).

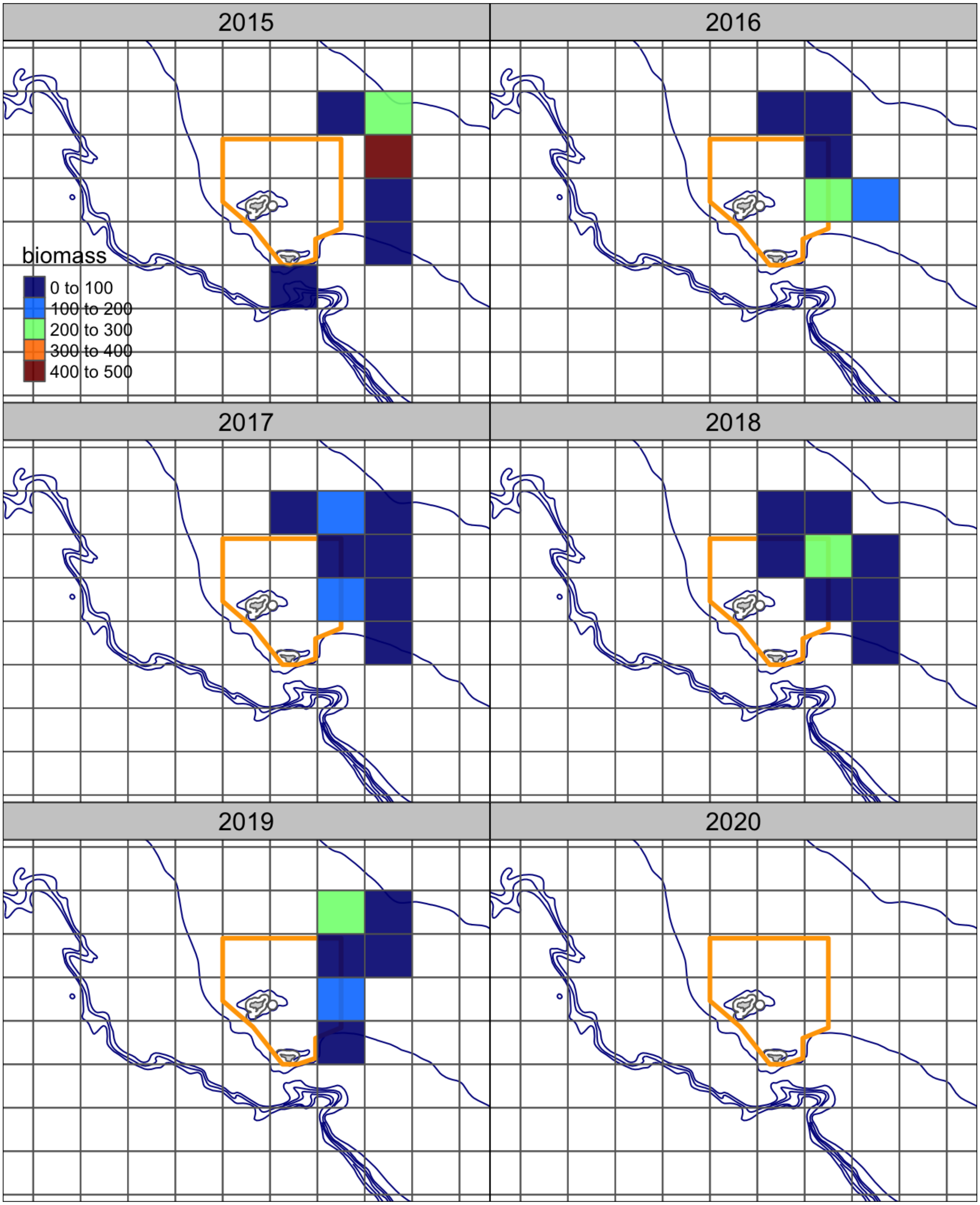

Figure 10: Estimated bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries, expanded from groundfish observer reports. (2 of 2).

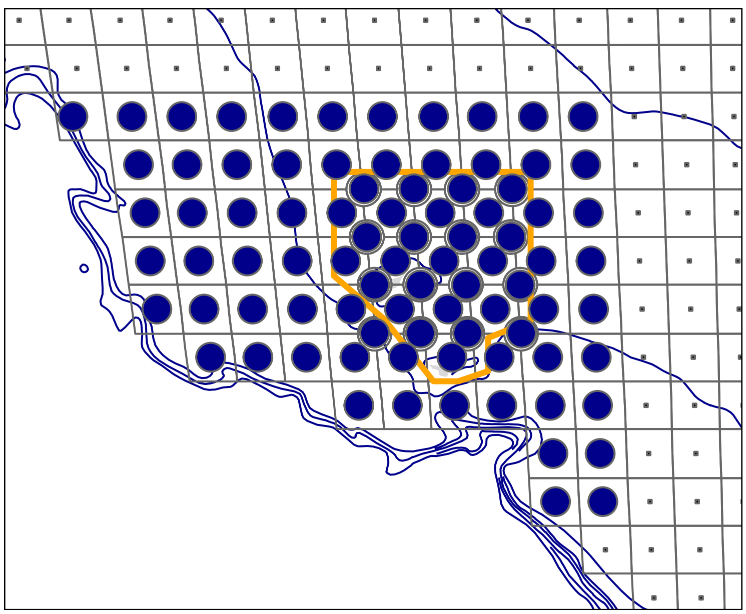

Figure 11: NMFS EBS Shelf Survey stations in the Pribilof District (large dots), the survey station grid (thin black lines), and the Pribilof Islands Habitat Conservation Zone (orange outline).

