2022 assessment for Pribilof Islands red king crab

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Executive summary

1. **Stock**: Pribilof islands red king crab (PIRKC), *Paralithodes camtschaticus*.
2. **Catches**: Retained catches have not occurred since 1998/1999. Bycatch has been sporadic since the late 2000s. In general, total bycatch is a small fraction of the overfishing level (OFL).
3. **Stock biomass**: In recent years, observed mature male biomass (>120mm carapace length) peaked in 2015, however this peak in biomass does not appear to represent the actual dynamics of the stock. The size composition data suggest that a cohort established in the early 2000s and fluctuations seen over that period in biomass were likely due to observation error. A new cohort appears to have entered the population in 2018. The stock is not overfished based on a tier 4 specification of B_{MSY} as 35% of the biomass from 2000-present (a period of no fishing), which was implemented in 2019.
4. **Recruitment**: Recruitment appears to be episodic, with three large cohorts having passed through the population since the late 1980s.
5. **Recent management statistics**: PIRKC is now on a triennial assessment cycle and was last assessed in 2019. GMACS is now used as the preferred assessment model.

Table 1: Historical status and catch specifications for Pribilof Islands red king crab (t).

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2014/15	2871	8894	0	0	1.3	1359	1019
2015/16	2756	9062	0	0	3.69	2119	1467
2016/17	2751	4788	0	0	1.12	1492	1096
2017/18	2751	3439	0	0	0.72	404	303
2018/19	866	5368	0	0	7.23	404	303
2019/20	866	6431	0	0	4.95	864	648
2020/21	866	6431	0	0	7.21	864	648
2021/22	854	3879	0	0	1.47	864	648
2022/23	854	3879				685	513.8

Table 2: Historical status and catch specifications for Pribilof Islands crab (millions of lbs). THIS TABLE IS NOT FINAL AND WILL BE MODIFIED.

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2014/15	6.33	19.61	0	0	0	3	2.25
2015/16	6.08	19.98	0	0	0.01	4.67	3.23
2016/17	6.06	10.56	0	0	0	3.29	2.42
2017/18	6.06	7.58	0	0	0	0.89	0.67
2018/19	1.91	11.83	0	0	0.02	0.89	0.67
2019/20	1.91	14.18	0	0	0.01	1.9	1.43
2020/21	1.91	14.18	0	0	0.02	1.9	1.43
2021/22	1.88	8.55	0	0	0	1.9	1.43
2022/23	1.88	8.55				1.51	1.13

6. **2022/2023 OFL projections**:

Table 3: Metrics used in designation of status and OFL (t). ‘Years’ indicate the year range over which recruitment is averaged for use in calculation of B35. ‘Status’ is the ratio between MMB and BMSY. ‘M’ is natural mortality. THIS TABLE IS NOT FINAL AND WILL BE MODIFIED

Year	Tier	BMSY	MMB	Status	FOFL	Years	M
2022/2023	4	1709	3879	2.27	0.21	2000-2021	0.21

7. **Probability distributions of the OFL**: No distribution of the OFL was calculated for this assessment cycle.

8. **Basis for ABC**: ABCs are calculated using a 25% buffer as recommended by the CPT and SSC in 2017.

A. Summary of major changes:

1. **Management**: This is the first assessment since PIRKC shifted to a triennial management cycle in 2019.
2. **Input data**: Survey and bycatch data were updated with the most recent data in this draft. Small adjustments were made to the recent years of bycatch data after a new download from AKFIN.
3. **Assessment methodology**: GMACS was adopted in 2019 as the assessment methodology for this stock. B_{MSY} was redefined in 2019 as 35% of the average MMB observed from 2000-present, which was a period of no fishing.
4. **Assessment results**: Overfishing did not occur from 2019-2021 and the stock was not overfished as of the summer of 2022.

B. CPT and SSC comments/requests from September 2019:

The CPT supported bringing Model 22.1 forward for SSC review in October but did not support models 22.1a or 22.1b. Instead, the CPT recommended three new models for consideration:

- Model 22.1c - Model 22.1 + ADF&G pot data
- Model 22.1d – Model 22.1 + trawl survey size composition
- Model 22.1e – Model 22.1 with both ADF&G pot data and trawl survey size composition.

In general, the SSC prefers to avoid considering new models in September that were no reviewed in June and requests that authors address SSC requests for model runs in time for review. In this case, the SSC notes that the recommended models are responsive to previous SSC requests and supports the CPT's recommended models moving forward. The SSC notes that any model brought forward in October, but not reviewed in June, will be held to a greater level of scrutiny.

As a compromise, only a model that adds the trawl bycatch size composition is included of these models, but an additional model that constrains the growth increment to be more similar to that observed for BBRKC is included to respond to concerns about the estimated growth increments. Pot survey data will be added in the next assessment cycle as it will require some effort to harmonize the data sets. The author understands the additional scrutiny, apologizes for the time constraints that did not allow for the presentation of these models in May, and offers that he only gets a chance every three years to alter the assessment.

The SSC also appreciates the exploration of BS-wide PIRKC stock connectivity and concurs with the CPT recommendation to continue this investigation. Further, the SSC encourages the continued development of PIRKC-specific life history characteristics (currently borrowed from BBRKC).

Figures from May are updated with the latest survey data. Estimation of trawl selectivity was a step towards more PIRKC-specific population processes in the model.

C. Introduction

Distribution

Red king crab, *Paralithodes camtschaticus*, (Tilesius, 1815) are anomurans in the family lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced in the Barents Sea (Jorstad et al. 2002). The distribution and density of red king crab on the Bering Sea shelf has changed somewhat over time (Figure 2). After the collapse in abundance in the mid-1980s, the stock was concentrated in Bristol Bay. Over time, the lower densities of crab were observed farther north (near Nunivak Island) and west (near the Pribilof Islands). The recent distribution of red king crab in the Bering Sea shifted farther north than historically seen.

The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58 39 N lat.), west of 168 W long., east of the United States-Russian convention line of 1867 as amended in 1991, north of 54.36 N lat. between 168.00 N and 171.00 W long. and north of 55.30 N lat. between 171 00 W. long and the US-Russian boundary (Figure 3). The distribution of red king crab within the Pribilof District is concentrated around the islands (see Figure 4 for a zoomed in version of Figure 2). The number of stations at which red king crab were observed around the Pribilof Islands was at an all time high in 2022 (Figure 5).

The connection between the crab in the three different 'districts' in the Bering Sea (Bristol Bay, Pribilof Islands, and Northern) is an open question. Much higher abundances of male crab occur in Bristol Bay (Figure 6), but it is unknown if the crab around the Pribilofs and in the Northern District migrate there from Bristol Bay or if larvae are advected there, settle, and grow. The numbers of males at size plotted by district can provide a clue to the dynamics of red king crab in the Bering Sea. Clear cohorts can be seen developing over time in Bristol Bay and the Pribilof Islands, but these are not seen in the Northern District (Figure 7). Although there appear to be three to four cohorts in the Pribilof District, five or more can be seen Bristol Bay. The larval crab that developed into the first cohort around the Pribilofs in the late 1980s clearly did not originate there, but it is not clear if the subsequent cohorts were supplied from the spawning stock in the Pribilofs or advected from Bristol Bay. Analyses of ocean currents around the time when the Pribilof Island cohorts established could provide some understanding of the origin of the subsequent cohorts.

