2023 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

William T. Stockhausen

2023-09-04

1 Executive Summary

1.1 *Stock*

Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*.

1.2 *Catches*

Retained catches have not occurred since 1998/99. Bycatch has been limited in recent years. Bycatch mortality in the crab (e.g., Tanner crab, snow crab) fisheries that incidentally take PIBKC was 0 t in 2022/23; the average discard mortality over the past five years in these fisheries was 0.004 t. Most bycatch mortality for PIBKC occurs in the BSAI groundfish fixed gear (pot and hook-and-line) fisheries (5-year average: 0.012 t) and trawl fisheries (5-year average: 0.218 t). In 2022/23, the estimated PIBKC bycatch mortality was 0.042 t in the groundfish fixed gear fisheries and 0.213 t in the groundfish trawl fisheries. Total fishing mortality in 2022/23 was 0.255 t, while the 5-year average was 0.234 t.

1.3 *Stock biomass*

Based on 5-year running average results from the NMFS EBS Shelf Survey (the time series for PIBKC starts in 1975), estimates of stock biomass were largest in the late 1970s (73,430 t), decreased by an order of magnitude by 2000 (to 3,936 t), and decreased by another order of magnitude by

2015 (577.0 t). Average biomass over the last five years is 453.9 t. Biomass 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. 2023 was the first year in which the NMFS EBS bottom trawl survey failed to catch any mature male crab within the Pribilof Islands stock area.

1.4 *Recruitment*

Recruitment indices (e.g., immature males < 120 mm CL) from the EBS trawl survey are not well understood for PIBKC. Juveniles 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. Immature females have not been caught in the survey since 2018. Two immature males were caught in 2023, but none in 2022.

1.5 *Management performance*

Management quantities related to stock biomass for PIBKC, B and B_{MSY}, are based on mature male biomass-at-mating (MMB). The Minimum Stock Size Threshold (MSST) is defined as $\frac{1}{2}B_{MSY}$: if current B is above the MSST, the stock is not overfished. Management quantities related to fishing mortality are based on total catch (retained + discards) mortality. If total catch mortality is less than the overfishing limit (OFL), then overfishing is not occurring. As summarized in Tables A and B, current B (180.4 t) is below the MSST determined in this assessment (2,098 t) and consequently the stock is overfished. Total catch mortality in 2022/23 (0.255 t) was less than the OFL (1.160 t) so overfishing did not occur in 2022/23.

Table A. Management performance (in metric tons).

Year	MSST	Biomass	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2020/21	2,049	181	closed	0	0	1.16	0.87
2021/22	2,098	235	closed	0	0.102	1.16	0.87
2022/23	2,098	180	closed	0	0.25	1.16	0.87
2023/24	–	181	closed	–	–	1.16	0.87
2024/25	–	181	closed	–	–	1.16	0.87

Table B. Management performance (in millions of pounds).

Year	MSST	Biomass	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2020/21	4.517	0.399	closed	0	0	0.0026	0.0019
2021/22	4.6250	0.5176	closed	0	0.0002	0.0026	0.0019
2022/23	4.6250	0.3978	closed	0	0.000562	0.0026	0.0019
2023/24	–	0.3980	closed	–	–	0.0026	0.0019
2024/25	–	0.3980	closed	–	–	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.

1.6 *Basis for the 2023/24 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 the disjoint time period [1980/81-1984/85, 1990/91-1997/98] is used as a proxy for B_{MSY}. The annual MMB-at-mating time series is estimated using a random walk model to reduce the inter-annual variability and large uncertainties associated with design-based estimates of MMB at the time of the survey. Subsequently, the model-estimated 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 4,196 t. The estimated current MMB-at-mating is 180.4 t. The ratio of current MMB-at-mating to B_{MSY} is less than the value of the F_{OFL} Control Rule parameter β (0.25), so directed fishing is not allowed. The MMB-at-mating for 2023/24 is 180.5 t, projected from the random walk model estimate of 2023 survey MMB to the time of mating (Feb. 15, 2024) based on natural mortality, assumptions regarding discard mortality in 2023/24, and the F_{OFL} control rule.

As per the rebuilding plan (Foy et al. 2014), 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 1.160 t for 2023/24.

Table C. Basis for the OFL (in metric tons).

Year	Tier	B_{MSY}	B	B/B_{MSY}	γ	Years to define B_{MSY}	M	P*
2019/20	4c	4,099	180	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2020/21	4c	4,099	181	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2021/22	4c	4,099	180	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2022/23	4c	4,099	180	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2023/24	4c	4,196	181	0.043	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer

Table D. Basis for the OFL (in millions of pounds).

Year	Tier	B_{MSY}	B	B/B_{MSY}	γ	Years to define B_{MSY}	M	P*
2019/20	4c	9.052	0.3976	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2020/21	4c	9.052	0.3981	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2021/22	4c	9.037	0.3976	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2022/23	4c	9.037	0.3976	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2023/24	4c	9.2500	0.3980	0.043	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer

1.7 *Probability density function for the OFL*

Not applicable for this stock.

1.8 *ABC*

The ABC was calculated using a 25% buffer on the OFL, as in assessments since 2015 (Stockhausen 2015). Thus, the ABC is 0.870 t (= 0.75 x 1.160 t).

1.9 *Rebuilding analyses results summary*

The stock has been overfished since 2002; a rebuilding plan was implemented in 2004 and revised in 2014. The revised rebuilding plan does not have a target rebuild date and NMFS cannot predict when or if rebuilding will occur. The 2023/24 stock assessment shows this stock is still overfished. The causes of the continued low abundance and failure to recover are not well-understood, but are thought to be predominantly due to environmental changes that inhibit recruitment. In April 2022, the Regional Administrator made the determination that PIBKC is "not making inadequate progress" towards rebuilding.

2 Summary of Major Changes

2.1 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 (NPFMC 2021). 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.

Full assessments for the PIBKC are conducted on a biennial (odd years) basis. The 2021 assessment (Stockhausen 2021) was conducted in May, prior to the 2021 NMFS EBS shelf survey and the completion of the crab year (July 1-June 30). The timing of the assessment was subsequently changed to September in order to be able to incorporate the current year's EBS shelf survey and bycatch data for the complete crab year. This assessment was completed in September, 2023.

2.2 2. Input data

Retained and discard catch time series were updated with data from the crab and groundfish fisheries for 2020/21-2022/23. Abundance and biomass data for PIBKC in the annual summer NMFS EBS bottom trawl surveys were added for the 2021-2023 NMFS EBS Shelf Bottom Trawl Surveys. The NMFS trawl survey was not conducted in 2020.

2.3 3. Assessment methodology

Since the 2017 assessment, PIBKC was moved to a triennial schedule for full assessments following stock prioritization (Stockhausen 2017). In 2018, a partial assessment was conducted in 2018 (Stockhausen 2018) to determine whether overfishing occurred in the previous year. However, the NMFS Alaska Regional Office (AKRO) noted, however, that there was a biennial requirement to review the rebuilding status for PIBKC and that the assessment and rebuilding review should occur on the same biennial basis. Consequently, the 2019 and 2021 assessments were full assessments (Stockhausen 2019, 2021). However, the timing for the 2021 full assessment was changed from September to May. This change required the use of several estimates for quantities used in the assessment model, including 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 were not available for the 2021 assessment, and a value projected by the random walk model used to estimate the survey MMB time series was used as a substitute to calculate MMB-at-mating for the 2021 assessment year. The directed fishery was closed in 2021/22 and thus there would be no retained catch or bycatch associated with it. However, the Tanner crab (*Chionoecetes bairdi*), snow crab (*C. opilio*), and groundfish fisheries were still being prosecuted at the time the 2021 assessment was conducted, necessitating the use of estimates for the bycatch in these fisheries. To avoid these complications in the future, the assessment was moved back to September for the 2023 assessment.

The methodology this year is the same as in the 2021 assessment, although the modeling used to estimate the random walk model for survey MMB was changed from a bespoke ADMB model to the R software *rema* package (R Core Team 2022; Sullivan 2022), which uses TMB (Kristensen et al. 2016) for optimizing the fit of the model to the data. The Tier 4 approach used in this assessment for status determination is identical to that adopted by the CPT and SSC in 2015 and used in subsequent assessments (Stockhausen 2015, 2016, 2017, 2019, 2021).

2.4 4. Assessment results

Overfishing did not occur in 2022/23. B_{MSY} increased to 4,196 t from the previous assessment (4,099 t) while the projected MMB-at-mating for 2023/24 (180.5 t) remained similar to the previous assessment (180.4 t). Stock status did not change: the stock remains in Tier 4c. The stock remains overfished and a directed fishery is prohibited in 2023/24. The recommended OFL (based on average catch), the ABC buffer, and the ABC are identical to last year's values (1.160 t, 0.25, and 0.870 t, respectively).

3 Responses to SSC and CPT Comments

3.1 Remarks pertinent to this assessment

3.1.1 CPT comments May 2023:

CPT comment

The CPT agreed (following the author's recommendation) with the change to use the **rema** R package for the assessment.

Author response

The *rema* R package, which underwent a favorable Center for Independent Experts (CIE) review during 2023, has been used to fit the random walk model to design-based estimates of MMB at the time of the survey.

3.1.2 SSC comments June 2023:

SSC Comment

The SSC concurs with the author and CPT recommended application of the **rema** R package for this Tier 4 assessment.

Author response

See Section 3.1.1.

SSC Comment

The SSC also looks forward to the SAFE section on rebuilding in September as the rebuilding plan nears its second decade.

Author response

The revised (2014) rebuilding plan does not have a target rebuild date and NMFS cannot predict when or if rebuilding will occur (NPFMC 2021). There is no new and unexpected information that would significantly alter the rebuilding expectations. The recent trajectory of the time series of MMB-at-survey time provides no evidence of an increasing trend. Further, survey size compositions provide no evidence for recent recruitment to the stock. The failure of the EBS shelf survey to catch any mature males this year does not raise the level of concern for this stock above what it has been in the recent past; the survey does not target blue king crab and the result is consistent with sampling a population at low (but non-zero) abundance. The causes of the continued low abundance and failure to recover are not well understood, but are thought to be predominantly due to environmental changes that inhibit recruitment. In April 2022, the last time a determination of overfished status was made was made, the Regional Administrator determined that PIBKC was "not making inadequate progress" towards rebuilding.

3.1.3 CPT comments September 2022:

None

3.1.4 SSC comments October 2022:

None

3.1.5 CPT comments May 2022:

None

3.1.6 SSC comments June 2022:

None

3.1.7 CPT comments September 2021:

None

3.1.8 SSC comments October 2021:

None

3.1.9 CPT comments May 2021:

CPT Comment

The CPT discussed the SAFE stock specification table with respect to PIBKC being a biennial assessment and whether the assessment should be brought back to a September CPT meeting cycle in order to fully account for any bycatch that occurs through the end of June. The advantages of an assessment review in September assessment are that the most recent survey and bycatch data through the end of the June fishing year would be available, and there would be no need to revise the assessment with the final catches. The disadvantage is that it would add incrementally to the September workload, both for the assessment author and CPT. It was noted that the September workload has been reduced during odd years by shifting the SMBKC assessment to a biennial cycle. Therefore the CPT recommends that future PIBKC assessments (starting in 2023) should be conducted for September meetings.

Author response

As recommended, this assessment was conducted for the September 2023 meeting.

CPT Comment

The CPT recommends exploring VAST for the PIBKC assessment.

Author response

As the CPT itself noted, "using VAST may be problematic when very small numbers of animals are caught at only a handful of stations (as with PIBKC)" and "biomass estimates from VAST may not be reliable, and estimated confidence intervals may be even less so". Consequently, this request was given a low priority (potential VAST applications in the Tanner crab assessment were addressed instead) and has not yet been addressed.

CPT Comment

The CPT recommends "…exploring smoothing the survey point-estimate CVs (e.g., apply median CV for all years)".

Author response

The random walk model implemented using the *rema* R package incorporates the annual variability in survey point estimates in a statistically-appropriate manner. Consequently, this recommendation has not been addressed.

3.1.10 SSC comments June 2021:

SSC comment (general)

Crab assessments should generally follow the default groundfish practice of projecting the current year's catches if one or more fisheries are incomplete at the time of the assessment.

Author response

Now that the PIBKC assessment is again conducted for September/October, this is no longer an issue for this assessment.

SSC Comment

The SSC supports the CPT recommendation to move the timing of the PIBKC assessment back to September for the CPT.

Author response

As recommended, this assessment was conducted for the September 2023 meeting.

SSC comment

The SSC looks forward to the report on the blue king crab stock structure template in the near future.

Author response

Staff capacity has not permitted progress on this request.

4 Introduction

4.1 Stock

Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*.

4.2 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 crab are found in widely-separated populations across the North Pacific (Figure 1). In the western Pacific, blue king crab 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).

4.3 Stock structure

The 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 during 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 was addressed in a previous assessment (Foy 2013). (Foy 2013) compared the spatial extent of both species 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 (numbering 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-occurence 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), PIBKC were managed by ADFG under the Bering Sea king crab Registration Area Q Pribilof District [ADFG (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 as shown 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.

4.4 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; Jensen et al. 1985; Somerton and MacIntosh 1985; Jensen and Armstrong 1989; Selin and A.Fedotov 1996). Blue king crab fecundity increases with size, from approximately 100,000 embryos for a 100-110 mm carapace length (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) and Armstrong et al. (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 a 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 crab 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 that 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 M.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 search 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 crab 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 CL and size at maturity for males, estimated from chela height relative to carapace length, is estimated to be 108-mm CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for 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.

4.5 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 2014; Stockhausen 2021). Bottom trawl gear and pot fishing for Pacific cod are currently excluded from the Pribilof Islands Habitat Conservation Zone (PIHCZ, Figure 3) to minimize 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 580 t by eight vessels (Table 1; Figure 4). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season (Table 1; Figure 4), with an associated increase in effort to 110 vessels (ADFG 2008). The fishery occurred September through January, but usually lasted less than six 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 estimated abundance of mature males or 20 percent of the estimated number of legal males (ADFG 2008).

PIBKC occasionally occur as bycatch in the eastern Bering Sea snow crab fishery, the western Bering Sea Tanner crab fishery, the Bering Sea hair crab (*Erimacrus isenbeckii*) fishery, and the

Pribilof red and blue king crab fisheries. In addition, blue king crab are taken as bycatch in groundfish fisheries by both fixed and trawl gear, primarily those targeting Pacific cod, flathead sole and yellowfin sole (Tables 3-6).

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), considering environmental conditions and the status and population biology of the stock (NPFMC 2014).

5 Data

5.1 Summary of new information

The time series of retained and discarded catch in the crab fisheries was updated for 2020/21 -2022/23from ADFG data (B. Daly, ADFG, pers. comm.): there was no retained catch and no observed (and thus no expanded) bycatch in any of these years. Similarly, the time series of PIBKC bycatch in the groundfish fisheries was updated for the past three fishing years using data served by AKFIN from the AKRO's Catch-in-Areas database: total (expanded) bycatch was 0.007 t and total mortality was 0.001 t in 2020/21, 0.139 t and 0.093 t in 2021/22, and 0.476 t and 0.255 t in 2022/23, respectively.

The survey MMB time series and related data for PIBKC were updated with results from the 2021-2023 NMFS EBS shelf bottom trawl surveys. Design-based estimates of survey MMB were 0.405 t in 9, 0.112 t in 2, and 0 t in 0. The corresponding numbers of mature males caught in the survey were 9, 2, and 0.

5.2 Crab fisheries

5.2.1 Retained catch

The directed fishery has been closed since 1999/2000. Historical retained catch data (Table 1, 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 allowed during the 2023/24 crab fishing season.

5.2.2 Bycatch and discard mortality

Estimates for annual bycatch of PIBKC in the crab fisheries is provided by ADFG for sublegal males (< 138 mm CL), legal males (≥ 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 2 and Figure 4), although data may be incomplete for some of these fisheries. Prior to 1998/99, observer data exist only for catcher-processor vessels, so discarded catch before this date are not included here. Catch weight was calculated by first determining the mean weight for crabs in the 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.

As in the previous assessment (Stockhausen 2021), a 20% handling mortality rate was applied to the bycatch estimates to calculate discard mortality on PIBKC in these pot fisheries. 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 2016). Estimates of bycatch and discard mortality (Table 2 and Figure 4) reached a maximum of 1.950 t for discard mortality by 1999/00, after which they decline to near zero, with an average over the last five years for discard mortality of only 0.004 t.

For 2022/23, discard mortality in the crab fisheries was 0 t (Ben Daly, ADFG, pers. comm. July 6, 2023).

5.3 Bycatch in the groundfish fisheries

Bycatch estimates of PIBKC in the groundfish fisheries are based on groundfish observer data sampling expanded to total catch. Historical estimates beginning in 1996 are available to 2009 from AKFIN using results from the old Catch Accounting System database. This data is limited in its spatial resolution to NMFS statistical areas, which do not conform to the PIBKC stock area. As with previous assessments, estimates of blue king crab bycatch in the groundfish fisheries from NMFS statistical area 513 are assumed to account for bycatch within the PIBKC stock area. More recent estimates, 2008-present, are available from AKFIN using results from the AKRO's Catch-In-Areas database, which provides standardized spatial resolution using ADFG statistical areas (among other improvements over the older Catch Accounting System). 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.

Here, bycatch in the groundfish fisheries during 1991/92-2022/23 is documented. The data was downloaded from AKFIN on July 20, 2023 for the current assessment. In order to apply gear-specific discard mortality rates to the bycatch data, trawl gear types (pelagic and non-pelagic) have been aggregated as "trawl" gear, while hook-and-line (longline) and pot gear have been aggregated as "fixed" gear. As in previous assessments, discard mortality rates of 0.2 and 0.8 have subsequently been applied by gear type (fixed and trawl, respectively) to the estimated bycatch biomass to estimate fishing-related mortality for the discarded crab (Stockhausen 2021). Since 2009/10, the maximum annual bycatch of PIBKC in the groundfish fisheries was 1.552 t in 2015/16, while the maximum total discard mortality was 0.795 t in 2015/16. In contrast, the average rate of bycatch over the last 5 years is 0.166 t, while the average discard mortality is 0.115 t.

5.3.1 Bycatch by gear type

Annual estimates of bycatch abundance, biomass, and discard mortality of PIBKC in the groundfish fisheries are presented in Table 3 and Figures 5 and 6 by (aggregated) gear type. In general, trawl gear takes more PIBKC than fixed gear, and with higher mortality, although exceptions occur (e.g., 2011/12, 2013/14, 2014/15). The average mortality on PIBKC taken by trawl gear over the last five years is 0.218 t while that taken by fixed gear is 0.012 t.

5.3.2 Bycatch by target type

Annual estimates of bycatch abundance, biomass, and discard mortality of PIBKC in the groundfish fisheries are presented by groundfish target type in Tables 4-6 and Figure 7. Groundfish targets with less than 10 kg bycatch over the 2009/10-2022/23 period have been dropped. PIBKC is primarily taken as bycatch in fisheries targeting flathead sole, yellowfin sole, northern rock sole, and Pacific cod. Although the Pacific cod fishery accounted for the highest bycatch of PIBKC (in 2015) across the time series, it generally ranks below the other fisheries as a source of mortality because the bycatch occurs primarily with fixed gear.

5.3.3 Spatial patterns of bycatch

Spatial patterns of PIBKC bycatch, by ADFG stat area, in the groundfish fisheries are illustrated by gear type in Figures 8 and 9. 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), although 2012 was an exception in which bycatch was concentrated along the western edge of the Zone. In contrast, bycatch taken by fixed gear is typically dispersed along the shelf edge, although it was concentrated within and near the Habitat Conservation Zone (Figure 3) in 2015/16.

5.4 Catch-at-length

No catch-at-length data is used in the assessment.

5.5 NMFS EBS bottom trawl shelf survey

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 added 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 10). 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 (e.g. Zacher et al. 2023). 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 7. Females were characterized as immature or mature based on abdominal flap morphology and egg presence (Zacher et al. 2023).

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. (2023)). 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 the total district area (Zacher et al. 2023).

Forty-five stations were included in survey strata for PIBKC in 1975, increasing to 86 by 1983 and remaining essentially constant since then (Tables 8 and 9). 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 (e.g., 1989 for both sexes). In 2023, a total of 2 (immature/sublegal) males and 7 (mature) females were caught at 2 and 1 stations, respectively, all in the high-density sampling area (Tables 8 and 9). No mature males were caught in 2023.

Annual survey abundance and biomass for PIBKC have declined precipitously over the course of the 45 year time series (Tables 10-15 and Figures 11-22). On decadal scales, mean survey abundance and biomass have declined for males from 13.141 million crab and 29.53 thousand t in the 1970s to 0.224 million crab and 0.402 thousand t in the 2010s. Similarly, mean survey abundance and biomass have declined for females from 8.862 million crab and 8.078 thousand t in the 1970s to 0.255 million crab and 0.230 thousand 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 1990s, followed by a decline to consistent low values since 1999 (a "blip" with large confidence intervals in 2005 was the exception). Females show a similar pattern, but lagged perhaps 5 years or so (without a "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 that 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 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 12 and 13, Figures 11-16) and biomass (Tables 14 and 15, Figures 17-22). 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, spiking 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 has followed trends similar to those in abundance.

Size frequencies across the entire time series are shown by sex in Figures 23-25. Based on patterns for crab > 50 mm CL, a single recruitment event starting in 1988 is evident in Figure 24, 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 26-29). Examining decadaly-averaged patterns, however, there appears to have been a fairly strong contraction in range from extending beyond the PIHCZ in the 1980s to contained within the PIHCZ currently. The current spatial pattern of PIBKC abundance is centered fairly compactly within the Pribilof District to the east of St. Paul Island and north of St. George Island, within a 60 nm radius of St. Paul.

6 Analytic Approach

6.1 History of modeling approaches

A catch survey analysis was used to assess the stock in the past (Zheng et al. 1997), but it is no longer in use. In October 2013, the SSC concurred with the CPT that the PIBKC stock falls under Tier 4 for status determination (SSC 2013). Stock status is determined by comparing current B to the Minimum Stock Size Threshold (MSST), where B is current MMB at the time of mating (by convention, MMB on Feb 15) and the MSST is $\frac{1}{2}B_{MSY}$. For a Tier 4 stock, it is not possible to determine B_{MSY} and MSST directly. Instead, time-averaged 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 is not directly observed. Instead, estimates of MMB at the time of the NMFS EBS Shelf Survey are combined with estimates of natural mortality (M), retained catch mortality (RM), and discard catch mortality of crab taken as bycatch in the directed fishery and other fisheries (DM). The current modeling approach uses M for king crab (0.18), and annual estimates of RM and DM to project design-based estimates of MMB at the time of the survey (July 1, by convention) forward to the time of mating.

The sampling-related uncertainty associated with annual design-based estimates of MMB from the survey is extremely large for PIBKC; thus, 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 AD Model Builder (Fournier et al. 2016) state space/random effects random walk (SS/RE RW) model was developed to estimate annual survey MMB to use in estimating B_{MSY}. One advantage of the SS/RE RW model over the IV approach is that it provided an estimate of process error in the MMB time series. Other advantages included handling missing data and providing a method to project uncertainty. An updated version of the SS/RE RW model utilizing the *rema* R package (R Core Team 2022; Sullivan 2022) used in the Tier 5 groundfish assessments was reviewed and endorsed by the CPT and SSC during the May and June, 2023 meetings CPT (2023). Thus, this assessment uses the *rema* SS/RE RW implementation, which reduces the observed variance in estimates of design-based annual survey MMB, estimates missing values (the survey was not conducted in 2020), and better characterizes the temporal trends in MMB at the time of the survey prior to calculating a MMB-at-mating time series.

Since 2017, PIBKC assessments have been conducted on an odd-year biennial schedule. The assessment timing was moved from September to May prior to the 2021 assessment, which 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. This proved to be unsatisfactory, resulting in the assessment timing moved back to September for this assessment, with the result that this 2023 assessment uses complete 2022/23 catch and survey data without any extrapolation.

6.2 Model Description

6.2.1 MMB at the time of the survey

Survey MMB in year y, MMB^s_y, is calculated from haul-level survey data by first calculating haul-level MMB, $MMB^s_{y,h}$, using:

$$MMB^s_{y,h} = \sum_z w_z \cdot P_z \cdot n^s_{y,h,z} \tag{3}$$

where w_z is male weight at size z (mm CL), P_z is the probability of maturity at size z, and $n^s_{y,h,z}$ is the number of males caught (expanded for sub-sampling) at size z in survey haul h in year y. For PIBKC, P_z is a knife-edge function, with all males larger than 119 mm CL being mature (Table 7). Haul-level $MMB^s_{y,h}$ is then expanded to survey-level MMB^s_y using standard design-based survey methods (Wakabayashi et al. 1985).

The SS/RE RW model is a statistical approach that models annual log-scale changes in "true" survey MMB as a random walk process using

$$p(< ln(MMB^s_y) > | < ln(MMB^s_{y-1}) >) \sim N(0, \phi^2) \tag{4}$$

as the state equation, where $< ln(MMB^s_y) >$ is the estimated "true" ln-scale survey MMB in year y, $p(x|\theta)$ denotes the probability of x conditional on θ, $N(\mu, v)$ indicates the normal distribution with mean μ and variance v, and ϕ^2 represents the estimated (ln-scale) process error variance. The associated observation equation is

$$ln(MMB^s_y) =< ln(MMB^s_y) > +\eta_y, \text{ where } \eta_y \sim N(0, {\sigma^s_y}^2) \tag{5}$$

where MMB^s_y is the design-based ("observed") survey MMB in year y, η_y represents normally-distributed ln-scale observation error, and ${\sigma^s_y}^2$ is the ln-scale design-based survey MMB variance in year y. The MMB^s_y's and σ^s_y's are observed quantities, while the $< ln(MMB_s) >$'s are estimated parameters regarded as random effects in the likelihood function. The process error variance ϕ^2 is parameterized on the ln-scale using $\phi^2 = exp(2 \cdot \lambda)$, where λ is an estimated fixed effect parameter.

Parameter estimates are obtained by minimizing the joint negative log-likelihood objective function

$$\Lambda = \sum_y \left[ln(2\pi\phi) + \left(\frac{< ln(MMB^s_y) > - < ln(MMB^s_{y-1}) >}{\phi} \right)^2 \right] + \sum_y \left(\frac{ln(MMB^s_y) - < ln(MMB^s_y) >}{\sigma^s_y} \right)^2 \tag{6}$$

and integrating out the random effects using the Laplace approximation.

One drawback associated with the SS/RE RW model described here is that the observed survey MMB is fit on a natural log scale, which cannot accommodate zeros as observations (the natural log of zero is negative infinity). This has not been an issue for the PIBKC assessment in the past but, unfortunately, this situation needs to be addressed in this assessment (and in future assessments) because the design-based estimate of survey MMB for 2023 is zero. The Groundfish Plan Teams (GPTs) and groundfish Tier 5 assessment authors have explored several alternative approaches to dealing with zeros in the data, including: 1) excluding them from the model fit (i.e., treating the associated surveys as "missing"), 2) replacing the zeros with small values for the estimates and large values for the associated cv's, and 3) fitting the data using a Tweedie, rather than lognormal, distribution to characterize the observation error (Monnahan et al. 2021). The GPTs' currently accepted method for dealing with zeros in a time series is alternative 1 (Jane Sullivan, AFSC, pers. comm.).

This 2023 assessment fits the SS/RE RW model to the survey data using the **rema** R package [version 0.1.0; Sullivan (2022)]. Model runs were completed for each of the three approaches noted above to dealing with zeroes in the data ("0s as NAs","small values", and "Tweedie") using the default settings for each approach. The author recommends adopting the GPTs' accepted method for this assessment: alternative 1, 0's as NAs. This is an area for coordinating future research with assessment authors and the CPT and GPTs.

6.2.2 MMB-at-mating

Annual estimates of MMB-at-mating (MMB^{am}_y) are calculated from the SS/RE RW estimates of MMB at the time of the annual NMFS EBS bottom trawl survey by accounting for natural and fishing mortality from the time of the survey to mating (nominally February 15 of the following year). Given the SS/RE RW estimates $< MMB_y^s >$ of MMB at the time of the survey in year y, MMB_y^{am} was calculated from MMB_y^s, MMB_y^{bf} (MMB just before the fisheries), and MMB_y^{af} (MMB just after the fisheries, which are assumed to occur instantaneously as a simplification), using:

$$MMB_y^{bf} =< MMB_y^s > \cdot e^{-M \cdot t_{sf}} \tag{7}$$

$$MMB_y^{af} = MMB_y^{bf} - RM_y - DM_y^{MM} \tag{8}$$

$$MMB_y^{am} = MMB_y^{af} \cdot e^{-M \cdot t_{fm}} \tag{9}$$

where M is natural mortality, RM_y is retained catch mortality on MMB in the directed fishery in year y, DM_y^{MM} is discard mortality on mature males (**not** on all crab) in all fisheries in year y, t_{sf} is the time between the survey and the fishery, t_{fm} is the time between the fishery and mating.

6.3 Model Selection and Evaluation

6.3.1 MMB at the time of the survey

All three SS/RE RW models for survey MMB achieved acceptable maximum gradients and are considered to have converged (Table 16). Estimated process errors, ϕ, are similar between the three SS/RE RW models and appear reasonable (Table 17). Given that the Tweedie parameter is limited to the range [1,2], the confidence interval associated with its estimate indicates the parameter may not be well-estimated (Table 17). MCMC results for the ln-scale process error (i.e., λ), the ln-scale terminal year survey year, and the arithmetic-scale terminal year survey biomass (Figures 30-35) do not indicate any issues with the non-Tweedie models. MCMC results could not be produced for the model using the Tweedie option; the MCMC process was terminated after running for 24 hours without completion (MCMC for the Tweedie option is known to take a long time for some models; Jane Sullivan, AFSC, pers. comm.).