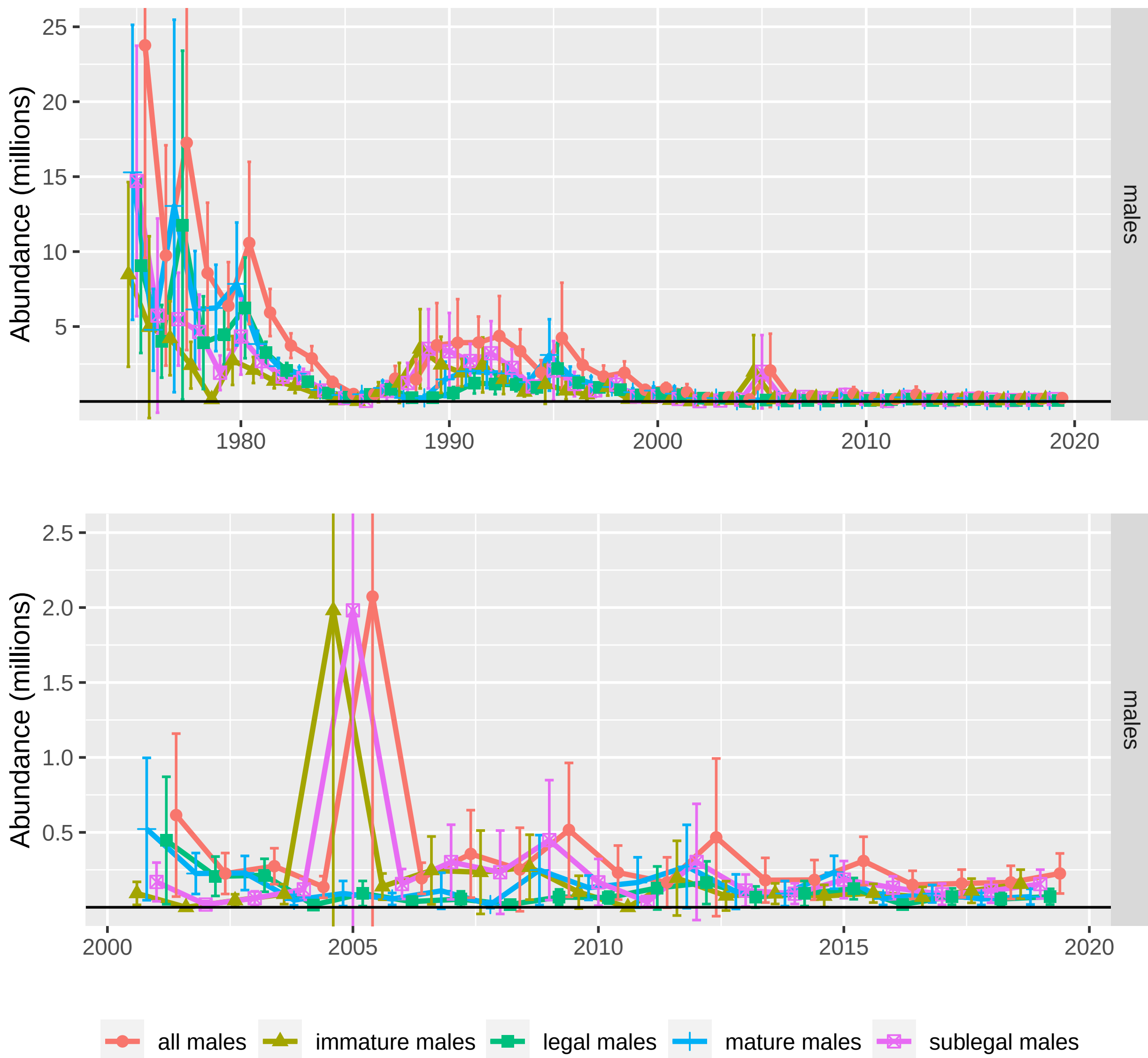

Figure 12: NMFS survey abundance time series for male PIBKC. The upper plot shows the entire time series, the lower plot is since 2001. The y-axis scale on the upper plot is capped at 25 million crab to show variability across most years. The y-axis scale on the lower plot is capped at 2.5 million.

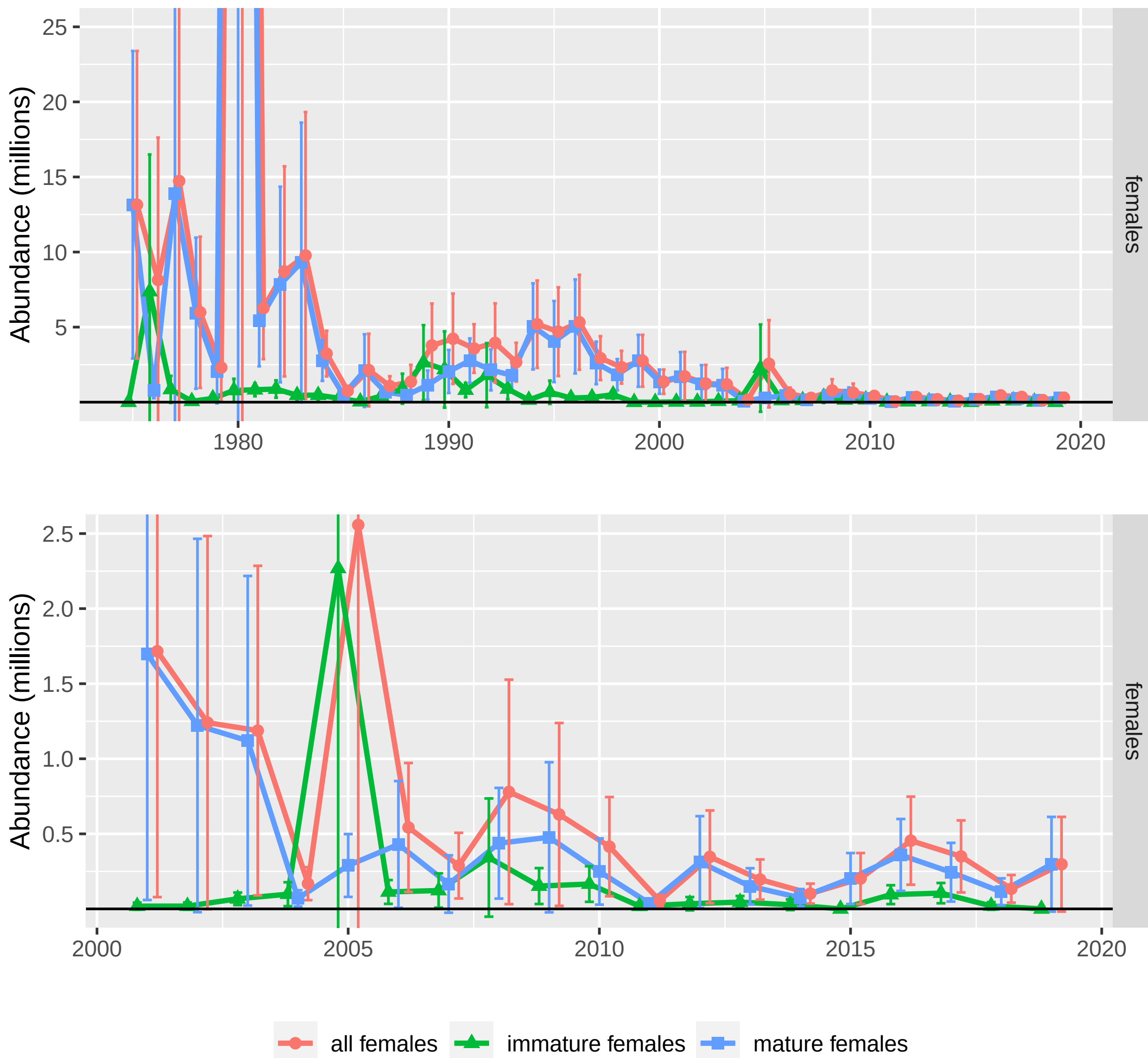

Figure 13: NMFS survey abundance time series for female PIBKC. The upper plot shows the entire time series, the lower plot is since 2001. The y-axis scale on the upper plot is capped at 25 million crab to show variability across most years; the abundance for mature females in 1980 is 182 million. The y-axis scale on the lower plot is capped at 2.5 million.