The lack of cohorts in the Northern District suggests that crab in the north migrated from either Bristol Bay or the Pribilof Islands. The gradual increase in numbers at size in the North paired with the gradual decrease in Bristol Bay is also suggestive of movement to the north. However, it is important to interpret Figure 7 with caution because the figures for each district are plotted relative to the maximum in that district. The decrease in abundance in Bristol Bay is nowhere near compensated for by the increase in the north (Figure 6).

The maximum size of observed crab in Bristol Bay is smaller than that of the crab around the Pribilof Islands, which is not particularly surprising given there is a commercial fishery in Bristol Bay and not around the Pribilof Islands (Figure 7; compare the numbers to the right of the vertical dashed line at 175 mm carapace length by district). The lack of larger crab in the Northern District may indicate that the crab in the north are migrating back and forth between Bristol Bay and ultimately caught. It is also possible that there are differences in growth and molting frequency between Bristol Bay and the Pribilof Islands stock, but tagging studies and laboratory work would be needed to describe these differences, if they exist.

Finally, if the crab in each district were actually one large population responding to similar environmental pressures, one might expect the mean size between districts to be correlated over time. However, there is no significant correlation between mean size (calculated as the mean size weighted by the abundance) between any of the districts (Figure 8). This does not exclude the possibility that the Pribilof Islands are supplied with larvae from Bristol Bay, but it does suggest that, if that is the case, the environmental conditions that support good recruitment in Bristol Bay may not be the same conditions that support good recruitment in the Pribilofs.

Stock structure

Populations of red king crab in the eastern Bering Sea (EBS) for which genetic studies have been performed appear to be composed of three stocks: Okhotsk Sea-Aleutian Islands-Norton Sound, Southeast Alaska, and the rest of the EBS (Grant and Cheng 2012).

Life history

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts, and copulation occurs within hours. The male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female's gonopores. Eggs are fertilized after copulation as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965).

Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 eggs per female for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however, approximately 103 mm CL was reported for eastern Bering Sea male red king crabs (Somerton 1980). In the recent history of the assessment of PIRKC, crab greater than 120 mm carapace length were used as a measure of mature male bioamss. Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at maturity in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age at maturity to be approximately 8 to 9 years after settlement.

Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006). Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990). Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data ranged from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males ranged from 0.54 to 0.70, however, the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, with higher mortality for crabs <125 mm CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded that natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24. Natural mortality based on empirical estimates for a maximum age of 21 from Hoenig (1983), Hamel (2015), and Then et al. (2015) are 0.21, 0.26, and 0.30, respectively. Assuming a maximum age of 25 (following BBRKC) results in natural mortalities of 0.18, 0.22, 0.26 for Hoenig, Hamel, and Then methodologies, respectively. The Hamel methodology and an assumed maximum age of 25 years were used to specify the natural mortality used in the assessment.

The reproductive cycle of Pribilof Islands red king crabs has not been established. However, in Bristol Bay the timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous (i.e. brooding their first egg clutch) Bristol Bay red king crab females extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (i.e. brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990), resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth studies have not been performed for Pribilof Islands red king crabs; however they have been performed for Bristol Bay red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crab are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL, and 16 mm for immature crab over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crab was reported to vary with age; during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment averages 17.5 mm irrespective of size (Weber 1974; see Figure 9 for a summary of tagging data used in the BBRKC assessment).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reported that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

Management history

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crab (*Paralithodes platypus*) being targeted (Figure 10). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof Islands red and blue king crab fisheries which was implemented in 1998. From 1999 to present the Pribilof Islands fishery was not open due to low blue king crab abundance, uncertainty around estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof Islands blue king crab was declared overfished in September of 2002 and is still considered overfished (see Bowers et al. 2011 for a more complete management history).

Amendment 21 to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 3) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

Pribilof Islands red king crab occur as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*), eastern Bering Sea Tanner crab (*Chionoecetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof Islands blue king crab fisheries (when there is one). Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries (see bycatch and discards section below). However, bycatch is currently very low compared to historical levels and the OFL.

D. Data

The following sources and years of data are available: NMFS trawl survey (1976-2019, 2021-present), retained catch (1993-present), trawl bycatch (1991-present), fixed gear bycatch (1991-present), and pot discards (1998 to present).

Retained catch

Red king crab were targeted in the Pribilof Islands District from the 1993/1994 season to 1998/1999. Live and deadloss landings data and effort data are available during that time period (Table 4), but no retained catch has been allowed since 1999.

Bycatch and discards

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (<138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382) and 2010 to 2013 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs.

$$w_l = \alpha l^{\beta} \tag{1}$$

$$w_{avg} = \frac{{}_l\, w_l N_l}{{}_l\, N_l} \tag{2}$$

Finally, weights, discards, and bycatch were the product of average weight, CPUE, and total pot lifts in the fishery. A 20% handling mortality rate was applied to these estimates (assumed the same as Bristol Bay red king crab).

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries although data may be incomplete for some of these fisheries. Limited observer data exists prior to 1998 for catcher-processor vessels only so non-retained catch before this date is not included here. In recent years, catch of PIRKC in other crab fisheries has been almost non-existent.

Bycatch from groundfish fisheries from 1989 to present are available in the AKFIN database and included in some models presented here as a single fishery with selectivity equal to the trawl fishery estimated in the BBRKC assessment (Figure 11). See Calahan et al. 2010 for a description of the methodology used to develop these data.

Catch-at-size

Catch-at-size data are not available for the directed fishery, but size compositions for bycatch can be calculated from the observer data (Figure 12). Model 22.1a and 22.1b use these data to estimate bycatch selectivity. Bycatch size composition data could be valuable indicators for incoming cohorts not yet sampled by the survey. For example, the most recent cohort in the Pribilof district appear in the survey data in 2018 at around 100 mm carapace length. This cohort can be seen as early as 2015 at around 70 mm carapace length in the observer size composition data.

Survey abundance and length composition

The most up-to-date NOAA Fisheries EBS bottom trawl survey results are included in this preliminary SAFE report (1976-2019, 2021; see Lang et al. 2018 for methodology). Data available for estimating the abundance of crab around the Pribilof Islands are relatively sparse. Male abundance varies widely over the history of the survey time series and uncertainty around area-swept estimates of abundance can be large due to relatively low sample sizes (Figure 13). Red king crab have been observed at 35 unique stations of the 44 stations in the Pribilof District over the years 1976 to present (22 stations on the 400 nm^2 grid).The number of stations at which at least one crab was observed in a given year ranges from 0-22 over the period from 1976-present (Figure 5). Male crabs were observed at 22 stations in the Pribilof District during the 2022 survey, which was the highest frequency of occurrence ever observed of red king crab in the Pribilof district. Although estimated numbers at length are variable from year to year, 3 to 4 cohorts can be discerned in the length composition data (Figure 14).