The SS/RE RW models appear to fit the survey MMB data well through most of the time series, but the “zeros as NAs” and “Tweedie” models do not fit the declining trend in the data during the final two years (Tables 18-21; Figures 36-37). One-step-ahead (OSA) residuals are shown in Figures 38 and 39 for the non-“Tweedie” models; OSAs for the **rema** model are considered an improved method over Pearson’s residuals for assessing model fit. The OSA residuals are slightly negative.

6.3.2 MMB-at-mating

MMB-at-mating was estimated using results from the “zeros as NAs” SS/RE RW model for MMB at the time of the survey (as per GPT-approved practice when dealing with zeros in the data being fit). Estimated MMB-at-mating was highest at the start of the time series (1975/76; 23,282 t) and declined rapidly until 1985/86 (1,003 t), after which it increased slowly, reaching a lower peak in 1993/94 (3,876 t) (Table 22, Figure 40). A subsequent decline started in 1995/1996. Since 2004/05, MMB-at-mating has fluctuated about a very low level (NA t). Following the initial period of large catches and concurrent high survey biomass in 1975/76-1984/85, fishing mortality has had little effect on the estimated MMB-at-mating since 1985/86. Estimated MMB-at-mating for 2022/23 is 180 t.

7 Calculation of the OFL

7.1 Tier Level:

In 2013 the CPT and SSC designated PIBKC as a Tier 4 for status determination, defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008a), based on data availability.

7.2 Parameters and stock sizes

7.3 OFL specification

7.3.1 Stock status level

The minimum stock size threshold (MSST) for Tier 4 stocks is specified as $\frac{1}{2}B_{MSY}$ (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 a proxy 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 (Figure 41). Alternative time periods (e.g., 1975 to 1979) have also been considered, but these were rejected (Foy 2013). Considerations for choosing the averaging time period include the following:

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)). The stock appears to have remained below this (unknown) threshold to the present.

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.

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 4). Following the re-opening of the fishery in 1995, total catch declined annually until the fishery was closed again in 1999. 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.

Recruitment

After increases in exploitation rates in the late 1980s and 1990s, estimates of ln(recruits/MMB) dropped, suggesting that exploitation rates at the levels of $F_{MSY_{proxy}} = M$ were not sustainable (Foy 2013).

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 42) as described in the following table:

The Tier 4 F_{OFL} Control Rule (see also Figure 42).

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, nominally equal to 1.0) 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 $B/B_{MSY_{proxy}}$ (NMFS 2008). Because the stock is overfished when $B <$ MSST, the stock *may* be overfished when the stock is level "b" but it is certainly overfished when the level is "c" .

In this assessment, $B_{MSY_{proxy}}$ is the average of MMB_{mating} over the years {1980:1984,1990:1997} (see Figure 41), i.e. 4,196 t. Because MMB-at-mating for 2022/23 is 180.4 t, the current stock status ratio is 0.0430078 and the stock is "overfished". The Tier level is Tier 4c.

7.3.2 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 (Section 6.2.2). For the assessment year, 2023/24, the fishery has not yet occurred so RM and DM are unknown. The amount of fishing mortality 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 (projected) MMB-at-mating. Also note that, while the retained mortality RM_{OFL} is based on the F_{OFL}, the discard mortality DM_{OFL} is assumed to be proportional to the MMB at the time of the fishery, with proportionality constant $\frac{\theta}{p_{male}}$.

The value of MMB at the time of the survey for the / fishing year is 201 t, Table 23). The constant θ was 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 3.0233236×10^{-4}, based on averaging over the last 3 years (Table 23).

7.3.3 Specification of F_{OFL}, OFL and other applicable measures

The iterative calculations to determine the Tier 4 F_{OFL}, OFL, and related measures are described in the previous section. Parameters for the calculations are listed in Table 23. The results are given in Table 24. Projected MMB-at-mating for crab fishery year / is 180.5 t and the associated status ratio is 0.043. Consequently, the stock is projected to be in Tier 4c, with $F_{OFL} = 0$ (directed fishing is prohibited). The resulting Tier 4 OFL would be 0.116 t.

The following tables summarize the basis for the OFL (repeating Tables C and D).

Basis for the OFL (biomass units in metric tons).

Year	Tier	B_{MSY}	B	B/B_{MSY}	γ	Years to define B_{MSY}	M	P*
2019/20	4c	4,099	180	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2020/21	4c	4,099	181	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2021/22	4c	4,099	180	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2022/23	4c	4,099	180	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2023/24	4c	4,196	181	0.043	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer

Basis for the OFL (biomass units in millions of lbs).

Year	Tier	B_{MSY}	B	B/B_{MSY}	γ	Years to define B_{MSY}	M	P*
2019/20	4c	9.052	0.3976	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2020/21	4c	9.052	0.3981	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2021/22	4c	9.037	0.3976	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2022/23	4c	9.037	0.3976	0.044	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer
2023/24	4c	9.2500	0.3980	0.043	1	1980/81-1984/85; 1990/91-1997/98	0.18	25% buffer

7.3.4 Specification of the retained catch portion of the total catch OFL

The retained portion of the total catch OFL for this stock is 0 t.

7.3.5 Recommendations

No alternative models were considered for this assessment: the methods used to determine stock status are the same as those used in the previous assessment. Based on this Tier 4 approach, and similar to conclusions reached in recent assessments, MMB-at-mating remains at historically low levels such that the stock is in Tier 4c, requiring that the directed fishery be closed and that F_{OFL} be set such that it is less than F_{MSY}. The rebuilding analysis (NMFS 2008) concluded that an OFL of 1.16 t (0.0026 million lbs), corresponding to a current fishing mortality rate of roughly 0.006 yr^{-1}, would be consistent with this requirement on F_{OFL} while allowing for a minimal amount of bycatch such that fisheries for other crab or groundfish targets could be be prosecuted. The author recommends continuing to use this approach.

8 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 is considered as a recommended ABC below ABC_{max}. For the PIBKC stock, the CPT has recommended, and the SSC has approved, a constant buffer of 25% to the OFL (NPFMC, 2014b).

8.1 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.

8.2 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 (cv) for the design-based estimate of survey MMB for the most recent survey (2022) is

0.7022, and has ranged between 0.17 and 1.00. The corresponding cv for the RW model-estimated MMB is 0.4512.

8.3 List of additional uncertainties considered for alternative σ_b applications to the ABC

No alternative σ_b applications were considered, but several sources of uncertainty are not included in the measures of uncertainty reported as part of the stock assessment:

- Natural mortality is pre-specified, not estimated. Survey catchability is essentially treated as 1, and not estimated.

- 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 1.0 and M is assumed to be known.

- 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}.

8.4 Recommendations

For 2023/24 $F_{directed} = 0$ and the total catch OFL is based on the catch biomass that would address the conservation needs for this stock while acknowledging 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 0.870 t. The following tables repeat the information in Tables A and B.

Management performance (in metric tons).

Year	MSST	Biomass	TAC	Retained Catch	Total Catch Mortality	OFL	ABC	yr
2020/21	2,049	181	closed	0	0	1.16	0.87	2020
2021/22	2,098	235	closed	0	0.102	1.16	0.87	2021
2022/23	2,098	180	closed	0	0.25	1.16	0.87	2022
2023/24	–	181	closed	–	–	1.16	0.87	2023
2024/25	–	181	closed	–	–	1.16	0.87	2024

Management performance (in millions of lbs).

Year	MSST	Biomass	TAC	Retained Catch	Total Catch Mortality	OFL	ABC	yr
2020/21	4.517	0.399	closed	0	0	0.0026	0.0019	2020
2021/22	4.6250	0.5176	closed	0	0.0002	0.0026	0.0019	2021
2022/23	4.6250	0.3978	closed	0	0.000562	0.0026	0.0019	2022
2023/24	–	0.3980	closed	–	–	0.0026	0.0019	2023
2024/25	–	0.3980	closed	–	–	0.0026	0.0019	2024

9 Rebuilding Analyses

A revised rebuilding 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 the revised plan (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 2014). The area has been closed to trawling since 1995.

A recently-developed qualitative network model that describes important biological interactions that may influence the productivity of PIBKC (Reum et al. 2020) found that, under a scenario of no projected climate change, predicted increases in PIBKC were reliable only when stock enhancement was implemented in a PIBKC 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 revised (2014) rebuilding plan does not have a target rebuild date and NMFS cannot predict when or if rebuilding will occur (NMFS 2022). There is no new and unexpected information that would significantly alter the rebuilding expectations. The recent trajectory of the time series of MMB-at-survey time provides no evidence of an increasing trend. Further, survey size compositions provide no evidence for recent recruitment to the stock. The failure of the EBS shelf survey to catch any mature males this year does not raise the level of concern for this stock above what it has been in the recent past; the survey does not target blue king crab and the result is consistent with sampling a population at low (but non-zero) abundance. The causes of the continued low abundance and failure to recover are not well understood, but are thought to be predominantly due to environmental changes that inhibit recruitment. In April 2022, the Regional Administrator made the determination that PIBKC was "not making inadequate progress" towards rebuilding (NMFS 2022).

10 Data Gaps and Research Priorities

The best way to handle the MMB time series when the NMFS EBS shelf survey fails to capture any mature male crab needs to be explored in coordination with the CPT, the GPTs, and other assessment authors because this issue occurs with other stocks.

Given the large CVs associated with the survey abundance and biomass estimates for PIBKC, 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, as a PhD student at University of Alaska Fairbanks, conducted research on alternative survey designs, including visual censuses, drop camera, and collector traps to better quantify PIBKC in a study funded by NPRB. Study results were presented 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. 2020). 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. As noted in Section H, (Reum et al. 2020) found that predicted increases in BKC under a scenario of no future climate change were reliable only when stock enhancement was implemented in a BKC hatchery-program. 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 settlement abundance in, these areas for both blue and red king crab, and 2) better characterize ecological interactions between adult blue and red king crab.

References

ADFG. 2008. Annual management report for the commercial and subsistence shellfsh fisheries of the Aleutian Islands, Bering Sea and the westward region's shellfsh ObserverProgram, 2006/07. Alaska Department of Fish; Game, Juneau, AK.

Armstrong, D.A., Armstrong, J.L., Jensen, G., R.Palacios, and William, G. 1987. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands. U.S. Dep. Commer., NOAA.

Armstrong, D.A., Armstrong, J.L., R.Palacios, Jensen, G., and Williams, G. 1985. Early life history of juvenile blue king crab, Paralithodes platypus, around the Pribilof Islands. University of Alaska Sea Grant, PO Box 755040 203 O'Neill Bldg. Fairbanks AK 99775-5040 USA.

Blau, F.S. 1997. Alaska king crabs: Wildlife notebook series. Alaska Department of Fish; Game. Available from http://www.adfg.state.ak.us/pubs/notebook/shellfsh/kingcrab.php.

Bowers, F., Herring, M.S.K., Salmon, M., Fitch, H., Alas, J., and Baechler, B. 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the westward region's shellfish observer program, 2009/2010. Alaska Department of Fish; Game.

CPT. 2023. Crab Plan Team report. North Pacific Fishery Management Council, Anchorage, AK. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=4ace502c-f13b-411f-8301-978c09746e6a.pdf&fileName=C1%20CPT%20Report%20May%202023.pdf.

Daly, B., Armistead, C., and Foy, R. 2014. The 2014 eastern Bering Sea continental shelf bottom trawl survey: Results for commercial crab species. NOAA.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnussona, A., Maunder, M.N., Nielsen, A., and Sibert, J. 2016. AD model builder: Using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. **27**(1).

Foy, R.J. 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2013 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/wp-content/PDFdocuments/resources/SAFE/CrabSAFE/CrabSAFE2013.pdf.

Foy, R.J., Miller, S., Stram, D., Fey, M., Lewis, S., Gasper, J.R., and Harrington, G.A. 2014. Final Environmental Assessment for proposed amendment 43 to the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs and proposed amendment 103 to the Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Islands To prevent overfishing and rebuild Pribilof Islands blue king crab. National Marine Fisheries Service. Available from https://repository.library.noaa.gov/view/noaa/18186/noaa_18186_DS1.pdf.

Jensen, G.C., and Armstrong, D. 1989. Biennial reproductive cycle of blue king crab, Paralithodes platypus, at the Pribilof Islands, Alaska, and comparison to a congener, P. camtschatica. Canadian Journal of Fisheries and Aquatic Sciences **46**(6): 932–940. Sch. Fish. WH-10, Univ. Washington, Seattle, WA 98195, USA.

Jensen, G.C., Armstrong, D.A., and Williams, G. 1985. Reproductive biology of the blue king crab, Paralithodes platypus, in the Pribilof Islands. University of Alaska Sea Grant, PO Box 755040 203 O'Neill Bldg. Fairbanks AK 99775-5040 USA.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B.M. 2016. TMB: Automatic differentiation and Laplace approximation. Journal of Statistical Software **70**(5): 1–21. doi:10.18637/jss.v070.i05.

Lauth, R.R., and Nichol, D.G. 2013. Results of the 2012 eastern Bering Sea continental shelf bottom trawl survey of groundfsh and invertebrate resources. U.S. National Oceanic; Atmospheric Administration (NOAA). Available from https://apps-afsc.fisheries.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-256.pdf.

Monnahan, C., Sullivan, J., Tribuzio, C., Thompson, G., and Hulson, P. 2021. Improving the consistency and transparency of Tier 4/5 assessments. *In* September 2021 plan team draft: Bering Sea, Aleutian Islands, and Gulf of Alaska SAFE. North Pacific Fishery Management Council, Anchorage, AK. p. 18. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=86098951-a0ed-4021-a4e1-95abe5a357fe.pdf&fileName=Tiers%204%20and%205%20assessment%20considerations.pdf.

NMFS. 2005. NOAA Fisheries, Juneau, AK.

NMFS. 2008. Final Environmental Assessment for Amendment 24 to the Fishery Management Plan for Bering Sea/ Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. National Marine Fisheries Service. Available from https://repository.library.noaa.gov/view/noaa/18139/noaa_18139_DS1.pdf.

NMFS. 2022. Agenda B-2: NMFS Management Report. National Marine Fisheries Service, PO Box 21668, Juneau, AK 99802-1668. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=11979d10-233b-4d66-bea3-4d1d2c2f0cfe.pdf&fileName=B2%20NMFS%20Report%20June%202022.pdf.

NPFMC. 1994. Environmental Assessment/RegulatoryImpact Review/Initial Regulatory Flexibility analysis for Amendment 21a to the Fishery Management Plan for Bering Sea and Aleutian Island Groundfsih. NMFS Alaska Region, PO Box 21668, Juneau, AK 99802-1668.

NPFMC. 2014. Final Environmental Assessment for proposed amendment 43 to the Fishery Management Plan for Bering Sea/Aleutian Island King and Tanner Crabs and proposed amendment 103 to the fishery management plan for groundfsh of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, Anchorage, AK.

NPFMC. 2021. BSAI Crab Fishery Management Plan Amendment Summaries. North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, AK. Available from https://www.npfmc.org/wp-content/PDFdocuments/Publications/Crab_Amendment_Summaries.pdf.

Otto, R.S., and Cummiskey, P.A. 1990. Growth of adult male blue king crab (Paralithodes platypus). *In* Proceedings of the International Symposium on King and Tanner crabs. University of Alaska Sea Grant, PO Box 755040 203 O'Neill Bldg. Fairbanks AK 99775-5040 USA. p. 633.

Paul, A.J., and M.Paul, J. 1980. The effect of early starvation on later feeding success of king crab zoeae. Journal of Experimental Marine Biology and Ecology **44**: 247–251.

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from https://www.R-project.org/.

Reum, J.C.P., McDonald, P.S., Long, W.C., Holsman, K.K., Divine, L., Armstrong, D., and Armstrong, J. 2020. Rapid assessment of management options for promoting stock rebuilding in data-poor species under climate change. Conservation Biology **34**(3): 611–621. Blackwell Publishing Ltd. doi:https://doi.org/10.1111/cobi.13427.

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

Siddeek, M., Watson, L.J., Blau, S.F., and Moore, H. 2002. Estimating natural mortality of king crabs from tag recapture data. *Edited by* A. Paul, E. Dawe, R. Elner, G. Jamieson, G. Kruse, R. Otto, B. Sainte-Marie, T. Shirley, and D.(eds). Woodby. University of Alaska Sea Grant, P.O. Box 755040 205 O'Neill Bldg. Fairbanks AK 99775-5040 USA, [URL:http://www.uaf.edu/seagrant/]. pp. 25–75.

Somerton, D.A. 1985. The disjunct distribution of blue king crab, Paralithodes platypus, in Alaska: Some hypotheses. *In* Proceedings of the international king crab symposium. University of Alaska Sea Grant, PO Box 755040 203 O'Neill Bldg. Fairbanks AK 99775-5040 USA.

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

Somerton, D., and MacIntosh, R.A. 1985. Reproductive biology of the female blue king crab Paralithodes platypus near the Pribilof Islands, Alaska. Journal of Crustacean Biology **5**: 365–376. Northwest; Alaska Fish. Cent., NMFS, 7600 Sand Point Way, N.E., BIN C15700, Build. 4, Seattle, WA 98115, USA.

SSC. 2013. REPORT of the SCIENTIFIC AND STATISTICAL COMMITTEE to the NORTH PACIFIC FISHERY MANAGEMENT COUNCIL. North Pacific Fishery Management Council, Anchorage, AK. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=3745f797-357c-4d23-a671-f5f142eba04c.pdf&fileName=SSC%20Minutes.pdf.

SSC. 2023. SCIENTIFIC AND STATISTICAL COMMITTEE DRAFT REPORT TO THE NORTH PACIFIC FISHERY MANAGEMENT COUNCIL. North Pacific Fishery Management Council, Anchorage, AK. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=db628102-a423-4d9b-b2d9-8d4a906ac4dc.pdf&fileName=SSC%20Report%20June%202023%20DRAFT.pdf.

Stauffer, G.A. 2004. NOAA protocols for groundfish bottom trawl surveys of the nation's fshery resources. U.S. National Oceanic; Atmospheric Administration (NOAA).

Stevens, B.S. 2006a. Embryo development and morphometry in the blue king crab Paralithodes platypus studiedbyusing image and cluster analysis. Journal of Shellfsh Research **25**(2). Available from 596--576.

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

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

Stockhausen, W.T. 2014. 2014 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2014 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=84a80bf9-a465-4e91-8da7-b84e414c0e3e.pdf&fileName=C3%20CRAB%20SAFE%202014_reduced.pdf.

Stockhausen, W.T. 2015. 2015 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2015 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/wp-content/PDFdocuments/resources/SAFE/CrabSAFE/CrabSAFE2015.pdf.

Stockhausen, W.T. 2016. 2016 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2016 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/wp-content/PDFdocuments/resources/SAFE/CrabSAFE/2016CrabSAFE_final.pdf.

Stockhausen, W.T. 2017. 2017 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2017 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/wp-content/PDFdocuments/resources/SAFE/CrabSAFE/CrabSAFE2017.pdf.

Stockhausen, W.T. 2018. 2018 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2018 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/wp-content/PDFdocuments/resources/SAFE/CrabSAFE/2018/SAFE_2018_Complete.pdf.

Stockhausen, W.T. 2019. 2019 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2019 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. Available from https://www.npfmc.org/wp-content/PDFdocuments/resources/SAFE/CrabSAFE/2019/SAFE_2019_Complete.pdf.

Stockhausen, W.T. 2021. 2021 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2021 final crab SAFE. North Pacific Fishery Management Council, Anchorage, AK. p. 83. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=6b1606ce-3b55-4273-935a-8ec90b8d5295.pdf&fileName=5%20Priblof%20Island%20Blue%20King%20Crab%20SAFE.pdf.

Stockhausen, W.T. (*Editor*). 2023. PIBKC: Random effects model comparisons. North Pacific Fishery Management Council, Juneau, AK. Available from https://meetings.npfmc.org/CommentReview/DownloadFile?p=5b0ede20-15e1-44fa-9931-35a952b76c50.pdf&fileName=PIBKC%202023%20Proposed%20model%20runs.pdf.

Stoutamore, J.L. 2014. Population genetics and mating structure of blue king crab (Paralithodes platypus). Master's thesis, University of Alaska, Fairbanks, Fairbanks, AK. Available from http://hdl.handle.net/11122/4547.

Sullivan, J. 2022. rema: A generalized framework to fit the random effects (RE) model, a state-space random walk model developed at the Alaska Fisheries Science Center (AFSC) for apportionment and biomass estimation of groundfish and crab stocks. Available from https://github.com/JaneSullivan-NOAA/rema, https://afsc-assessments.github.io/rema/.

Wakabayashi, K., Bakkala, R.G., and Alton, M.S. 1985. Methods of the U.S.-Japan demersal trawl surveys. *In* Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during may-august 1979. *Edited by* K. Wakabayashi. Int. North Pac. Fish. Comm. Bull. pp. 7–29.

Zacher, L.S., Richar, J.I., Fedewa, E.J., Ryznar, E.R., and Litzow, M.A. 2023. The 2022 eastern and northern Bering Sea continental shelf trawl surveys: Results for commercial crab species. U.S. National Oceanic; Atmospheric Administration (NOAA). doi:https://doi.org/10.25923/r6px-9707.

Zacher, L.S., Richar, J.I., and Foy, R.J. 2020. The 2019 eastern and northern Bering Sea continental shelf trawl surveys: Results for commercial crab species. U.S. National Oceanic; Atmospheric Administration (NOAA). doi:https://doi.org/10.25923/8jdb-5p39.

Zheng, J. 2016. 2016 Stock Assessment and Fishery Evaluation Report for the bristol bay red king crab fisheries of the Bering Sea and Aleutian Islands regions. *In* Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands regions 2016 final crab SAFE. North Pacific Fishery Management Council. Available from https://www.npfmc.org/wp-content/PDFdocuments/resources/SAFE/CrabSAFE/2016CrabSAFE_final.pdf.

Zheng, J., Murphy, M.C., and Kruse, G.H. 1997. Application of a catch-survey analysis to blue king crab stocks near pribilof and st. Matthew islands. Alaska Fishery Research Bulletin **4**(1): 62–74. Alaska Dep. Fish; Game, Commercial Fish. Manage.; Dev. Div., P.O. Box 25526, Juneau, AK 99802-5526, USA.

Tables

List of Tables

Table 1. 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

(continued)

crab year	number	biomass (t)	avg. cpue (num. legal crab/pot lift)
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 2. 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.

crab year	females	sublegal males	legal males	catch total catch	discard 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
2021/22	0.000	0.000	0.000	0.000	0.000
2022/23	0.000	0.000	0.000	0.000	0.000

Table 3. Bycatch of PIBKC in the groundfish fisheries, by gear type. Biomass and (discard) mortality are in kilograms. Number of vessels and bycatch in numbers are only available after 2008/09. 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
1991/92	NA	67	13	NA	6199	4959
1992/93	NA	879	176	NA	60791	48633
1993/94	NA	0	0	NA	34232	27385
1994/95	NA	35	7	NA	6856	5485
1995/96	NA	108	22	NA	1284	1028
1996/97	NA	31	6	NA	67	54
1997/98	NA	1462	292	NA	130	104
1998/99	NA	19800	3960	NA	79	64
1999/00	NA	795	159	NA	20	16
2000/01	NA	116	23	NA	23	19
2001/02	NA	833	167	NA	29	24
2002/03	NA	71	14	NA	297	238
2003/04	NA	345	69	NA	227	181
2004/05	NA	816	163	NA	2	1
2005/06	NA	353	71	NA	1339	1071
2006/07	NA	138	28	NA	74	59
2007/08	NA	3993	799	NA	132	106
2008/09	NA	141	28	NA	473	379
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	63	93	19	524	455	364
2017/18	2	4	1	265	378	303
2018/19	24	38	8	398	466	373
2019/20	10	18	4	226	522	418
2020/21	5	7	1	0	0	0
2021/22	22	30	6	46	109	87
2022/23	124	211	42	91	266	213

Table 4. Bycatch (numbers of crab) of PIBKC in the groundfish fisheries, by target type (avalable only after 2008/09). Discard mortality rates were not applied.

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	63	0	432	92
2017/18	95	2	0	0	170
2018/19	0	24	97	0	300
2019/20	0	10	0	55	170
2020/21	0	5	0	0	0
2021/22	0	22	0	0	46
2022/23	0	124	0	23	68

Table 5. Bycatch (biomass, in kg) of PIBKC in the groundfish fisheries, by target type (avalable only after 2008/09). Discard mortality rates were not applied.

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	91	0	368	87
2017/18	227	4	0	0	151
2018/19	0	38	23	0	442
2019/20	0	18	1	189	332
2020/21	0	7	0	0	0
2021/22	0	30	0	0	109
2022/23	0	211	0	106	160

Table 6. 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	18	0	294	70
2017/18	182	1	0	0	121
2018/19	0	8	19	0	354
2019/20	0	4	1	151	265
2020/21	0	1	0	0	0
2021/22	0	6	0	0	87
2022/23	0	42	0	84	128

Table 7. 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 8. 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

(continued)

year	survey number of hauls	immature males non-0 hauls	immature males no. crab	mature males non-0 hauls	mature males no. crab	sublegal males non-0 hauls	sublegal males no. crab	legal males non-0 hauls	legal males no. crab	all males non-0 hauls	all males no. crab
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
2021	86	1	1	5	9	3	4	4	6	5	10
2022	86	0	0	2	2	0	0	2	2	2	2
2023	86	2	2	0	0	2	2	0	0	2	2

Table 9. 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

(continued)

year	survey number of hauls	immature females non-0 hauls	immature females no. crab	mature females non-0 hauls	mature females no. crab	all females non-0 hauls	all females no. crab
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
2021	86	0	0	3	12	3	12
2022	86	0	0	4	7	4	7
2023	86	0	0	1	7	1	7

Table 10. Summary statistics for trawl survey abundance by decade, in millions.

												decade
		1970		1980		1990		2000		2010		2020
category	mean	max	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	0.00000	0.00000
mature females	7.156	13.880	21.3116	182.903	3.008	5.047	0.7272	1.6975	0.20400	0.3594	0.15579	0.22932
all females	8.862	14.732	22.0762	183.684	3.764	5.322	1.0472	2.5573	0.25516	0.4544	0.15579	0.22932
immature males	4.042	8.476	1.3213	3.515	1.237	2.450	0.3257	1.9813	0.09662	0.1945	0.01755	0.03322
mature males	9.099	15.288	1.8942	7.842	1.619	3.102	0.2274	0.7251	0.12712	0.2722	0.06947	0.17362
sublegal males	6.497	14.712	1.6675	4.331	1.791	3.349	0.3850	1.9813	0.13763	0.3026	0.03718	0.07831
legal males	6.644	11.769	1.5480	6.244	1.065	2.186	0.1681	0.5276	0.08610	0.1642	0.04984	0.11475
all males	13.141	23.764	3.2155	10.575	2.856	4.371	0.5531	2.0733	0.22373	0.4668	0.08702	0.19306

Table 11. Summary statistics for trawl survey biomass by decade, in 1,000s t.

												decade
		1970		1980		1990		2000		2010		2020
category	mean	max	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	0.00000	0.00000
mature females	6.953	13.154	24.4680	211.6037	2.9518	5.408	0.81884	1.8163	0.20584	0.41163	0.17590	0.26241
all females	8.078	13.572	24.7829	212.3032	3.3281	5.585	0.91115	1.8167	0.23006	0.41163	0.17590	0.26241
immature males	3.811	8.341	0.7711	2.0838	0.9836	2.004	0.13309	0.3258	0.07633	0.16471	0.01297	0.02392
mature males	25.721	42.618	5.7347	23.5529	4.0885	8.360	0.65383	2.0913	0.32571	0.64394	0.17224	0.40462
sublegal males	8.148	19.378	1.3954	4.9581	1.9477	3.567	0.23745	0.5649	0.14687	0.34967	0.04867	0.12211
legal males	21.383	40.366	5.1104	20.6786	3.1245	6.787	0.54947	1.7457	0.25518	0.45898	0.13654	0.29751
all males	29.532	46.395	6.5058	25.6367	5.0721	9.328	0.78692	2.2047	0.40204	0.80865	0.18521	0.41962

Table 12. 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	est.	cv	est.	cv	est.	cv	est.	cv	est.	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

(continued)

	immature males		mature males		sublegal males		legal males		all males	
year	est.	cv	est.	cv	est.	cv	est.	cv	est.	cv
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
2021	0.019	1.000	0.174	0.495	0.078	0.600	0.115	0.568	0.193	0.516
2022	0.000	0.000	0.035	0.698	0.000	0.000	0.035	0.698	0.035	0.698
2023	0.033	0.699	0.000	0.000	0.033	0.699	0.000	0.000	0.033	0.699

Table 13. Estimated annual abundance (millions of crab) of female PIBKC population components from the NMFS EBS trawl survey.

	immature females		mature females		all females	
year	est.	cv	est.	cv	est.	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

(continued)

	immature females		mature females		all females	
year	est.	cv	est.	cv	est.	cv
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
2021	0.000	0.000	0.229	0.671	0.229	0.671
2022	0.000	0.000	0.121	0.617	0.121	0.617
2023	0.000	0.000	0.117	1.000	0.117	1.000

Table 14. Estimated annual biomass (1,000s t) of male PIBKC population components from the NMFS EBS trawl survey.

	immature males		mature males		sublegal males		legal males		all males	
year	est.	cv	est.	cv	est.	cv	est.	cv	est.	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

(continued)

	immature males		mature males		sublegal males		legal males		all males	
year	est.	cv	est.	cv	est.	cv	est.	cv	est.	cv
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
2021	0.015	1.000	0.405	0.503	0.122	0.653	0.298	0.576	0.420	0.512
2022	0.000	0.000	0.112	0.702	0.000	0.000	0.112	0.702	0.112	0.702
2023	0.024	1.000	0.000	0.000	0.024	1.000	0.000	0.000	0.024	1.000

Table 15. Estimated annual biomass (1,000s t) of female PIBKC population components from the NMFS EBS trawl survey.

	immature females		mature females		all females	
year	est.	cv	est.	cv	est.	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

(continued)

	immature females		mature females		all females	
year	est.	cv	est.	cv	est.	cv
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
2021	0.000	0.000	0.262	0.632	0.262	0.632
2022	0.000	0.000	0.146	0.663	0.146	0.663
2023	0.000	0.000	0.119	1.000	0.119	1.000

Table 16. Maximum objective function gradient after SS/RE RW model optimization, by "zeros option".

zeros option	max gradient
0's as NAs	5.4e-14
small constant	2.2e-14
Tweedie	2e-11

Table 17. Maximum objective function gradient after SS/RE RW model optimization, by "zeros option".