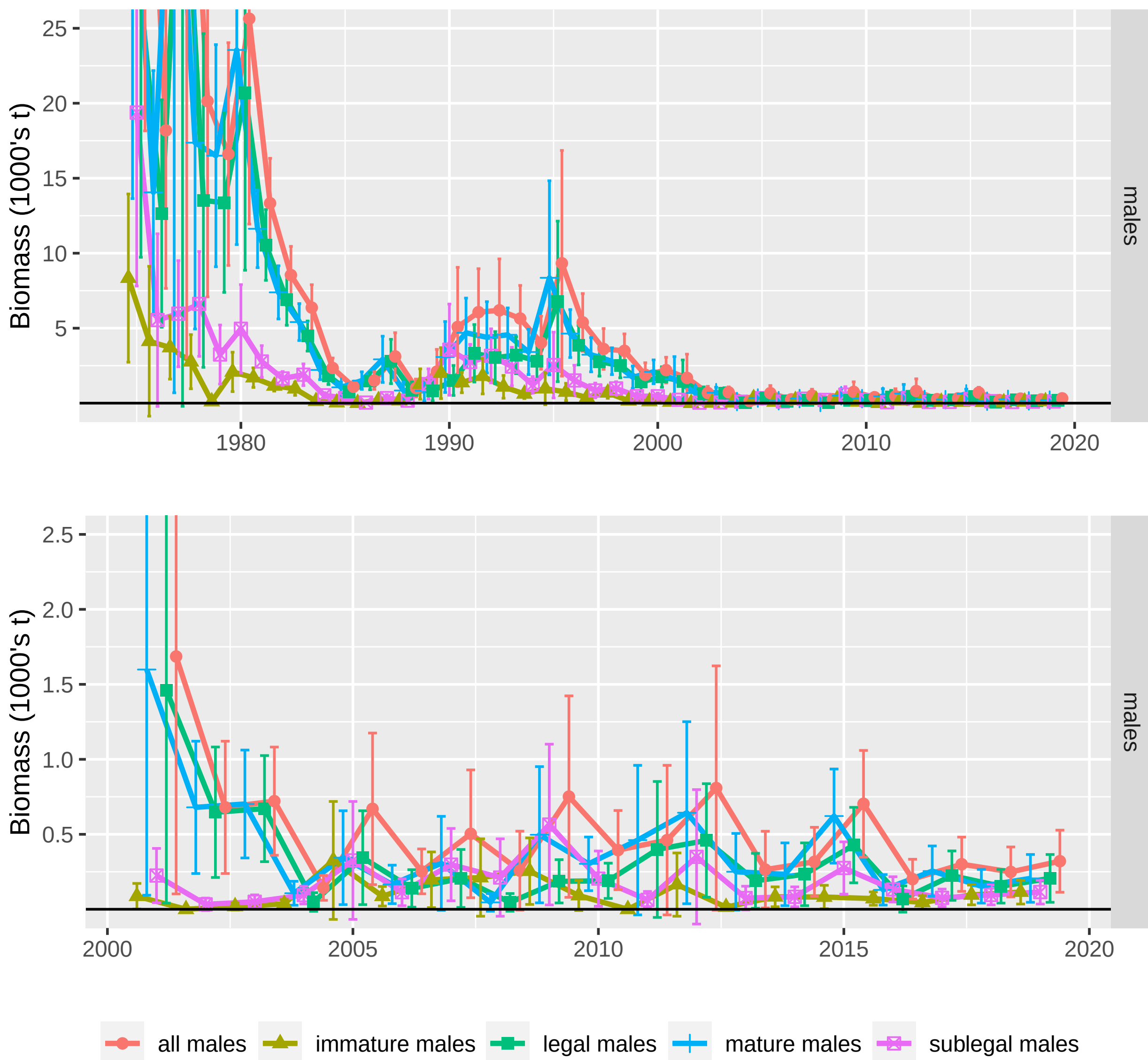

Figure 14: NMFS survey biomass time series for male PIBKC. The upper plot shows the entire time series, the lower plot is since 2001. The y-axis scale on the upper plot is capped at 25,000 t to show variability across most years. The y-axis scale on the lower plot is capped at 2,500 t.

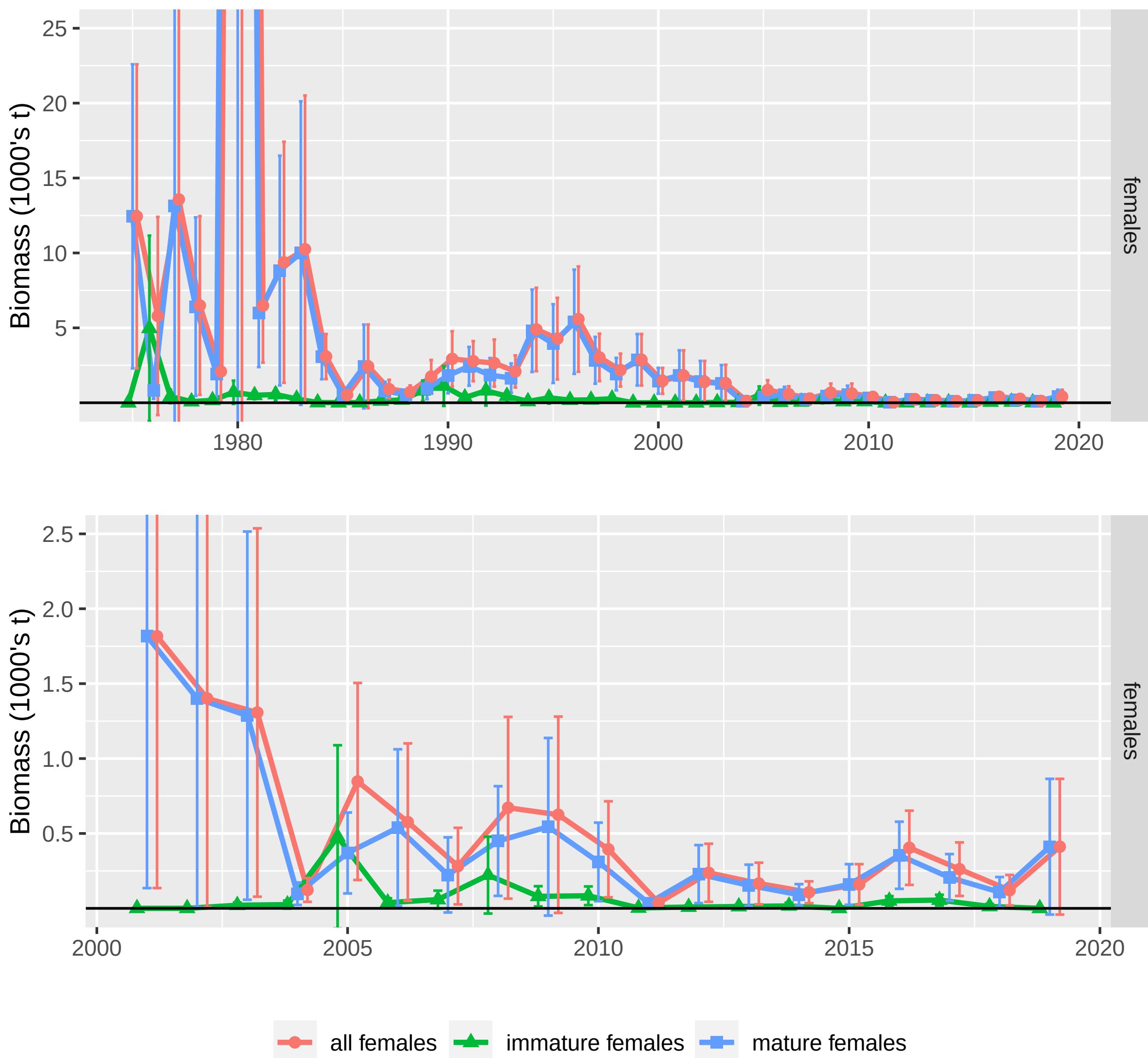

Figure 15: NMFS survey biomass time series for female PIBKC. The upper plot shows the entire time series, the lower plot is since 2001. The y-axis scale on the upper plot is capped at 25,000 t to show variability across most years. The y-axis scale on the lower plot is capped at 2,500 t.