The centers of distribution for both males and females have moved around St. Paul Island. The center of the red king crab distribution moved to the northeast of St. Paul Island as the population abundance increased in the 1980s and remained in that region until the 1990s. Currently, the largest tows were also observed north and east of St. Paul Island (Figure 4). Mature male biomass (>120 mm) at the time of the survey has declined in recent years to a low in 2018 (Figure 15). However, a pseudocohort was observed in the 2018 survey data and appears to have persisted through the size classes to 2022 (Figure 14).

E. Analytical approaches

History of modeling

An inverse-variance weighted 3-year running average of male biomass (>=120mm carapace length) based on densities estimated from the NMFS summer trawl survey was used before 2019 to set the acceptable biological catches. The Tier 4 harvest control rule (HCR) has been used in conjunction with estimates of MMB to calculate the OFL. In the Tier 4 HCR, natural mortality is used as a proxy for the fishing mortality at which maximum sustainable yield occurs (F_{MSY}) and target biomasses are set by identifying a range of years over which the stock was thought to be near B_{MSY}. The Tier 4 B_{MSY} proxy for PIRKC was calculated in 2017 as the average of the 1991/92 to the present year of observed survey data projected forward to February 15, removing the observed catch. Given the fishing history of PIRKC, accommodating this stock with the current Tier 4 rule is challenging because it has only been fished for 6 year out of the more than 40 years of available survey data. GMACS was adopted as the assessment methodology for PIRKC in 2019 in addition to a change in the definition of $\mathrm{B_{MSY}}$. Both are briefly described below.

GMACS

Results from an integrated assessment framework have been presented since 2014 (Szuwalski, Turnock, and Foy, 2015), and an integrated assessment using GMACS was accepted for use in management in 2019. Previous integrated assessments fit to male abundance, but the GMACS model fits male biomass >120 mm carapace length. Retained catches and bycatch have historically been fit using assumed selectivities from the BBRKC assessment (Zheng et al., 2018). Growth was estimated and informed by cohorts moving through the population and assumptions about natural mortality and molting probabilities. Molting probabilities and survey catchability were fixed based on the estimates from the 2018 BBRKC assessment. 127 parameters were estimated (Table 5) and 7 parameters were fixed (Table 6) in the base assessment. A bin size of 5 mm was selected to model numbers at length in the integrated assessment based on Szuwalski (2015).

Four models are presented here:

- 19.1 : the accepted GMACS model from 2019

- 22.1 : 19.1 with updated data and .TPL (some bugs were addressed between 2019 and 2022)
- 22.1a: 22.1 with the bycatch size composition data fit incorporated into the assessment, which allowed estimation of the bycatch selectivity
- 22.1b: 22.1a with the slope of the growth increments model fixed to zero and the intercept estimated in order to more closely match to the observed biology from tagging data used in the BBRKC assessment.

Input sample sizes were set to the actual number of crabs observed to calculate the size composition in a given year, but, if that number exceeded 200, it was set to 200. See appendix A and B for .DAT and .CTL files for the author-preferred model.

Fits to data and estimated and assumed population processes

Survey biomass and length composition data

Fits to the survey biomass were similar in that they all present three peaks in biomass, but the timing and magnitude of those peaks differed by model (Figure 15). Fits of the last four years of data varied by model with the model with bycatch size composition data (22.1b) and 22.1 offering similar fits. Model 22.1a missed the CIs of 2019 and 2021 altogether. The large increases in survey MMB in 2014 and 2015 are not fit well by any of the models, but this is an important feature of the models. The large survey estimates in 2014 and 2015 were driven by large tows at a single station in years in which the frequency of occurrence (i.e. the number of stations at which crab were observed) was relatively low (Figure 4). The size composition data indicate the presence of a cohort that began to be seen in the survey gear in the mid-2000s and then no further cohorts appeared until the late 2010s. A cohort should get smaller over time as a result of natural mortality, not grow in size, which suggests that the large increased in survey MMB in 2014 and 2015 are due to measurement error.

All models estimate three large pulses of survey biomass and differences between fits to survey size composition data were relatively small (Figure 16). One of the largest differences comes in the first two years of size composition data in which the model predictions for the largest size classes are much higher than the observations for 22.1 and 22.1a. The issue of odd fits to the largest size classes was solved for snow crab in GMACS by changing the way initial conditions are estimated. However, PIRKC already uses the ‘free parameters’ option, so further exploration is required. The years 2019 and 2021 were also years for relatively large differences among models that likely is related to the differences in trajectory of estimated survey MMB. Smaller differences in fits to the size composition data are likely related to differences in estimated survey selectivity (Figure 17). Both the midpoint and slope parameter (‘log_slx_pars[5] & ’log_slx_pars[6]’ in GMACS; Table 5) for the logistic function varied among models. Bycatch size composition data were fairly well fit (Figure 18), but 22.1a also displayed issues with fits to the first couple of years of data. Including the bycatch size composition data resulted in rather large changes to the estimated survey selectivity.

Trajectories of predicted mature male biomass at the time of mating diverged during the beginning of the time series, but were similar in the recent past except for 22.1a, in which estimates of MMB were the highest in the time series in 2020 (Figure 19). In all models, the cohort comprising the bulk of population currently appears to have aged beyond the point at which accumulation of biomass as a result of growth overshadows losses due to natural mortality. Consequently, the estimated mature biomass at the time of mating is declining in all updated models.

Retained catches, bycatches, and estimated fishing mortality

Retained catches and bycatches were fit essentially identically by all models with the same input data (Figure 20), but the inferred influence of the directed fishery on the population as seen through the estimated fishing mortality varied by model (Figure 21). The model incorporating the bycatch size composition data and a strong prior on the slope of the growth increment model (22.1b) returned lower estimates of directed and non-directed fishing mortality. Fits from models with updated data through 2022 reflect changes in the calculation of bycatch (compare the pink line in Figure 20 in the trawl panel to the other lines).

Molting probability and growth

Growth was estimated within each model and varied strongly among models. Model 22.1b fixed the slope of the growth increment model to zero and estimated the intercept to match the observed growth increment models derived from tagging data for BBRKC. Fairly large differences existed among the other models as well, with a difference of approximately 2.5 mm carapace length per molt for crab over 200 mm carapace length (Figure 22). Molting probability was fixed according to the estimates from the 2018 BBRKC assessment (Figure 23). No growth data exist to fit to, so the information to estimate growth comes from the modes of the survey size composition data, input natural mortality, probability of molting by size, and priors on the slope of the growth increment model (for 22.1b).

Estimated recruitment

Three large pseudo-cohorts were estimated by all models (Figure 24). Estimates of the second recruitment pulse (around the early 1990s) were the most variable in size and timing across models. This seems to be primarily a result of different fits to somewhat noisy length compositions in 1996-99.