		0's as NAs			small constant			Tweedie	
parameter	estimate	lci	uci	estimate	lci	uci	estimate	lci	uci
process_error	0.4255	0.3393	0.5337	0.7766	0.5827	1.035	0.3948	0.3138	0.4967
tweedie_p	–	–	–	–	–	–	1.5947	1.2981	1.8352

Table 18. “Zeros as NAs” model fits to mature male survey biomass. lci: lower confidence bound; uci: upper confidence bound; observed: design-based survey estimates; base: model results from last assessment; model: “Zeros as NAs” model results. Confidence intervals are 80%.

		value			lci			uci	
year	observed	base	model	observed	base	model	observed	base	model
1975	38054	26785	27014	20760	17035	16993	69754	42116	42944
1976	14059	19947	20468	8104	13547	13798	24391	29369	30363
1977	42618	21190	22406	17814	13764	14440	101958	32620	34768
1978	17370	16960	19078	8912	11463	12779	33852	25093	28482
1979	16502	13352	17294	10673	9817	12456	25516	18159	24012
1980	23553	15539	16871	13894	11082	11983	39925	21788	23752
1981	11628	11412	11525	9321	9362	9451	14507	13911	14055
1982	7389	7448	7458	5825	6063	6068	9373	9148	9166
1983	5409	5075	5068	4316	4157	4150	6778	6194	6190
1984	2216	2352	2357	1659	1850	1852	2959	2989	2999
1985	1055	1357	1365	754	1030	1034	1476	1787	1801
1986	1505	1557	1559	1030	1164	1163	2199	2083	2090
1987	2923	1923	1917	1761	1360	1351	4853	2718	2720
1988	842	1436	1446	446	964	965	1591	2138	2167
1989	827	1610	1623	392	1051	1051	1749	2465	2505
1990	3078	2603	2604	1513	1741	1730	6261	3893	3920
1991	4690	3800	3787	2910	2691	2671	7556	5367	5369
1992	4391	4173	4164	2612	2959	2942	7382	5886	5895
1993	4556	4324	4319	3100	3214	3202	6694	5819	5826
1994	3410	4021	4025	2220	2929	2923	5240	5519	5541
1995	8360	4922	4898	4091	3363	3331	17086	7204	7201
1996	4641	4376	4366	3309	3324	3310	6509	5761	5758
1997	3233	3322	3322	2284	2534	2530	4575	4354	4361
1998	2798	2704	2703	2043	2092	2088	3833	3494	3498
1999	1729	1978	1981	1136	1461	1460	2631	2678	2688
2000	2091	1832	1827	1443	1362	1355	3031	2464	2464
2001	1599	1262	1259	689	840	833	3710	1896	1904
2002	680	784	785	369	535	532	1254	1151	1158
2003	702	548	548	428	385	383	1150	781	785
2004	107	281	284	53	184	184	214	429	437
2005	344	267	268	152	172	171	780	414	421
2006	166	226	228	81	146	145	339	351	356
2007	306	231	232	125	145	144	753	368	374
2008	46	212	214	16	130	129	134	345	353
2009	497	294	294	219	189	187	1130	458	463
2010	303	321	321	173	216	215	532	476	479
2011	461	371	370	180	235	232	1180	583	588
2012	644	396	395	277	251	247	1496	627	631
2013	250	344	344	102	218	216	615	542	549
2014	233	336	337	104	219	217	524	516	522
2015	622	390	390	382	271	270	1011	561	563

(continued)

		value			lci			uci	
year	observed	base	model	observed	base	model	observed	base	model
2016	130	247	251	63	164	166	267	371	379
2017	255	229	234	137	154	157	473	341	350
2018	154	197	206	78	129	135	303	302	314
2019	206	201	218	101	122	139	421	330	342
2020	NA	201	238	NA	99	140	NA	405	405
2021	405	201	261	220	87	166	743	465	410
2022	112	–	201	50	–	116	252	–	348
2023	NA	–	201	NA	–	92	NA	–	436

Table 19. “Small constant” model fits to mature male survey biomass (1975-2019). lci: lower confidence bound; uci: upper confidence bound; observed: design-based survey estimates; base: model results from last assessment; model: “small constant” model results. Confidence intervals are 80%.

	value			lci			uci		
year	observed	base	model	observed	base	model	observed	base	model
1975	38054	26785	31252	20760	17035	18280	69754	42116	53431
1976	14059	19947	18376	8104	13547	11537	24391	29369	29268
1977	42618	21190	25887	17814	13764	14268	101958	32620	46966
1978	17370	16960	19058	8912	11463	11406	33852	25093	31842
1979	16502	13352	17244	10673	9817	11764	25516	18159	25277
1980	23553	15539	19623	13894	11082	12707	39925	21788	30302
1981	11628	11412	11668	9321	9362	9438	14507	13911	14425
1982	7389	7448	7434	5825	6063	5931	9373	9148	9318
1983	5409	5075	5270	4316	4157	4246	6778	6194	6540
1984	2216	2352	2253	1659	1850	1721	2959	2989	2948
1985	1055	1357	1171	754	1030	859	1476	1787	1597
1986	1505	1557	1529	1030	1164	1089	2199	2083	2146
1987	2923	1923	2229	1761	1360	1446	4853	2718	3435
1988	842	1436	1141	446	964	685	1591	2138	1899
1989	827	1610	1227	392	1051	697	1749	2465	2158
1990	3078	2603	2645	1513	1741	1555	6261	3893	4499
1991	4690	3800	4238	2910	2691	2807	7556	5367	6400
1992	4391	4173	4372	2612	2959	2848	7382	5886	6714
1993	4556	4324	4441	3100	3214	3148	6694	5819	6266
1994	3410	4021	3806	2220	2929	2609	5240	5519	5553
1995	8360	4922	5881	4091	3363	3477	17086	7204	9947
1996	4641	4376	4595	3309	3324	3368	6509	5761	6267
1997	3233	3322	3292	2284	2534	2405	4575	4354	4508
1998	2798	2704	2742	2043	2092	2052	3833	3494	3666
1999	1729	1978	1869	1136	1461	1296	2631	2678	2696
2000	2091	1832	1973	1443	1362	1407	3031	2464	2765
2001	1599	1262	1368	689	840	774	3710	1896	2419
2002	680	784	763	369	535	469	1254	1151	1243
2003	702	548	579	428	385	379	1150	781	884
2004	107	281	200	53	184	115	214	429	347
2005	344	267	251	152	172	140	780	414	448
2006	166	226	197	81	146	113	339	351	342
2007	306	231	216	125	145	116	753	368	402
2008	46	212	154	16	130	77	134	345	308
2009	497	294	313	219	189	173	1130	458	565
2010	303	321	324	173	216	202	532	476	519
2011	461	371	412	180	235	221	1180	583	766
2012	644	396	461	277	251	251	1496	627	848
2013	250	344	324	102	218	174	615	542	601
2014	233	336	312	104	219	175	524	516	556
2015	622	390	466	382	271	303	1011	561	715
2016	130	247	208	63	164	121	267	371	357
2017	255	229	226	137	154	138	473	341	370
2018	154	197	180	78	129	106	303	302	304
2019	206	201	200	101	122	114	421	330	352

Table 20. "Small constant" model fits to mature male survey biomass (2020-2023). lci: lower confidence bound; uci: upper confidence bound; observed: design-based survey estimates; base: model results from last assessment; model: "small constant" model results. Confidence intervals are 80%.

	value			lci			uci		
year	observed	base	model	observed	base	model	observed	base	model
2020	*NA*	200.5510	210.8086	*NA*	99.3721	92.6249	*NA*	404.7486	479.7878
2021	404.6204	200.5510	222.0672	220.2023	86.5192	127.2285	743.4874	464.8758	387.6005
2022	112.1007	–	46.9786	49.7997	–	25.3017	252.3422	–	87.2271
2023	0.0100	–	2.6860	0.0025	–	0.6381	0.0402	–	11.3069

Table 21. "Tweedie" model fits to mature male survey biomass. lci: lower confidence bound; uci: upper confidence bound; observed: design-based survey estimates; base: model results from last assessment; model: "Tweedie" model results. Confidence intervals are 80%.

		value			lci			uci	
year	observed	base	model	observed	base	model	observed	base	model
1975	38054	26785	27264	20760	17035	17874	69754	42116	41587
1976	14059	19947	21653	8104	13547	14160	24391	29369	33110
1977	42618	21190	22708	17814	13764	15185	101958	32620	33958
1978	17370	16960	18993	8912	11463	12746	33852	25093	28303
1979	16502	13352	17107	10673	9817	12324	25516	18159	23747
1980	23553	15539	16613	13894	11082	12241	39925	21788	22548
1981	11628	11412	11431	9321	9362	9409	14507	13911	13887
1982	7389	7448	7412	5825	6063	6043	9373	9148	9091
1983	5409	5075	5024	4316	4157	4151	6778	6194	6081
1984	2216	2352	2391	1659	1850	1862	2959	2989	3071
1985	1055	1357	1455	754	1030	1058	1476	1787	2002
1986	1505	1557	1607	1030	1164	1189	2199	2083	2173
1987	2923	1923	2038	1761	1360	1483	4853	2718	2800
1988	842	1436	1738	446	964	1091	1591	2138	2767
1989	827	1610	1959	392	1051	1192	1749	2465	3218
1990	3078	2603	2746	1513	1741	1822	6261	3893	4137
1991	4690	3800	3766	2910	2691	2730	7556	5367	5196
1992	4391	4173	4076	2612	2959	2923	7382	5886	5685
1993	4556	4324	4250	3100	3214	3180	6694	5819	5679
1994	3410	4021	4050	2220	2929	2911	5240	5519	5635
1995	8360	4922	4863	4091	3363	3457	17086	7204	6839
1996	4641	4376	4296	3309	3324	3301	6509	5761	5591
1997	3233	3322	3283	2284	2534	2507	4575	4354	4300
1998	2798	2704	2669	2043	2092	2076	3833	3494	3432
1999	1729	1978	1980	1136	1461	1449	2631	2678	2705
2000	2091	1832	1794	1443	1362	1357	3031	2464	2371
2001	1599	1262	1236	689	840	835	3710	1896	1831
2002	680	784	806	369	535	540	1254	1151	1203
2003	702	548	595	428	385	416	1150	781	850
2004	107	281	378	53	184	228	214	429	626
2005	344	267	318	152	172	194	780	414	521
2006	166	226	269	81	146	160	339	351	454
2007	306	231	274	125	145	163	753	368	459
2008	46	212	280	16	130	163	134	345	480
2009	497	294	326	219	189	210	1130	458	506
2010	303	321	329	173	216	219	532	476	497
2011	461	371	364	180	235	233	1180	583	568
2012	644	396	392	277	251	254	1496	627	605
2013	250	344	356	102	218	220	615	542	578
2014	233	336	359	104	219	227	524	516	566
2015	622	390	414	382	271	299	1011	561	573

(continued)

		value			lci			uci	
year	observed	base	model	observed	base	model	observed	base	model
2016	130	247	286	63	164	183	267	371	448
2017	255	229	248	137	154	162	473	341	378
2018	154	197	218	78	129	136	303	302	347
2019	206	201	225	101	122	140	421	330	361
2020	NA	201	249	NA	99	149	NA	405	416
2021	405	201	276	220	87	181	743	465	422
2022	112	–	232	50	–	125	252	–	431
2023	0	–	232	NA	–	104	NA	–	516

Table 22. Components in calculation of MMB-at-mating time series, as well as MMB-at-mating calculated for the last assessment. Fishing mortality is only on mature males. All values are in t.

year	MMB at survey	MMB before fishery	fishing mortality	MMB after fishery	MMB-at-mating	last assmt
1975	27014.0	25825.3	$1.104e+03$	24721.3	23281.7	23077.1
1976	20467.9	19567.2	$2.999e+03$	16568.2	15603.4	15134.9
1977	22406.4	21420.5	$2.929e+03$	18491.5	17414.6	16318.0
1978	19077.9	18238.4	$2.901e+03$	15337.4	14444.2	12535.6
1979	17294.1	16533.1	$2.719e+03$	13814.1	13009.6	9458.2
1980	16870.8	16128.4	$4.976e+03$	11152.4	10502.9	9303.7
1981	11525.1	11017.9	$4.119e+03$	6898.9	6497.2	6396.0
1982	7458.1	7129.9	$1.998e+03$	5131.9	4833.1	4821.5
1983	5068.3	4845.3	$9.950e+02$	3850.3	3626.1	3633.4
1984	2356.8	2253.1	$1.390e+02$	2114.1	1991.0	1984.7
1985	1364.7	1304.7	$2.400e+02$	1064.7	1002.7	994.9
1986	1559.2	1490.5	$1.170e+02$	1373.5	1293.6	1290.7
1987	1917.1	1832.7	$3.180e+02$	1514.7	1426.5	1432.0
1988	1446.1	1382.5	$0.000e+00$	1382.5	1302.0	1292.8
1989	1622.7	1551.3	$0.000e+00$	1551.3	1461.0	1449.3
1990	2604.0	2489.4	$0.000e+00$	2489.4	2344.5	2343.7
1991	3786.8	3620.2	$2.486e+00$	3617.7	3407.0	3419.3
1992	4164.1	3980.9	$2.440e+01$	3956.5	3726.1	3734.5
1993	4319.0	4128.9	$1.369e+01$	4115.2	3875.6	3880.5
1994	4024.5	3847.4	$2.746e+00$	3844.7	3620.8	3617.2
1995	4897.7	4682.2	$6.285e+02$	4053.7	3817.6	3841.0
1996	4366.0	4173.9	$4.250e+02$	3748.9	3530.6	3538.3
1997	3321.7	3175.5	$2.322e+02$	2943.3	2771.9	2772.8
1998	2702.5	2583.6	$2.365e+02$	2347.1	2210.5	2209.9
1999	1981.2	1894.0	$7.862e-01$	1893.2	1783.0	1780.5
2000	1827.2	1746.8	$2.097e-02$	1746.8	1645.1	1649.6
2001	1259.1	1203.7	$9.507e-02$	1203.6	1133.5	1136.2
2002	784.9	750.4	$1.261e-01$	750.3	706.6	706.1
2003	548.5	524.3	$1.252e-01$	524.2	493.7	493.7
2004	283.6	271.1	$8.217e-02$	271.0	255.2	252.6
2005	268.4	256.6	$5.711e-01$	256.1	241.2	239.9
2006	227.6	217.6	$4.334e-02$	217.5	204.9	203.6
2007	232.1	221.9	$4.523e-01$	221.4	208.5	207.6
2008	213.7	204.3	$2.035e-01$	204.1	192.2	190.6
2009	294.0	281.1	$1.043e-01$	281.0	264.6	264.6
2010	320.8	306.7	$2.695e-02$	306.7	288.8	288.9
2011	369.5	353.3	$1.401e-02$	353.3	332.7	333.7
2012	394.9	377.6	$2.845e-01$	377.3	355.3	356.7
2013	344.0	328.8	$6.464e-03$	328.8	309.7	309.3
2014	336.8	322.0	$1.447e-02$	322.0	303.2	302.5
2015	389.6	372.5	$3.975e-01$	372.1	350.4	350.9
2016	250.6	239.6	$1.914e-01$	239.4	225.4	222.1
2017	234.4	224.1	$1.516e-01$	224.0	210.9	206.5
2018	205.8	196.7	$1.901e-01$	196.5	185.1	177.5
2019	217.9	208.3	$2.106e-01$	208.1	196.0	180.4
2020	238.4	227.9	$6.725e-04$	227.9	214.6	180.6
2021	260.8	249.4	$4.648e-02$	249.3	234.8	–
2022	200.6	191.7	$1.274e-01$	191.6	180.4	–
2023	200.6	191.7	–	–	–	–

Table 23. Values required to determine the Tier 4 OFL.

	quantity	value	units	description
1	MMB_s	201	t	current survey MMB
2	B_{MSY}	4,196	t	Tier 4 B_{MSY} proxy
3	θ	0.000302	–	mean MMB exploitaion ratio
4	M	0.18	$year^{-1}$	assumed natural mortality
5	γ	1	–	control rule parameter
6	α	0.1	–	control rule parameter
7	β	0.25	–	control rule parameter
8	t_{sf}	0.25	years	time from survey to fishery
9	t_{fm}	0.333	years	time from survey to fishery

Table 24. Results from the Tier 4 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 2023/24.

	quantity	units	value
1	B	t	181
2	B_{MSY}	t	4,196
3	stock status	–	overfished
4	F_{OFL}	$year^{-1}$	0
5	RM_{OFL}	t	0
6	DM_{OFL}	t	0.116
7	OFL	t	0.116

Figures

List of Figures

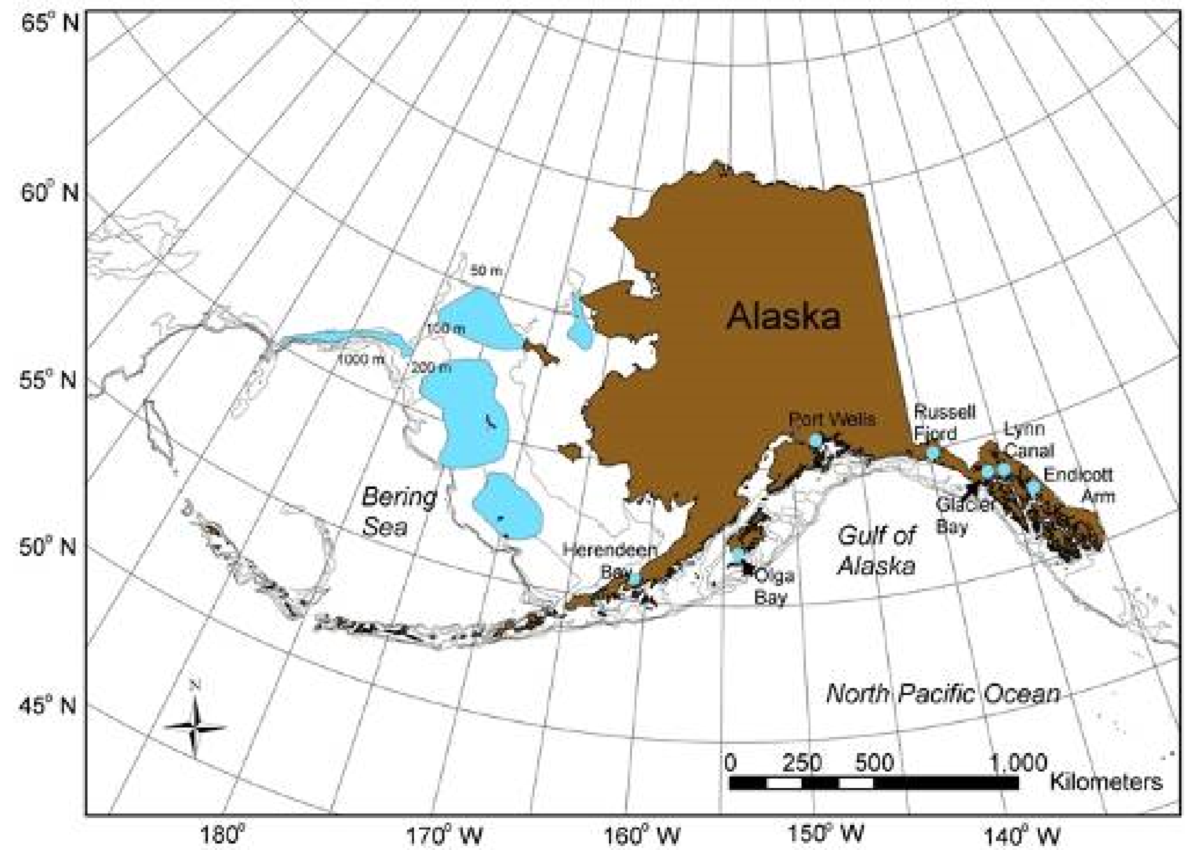

Figure 1. Distribution of blue king crab, *Paralithodesplatypus*, in Alaskan waters.

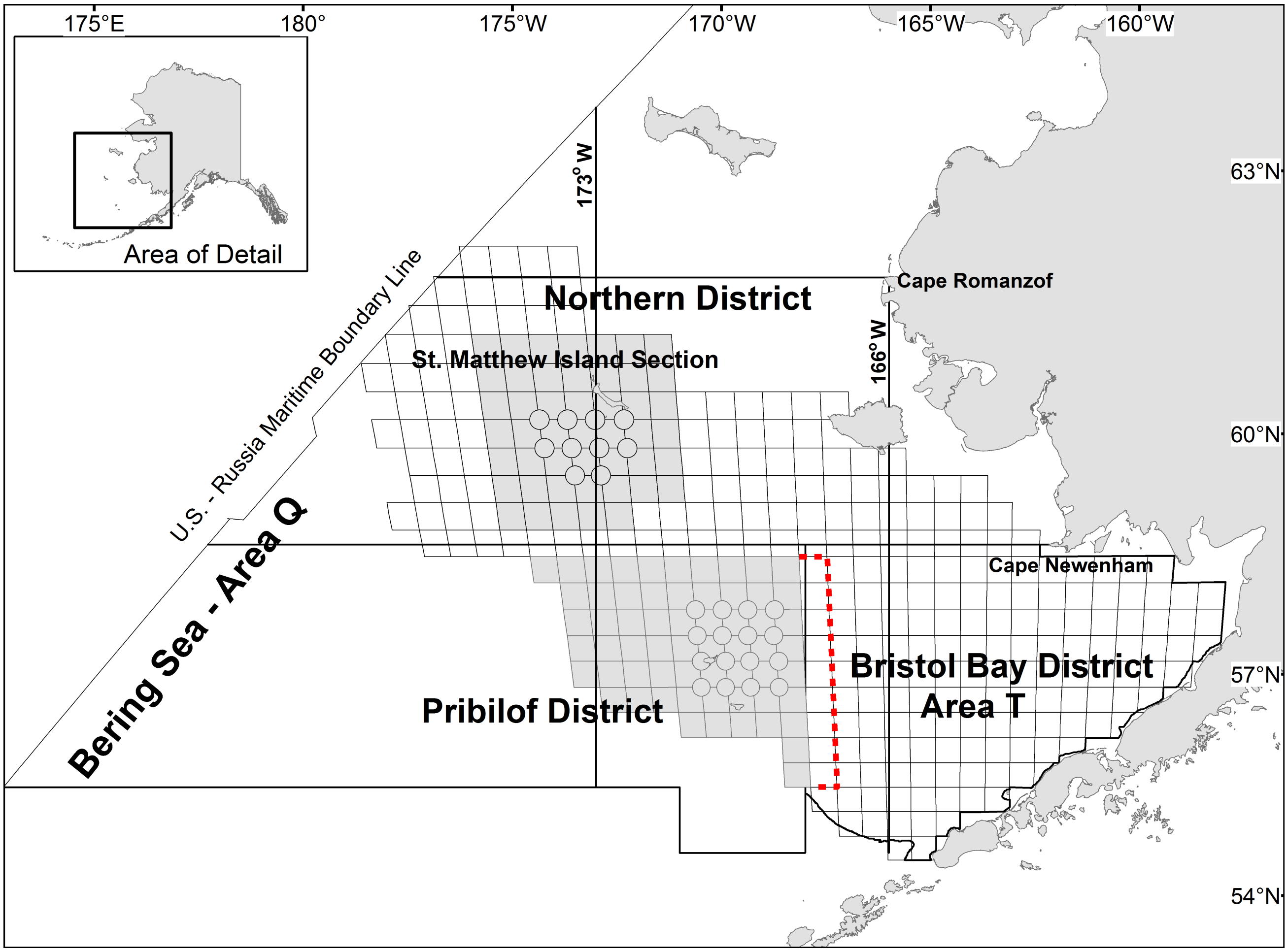

Figure 2. Map of the ADFG King Crab Registration Area Q (Bering Sea), showing (among others) the Pribilof District, which constitutes the stock boundary for PIBKC. The figure also indicates NMFS EBS Shelf survey grid (squares and circles), the original area used to calculate survey biomass and fishery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

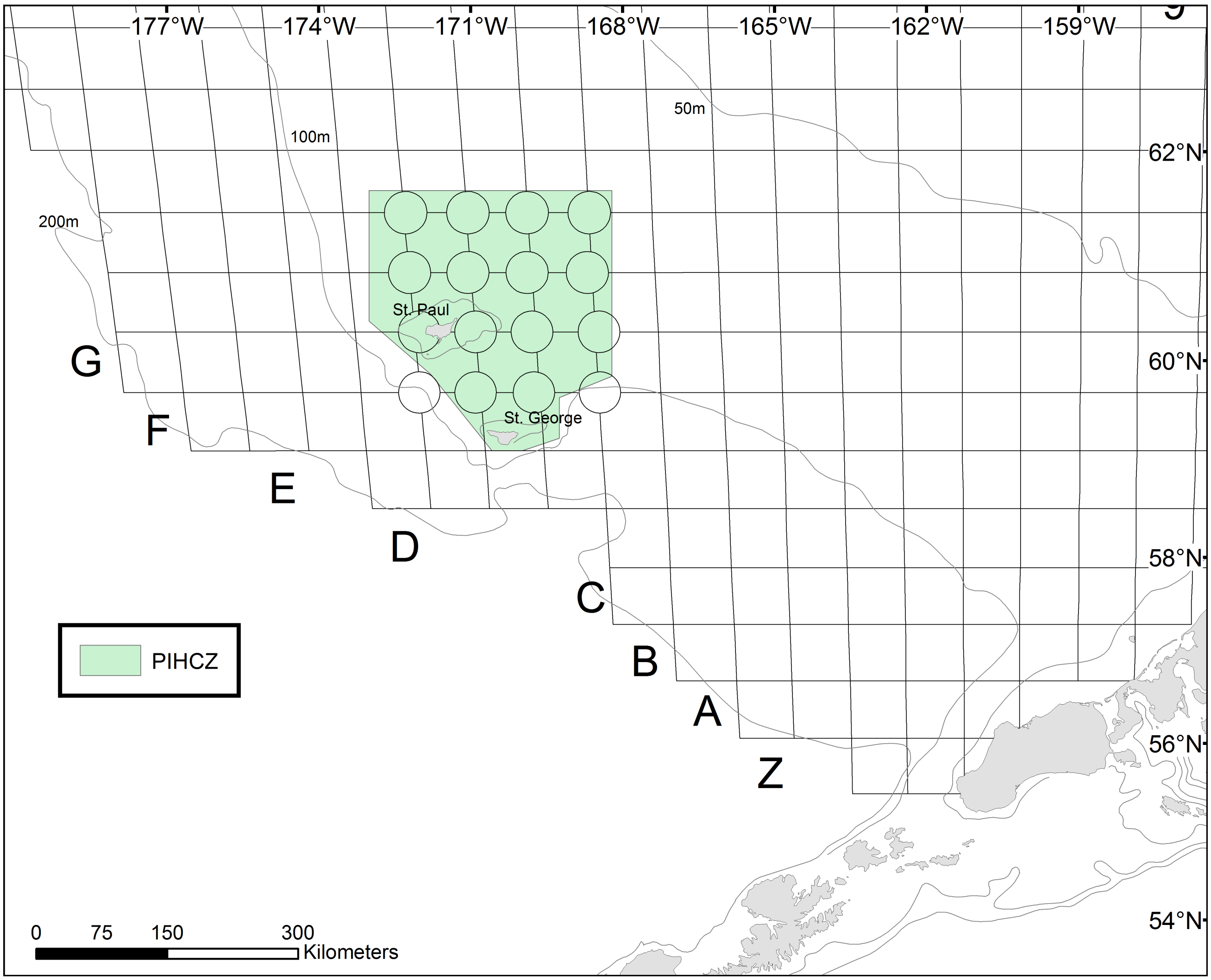

Figure 3. The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid (squares and circles).