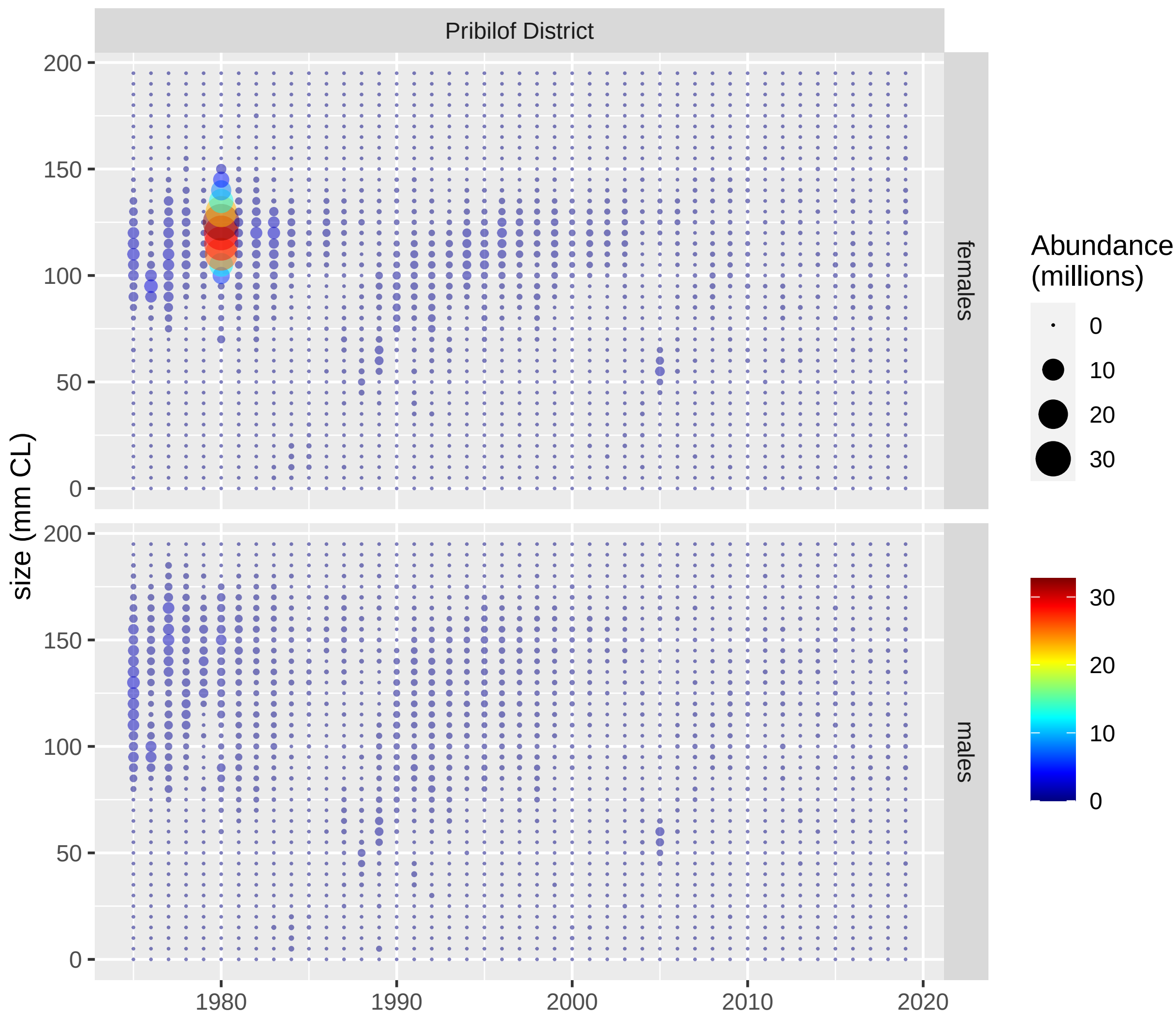

Figure 16: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period.

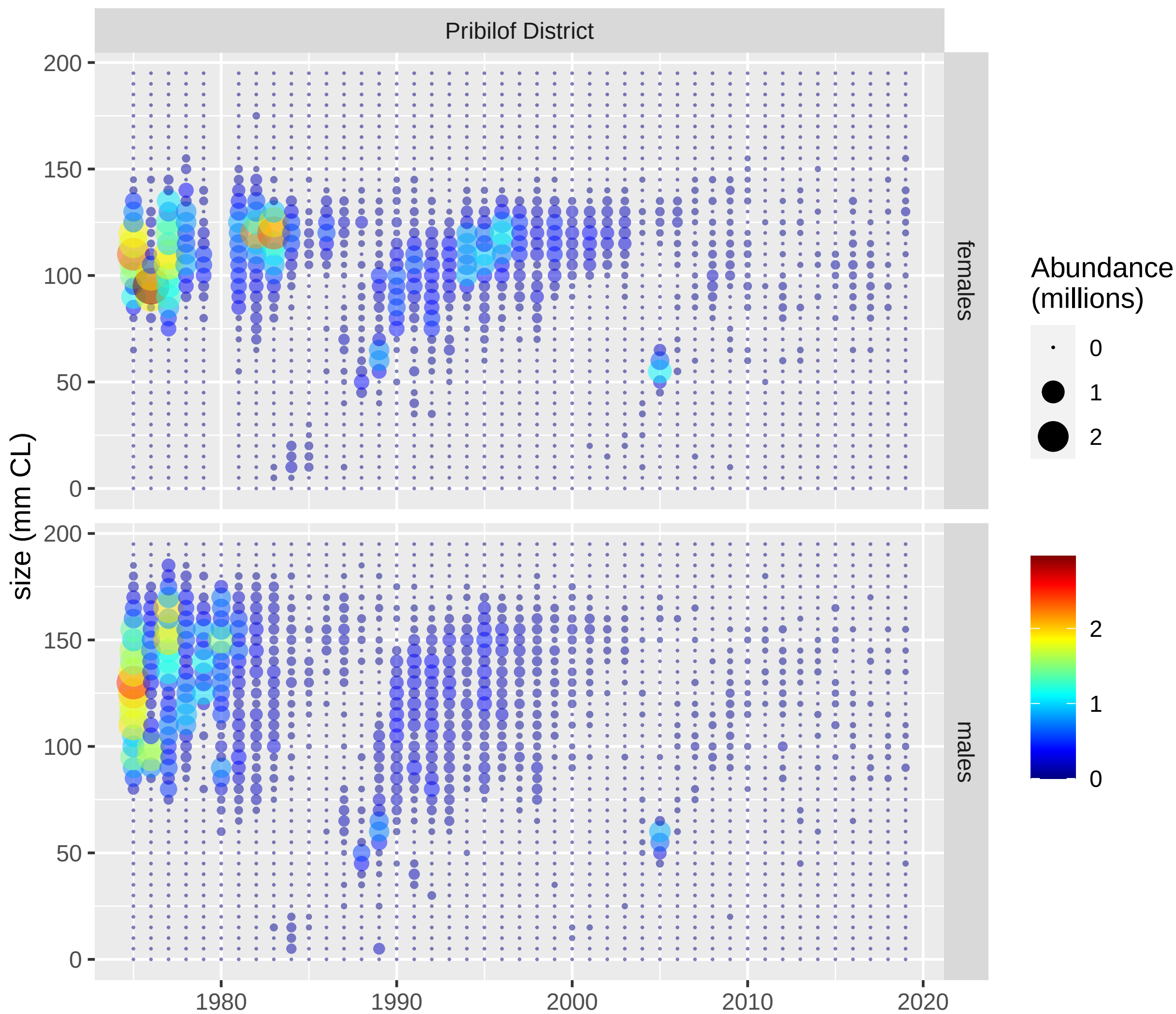

Figure 17: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period, except that females in 1980 have been removed to show detail.