F. Calculation of reference points

Tier 4 OFL and B_{MSY}

Historically, Tier 4 control rules used natural mortality as a proxy for F_{MSY} and calculated a proxy for B_{MSY} by averaging the biomass over a period of time when the stock was thought to have been at B_{MSY}. However, given that PIRKC has only been fished for six years in its history, identifying a period of time during which it was fished at $\mathrm{F_{MSY}}$ is difficult. In 2019, the CPT chose a different strategy and defined the proxy for $\mathrm{B_{MSY}}$ as 35% of the average MMB over the years 2000-present minus 1 (provided the stock remains unfished). This strategy retains the intention of the original definition and incorporates the concept of $\mathrm{B_{35\%}}$ used for tier 3 stocks. Using this redefined proxy for $\mathrm{B_{MSY}}$ and natural mortality as a proxy for $\mathrm{F_{MSY}}$, the OFL is calculated for PIRKC by applying a fishing mortality determined by the harvest control rule below to the mature male biomass at the time of fishing.

$$F_{OFL} = \begin{cases} Bycatchonly & if \frac{MMB}{MMB_{MSY}} \leq 0.25 \\ \\ \frac{\lambda M(\frac{MMB}{MMB_{MSY}}-\alpha)}{1-\alpha} & if 0.25 < \frac{MMB}{MMB_{MSY}} < 1 \\ \\ \lambda M & if MMB > MMB_{MSY} \end{cases} \tag{3}$$

Where MMB is the mature male biomass projected to the time of mating, MMB_{MSY} is 35% of the average mature male biomass over the years 2000-present, M is natural mortality, and α determines the slope of the descending limb of the HCR (here set to 0.1).

A range of terminal year MMBs were estimated by the presented scenarios (3879-7661 t). Similarly, the resulting B_{MSY} varied somewhat (1529-1709 t) along with the calculated OFLs (685-1353 t).

Acceptable biological catches

ABCs are calculated for crab stocks in the Bering Sea by multiplying the OFL by a buffer determined by the CPT and SSC. Stocks with similar levels of uncertainty use a buffer of 25% and this was the percentage recommended by the CPT and SSC in 2017. Consequently, the ABC for the author's preferred model 22.1b is 513.75 t.

Variables related to scientific uncertainty in the OFL probability distribution

Uncertainty in the time series of survey estimated of biomass for Pribilof Islands red king crab is relatively high due to small sample sizes. However, the coefficient of variation for the estimate of male abundance for 2021 was 0.296, which is the lowest on record due in part to the highest frequency of occurence on record. The c.v. has ranged between 0.297 and 0.92 since the 1991 peak in biomass (Figure 15). Recruitment, growth, and survey selectivity were estimated within the integrated assessment, but maturity, survey catchability, fishery selectivity, and natural mortality were fixed to values from the BBRKC assessment. Fitting to data to inform these processes might increase both the accuracy and uncertainty in estimates of management quantities. F_{MSY} was assumed to be equal to natural mortality, which is poorly known.

G. Author Recommendation

The author's preferred model is 22.1b based on the incorporation of new data source to estimate PIRKC specific bycatch mortality and modifications in assumptions about growth that are more consistent with the best available information about the biology of red king crab in the Bering Sea. Model 22.1a fits the data better (Table 10), but does so by employing assumptions that do not reflect the tagging data for BBRKC.

H. Data gaps and research priorities

The largest data gap is the number of observations from which the population size and biomass is extrapolated and this will not likely change appreciably in the future. The small sample sizes (and no expected increases in sample size) support the use of as much of the available data as possible in assessment efforts. Research on the probability of molting at length for males would allow the use of data specific to PIRKC in specifying molting probability in the assessment. Research aimed at the catchability and availability of PIRKC in the NMFS survey may also shed some light on divergent changes in abundance in recent years. The Bering Sea Fisheries Research Foundation (BSFRF) selectivity studies sampled crab around the Pribilof Islands in 2017 and 2018, so it is possible some analysis could be performed with those data. Retrospective analyses should be performed in future assessments. Finally, Bayesian methods with relatively uninformative priors for population processes is a potential methodology to better account for uncertainties.

I. Ecosystem Considerations

The impact of a directed fishery for Pribilof Islands red king crab on the population of Pribilof island blue king crab will likely continue to be the largest ecosystem consideration facing this fishery and preclude the possibility of a directed fishery for red king crab. Linking changes in productivity as seen in the 1980s with environmental influences is a potential avenue of research useful in selecting management strategies for crab stocks around the Pribilof Islands (e.g. Szuwalski and Punt, 2013a). It is possible that the large year class in the mid-1980s reflected changing environmental conditions, similar to proposed relationships between the Pacific Decadal Oscillation and/or Arctic Oscillation with snow crab recruitment in the EBS (Szuwalski and Punt, 2013b; Overland et al., 2008; Szuwalski et al., 2020). Ocean acidification also appears to have a detrimental effect on red king crab (Long et al., 2013), which may impact the productivity of this stock in the future. Finally, an understanding of meta-population dynamics for red king crab in the Bering Sea could help in understanding potential futures for this stock.

J. References

Some references are not cited, but were retained in this list given relevance to PIRKC.

Bell, M. C. 2006. Review of Alaska crab overfishing definitions: Report to University of Miami Independent System for peer reviews. April 24-28, 2006 Seattle, Washington, 35 p.

Bowers, F., M. Schwenzfeier, K. Herring, M. Salmon, H. Fitch, J. Alas, B. Baechler. 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Regions Shellfish Observer Program, 2009/2010.

Cahalan, J., J. Mondragon, and J. Gasper. 2010. Catch sampling and estimation in the Federal groundfish fisheries off Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-205, 42 p.

Grant, S.G. and Cheng, W. 2012. Incorporating deep and shallow components of genetic structure into the management of Alaskan red king crab. Evol. Appl. 5(8): 820-837.

Hamel, O. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES Journal of Marine Science. 72: 62-69.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Jensen, G.C. 1995. Pacific Coast Crabs and Shrimps. Sea Challengers, Monterey, California, 87p.

Jørstad, K.E., E. Farestveit, H. Rudra, A-L. Agnalt, and S. Olsen. 2002. Studies on red king crab (Paralithodes camtschaticus) introduced to the Barents Sea, p. 425-438. In A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley and D. Woodby (editors), Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant College Program Report No. AK-SG-02-01, University of Alaska, Fairbanks, AK.

Lang, C. A., J. I. Richar, and R. J. Foy. 2019. The 2018 eastern Bering Sea continental shelf and northern Bering Sea trawl surveys: Results for commercial crab species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-386, 220 p.

Livingston, P. A., A. Ward, G. M. Lang, and M.S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. United States Department of Commerce, NOAA Technical Memorandum. NMFD-AFSC-11, 192 p.

Livingston, P.A. 1989. Interannual trends in Pacific cod, Gadus macrocephalus, predation on three commercially important crab species in the Eastern Bering Sea. Fishery Bulletin 87:807-827.

Loher, T. and D.A. Armstrong. 2005. Historical changes in the abundance and distribution of ovigerous red king crabs (Paralithodes camtschaticus) in Bristol Bay (Alaska), and potential relationship with bottom temperature. Fisheries Oceanography 14:292-306.