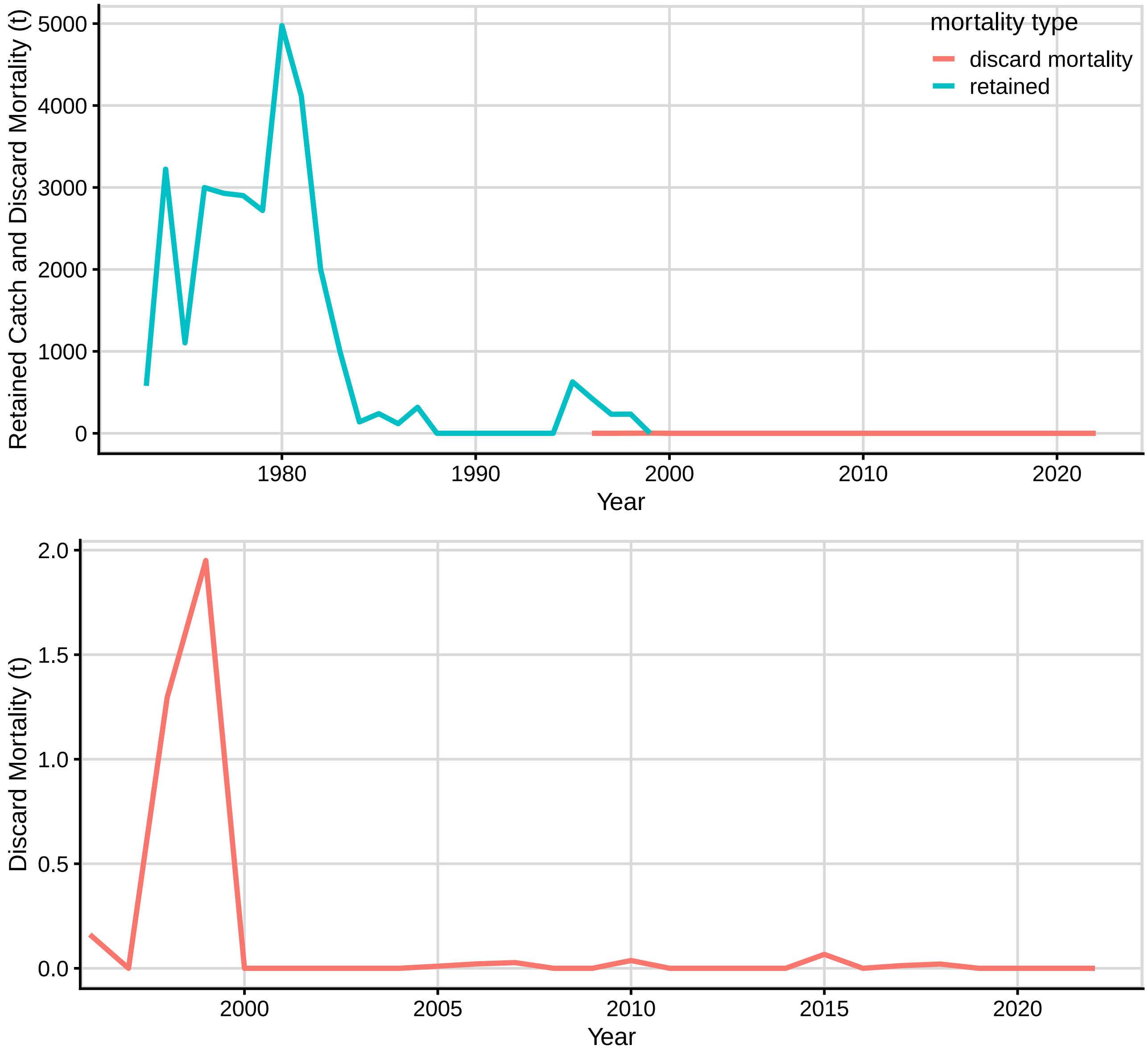

Figure 4. Retained catch and discard mortality, in t, for PIBKC in the crab fisheries. A discard mortality rate of 0.2 was used to convert bycatch biomass to mortality. The lower plot shows discard mortality in the crab fisheries on an expanded y-axis scale to show annual details.

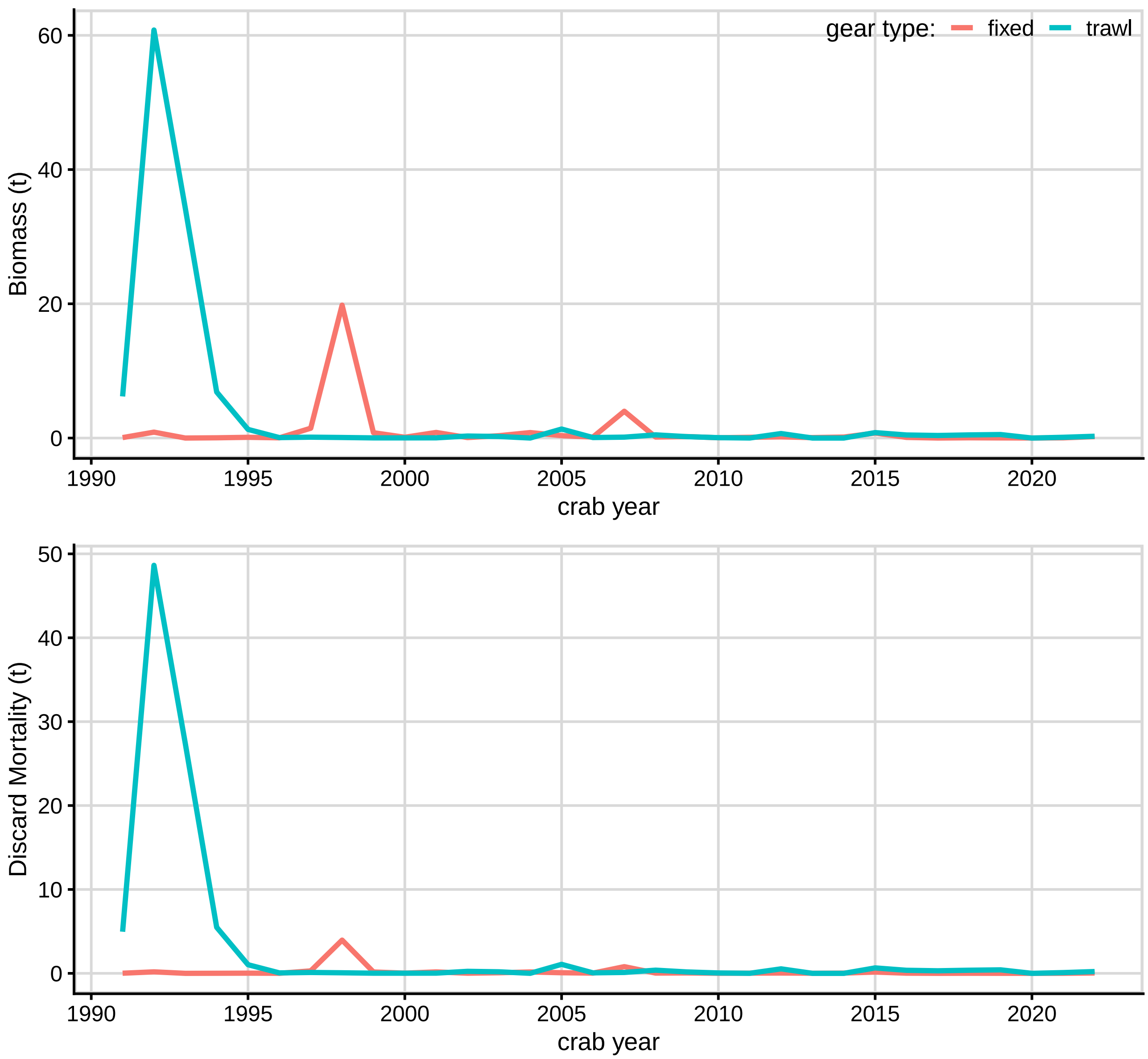

Figure 5. Upper plot: Bycatch of PIBKC in the groundfish fisheries since 1991/92 by gear type (no mortality applied). Lower plot: Discard mortality of PIBKC in the groundfish fisheries since 1991/92 by gear type. Gear-specific discard mortality rates of 0.2 and 0.8 were applied to bycatch from fixed and trawl gear, respectively

Figure 6. Upper plot: Bycatch of PIBKC in the groundfish fisheries since 2009/10 by gear type (no mortality applied). Lower plot: Discard mortality of PIBKC in the groundfish fisheries since 2009/10 by gear type. Gear-specific discard mortality rates of 0.2 and 0.8 were applied to bycatch from fixed and trawl gear, respectively

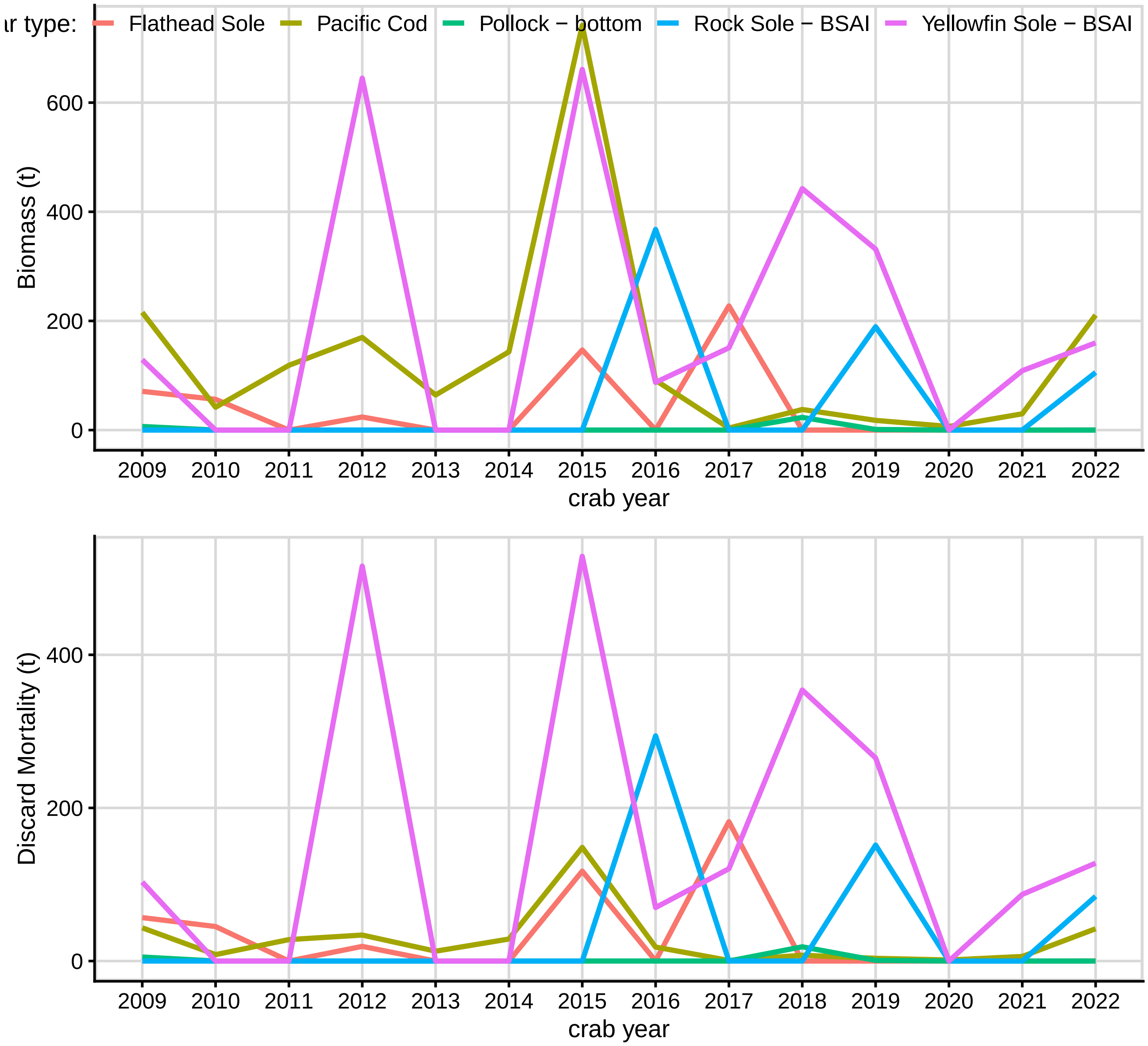

Figure 7. Upper plot: Bycatch of PIBKC in the groundfish fisheries since 2009/10 by target type (no mortality applied). Lower plot: Discard mortality of PIBKC in the groundfish fisheries since 2009/10 by target type. Gear-specific discard mortality rates of 0.2 and 0.8 were applied to bycatch from fixed and trawl gear, respectively

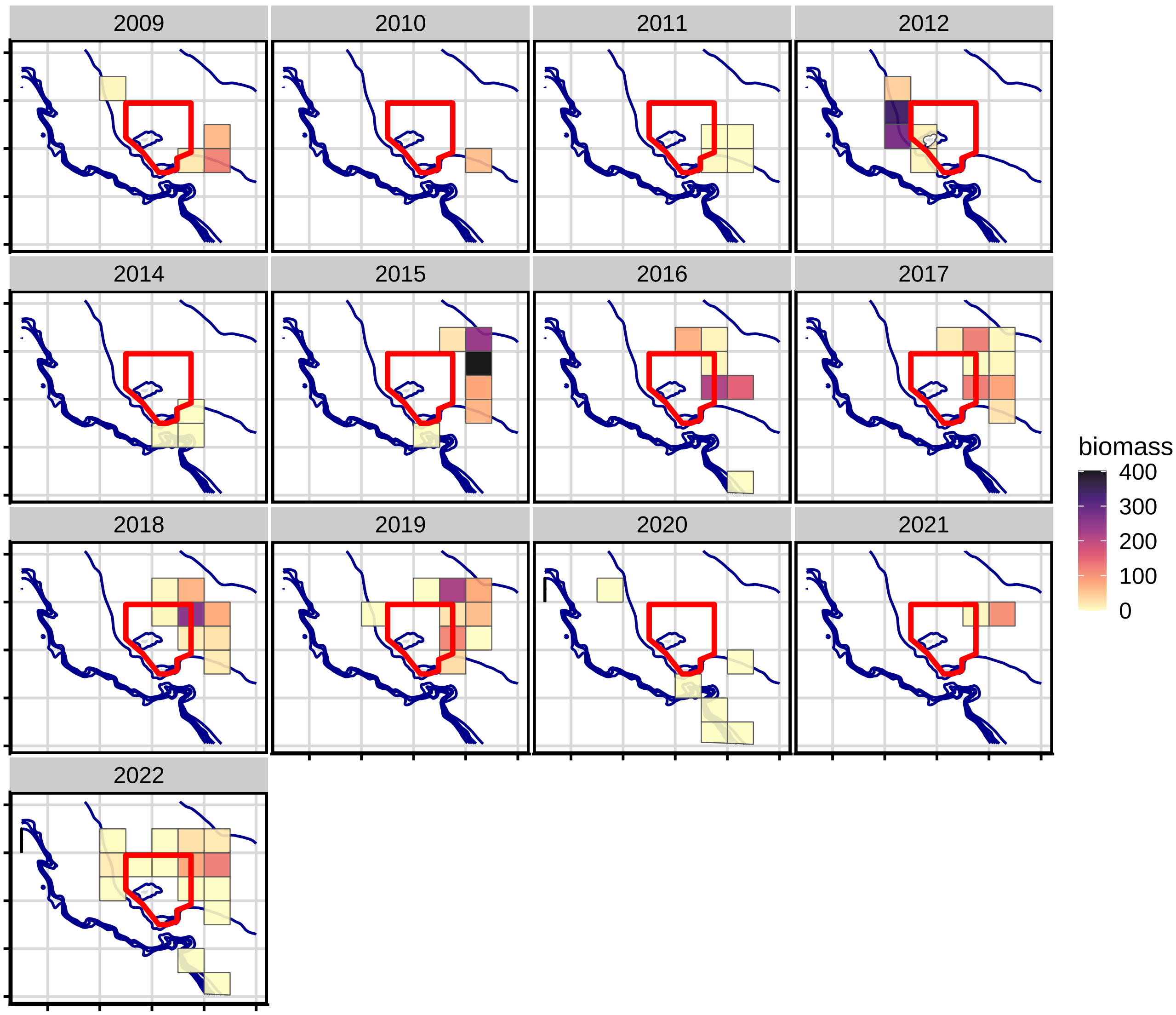

Figure 8. Estimated bycatch of PIBKC in the groundfish trawl gear fisheries by ADFG stat area, expanded from groundfish observer reports. Red line: boundary of the PIHCZ.

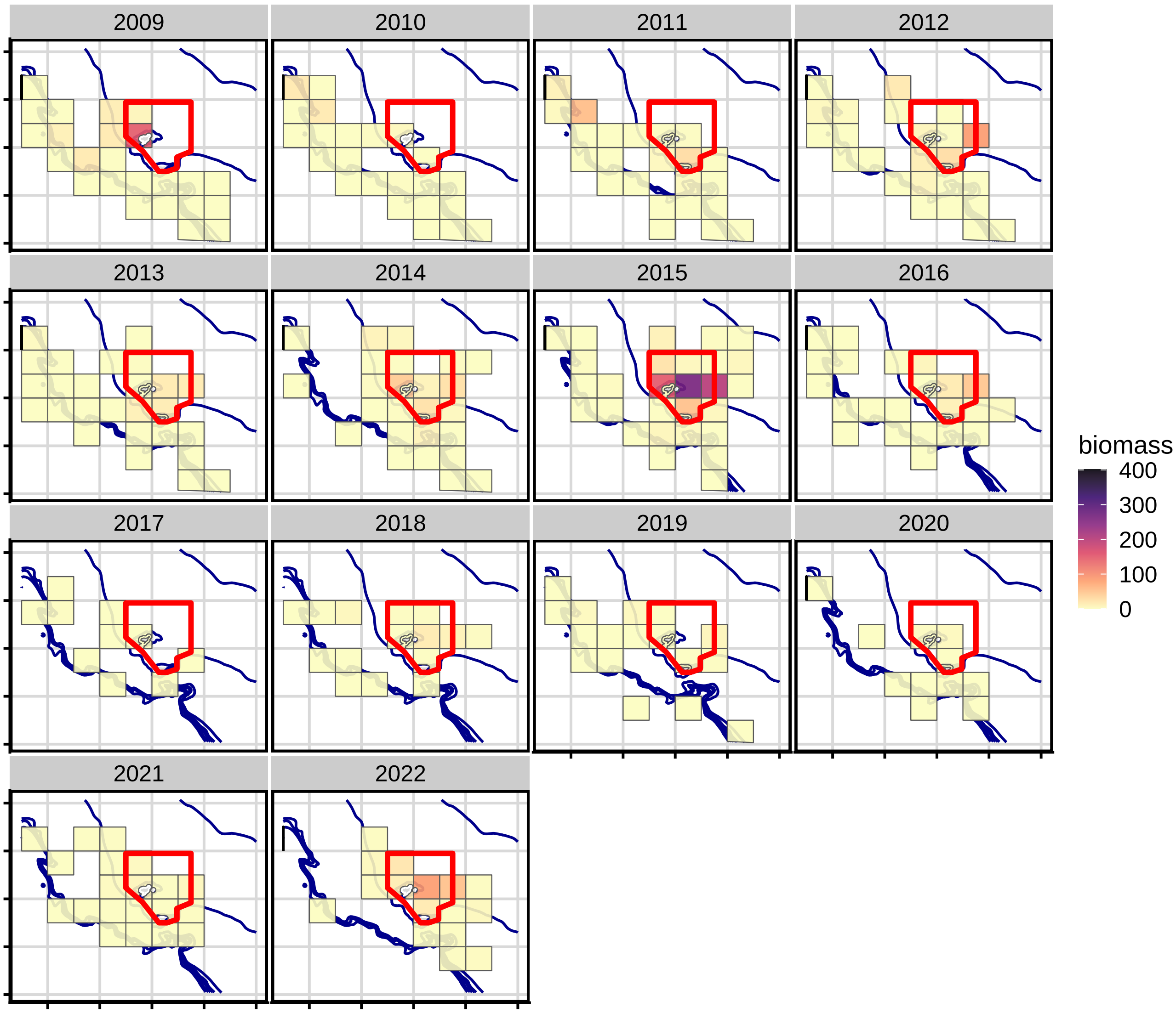

Figure 9. Estimated bycatch of PIBKC in the groundfish fixed gear fisheries by ADFG stat area, expanded from groundfish observer reports. Red line: boundary of the PIHCZ.

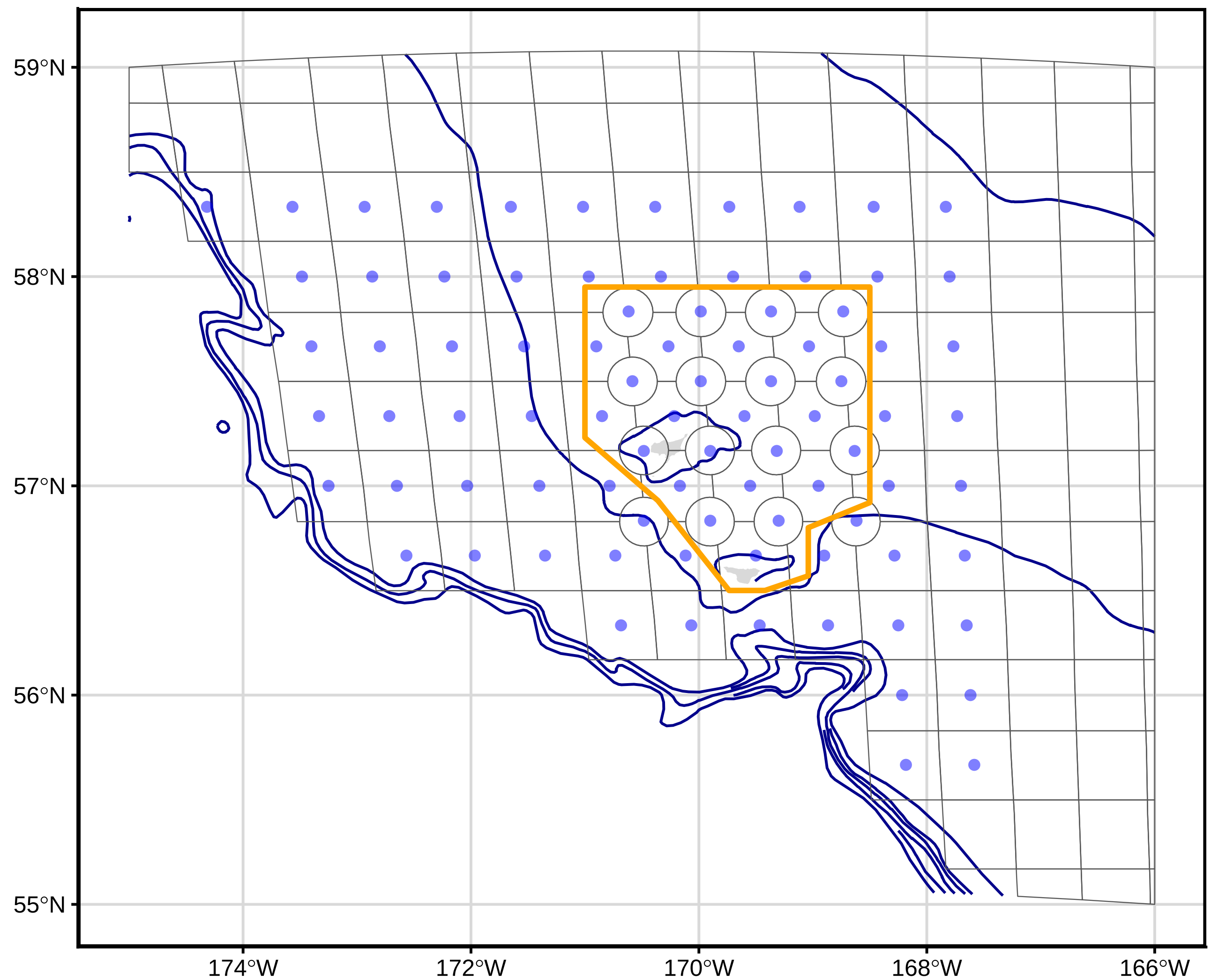

Figure 10. NMFS EBS Shelf Survey stations in the Pribilof District (large dots), the survey station grid (thin black lines), and the Pribilof Islands Habitat Conservation Zone (orange outline).

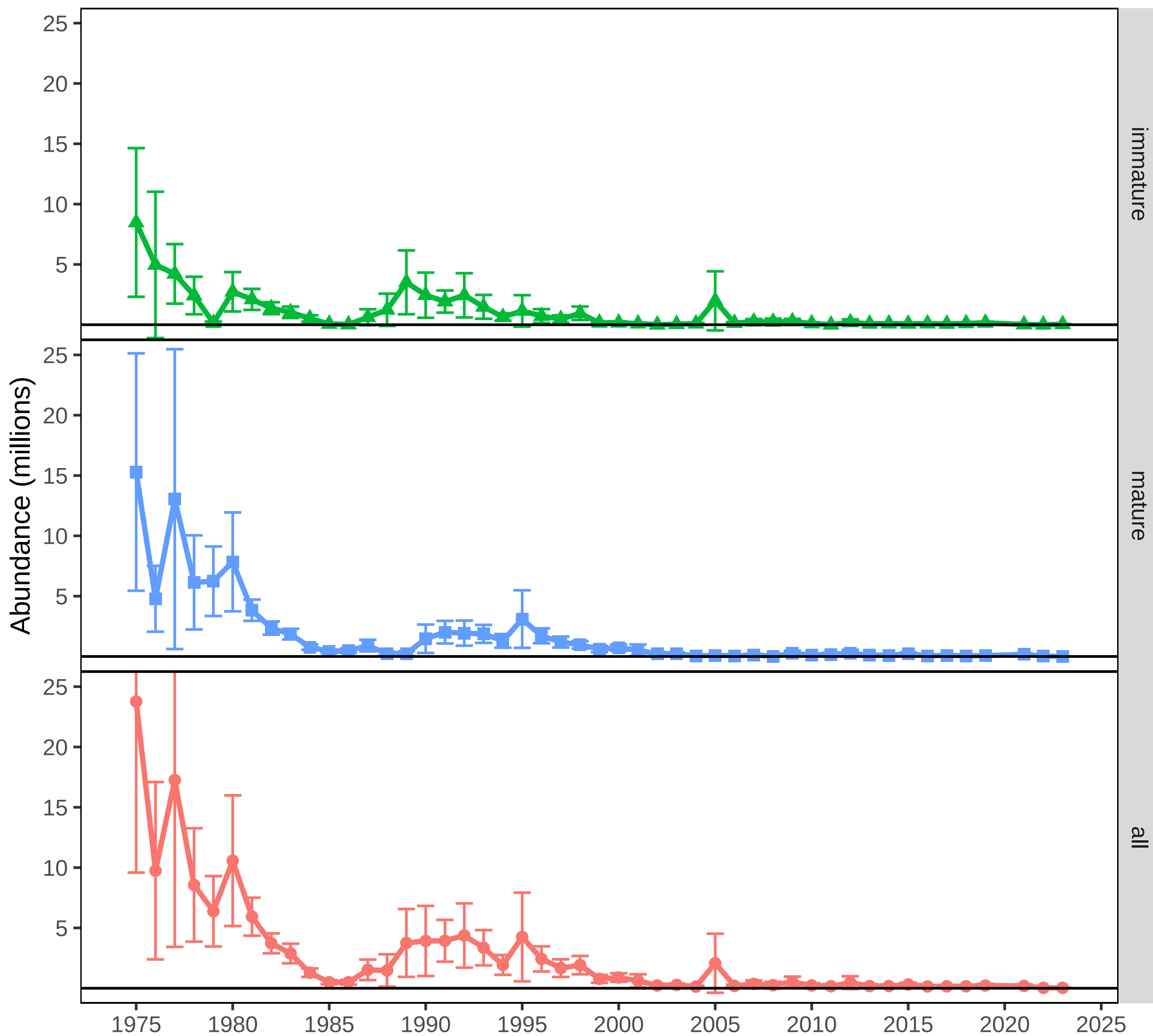

Figure 11. NMFS survey abundance time series for male PIBKC, by maturity category.

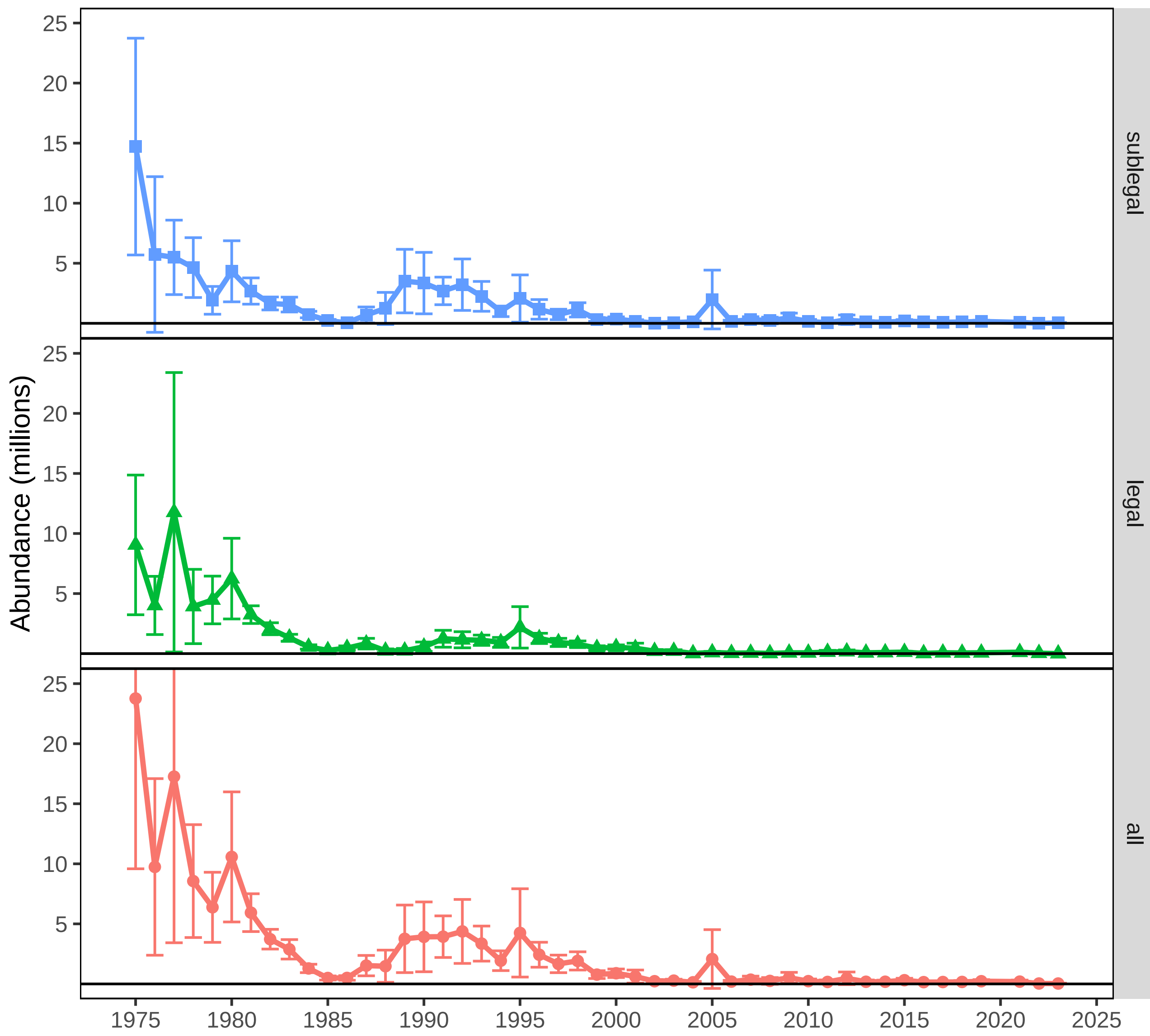

Figure 12. NMFS survey abundance time series for male PIBKC, by fishery category.