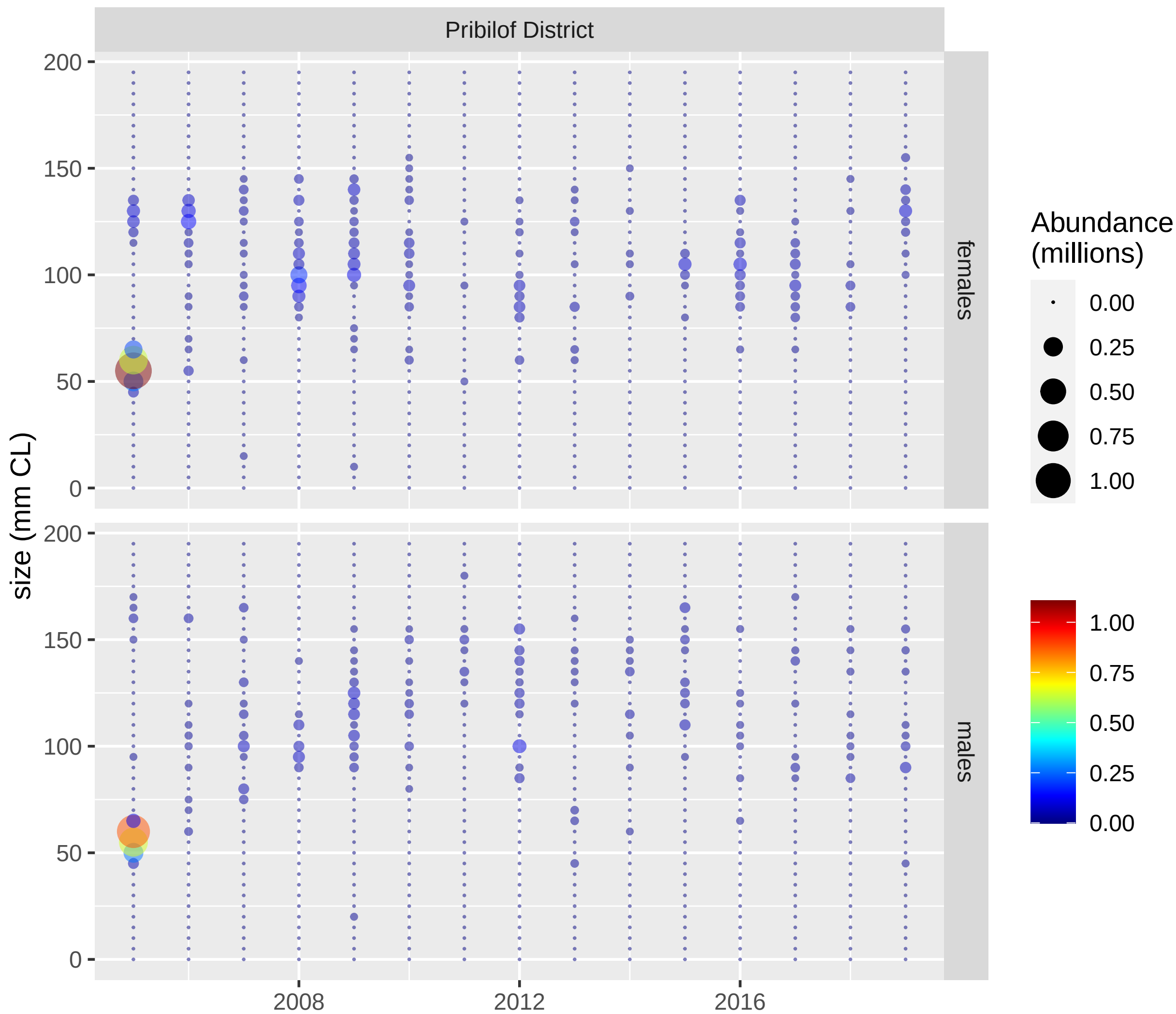

Figure 18: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, since 2005.

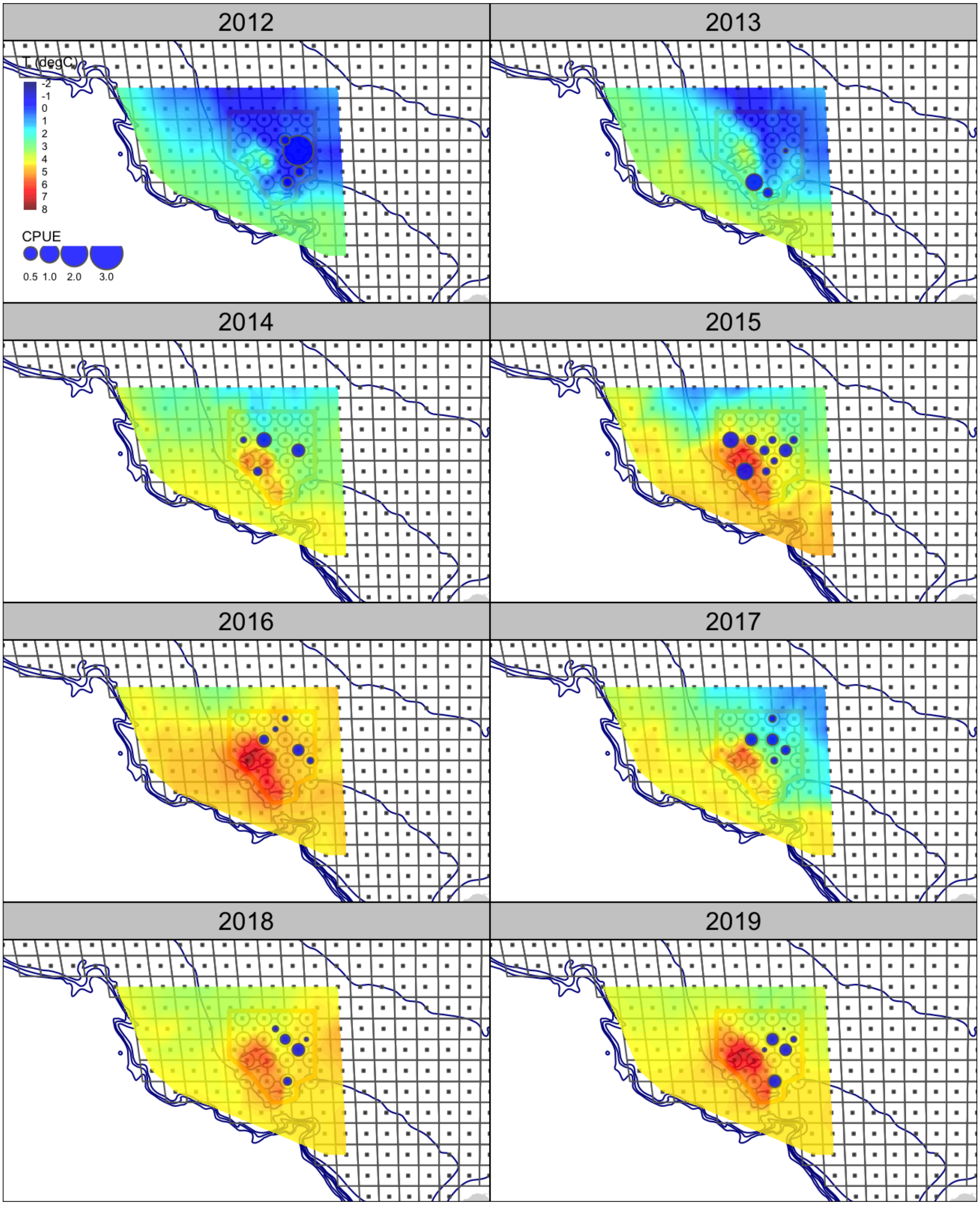

Figure 19: Survey CPUE (t/nmi^2) for PIBKC males. Page 1 of 1.