Loher, T., D.A. Armstrong, and B. G. Stevens. 2001. Growth of juvenile red king crab (Paralithodes camtschaticus) in Bristol Bay (Alaska) elucidated from field sampling and analysis of trawl-survey data. Fishery Bulletin 99:572-587.

Long, W.C., Swiney, K.M., Harris, C., Page, H.N., Foy, R.J. 2013. Effects of ocean acidification on juvenile red king crab (Paralithodes camtschaticus) and Tanner crab (Chionoecetes bairdi) growth, condition, calcification, and survival. PLoS ONE 8(4): e60959.

Marukawa, H. 1933. Biological and fishery research on Japanese king crab Paralithodes camtschatica (Tilesius). Fish. Exp. Stn, Tokyo 4:1-152.

Matsuura, S. and Takeshita, K. 1990. Longevity of red king crab, Paralithodes camtschatica, revealed by long-term rearing study, p. 65-90. In B. Melteff (editor) International Symposium on King and Tanner crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

NMFS. 2000. Endangered Species Act Section 7 Consultation Biological Assessment: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. National Marine Fisheries Service, Alaska Region, 14 p.

NMFS. 2002. Endangered Species Act Section 7 Consultation Biological Assessment: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. National Marine Fisheries Service, Alaska Region, 59 p.

NMFS. 2004. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, Alaska Region

NPFMC (North Pacific Fishery Management Council). 1994. Environmental Assessment/Regulatory Impact/Review/Initial Regulatory Flexibility analysis for Amendment 21a to the Fishery Management Plan for Bering Sea and Aleutian Islands Groundfish. Anchorage, Alaska.

NPFMC (North Pacific Fishery Management Council). 1998. Fishery Management Plan for the Bering Sea/Aleutian Islands king and Tanner crabs. Anchorage, Alaska 105 p.

NPFMC (North Pacific Fishery Management Council). 2003. Environmental Assessment for Amendment 17 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands: A rebuilding plan for the Pribilof Islands blue king crab stock. Anchorage, Alaska 87 p.

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

Otto R.S., R.A. MacIntosh, and P.A. Cummiskey. 1990. Fecundity and other reproductive parameters of female red king crab (Paralithodes camtschatica) in Bristol Bay and Norton Sound, Alaska, p. 65-90 In B. Melteff (editor) Proceedings of the International Symposium on King and Tanner crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

Overland, J., Rodionov, S., Minobe, S., and Bond, N. 2008. North Pacific regime shifts: definitions, issues, and recent transitions. Progress in Oceanography, 77: 92-102.

Powell G.C. and R.B. Nickerson. 1965. Reproduction of king crabs, Paralithodes camtschatica (Tilesius). Journal of Fisheries Research Board of Canada 22:101-111.

Powell, G.C. 1967. Growth of king crabs in the vicinity of Kodiak Island, Alaska. Informational Leaflet 92, Alaska Department of Fish and Game, 58 p.

Punt, A.E., Szuwalski, C.S., and Stockhausen, W. 2014. An evaluation of stock-recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act. Fish. Res., 157: 28-40.

Seeb J.E., Kruse G.H., Seeb L.W., Weck R.G. Proceedings of the International Symposium on King and Tanner Crabs. 1990. Genetic structure of red king crab populations in Alaska facilitates enforcement of fishing regulations; pp. 491–502. Alaska Sea Grant College Program Report, 90-04.

Shirley, S. M. and T. C. Shirley. 1989. Interannual variability in density, timing and survival of Alaskan red king crab Paralithodes camtschatica larvae. Marine Ecology Progress Series 54:51-59.

Shirley, T. C., S. M. Shirley, and S. Korn. 1990. Incubation period, molting and growth of female red king crabs: effects of temperature, p. 51-63. In B. Melteff (editor) Proceedings of the International Symposium on King and Tanner Crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

Siddeek, M.S.M, L. J. Watson, S. F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data, p. 51-75. In A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley and D. Woodby (editors), Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant College Program Report No. AK-SG-02-01, University of Alaska, Fairbanks, AK.

Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Canadian Journal of Fisheries and Aquatic Science 37: 1488-1494.

Stevens, B.B. 1990. Temperature-dependent growth of juvenile red king crab (Paralithodes camtschatica), and its effects on size-at-age and subsequent recruitment in the eastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences 47:1307-1317.

Stevens, B.G. and K. M. Swiney. 2007b. Growth of female red king crabs Paralithodes camtshaticus during pubertal, primiparous, and multiparous molts. Alaska Fisheries Research Bulletin 12:263-270.

Stevens, B.G. and K.M. Swiney. 2007a. Hatch timing, incubation period, and reproductive cycle for primiparous and multiparous red king crab Paralithodes camtschaticus. Journal of Crustacean Biology 27:37-48.

Szuwalski, C.S., R. Foy and B.J. Turnock (2015). 2015 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions. In: Bering Sea and Aleutian Islands Crab Stock Assessment and Fishery Evaluation 2015. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Szuwalski, C.S. (2015) Biases in biomass estimates and selecting bind width in size-structured assessment methods. Fisheries Research.

Szuwalski, C.S. and Punt, A.E. 2013a. Regime shifts and recruitment dynamics of snow crab, Chionoecetes opilio, in the eastern Bering Sea. Fish. Ocean., 22(5): 345-354.

Szuwalski, C. S., and Punt, A. E. 2013b. Fisheries management for regime-based ecosystems: a management strategy evaluation for the snow crab fishery in the eastern Bering Sea. ICES J. Mar. Sci.,70: 955-967.

Then, A. Y., Hoenig, J. M., Hall, N. G., and Hewitt, D. A. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72: 82–92.

Turnock, B.J., C.S. Szuwalski, and R.J. Foy. 2016. 2016 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions. In: Bering Sea and Aleutian Islands Crab Stock Assessment and Fishery Evaluation 2016. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Weber, D. D. 1967. Growth of the immature king crab Paralithodes camtschatica (Tilesius). Bulletin No. 21, North Pacific Commission, 53 p.

Weber, D.D. 1974. Observations on growth of southeastern Bering Sea king crab, Paralithodes camtschatica, from a tag-recovery study, 1955-65. Data Report 86, National Marine Fisheries Service, 122 p.

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

Zheng, J. M.C. Murphy, and G.H. Kruse. 1995. A length-based population model and stock-recruitment relationships for red king crab, Paralithodes camtschaticus, in Bristol Bay, Alaska. Canadian Journal of Fisheries and Aquatic Science 52:1229-1246.