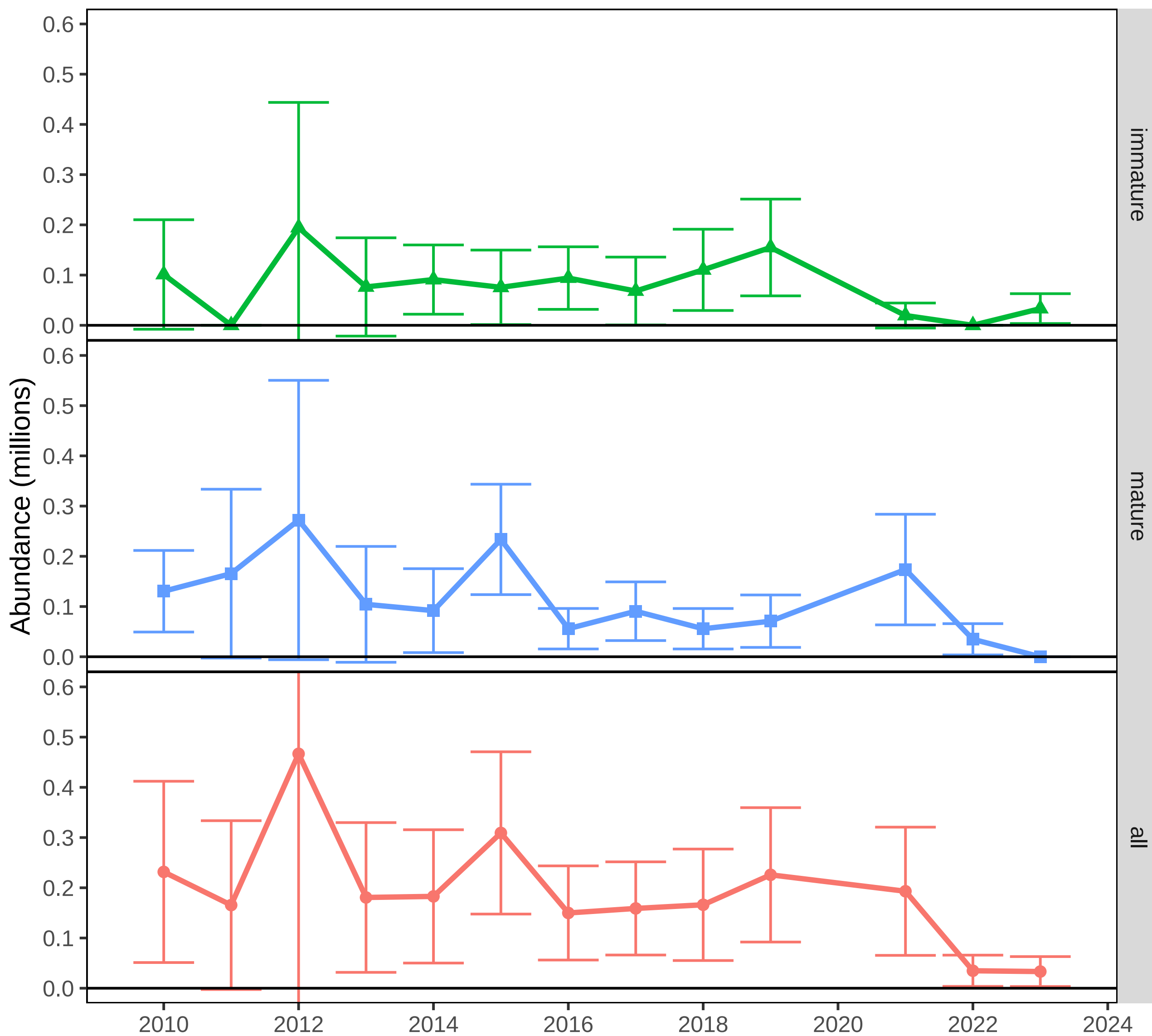

Figure 13. NMFS survey abundance time series for male PIBKC, by population category, from 2010.

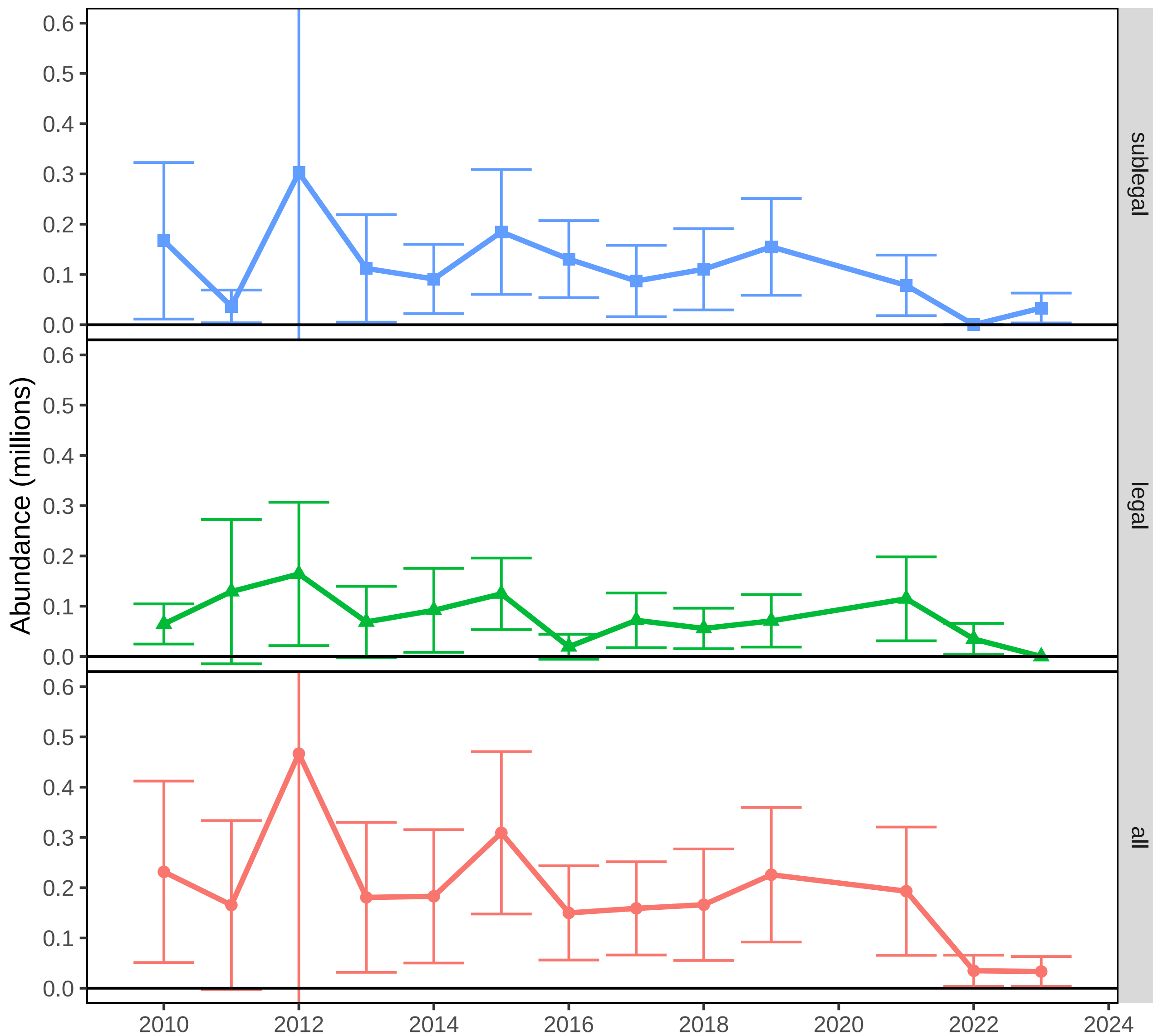

Figure 14. NMFS survey abundance time series for male PIBKC, by fishery category, from 2010.

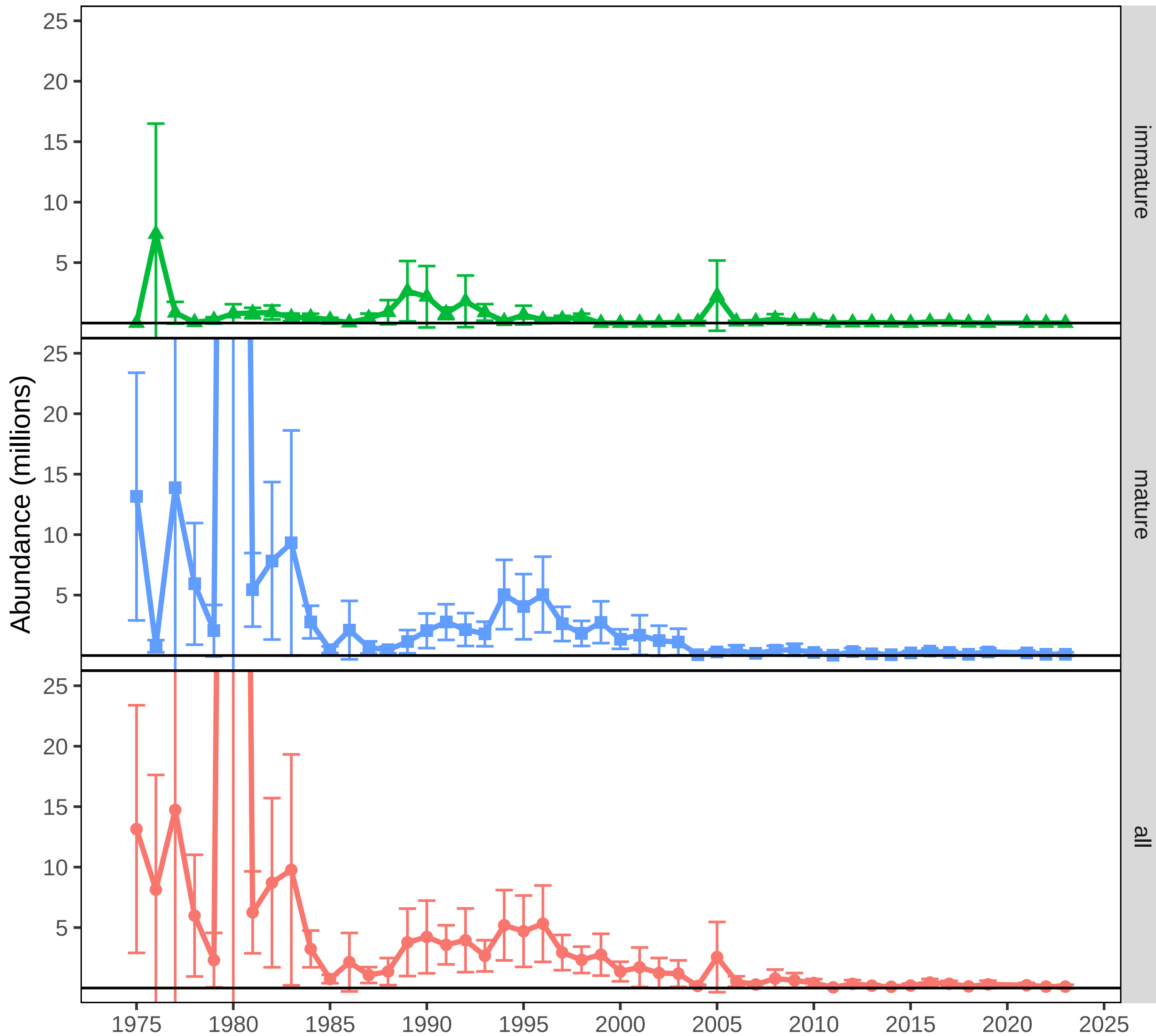

Figure 15. NMFS survey abundance time series for female PIBKC, by population category. The values for mature and all females for 1980 are off-scale to better show details of remaining values.

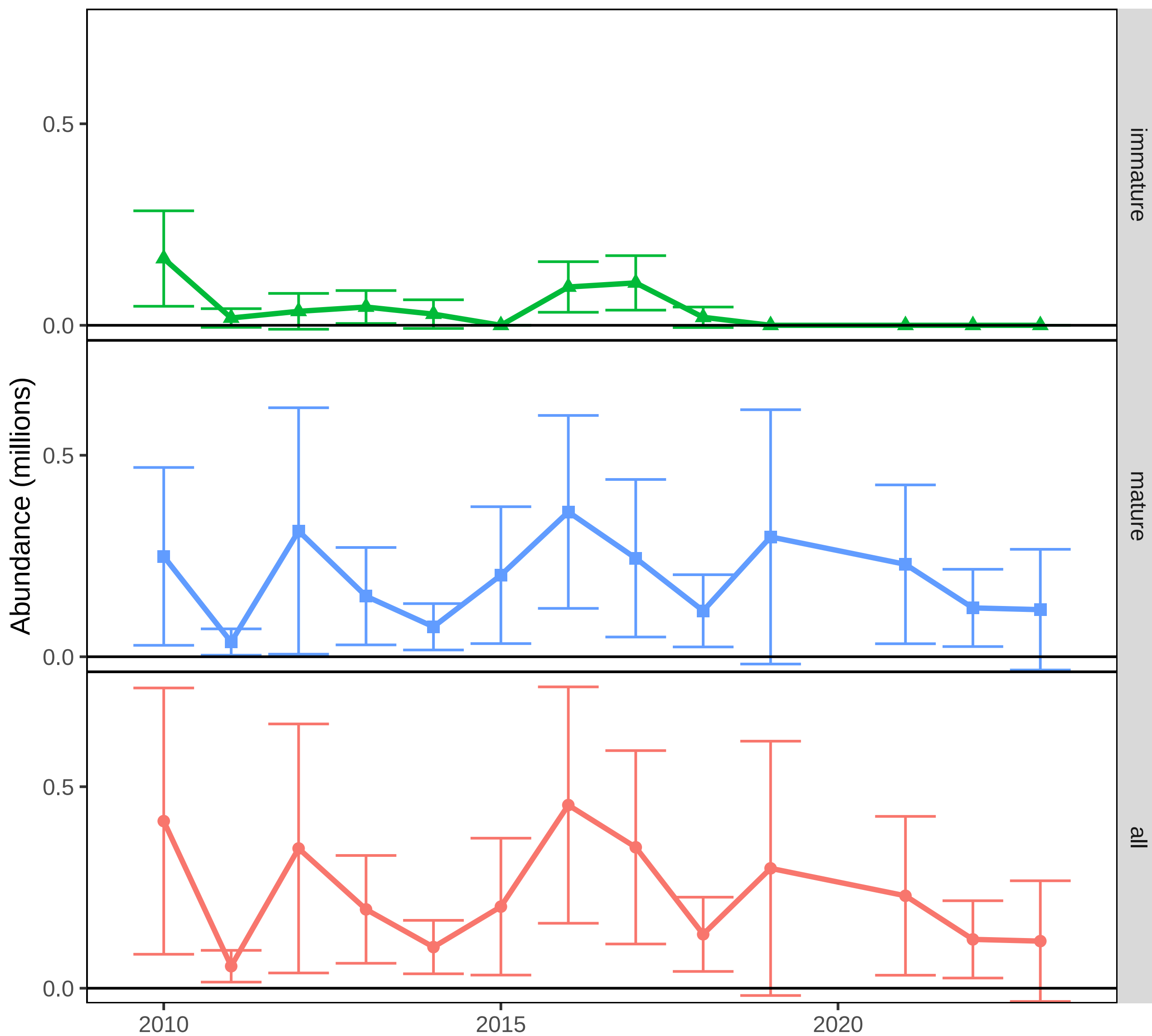

Figure 16. NMFS survey abundance time series for female PIBKC, by population category, from 2010.

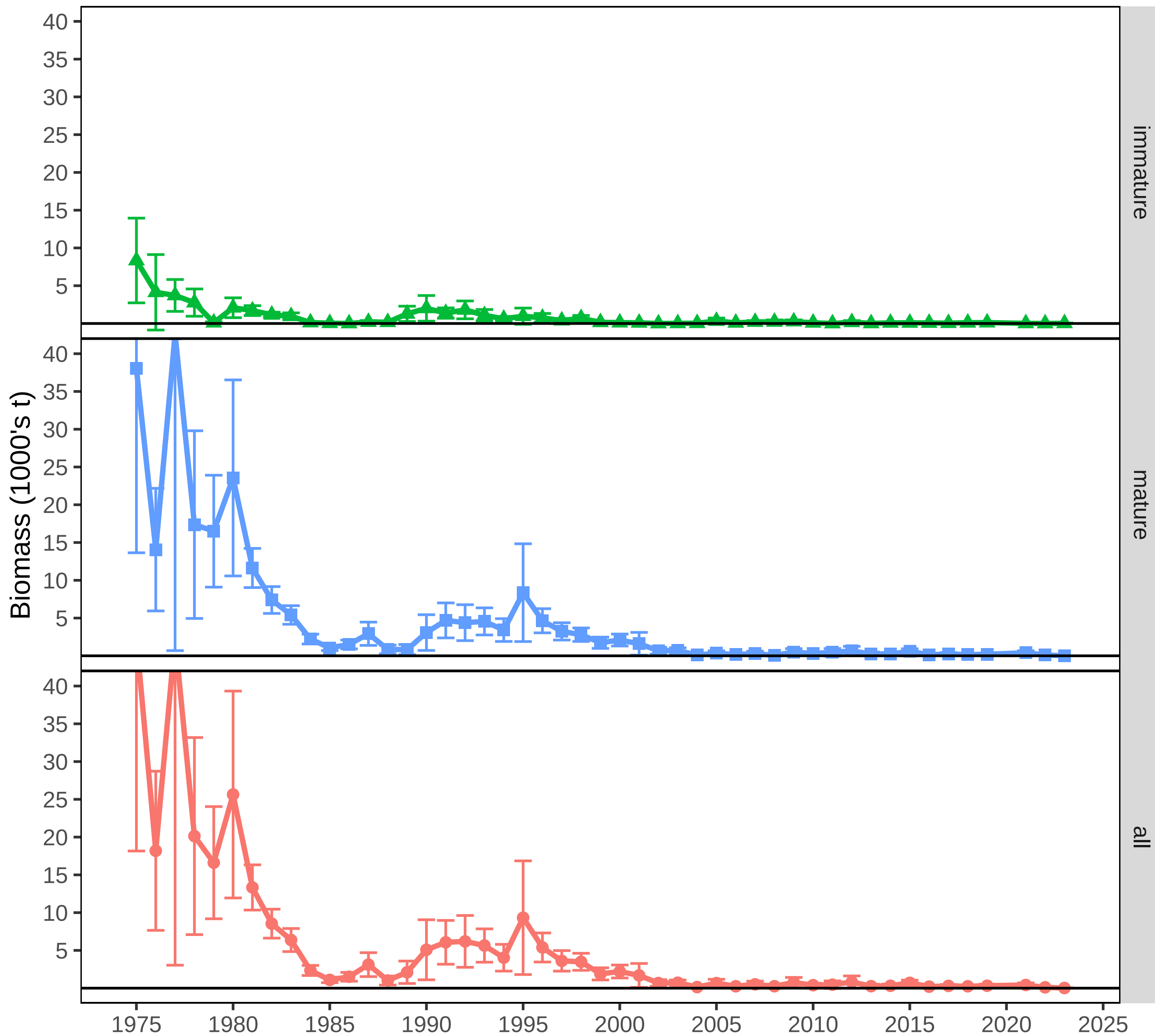

Figure 17. NMFS survey biomass time series for male PIBKC, by maturity category.

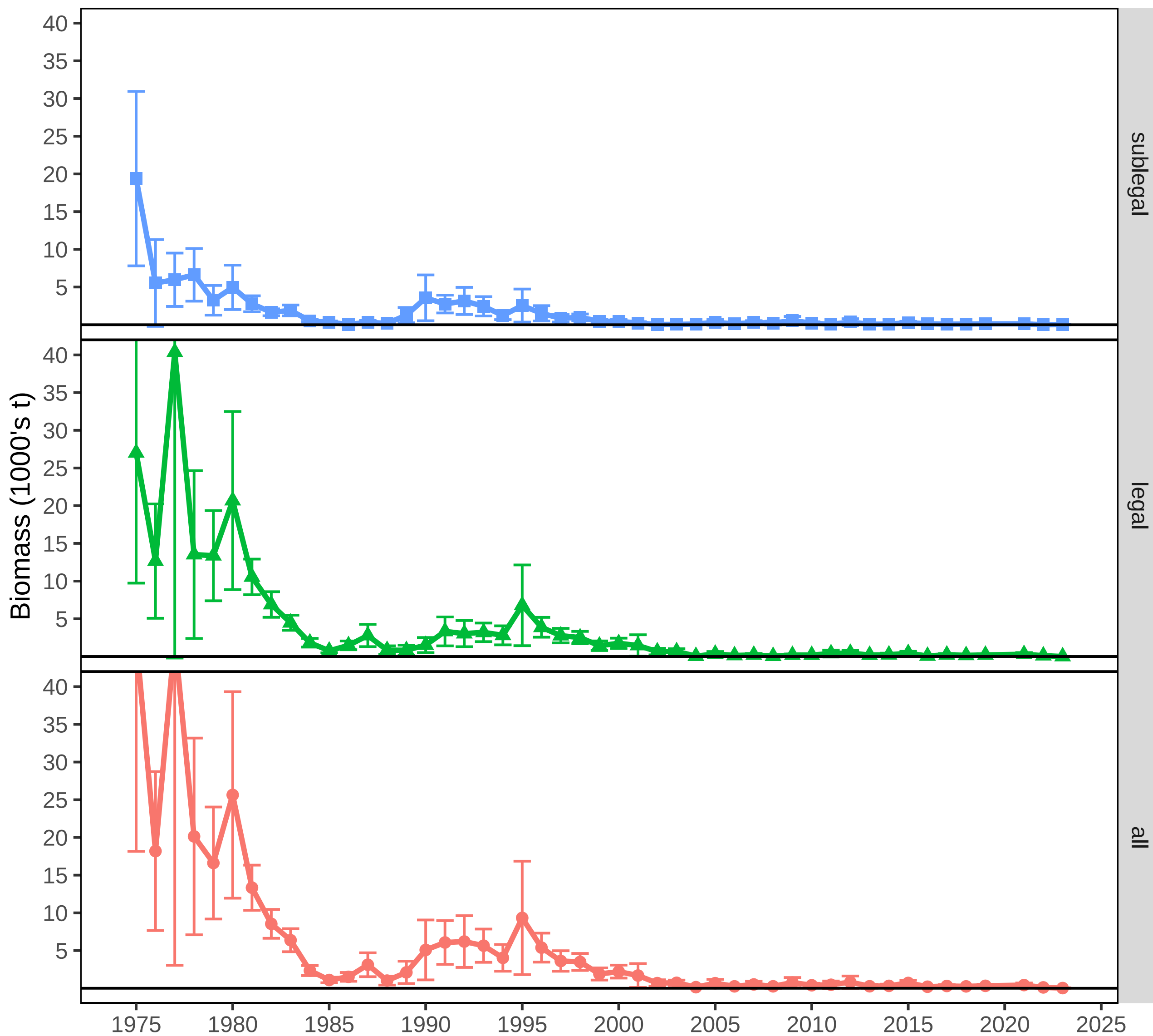

Figure 18. NMFS survey biomass time series for male PIBKC, by fishery category.

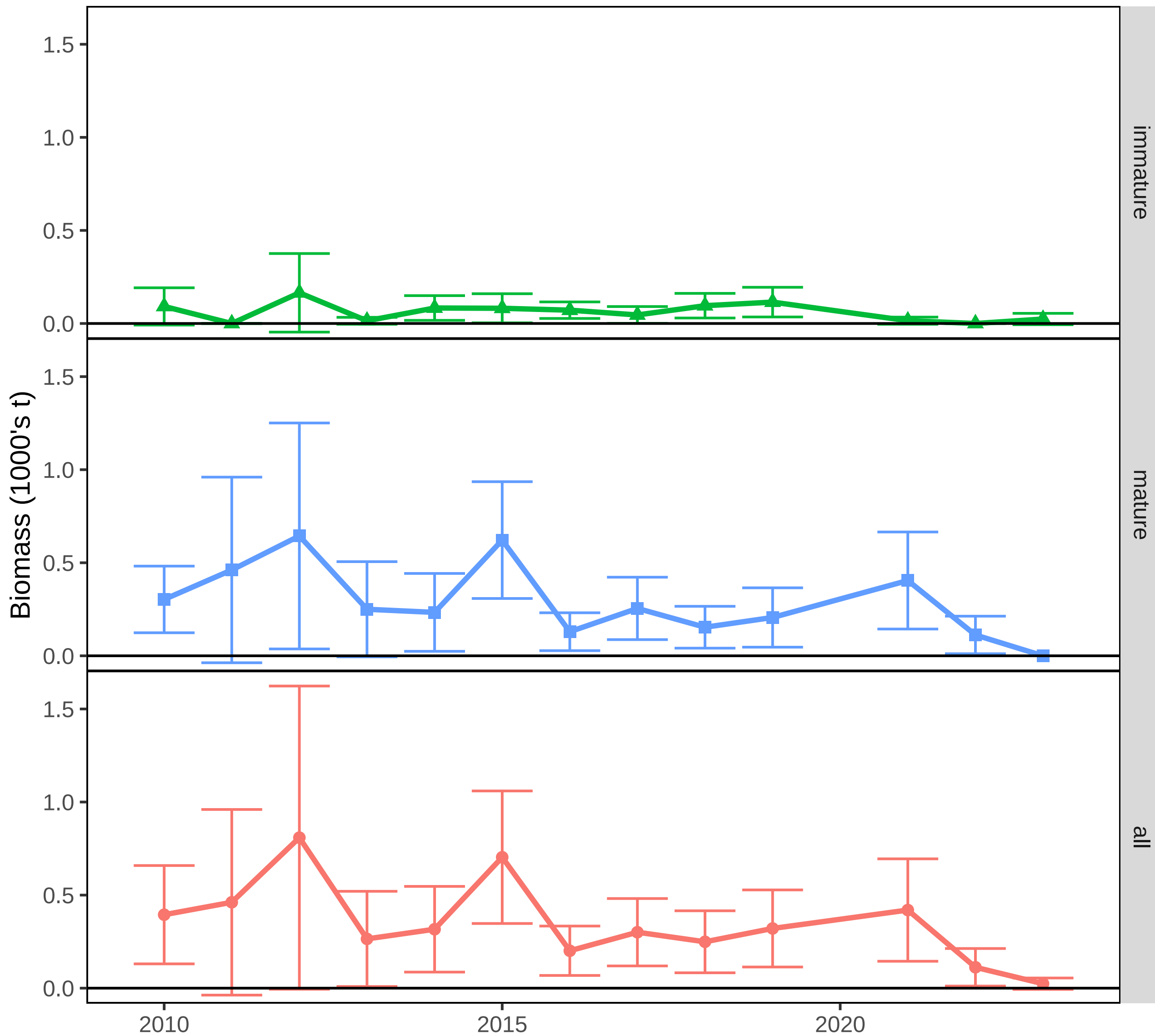

Figure 19. NMFS survey biomass time series for male PIBKC, by maturity category, from 2010.