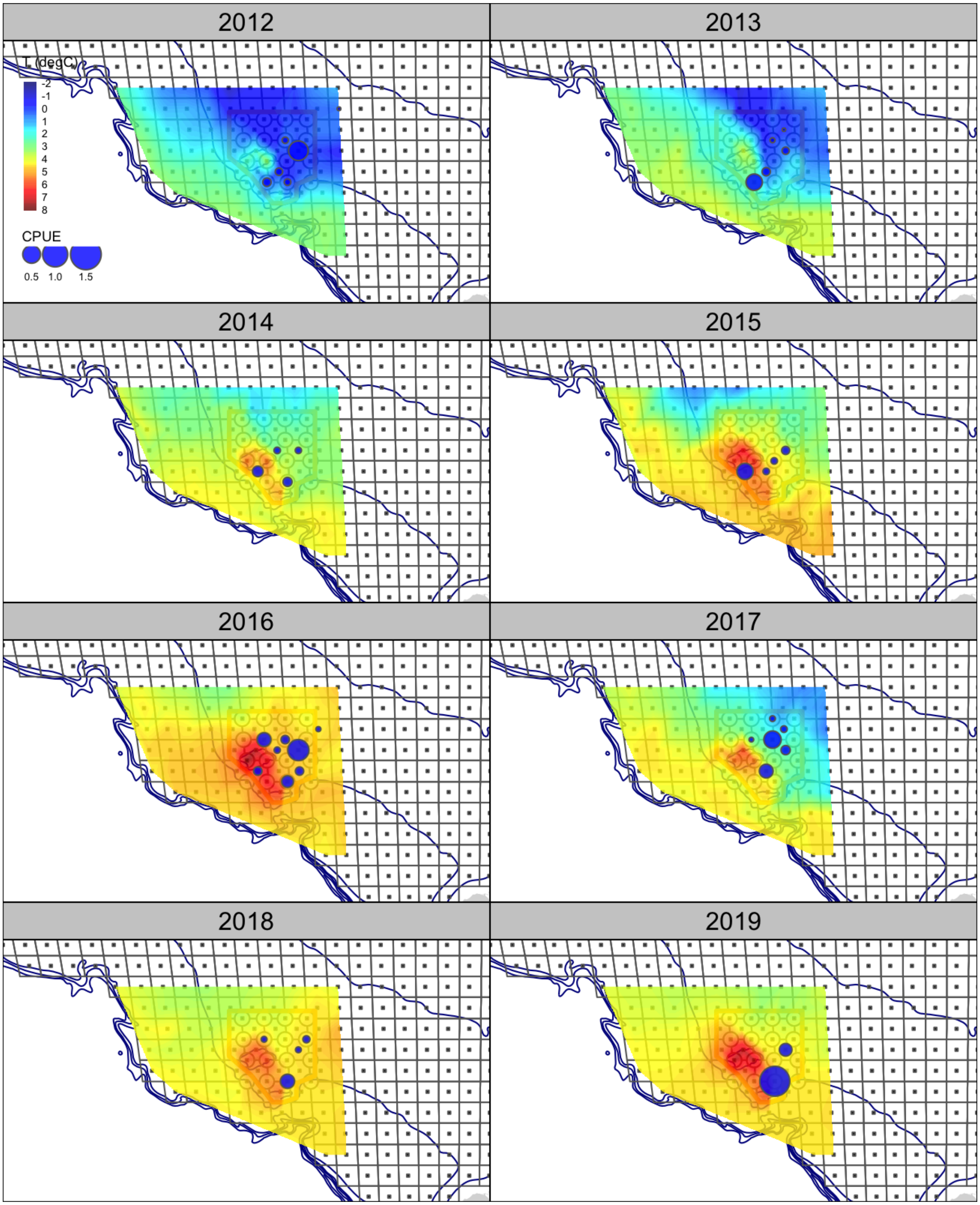

Figure 20: Survey CPUE (t/nmi^2) for PIBKC females. Page 1 of 1.