Zheng, J. and Siddeek, M.S.M. 2018. Bristol Bay red king crab stock assessment. In: Bering Sea and Aleutian Islands Crab Stock Assessment and Fishery Evaluation 2018. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Table 4: Observed retained catches and bycatch in tonnes

year	Pot	Trawl bycatch
1976	0.00	0.00
1977	0.00	0.00
1978	0.00	0.00
1979	0.00	0.00
1980	0.00	0.00
1981	0.00	0.00
1982	0.00	0.00
1983	0.00	0.00
1984	0.00	0.00
1985	0.00	0.00
1986	0.00	0.00
1987	0.00	0.00
1988	0.00	0.00
1989	0.00	0.00
1990	0.00	0.00
1991	0.00	1.89
1992	0.00	50.31
1993	1304.73	43.25
1994	669.83	5.89
1995	449.23	0.43
1996	100.22	0.92
1997	378.61	0.47
1998	272.32	2.36
1999	0.00	5.93
2000	0.00	1.85
2001	0.00	0.42
2002	0.00	0.34
2003	0.00	1.97
2004	0.00	4.67
2005	0.00	7.10
2006	0.00	17.99
2007	0.00	2.01
2008	0.00	9.11
2009	0.00	1.51
2010	0.00	9.06
2011	0.00	6.48
2012	0.00	17.33
2013	0.00	2.95
2014	0.00	1.30
2015	0.00	3.69
2016	0.00	1.12
2017	0.00	0.72
2018	0.00	7.23
2019	0.00	4.95
2020	0.00	7.21
2021	0.00	1.47
2022	0.00	0.00

Table 5: Parameter estimates and standard deviations from considered models.

			Model 22.1a		Model 22.1b	
Parameter	Model 22.1 est	SD	est	SD	est	SD
theta[4]	-6.71	1.12	-6.76	1.1	-6.35	1.16
theta[10]	-8.81	1.64	-9.36	1.68	-7.16	1.37
theta[11]	-8.81	1.58	-9.36	1.63	-7.15	1.31
theta[12]	-8.8	1.53	-9.36	1.57	-7.13	1.25
theta[13]	-8.79	1.48	-9.35	1.52	-7.11	1.21
theta[14]	-8.77	1.44	-9.34	1.47	-7.07	1.17
theta[15]	-8.75	1.39	-9.32	1.43	-7.03	1.13
theta[16]	-8.73	1.35	-9.31	1.39	-6.98	1.1
theta[17]	-8.7	1.32	-9.29	1.34	-6.92	1.07
theta[18]	-8.67	1.28	-9.26	1.3	-6.86	1.05
theta[19]	-8.64	1.25	-9.23	1.27	-6.79	1.03
theta[20]	-8.6	1.21	-9.2	1.23	-6.72	1
theta[21]	-8.55	1.18	-9.16	1.19	-6.64	0.98
theta[22]	-8.5	1.15	-9.12	1.16	-6.55	0.96
theta[23]	-8.45	1.12	-9.08	1.12	-6.46	0.94
theta[24]	-8.39	1.09	-9.02	1.09	-6.37	0.92
theta[25]	-8.32	1.07	-8.97	1.06	-6.27	0.89
theta[26]	-8.25	1.04	-8.9	1.03	-6.17	0.87
theta[27]	-8.17	1.01	-8.83	1	-6.07	0.84
theta[28]	-8.08	0.97	-8.75	0.97	-5.97	0.81
theta[29]	-7.98	0.95	-8.67	0.93	-5.86	0.78
theta[30]	-7.88	0.92	-8.58	0.9	-5.75	0.75
theta[31]	-7.76	0.88	-8.47	0.87	-5.64	0.72
theta[32]	-7.64	0.85	-8.35	0.84	-5.52	0.7
theta[33]	-7.49	0.82	-8.23	0.8	-5.41	0.67
theta[34]	-7.33	0.79	-8.08	0.76	-5.3	0.63
theta[35]	-7.16	0.74	-7.91	0.73	-5.18	0.61
theta[36]	-6.97	0.7	-7.71	0.69	-5.04	0.59
theta[37]	-6.74	0.66	-7.52	0.64	-4.93	0.56
theta[38]	-6.45	0.63	-7.27	0.59	-4.83	0.52
theta[39]	-6.14	0.58	-6.94	0.55	-4.71	0.49
theta[40]	-5.8	0.51	-6.54	0.5	-4.56	0.46
theta[41]	-5.38	0.42	-6.15	0.4	-4.47	0.41
theta[42]	-4.76	0.34	-5.51	0.29	-4.37	0.38
theta[43]	-3.47	0.31	-3.98	0.27	-4.3	0.39
theta[44]	-2.2	0.21	-1.81	0.16	-4.3	0.47
Grwth[1]	8.44	0.23	10.64	0.14	18.02	0.04
Grwth[2]	-0.1	0	-0.06	0	NA	NA
log_slx_pars[5]	4.79	0.01	4.91	0.02	4.91	0.02
log_slx_pars[6]	1.97	0.05	2.2	0.05	2.37	0.07
log_fbar[1]	-1.81	0.14	-2.21	0.11	-2.85	0.11
log_fbar[2]	-6.81	0.09	-7.17	0.09	-7.46	0.09
log_fbar[3]	-5.62	21703	-4.69	22459	-4.69	22460
log_fdev[1]	NA	NA	NA	NA	NA	NA
log_fdev[2]	NA	NA	NA	NA	NA	NA
log_fdev[3]	0	0.01	0	0.01	0	0.01
rec_dev_est	NA	NA	NA	NA	NA	NA
log_slx_pars[3]	NA	NA	4.89	0.01	4.89	0.01

Parameter	Model 22.1 est	SD	Model 22.1a est	SD	Model 22.1b est	SD
log_slx_pars[4]	NA	NA	1.75	0.05	1.95	0.07

Table 6: Parameters fixed in the assessment. Parameters for trawl fishery selectivity were estimated in 22.1a and 22.1b

Fixed.parameter	Value
Survey catchability	0.925
Size at 50% capture in fishery	138.000
SD of above	0.100
Size at 50% capture in trawl fishery	150.000
SD of above	10.000
Size at 50% molting probability	139.770
SD of above	0.093
Natural mortality	0.180

Table 7: Observed male biomass >120 mm carapace length in the NMFS summer trawl survey in tonnes.

Year	Survey.MMB	Survey.CV
1976	165.08	1.00
1977	118.61	1.00
1978	1249.50	0.83
1979	555.79	0.52
1980	1268.98	0.38
1981	312.29	0.58
1982	1463.68	0.70
1983	526.74	0.53
1984	317.23	0.55
1985	61.48	1.00
1986	137.62	0.70
1987	53.58	1.00
1988	106.65	1.00
1989	1529.46	0.91
1990	1141.08	0.93
1991	4429.98	0.80
1992	3304.81	0.60
1993	9873.34	0.92
1994	9138.78	0.77
1995	18055.70	0.60
1996	2361.50	0.37
1997	6158.83	0.62
1998	2323.52	0.36
1999	5522.92	0.67
2000	4320.46	0.37
2001	8603.17	0.79
2002	7037.32	0.69
2003	5372.97	0.66
2004	3621.91	0.59
2005	1238.27	0.59
2006	7002.93	0.38
2007	5223.70	0.49
2008	5462.27	0.51
2009	2500.34	0.64
2010	4404.99	0.44
2011	3834.34	0.65
2012	4477.11	0.57
2013	7749.45	0.62
2014	12046.84	0.78
2015	15172.86	0.74
2016	4150.36	0.70
2017	3658.47	0.65
2018	928.70	0.43
2019	2086.41	0.34
2021	3743.94	0.30
2022	5104.68	0.30