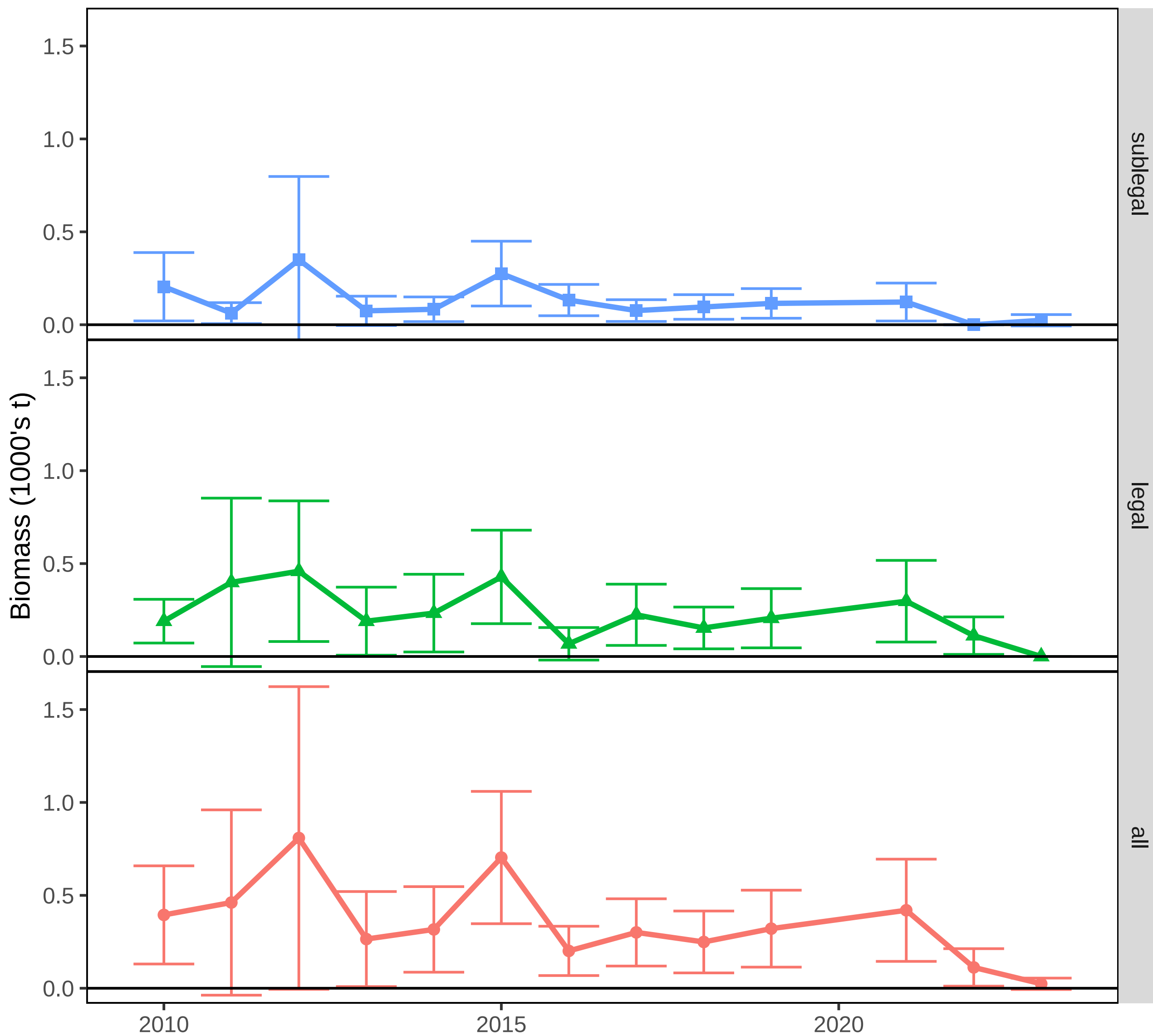

Figure 20. NMFS survey biomass time series for male PIBKC, by fishery category, from 2010.

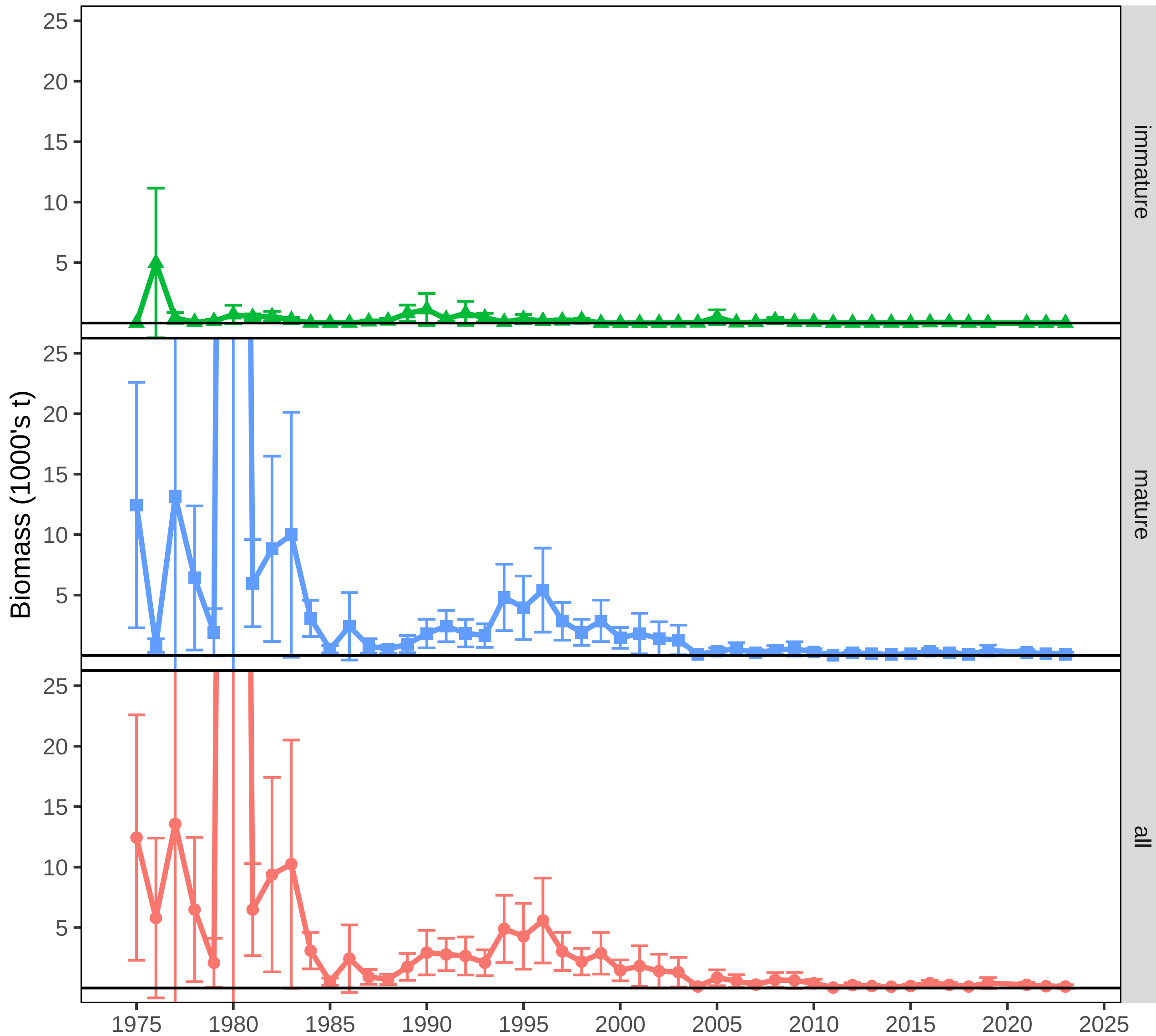

Figure 21. NMFS survey biomass time series for female PIBKC, by population category. The values for mature and all females for 1980 are off-scale to better show details of remaining values.

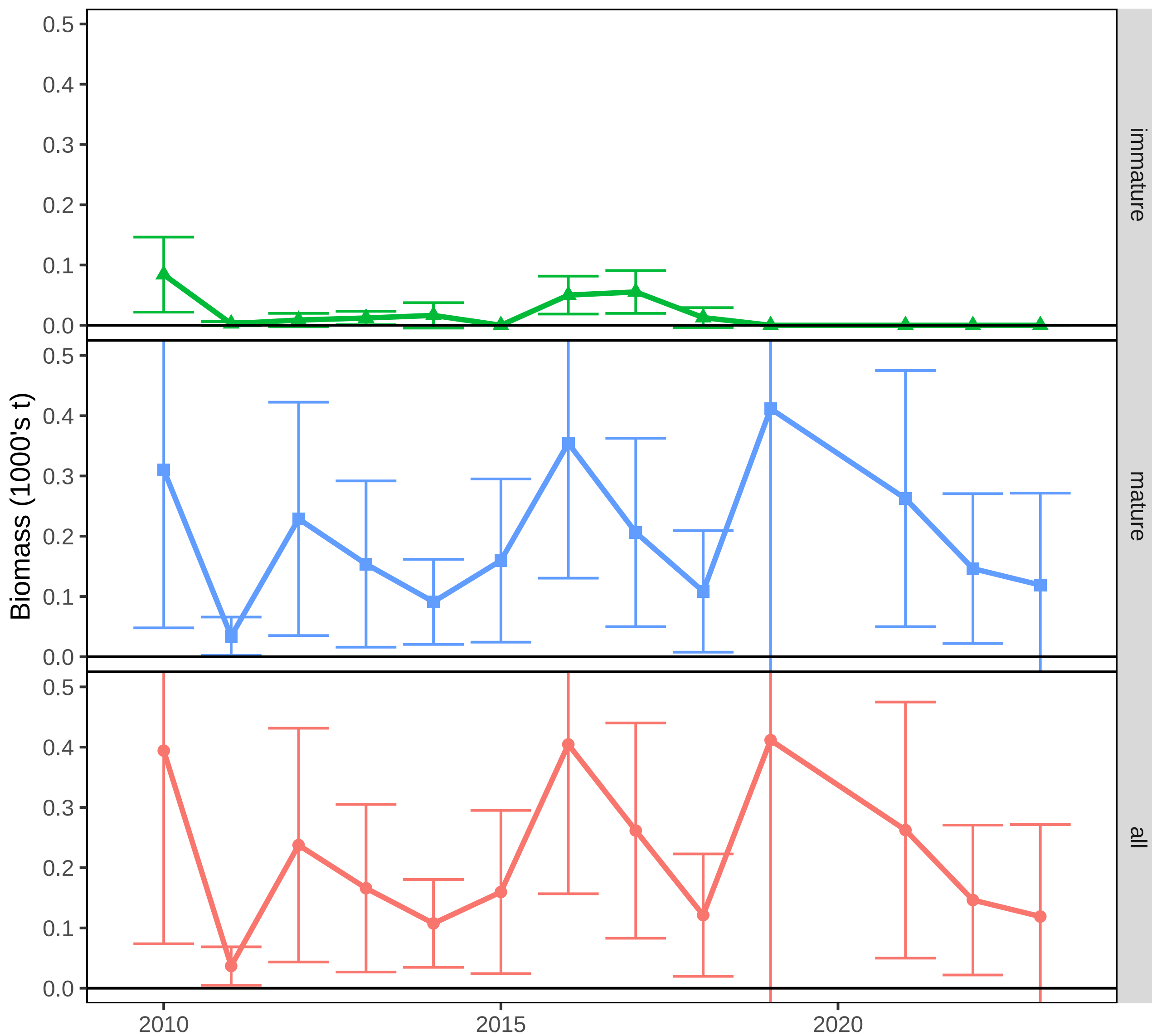

Figure 22. NMFS survey biomass time series for female PIBKC, by population category, from 2010.

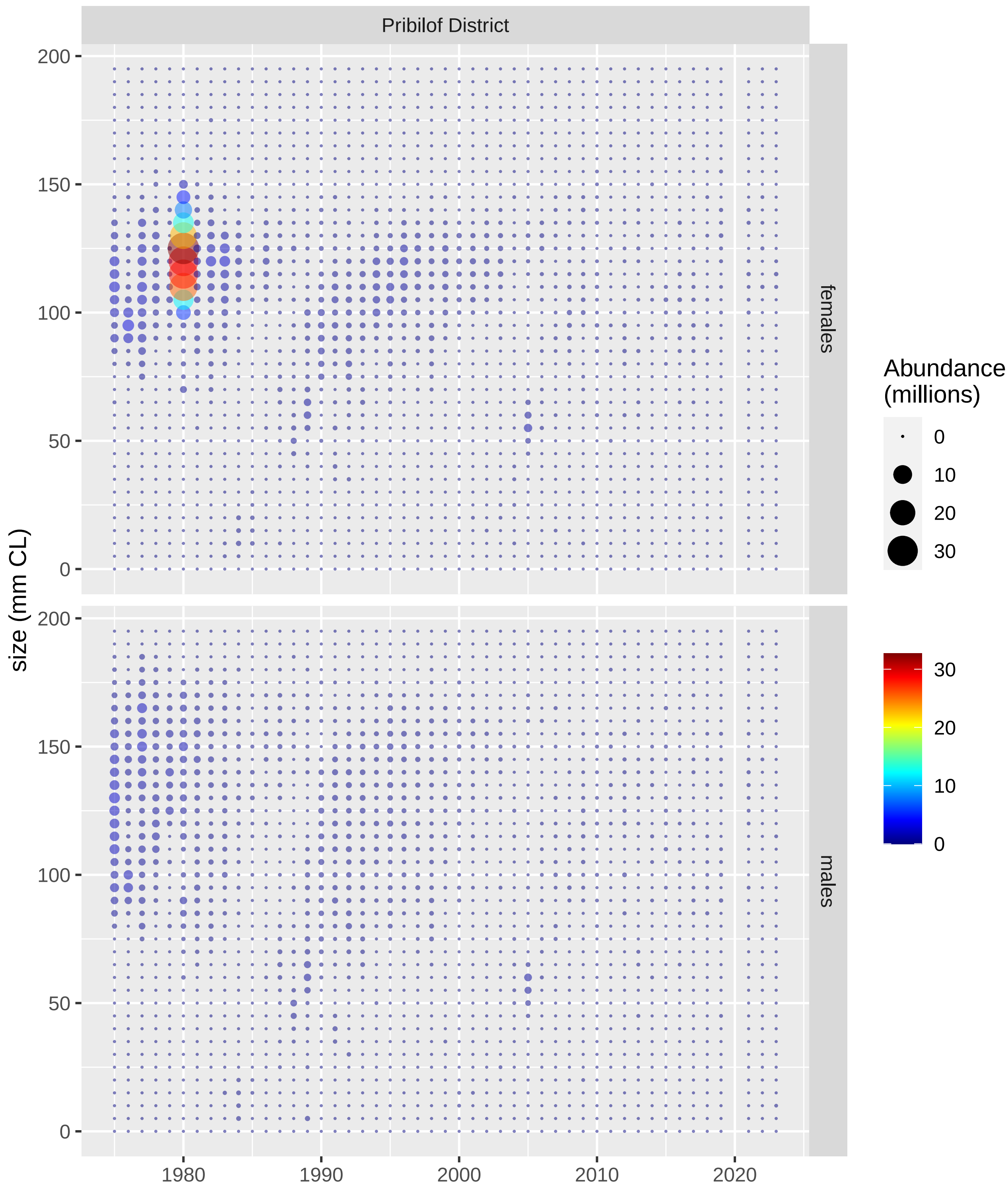

Figure 23. Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period. The survey was not conducted in 2020.

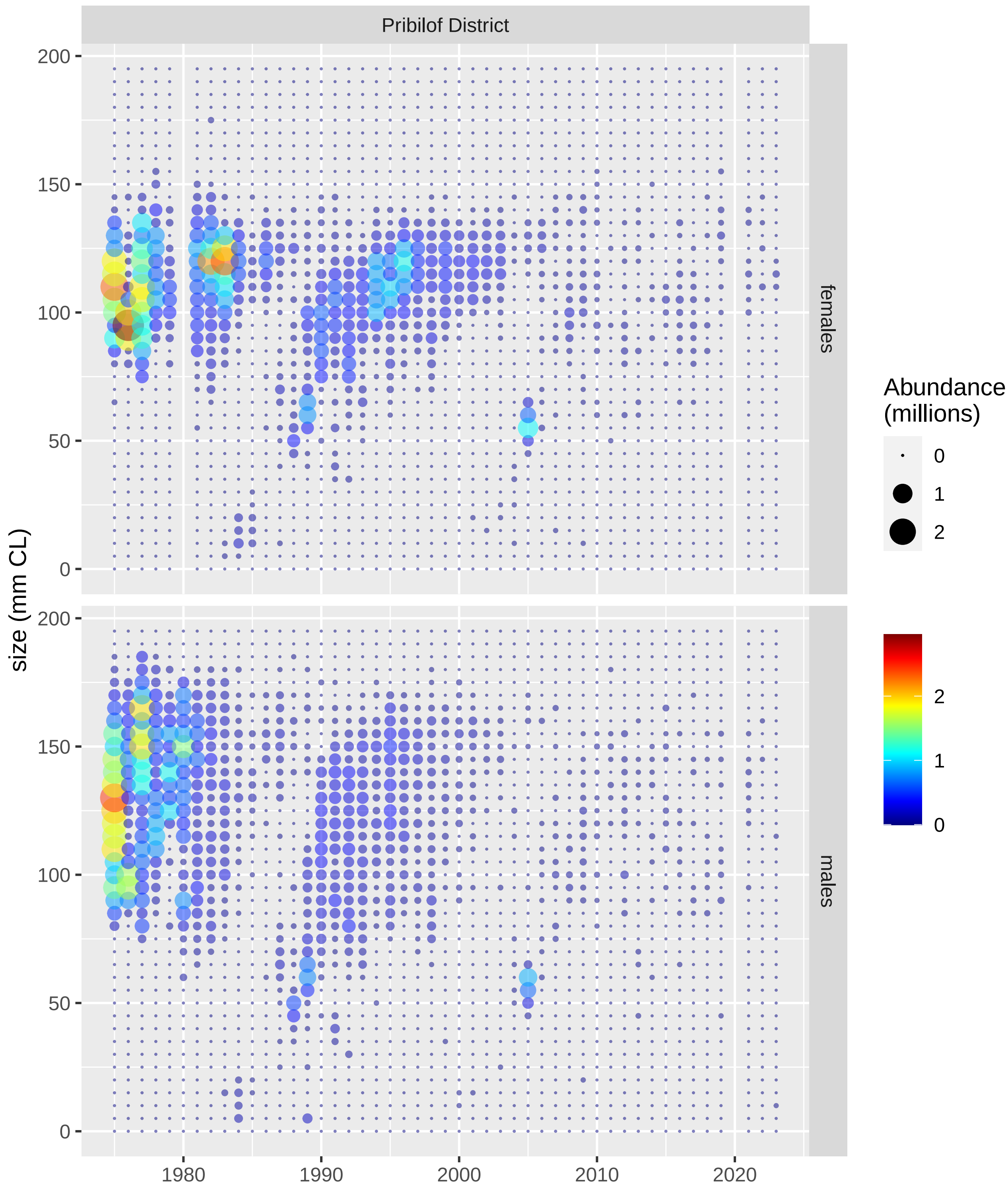

Figure 24. Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period, except that females in 1980 have been removed to show detail. The survey was not conducted in 2020.

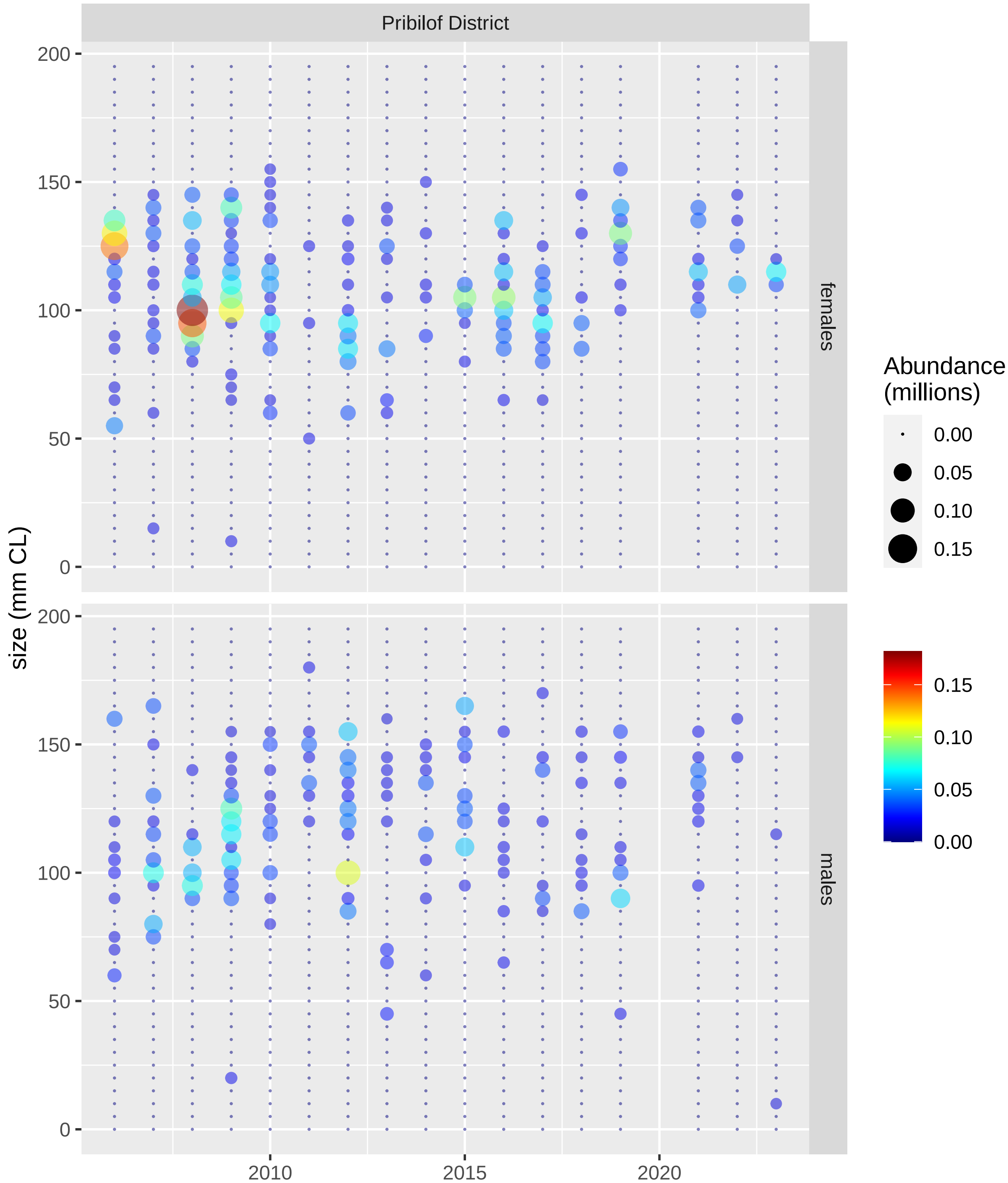

Figure 25. Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, since 2006. The survey was not conducted in 2020.

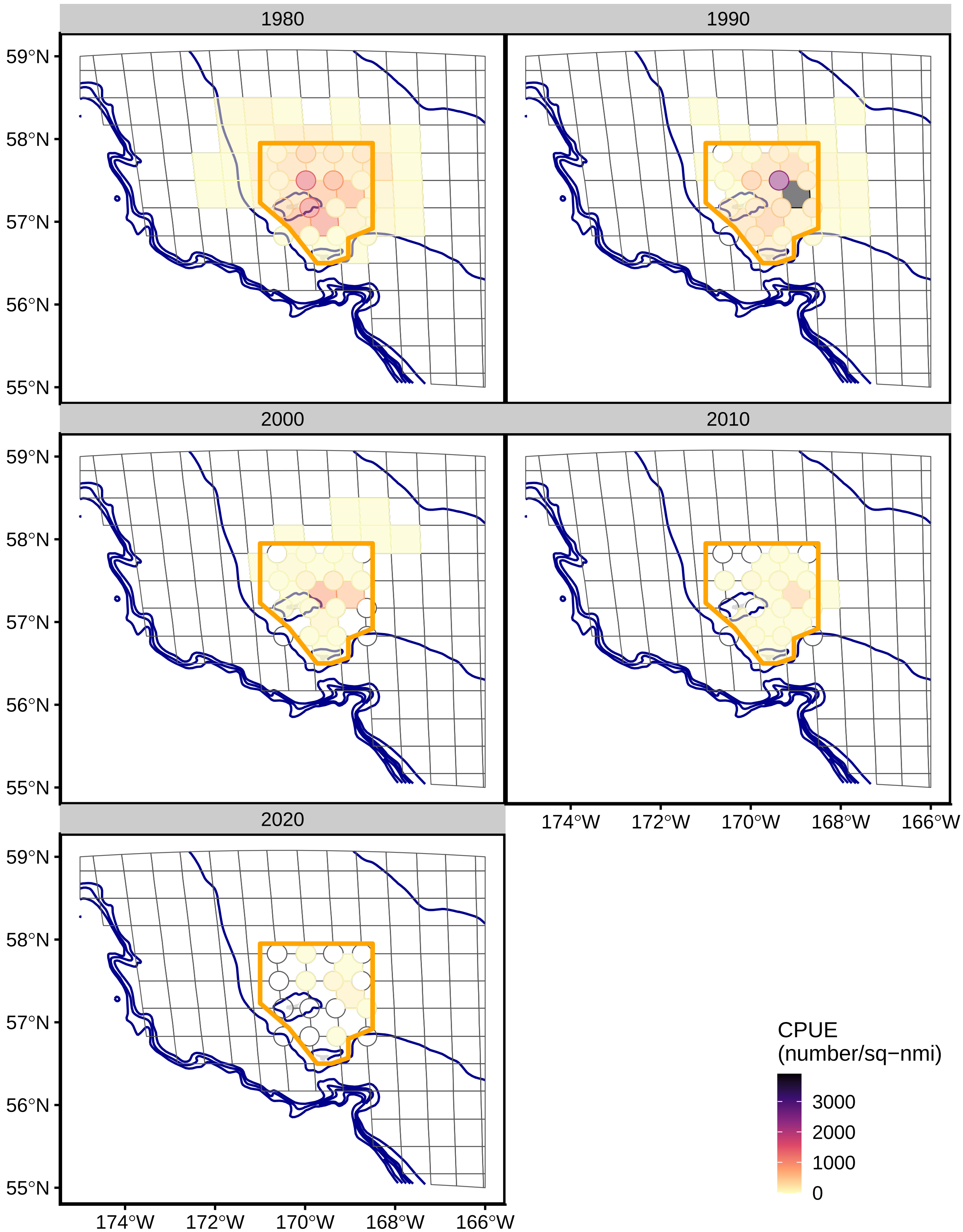

Figure 26. Decadal-average abundance CPUE (number/sq-nmi) by for male PIBKC in the NMFS EBS trawl survey

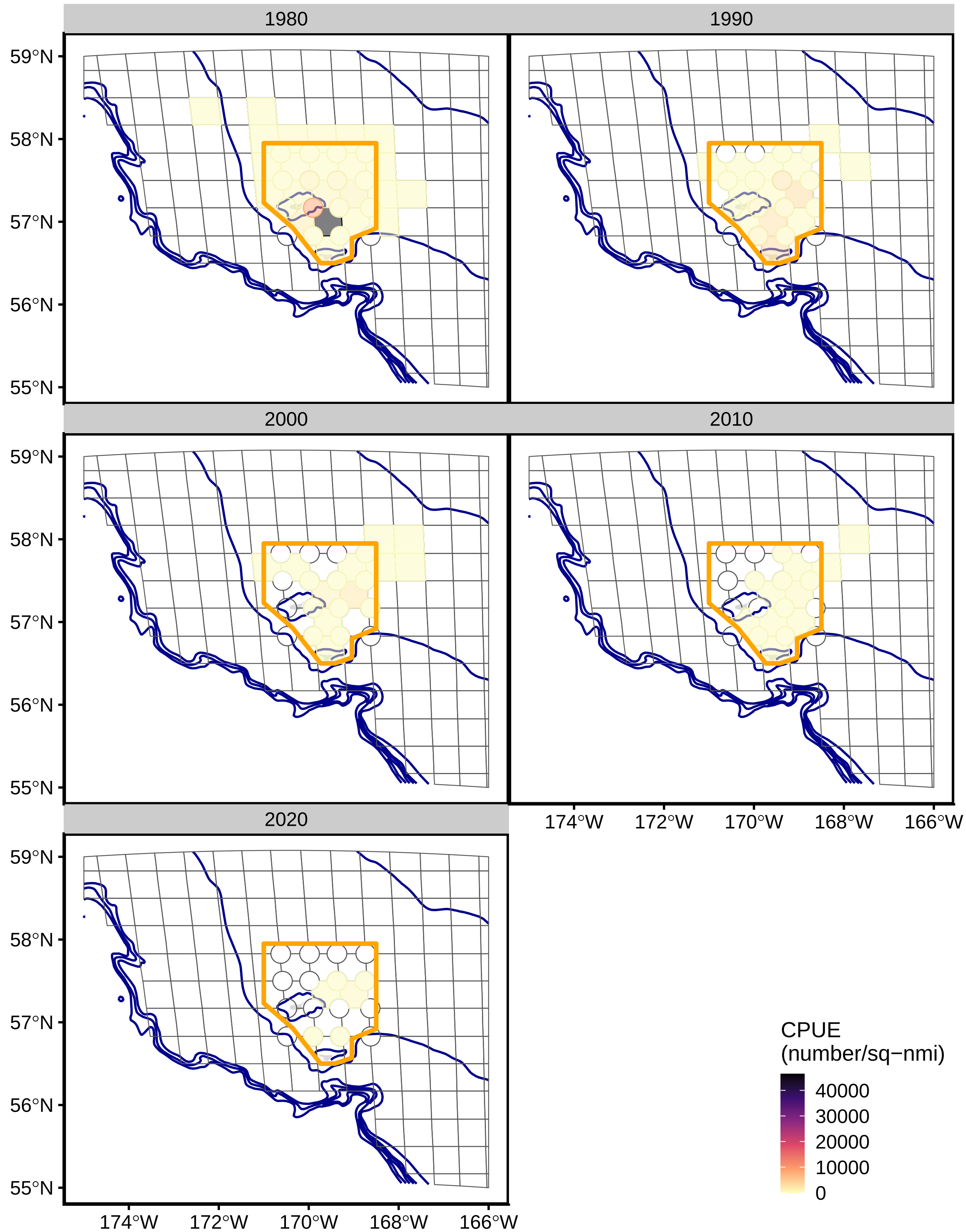

Figure 27. Decadal-average abundance CPUE (number/sq-nmi) by for female PIBKC in the NMFS EBS trawl survey