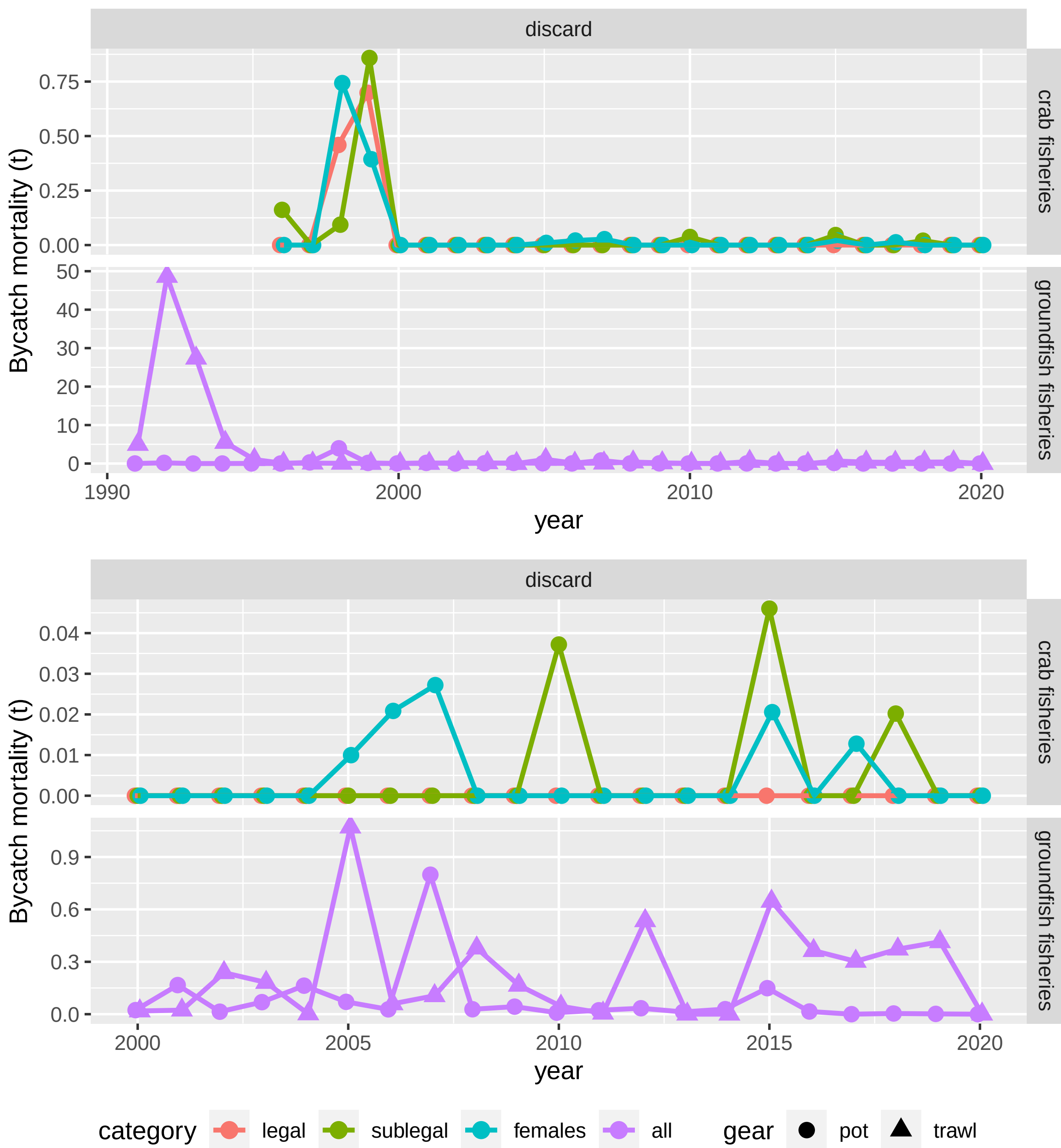

Figure 21: Time series of PIBKC bycatch mortality in the crab and groundfish fisheries. Upper plot: full time series. Lower plot: recent time period. Discard mortality rates of 0.2 and 0.8 were applied to bycatch by pot and trawl gear, respectively.

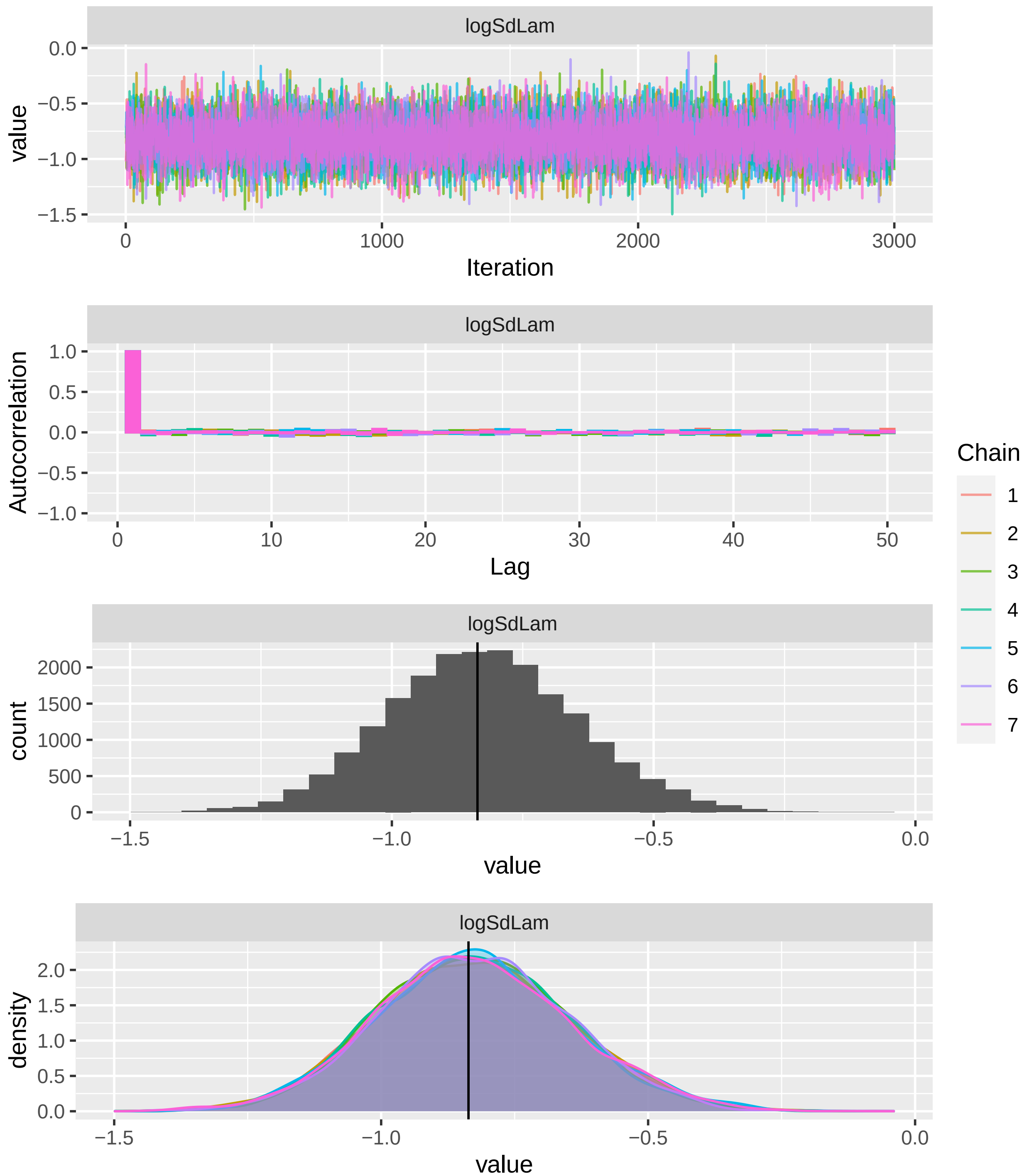

Figure 22: Diagnostic plots for the random effects model, based on 7 MCMC chains run using the R package adnuts (Monahan, 2018; Monahan and Kristensen, 2018). Shown are plots for the ln-scale process error standard deviation ('logSdLam'). Top row: trace plot; upper middle: autocorrelation plot; lower middle: histogram (across all chains); bottom plot: density plots. The vertical black line in the lower two plots represents the converged model parameter estimate.