Table 8: Estimated mature male biomass by model in tonnes.

year	19.1	22.1	22.1a	22.1b
1976	514	1040	1250	549
1977	475	846	1015	465
1978	435	688	824	392
1979	394	560	669	330
1980	354	456	543	276
1981	315	371	441	230
1982	284	301	358	192
1983	263	245	291	159
1984	233	200	236	132
1985	202	163	192	110
1986	174	133	156	93
1987	151	110	128	81
1988	285	105	105	133
1989	591	155	94	766
1990	2111	1235	1111	3725
1991	5013	3781	4391	8944
1992	5679	4546	5351	10140
1993	4416	3466	4286	8773
1994	3571	2766	3673	7561
1995	2934	2227	3493	6522
1996	2541	1992	3566	6041
1997	2169	2103	4212	6661
1998	4251	3997	7025	10076
1999	8294	6577	7812	10671
2000	9276	7681	7573	10107
2001	9277	7808	6917	9113
2002	8596	7320	6119	7998
2003	7669	6579	5315	6908
2004	6690	5777	4598	5954
2005	5823	5059	4144	5356
2006	5124	4522	4022	5215
2007	4549	4157	3910	5026
2008	4246	4051	3961	5039
2009	3954	3989	3713	4741
2010	3508	3689	3322	4248
2011	3042	3295	2900	3715
2012	2636	2916	2501	3211
2013	2346	2635	2201	2827
2014	2084	2396	2066	2649
2015	1808	2163	1950	2486
2016	1595	1988	1923	2470
2017	1449	1886	2089	2878
2018	2532	2707	3775	4350
2019	4894	4773	7598	4930
2020	NA	5275	8575	4803
2021	NA	5130	8362	4389
2022	NA	4704	7661	3879

Table 9: Changes in management quantities for each scenario considered. Reported management quantities are derived from maximum likelihood estimates. Reported natural mortality is for mature males, average recruitment is for males, and status and MMB were estimates for February 15 of the completed crab year.

Model	MMB	B35	F35	FOFL	OFL	M	avg_rec	Status
19.1	4893.79	1594	0.21	0.21	864.29	0.21	0.97	3.07
22.1	4703.93	1529	0.21	0.21	830.76	0.21	0.84	3.08
22.1a	7661.25	1601	0.21	0.21	1353.05	0.21	1.06	4.79
22.1b	3878.98	1709	0.21	0.21	685.07	0.21	0.96	2.27

Table 10: Contributions to the objective function by likelihood component.

Likelihood	Model.22.1	Model.22.1a	Model.22.1b
Directed fishery	-12.43	-12.45	-12.45
Bycatch	-64.40	-64.40	-64.40
Survey	24.94	33.11	31.42
Size comp survey	-4305.89	-4256.10	-4213.59
Size comp bycatch	NA	-4072.22	-4055.58