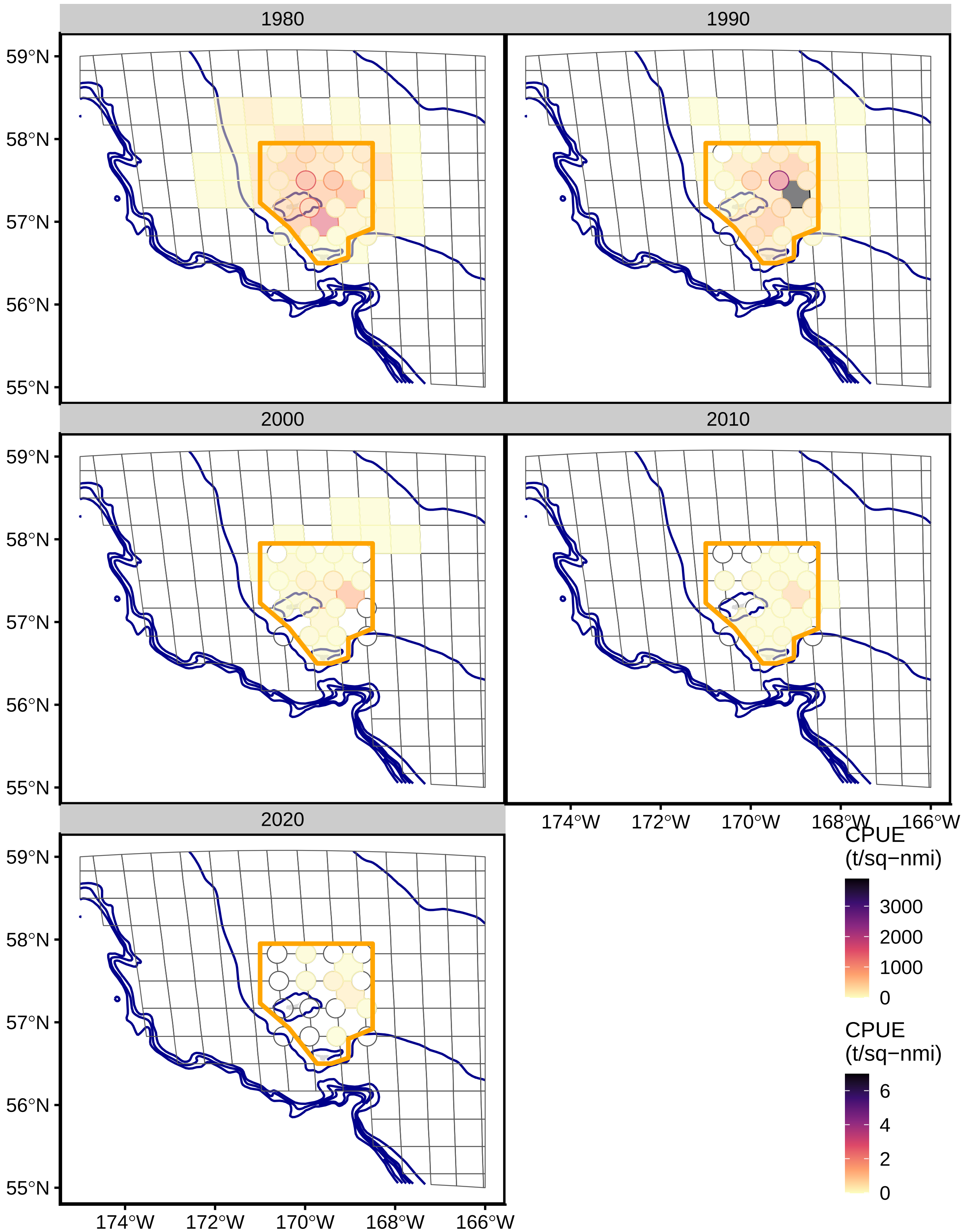

Figure 28. Decadal-average biomass CPUE (t/sq-nmi) by for male PIBKC in the NMFS EBS trawl survey

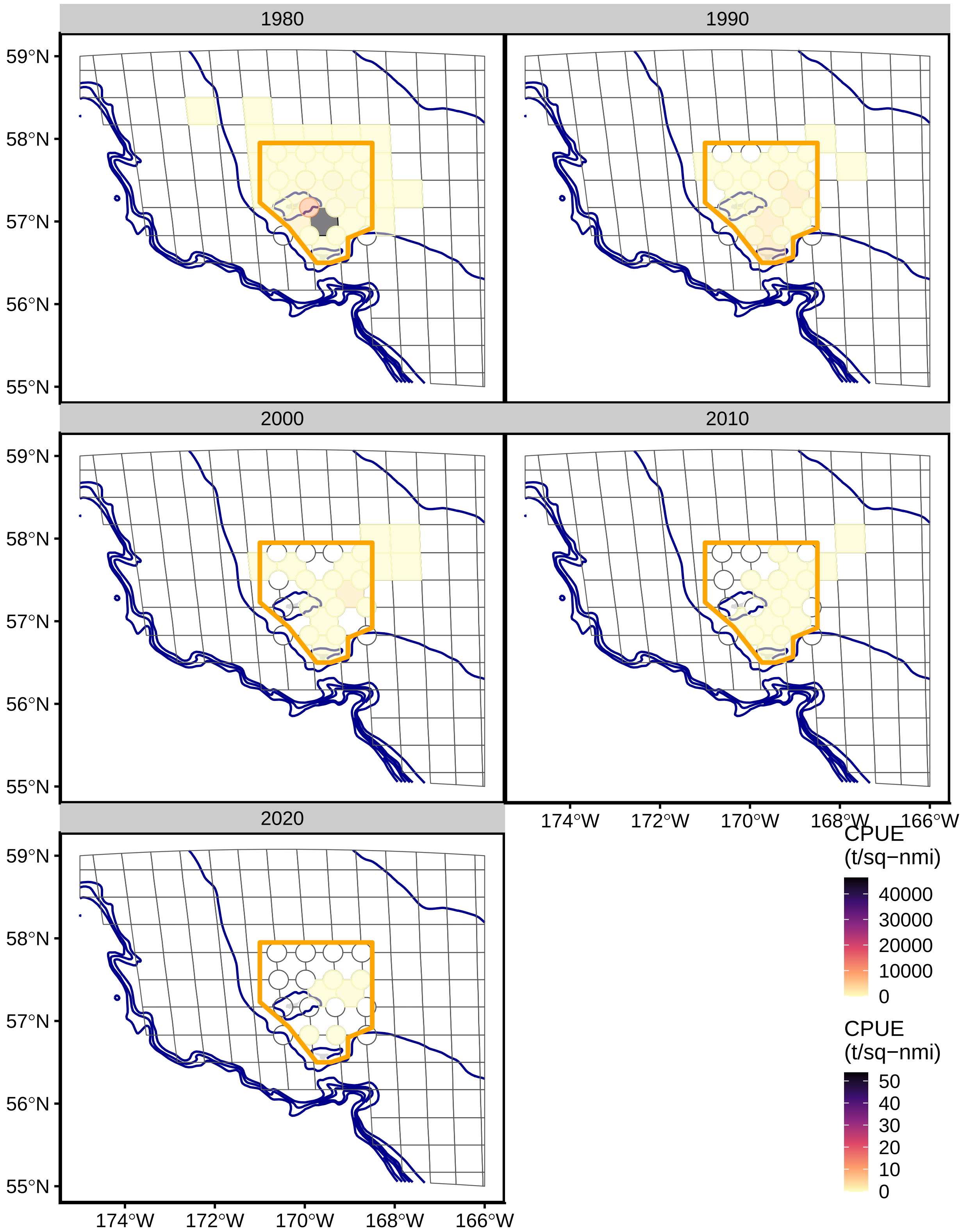

Figure 29. Decadal-average biomass CPUE (t/sq-nmi) by for female PIBKC in the NMFS EBS trawl survey

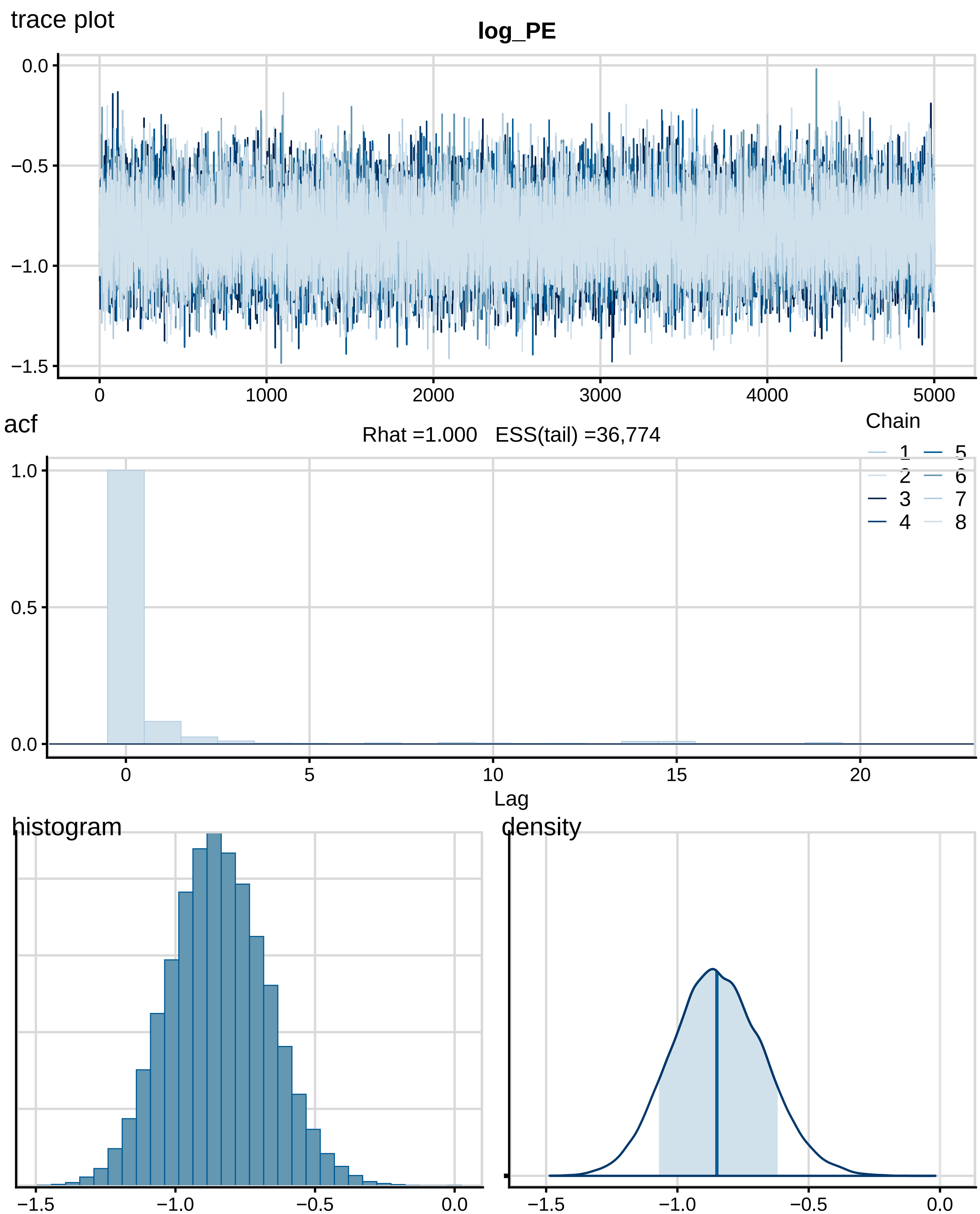

Figure 30. MCMC diagnostics for the ln-scale process error parameter from the "zeros as NAs" model. Top row: trace plot; center row: autocorrelation plot; bottom row: histogram (left) and estimated posterior density with median (vertical line) and 80% confidence interval (shading). rHat (<1.05) and ESS (>100) are measures of acceptable MCMC mixing.

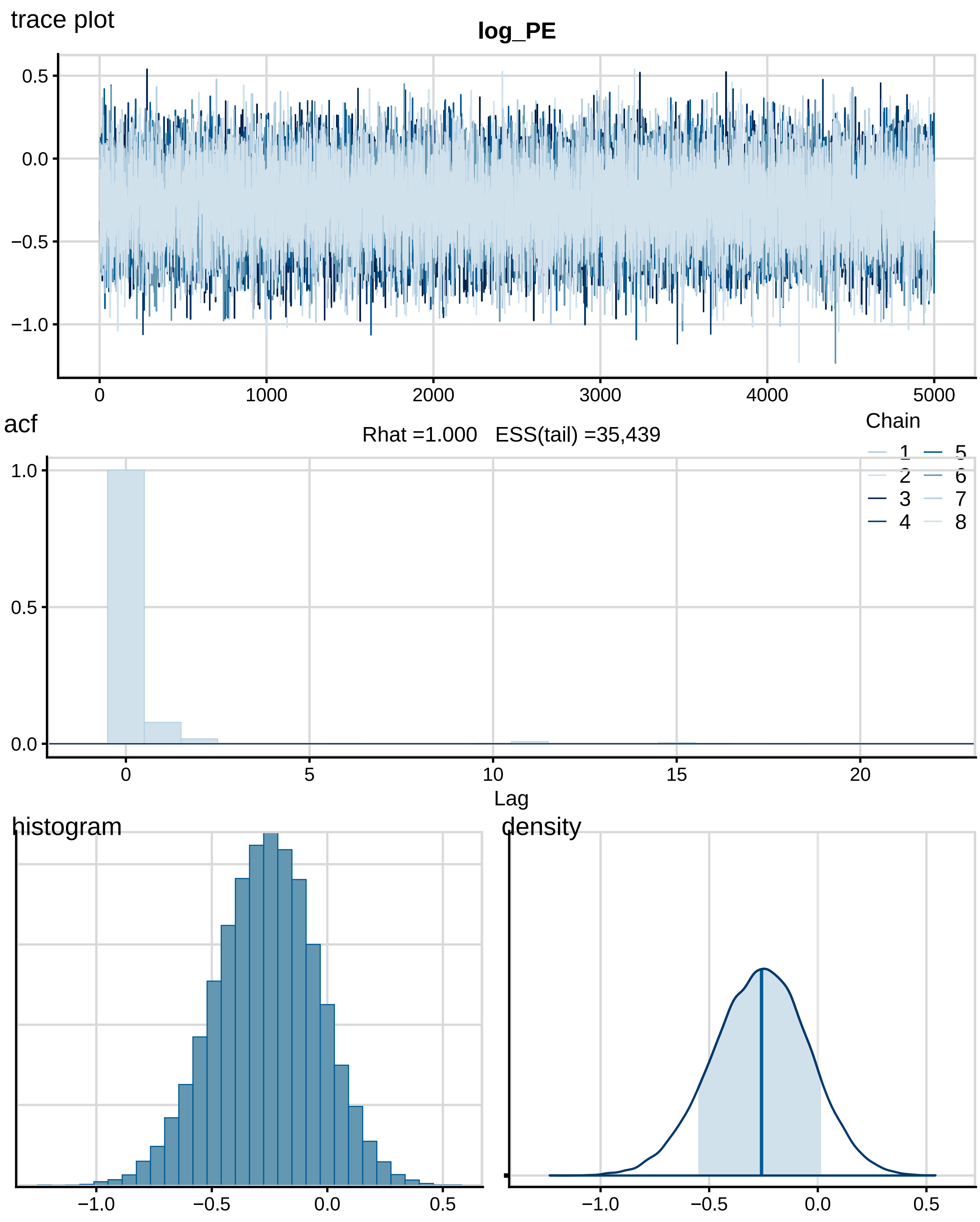

Figure 31. MCMC diagnostics for the ln-scale process error parameter from the "small constant" model. Top row: trace plot; center row: autocorrelation plot; bottom row: histogram (left) and estimated posterior density with median (vertical line) and 80% confidence interval (shading). rHat (<1.05) and ESS (>100) are measures of acceptable MCMC mixing.

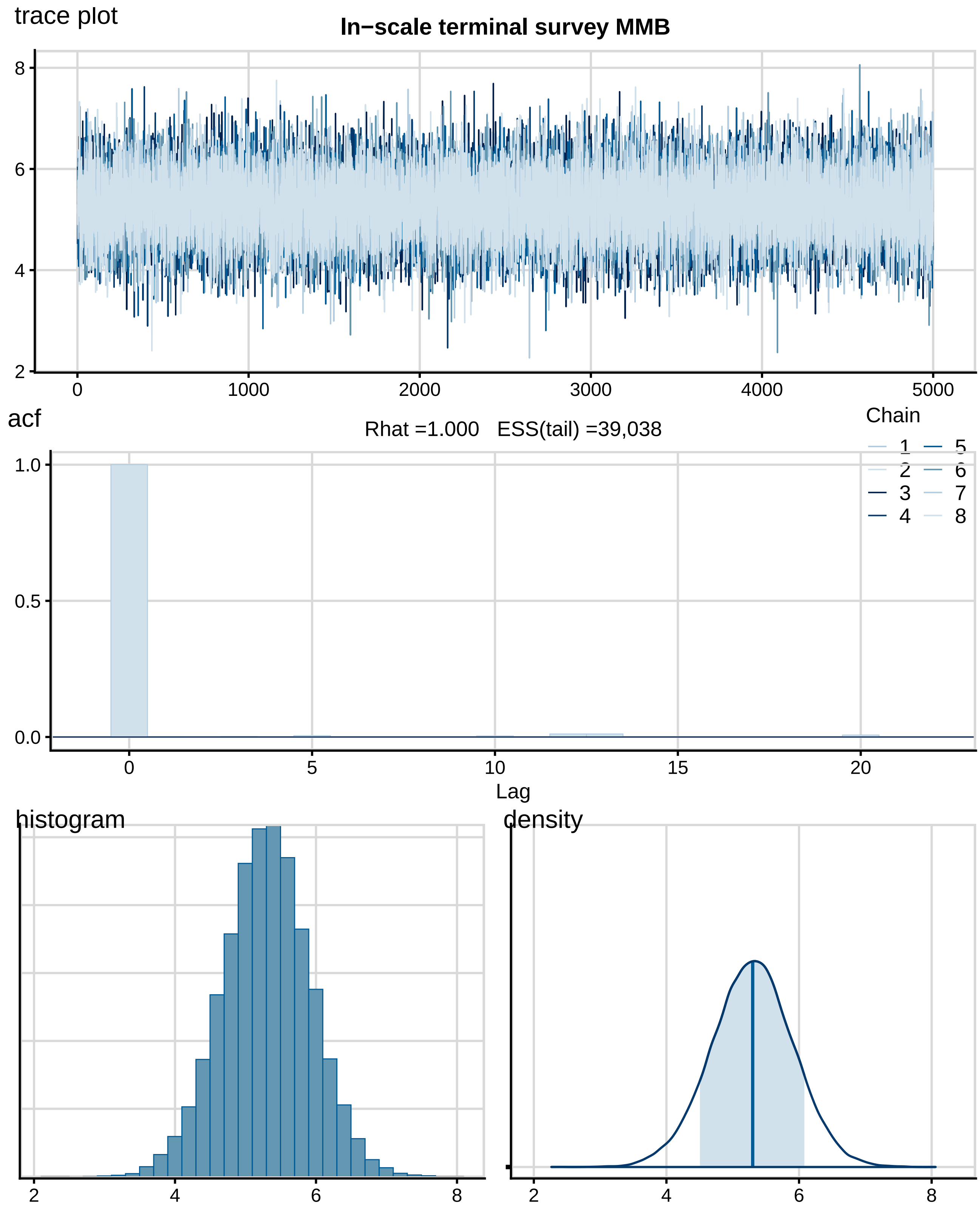

Figure 32. MCMC diagnostics for the ln-scale terminal year survey MMB from the "zeros as NAs" model. Top row: trace plot; center row: autocorrelation plot; bottom row: histogram (left) and estimated posterior density with median (vertical line) and 80% confidence interval (shading). rHat (<1.05) and ESS (>100) are measures of acceptable MCMC mixing.

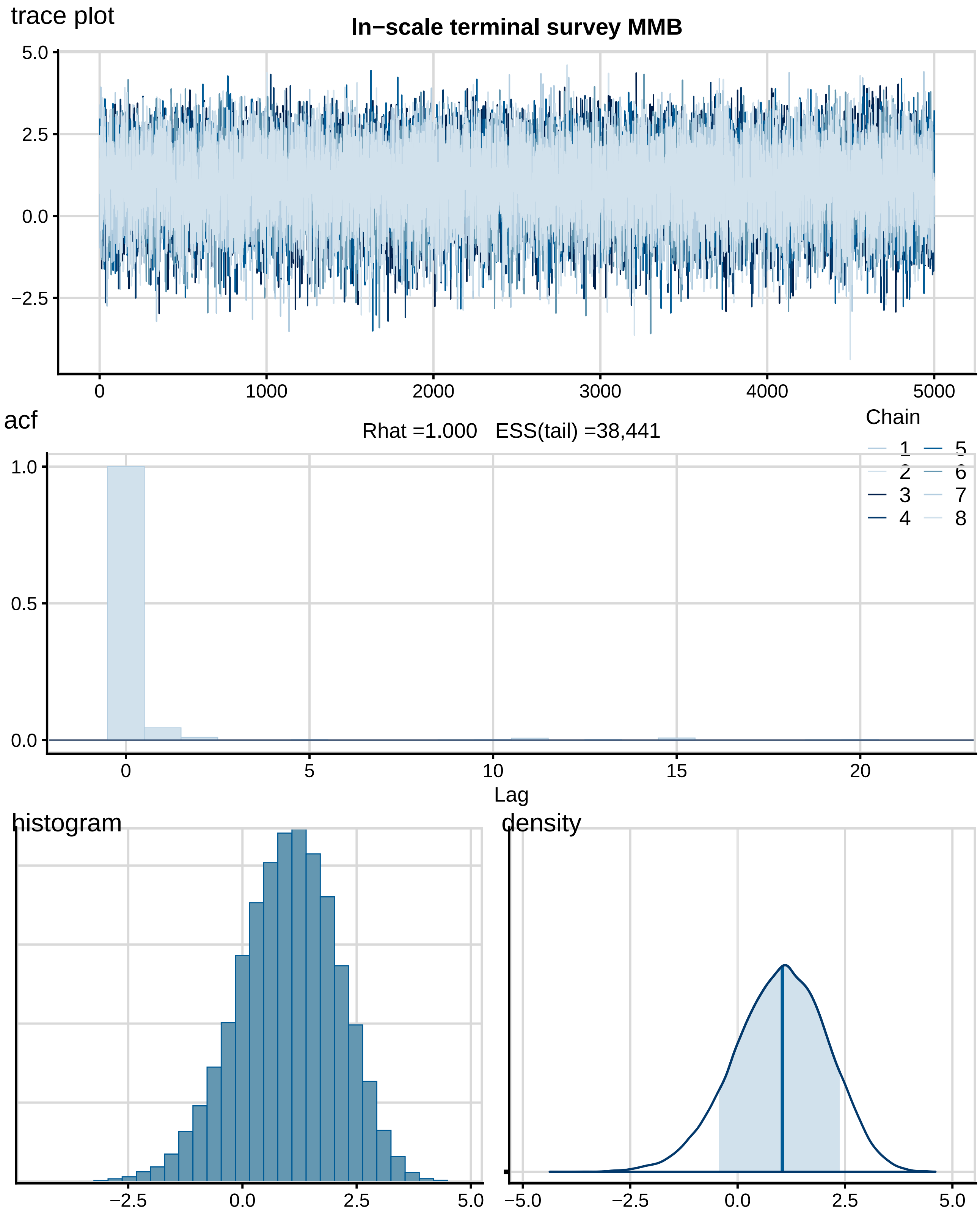

Figure 33. MCMC diagnostics for the ln-scale terminal year survey MMB from the "small constant" model. Top row: trace plot; center row: autocorrelation plot; bottom row: histogram (left) and estimated posterior density with median (vertical line) and 80% confidence interval (shading). rHat (<1.05) and ESS (>100) are measures of acceptable MCMC mixing.

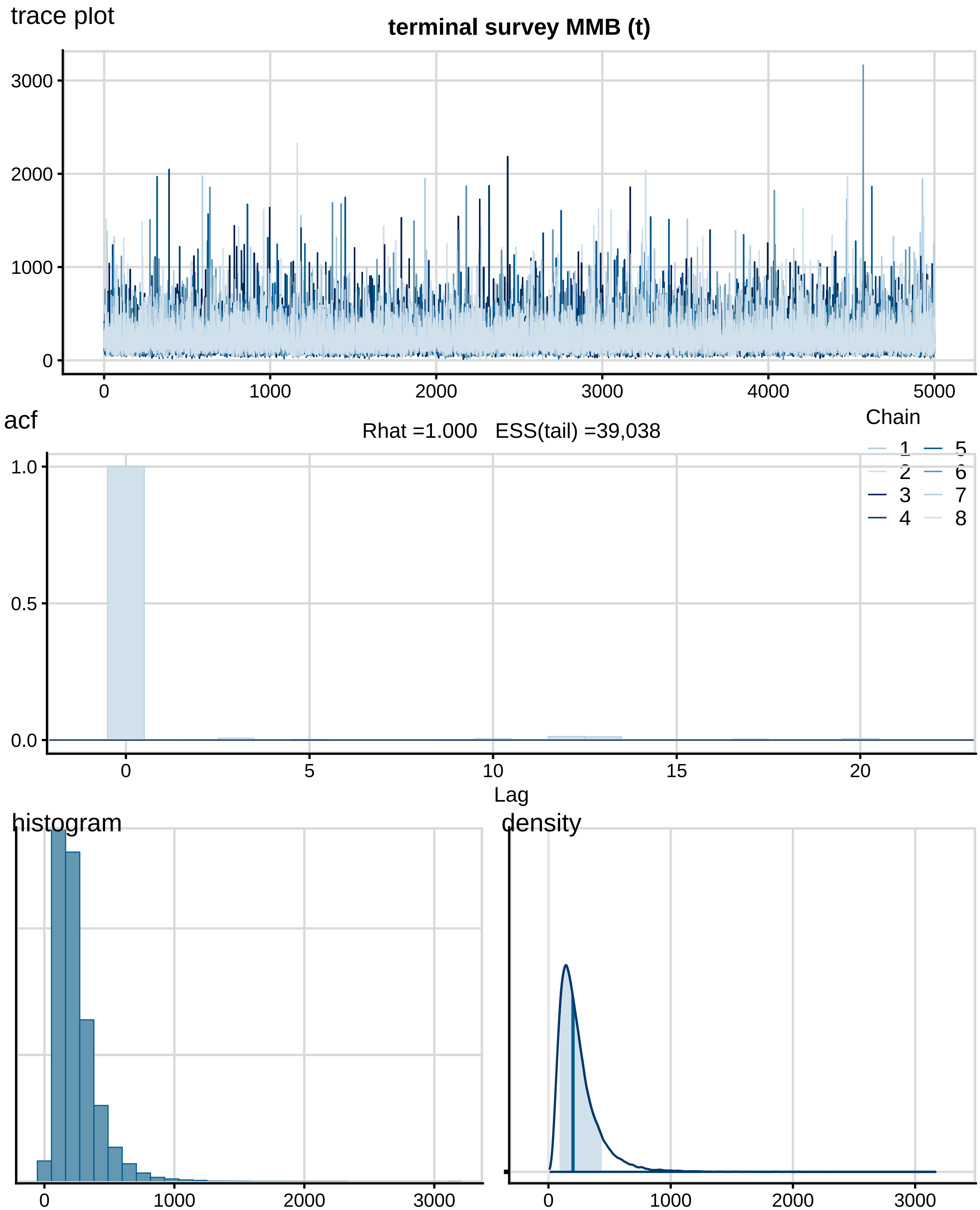

Figure 34. MCMC diagnostics for the terminal year survey MMB from the "zeros as NAs" model. Top row: trace plot; center row: autocorrelation plot; bottom row: histogram (left) and estimated posterior density with median (vertical line) and 80% confidence interval (shading). rHat (<1.05) and ESS (>100) are measures of acceptable MCMC mixing.