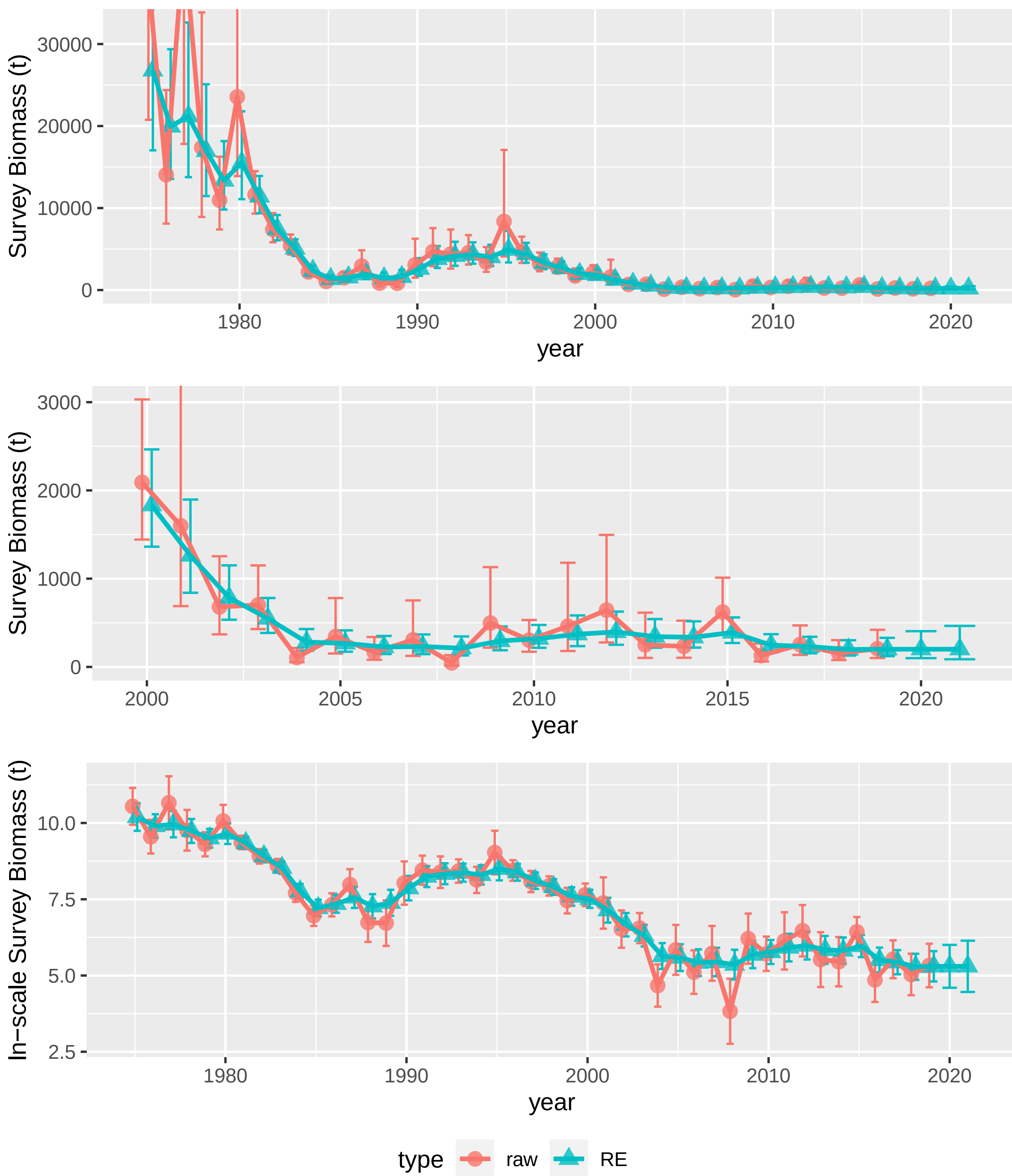

Figure 23: 'Raw' and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The two final smoothed values are 1- and 2-step predictions. Upper plot: arithmetic scale, full time series. Middle plot: arithmetic scale, recent time period. Lower plot: ln-scale.

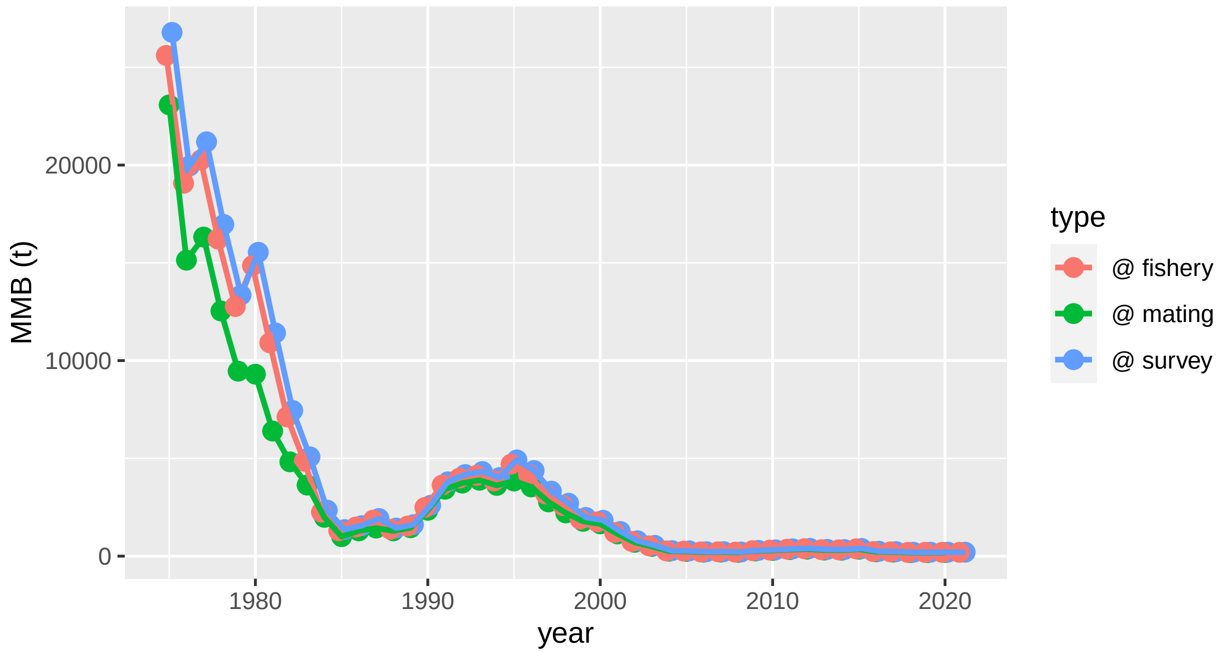

Figure 24: Estimated time series for MMB using the RE method at the time of the survey (the random effects model time series), at the time of the fishery, and at the time of mating. The value for MMB at the time of the survey in this assessment year is a 2-step ahead prediction because the survey was not conducted in 2020 and has not yet been conducted this year. Values for MMB at the time of the fishery and the time of mating are unavailable (projected values for these quantities in the assessment year are determined as part of the OFL calculation).

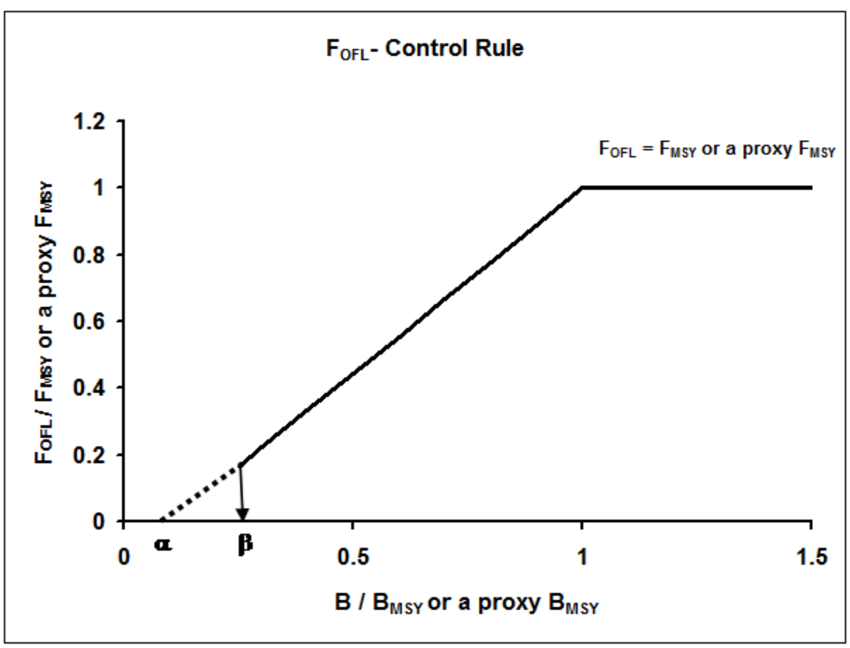

Figure 25: F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).