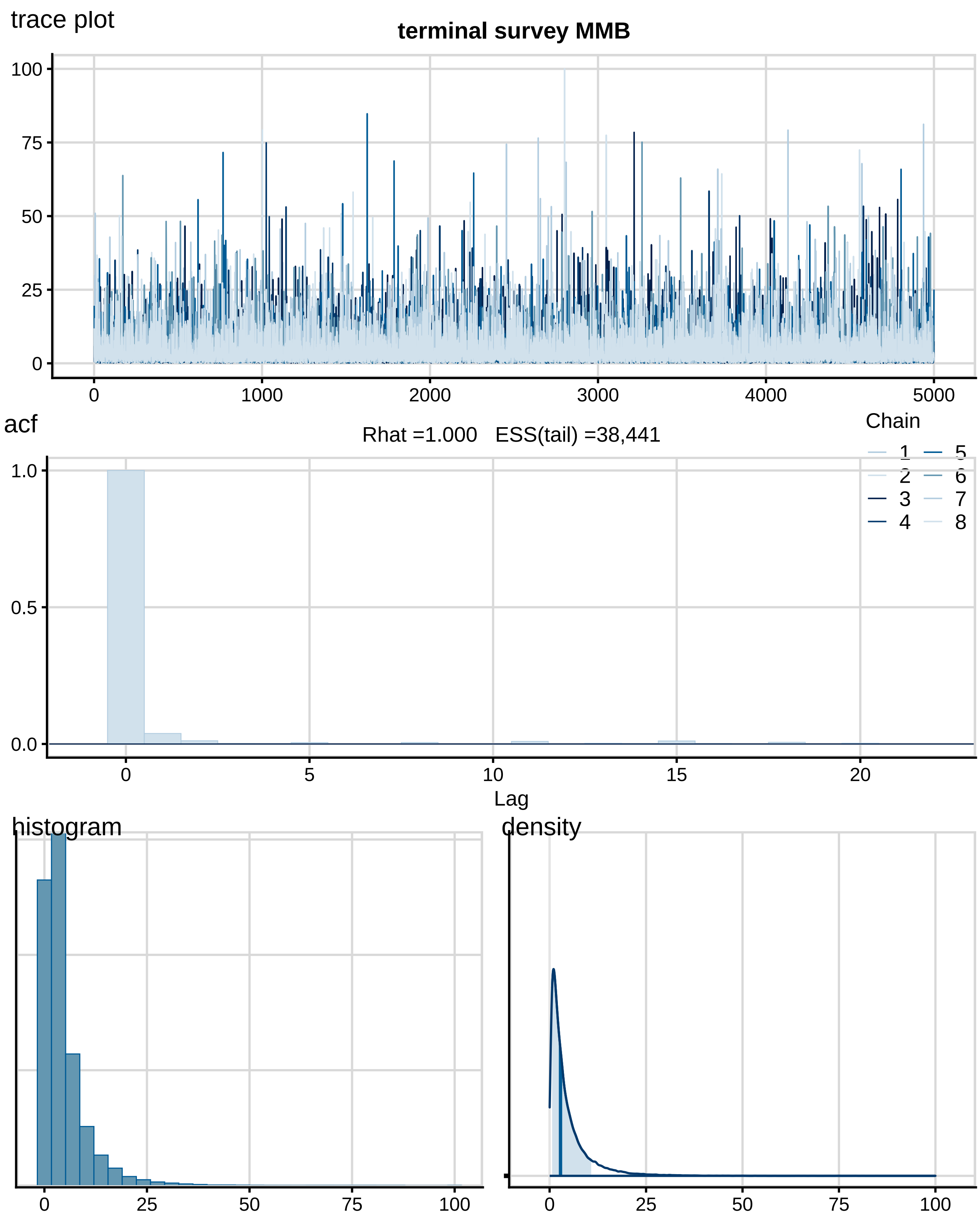

Figure 35. MCMC diagnostics for the terminal year survey MMB from the "small constant" model. Top row: trace plot; center row: autocorrelation plot; bottom row: histogram (left) and estimated posterior density with median (vertical line) and 80% confidence interval (shading). rHat (<1.05) and ESS (>100) are measures of acceptable MCMC mixing.

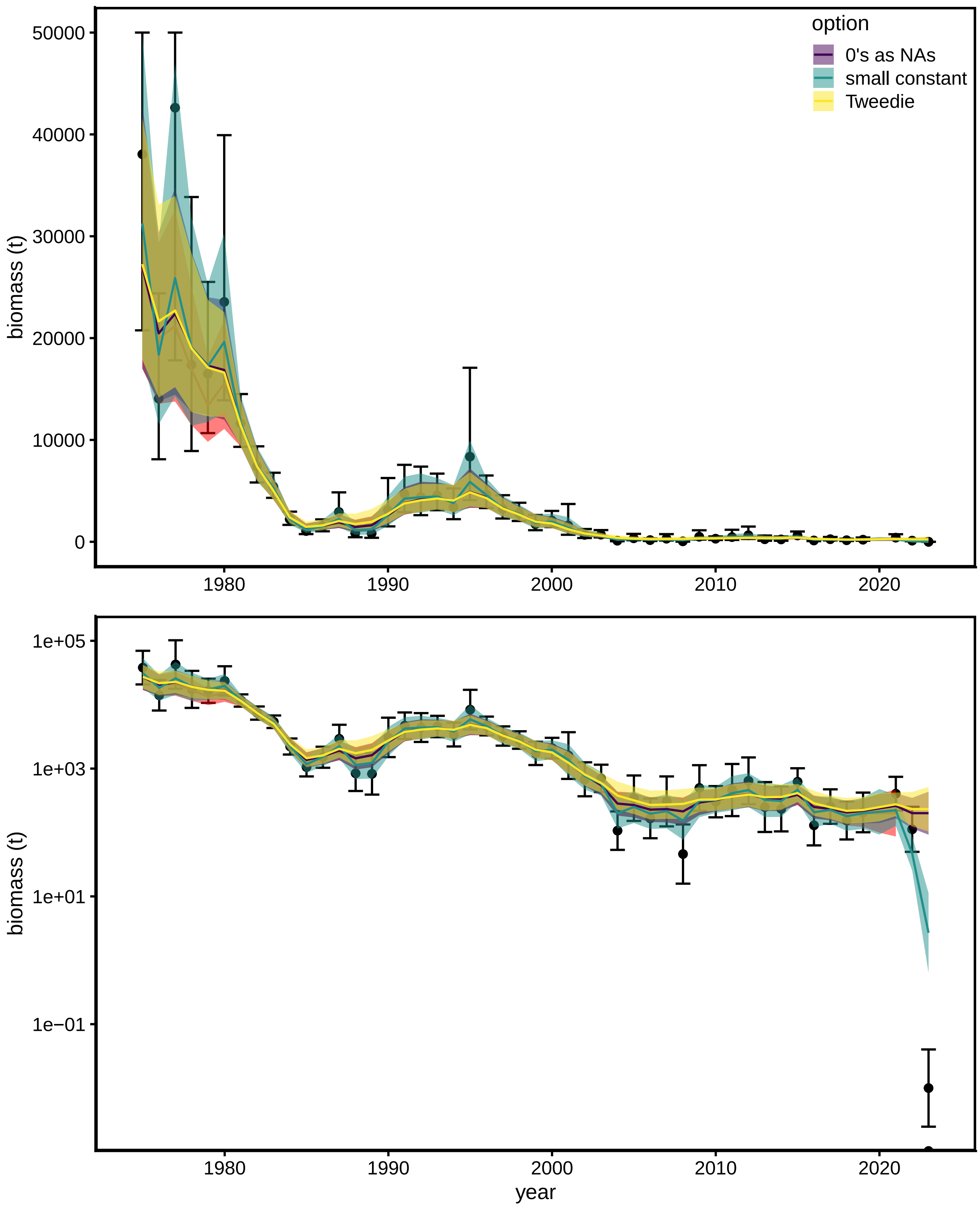

Figure 36. Results for the random walk model fits to mature survey biomass. Design-based estimates: points and error bars; last assessment: red line + red shading; current assessment: indicated colored lines + shading. Upper plot: arithmetic scale; lower plot: log-scale. Confidence intervals are 80%.

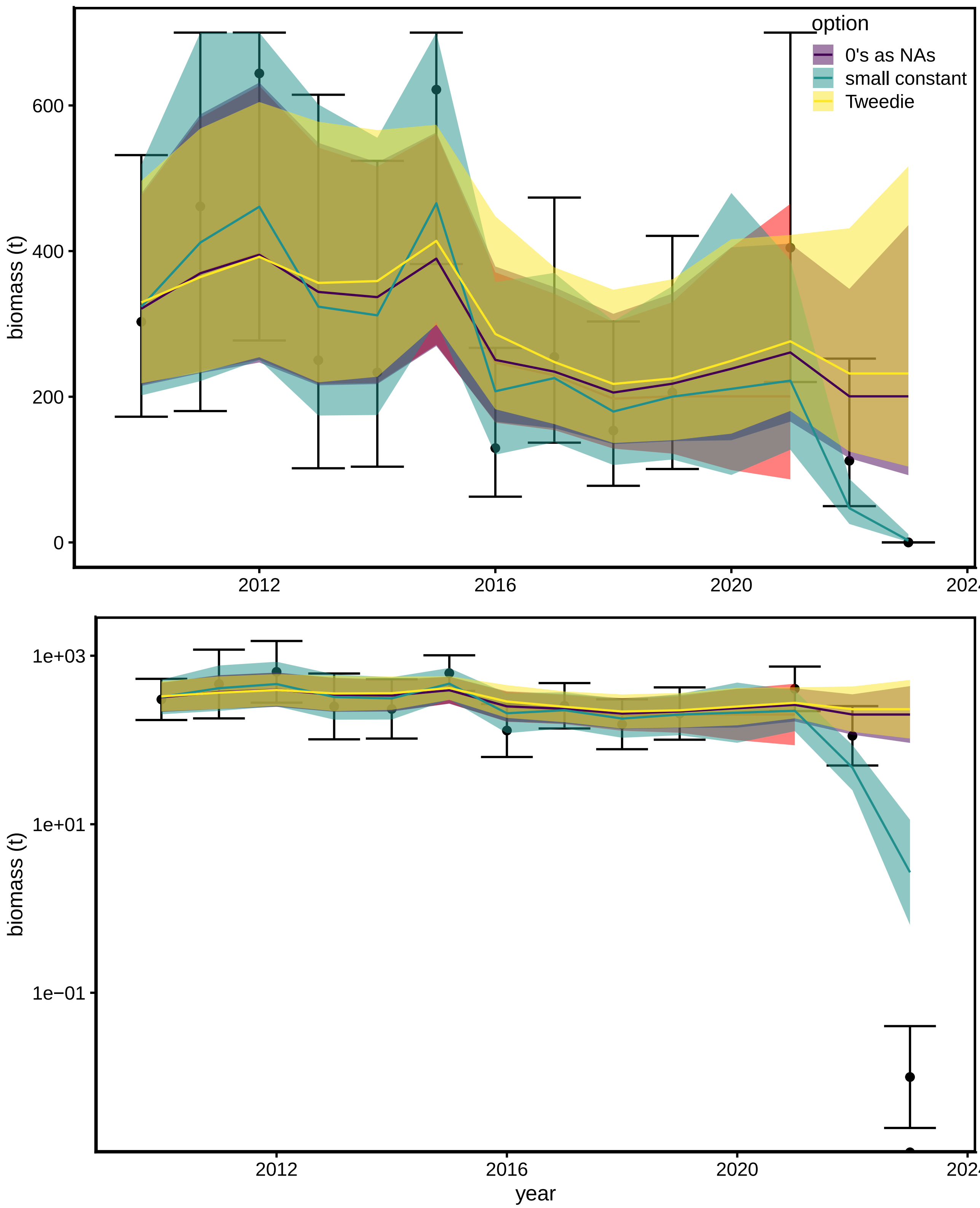

Figure 37. Results for the random walk model fits to mature survey biomass, showing recent time period. Design-based estimates: points and error bars (to 700 t); last assessment: red line + red shading; current assessment: indicated colored lines + shading. Upper plot: arithmetic scale; lower plot: log-scale. Confidence intervals are 80%.

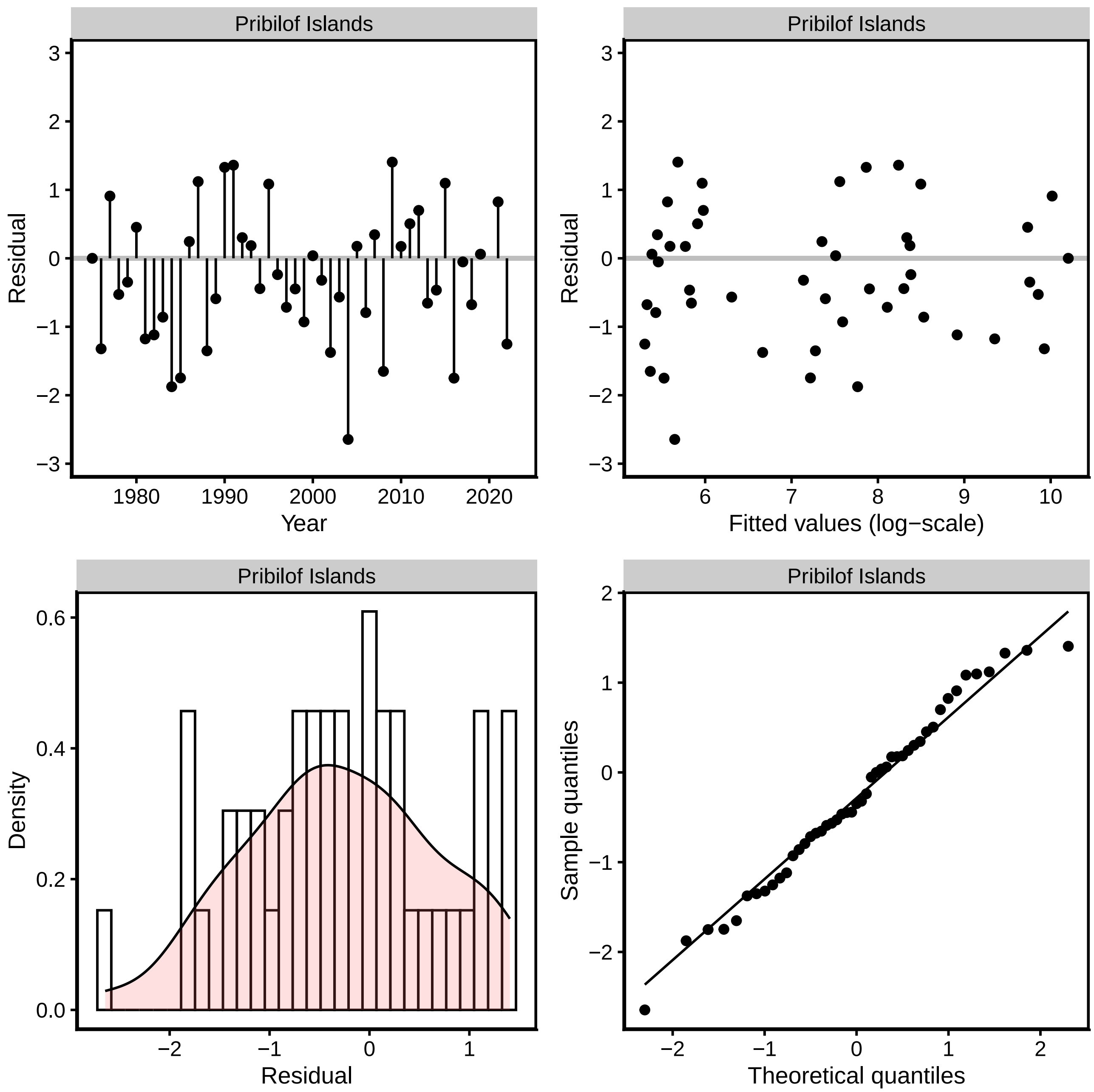

Figure 38. One-step-ahead (OSA) residual diagnostic plots for the "zeros as NAs" random walk model. Upper left: OSA residuals vs. year; Upper right: OSA residuals vs. fitted values; Lower left: histogram and kernel density of the OSA residuals; Lower right: qqplot for the OSA residuals;

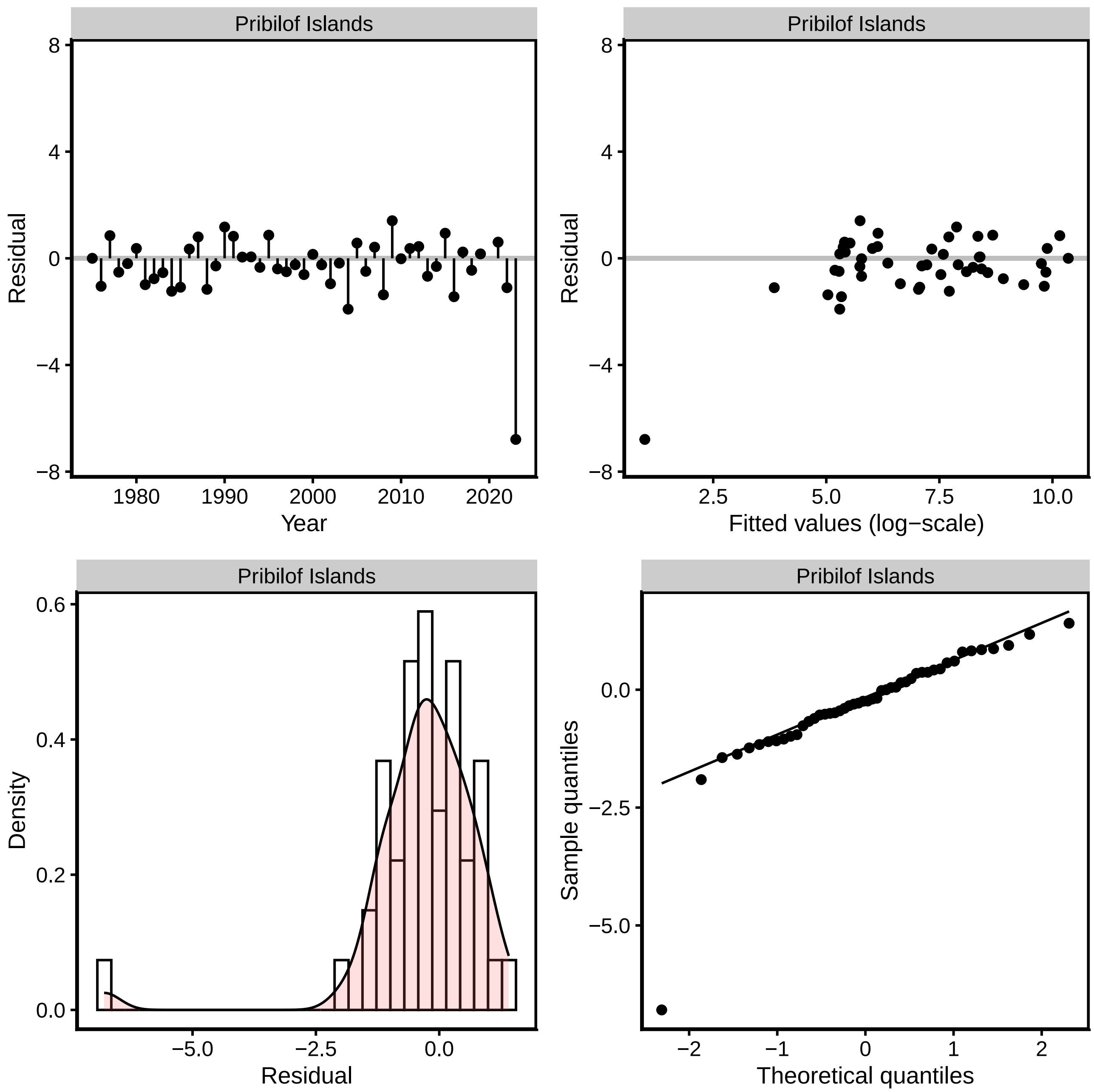

Figure 39. One-step-ahead (OSA) residual diagnostic plots for the "small constant" random walk model. Upper left: OSA residuals vs. year; Upper right: OSA residuals vs. fitted values; Lower left: histogram and kernel density of the OSA residuals; Lower right: qqplot for the OSA residuals;

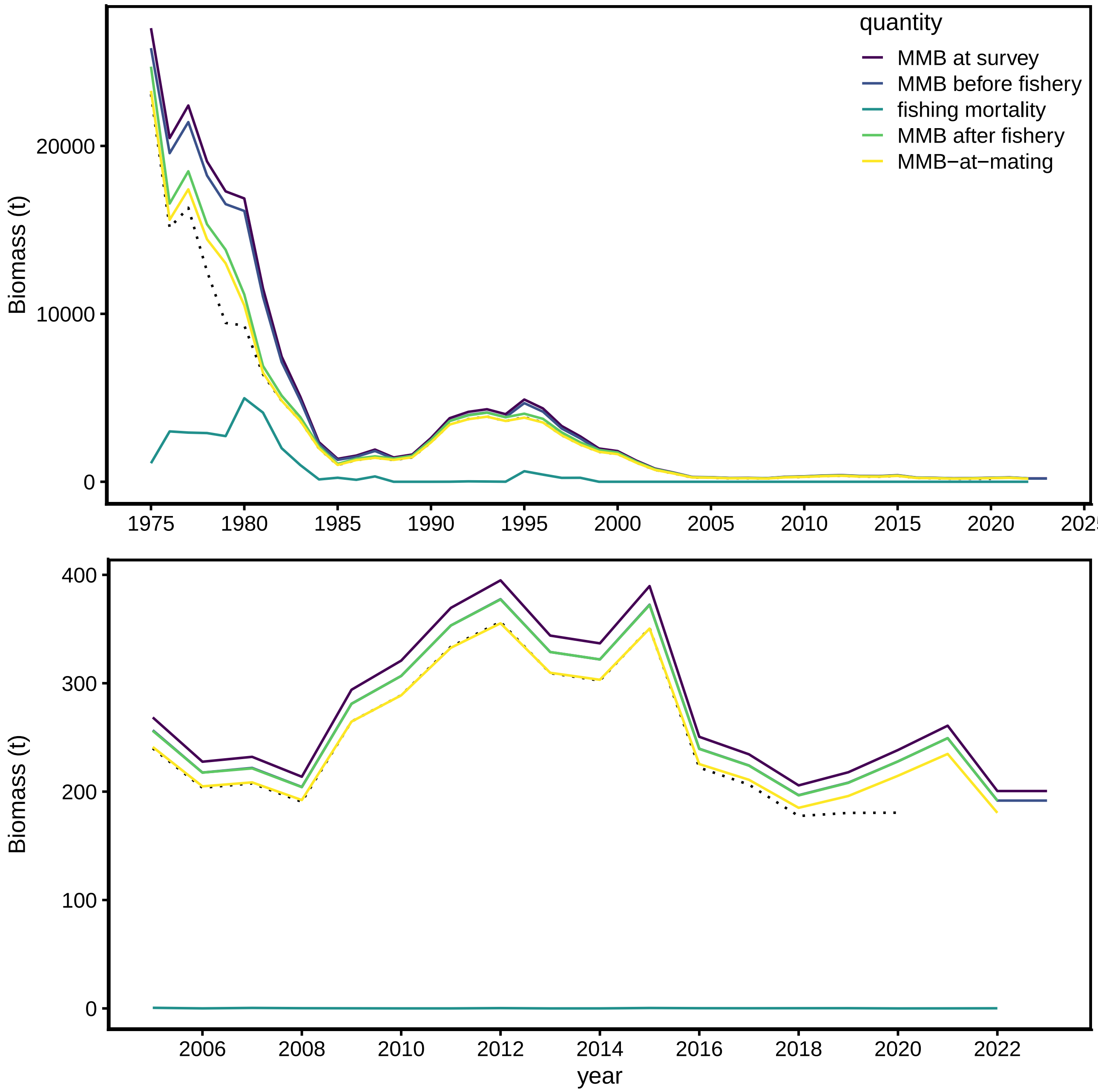

Figure 40. Estimated MMB-at-mating. Upper plot: full time series. Lower plot: detail for 2005/06+. Dotted line is estimated time series from last assesment.

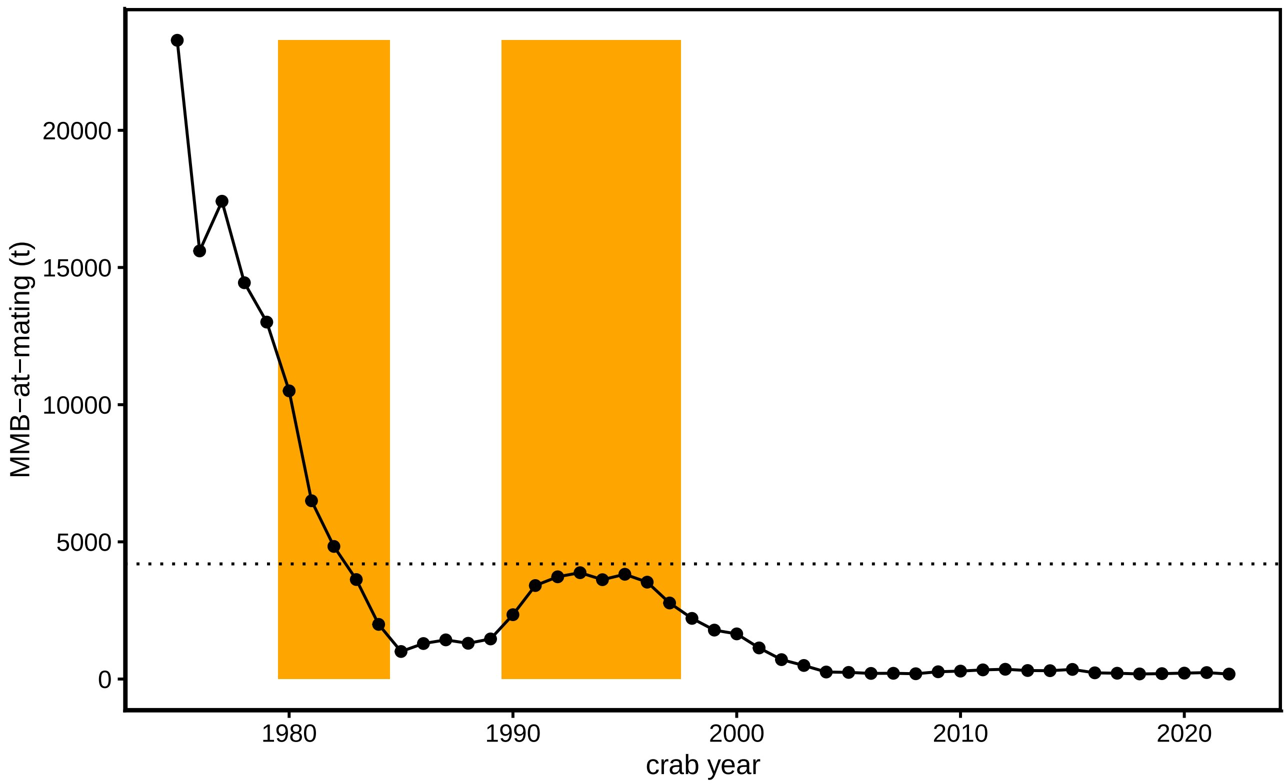

Figure 41. Time frame and time series to determine the Tier 4 B_{MSY}. Line and points: MMB-at-mating time series. Grey fill: time frame used for averaging to determine B_{MSY}. Dotted line: B_{MSY}.

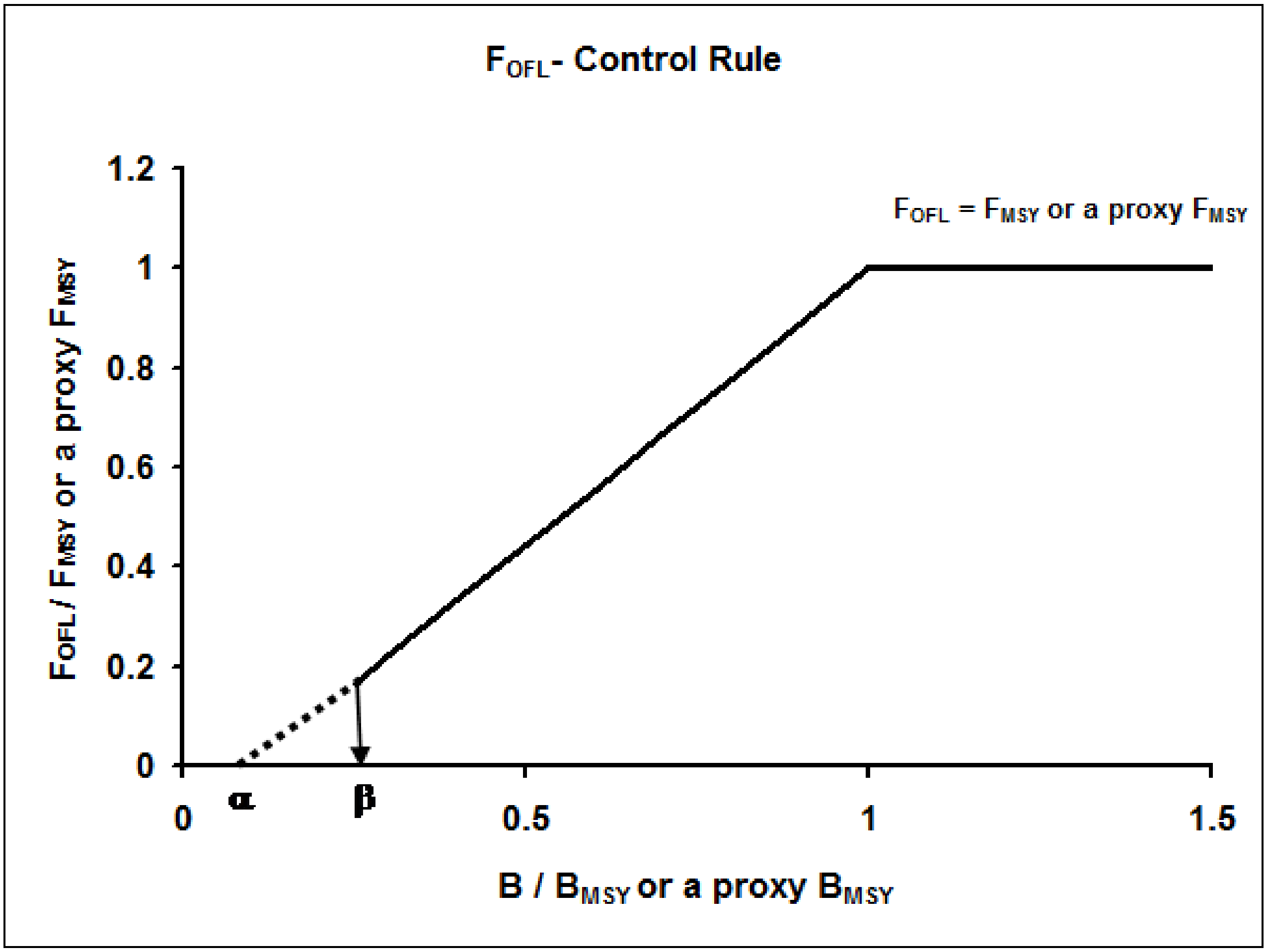

Figure 42. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fshery management plan. Directed fshing mortality is set to 0 below (β = 0.25).