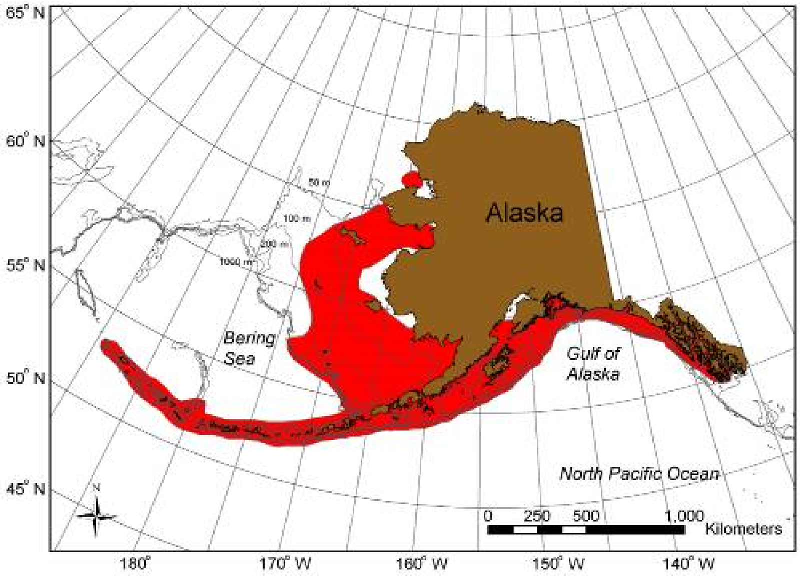

Figure 1: Red king crab distribution in the North Pacific

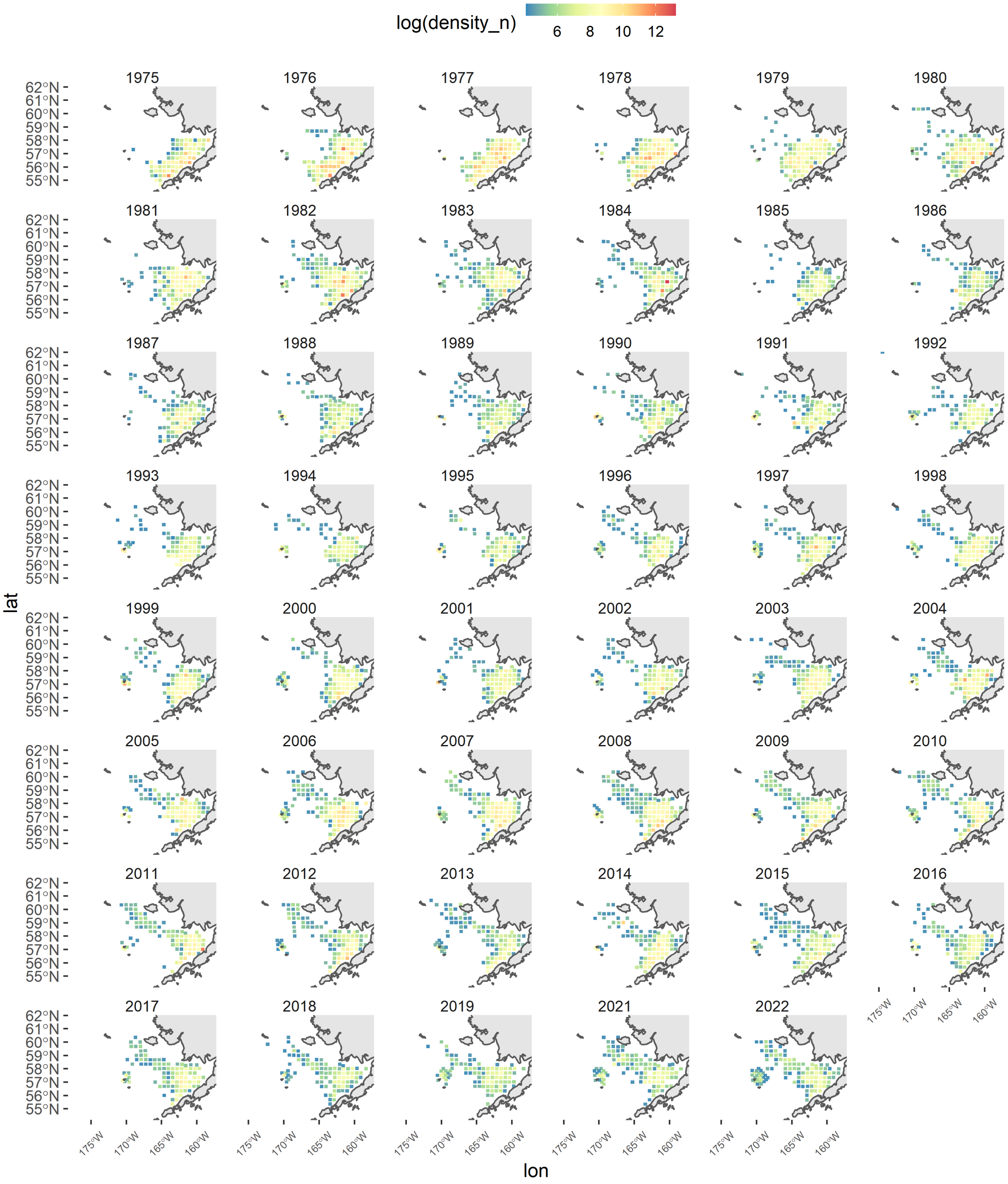

Figure 2: Distribution and density of red king crab observed in the NMFS summer survey.

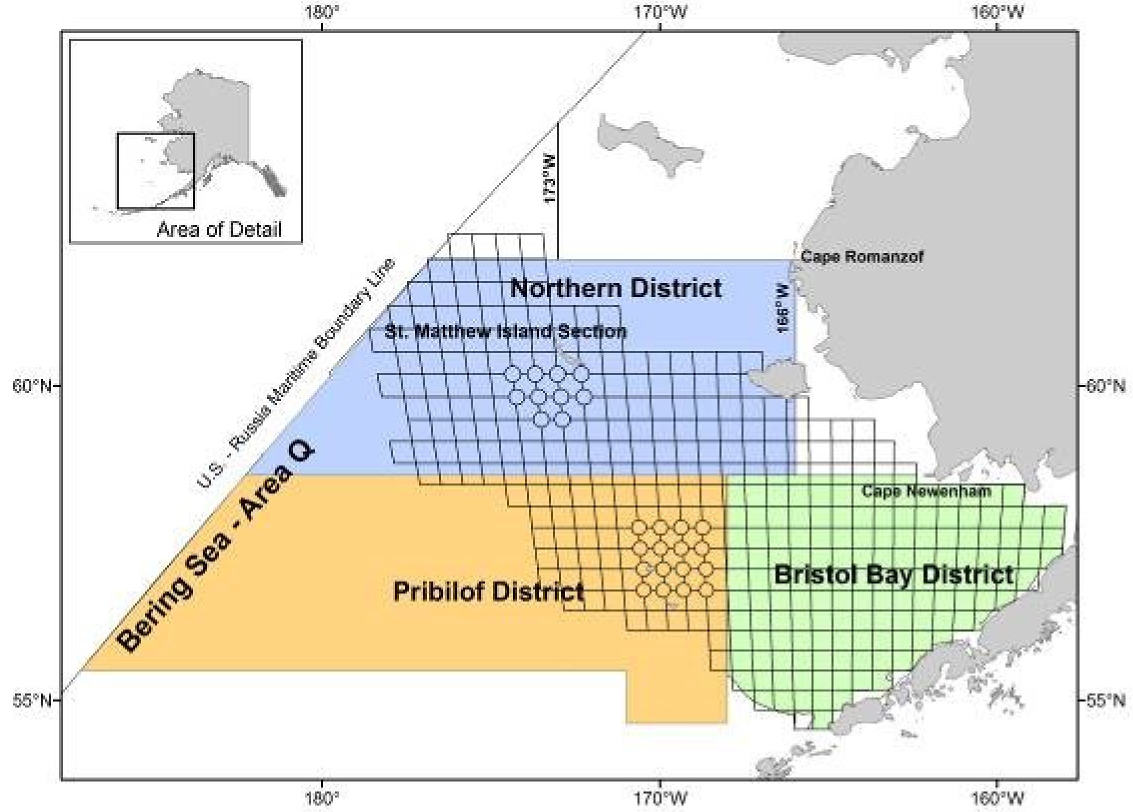

Figure 3: Management areas in the Bering Sea.

Figure 4: Distribution and density of red king crab observed in the NMFS summer survey around the Pribilof Islands.

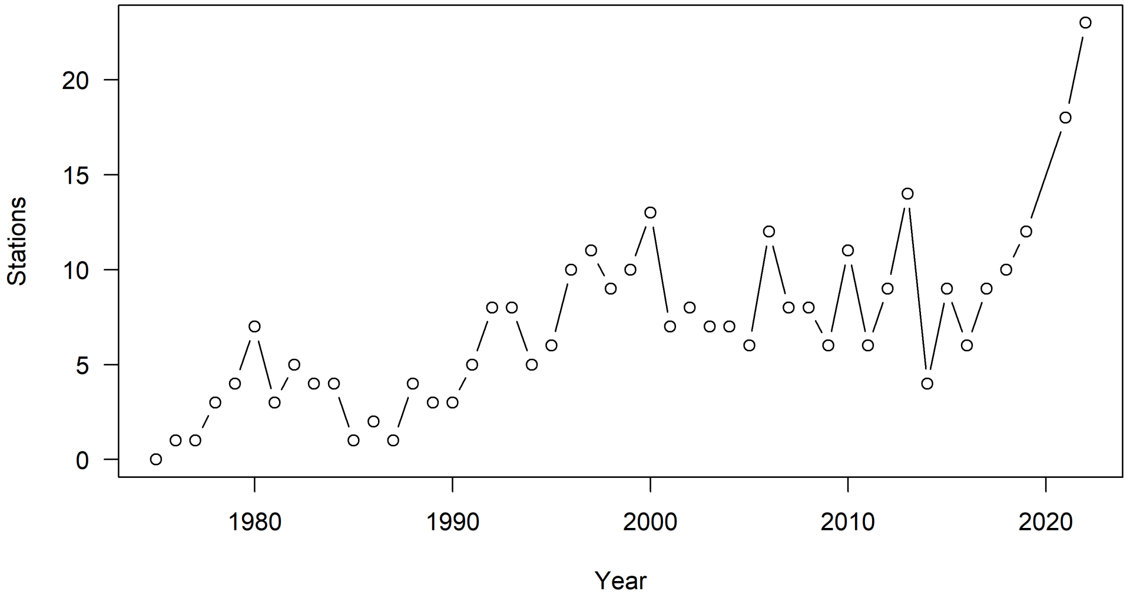

Figure 5: The number of stations at which crab were observed in the Pribilof District in the NMFS summer survey over time.

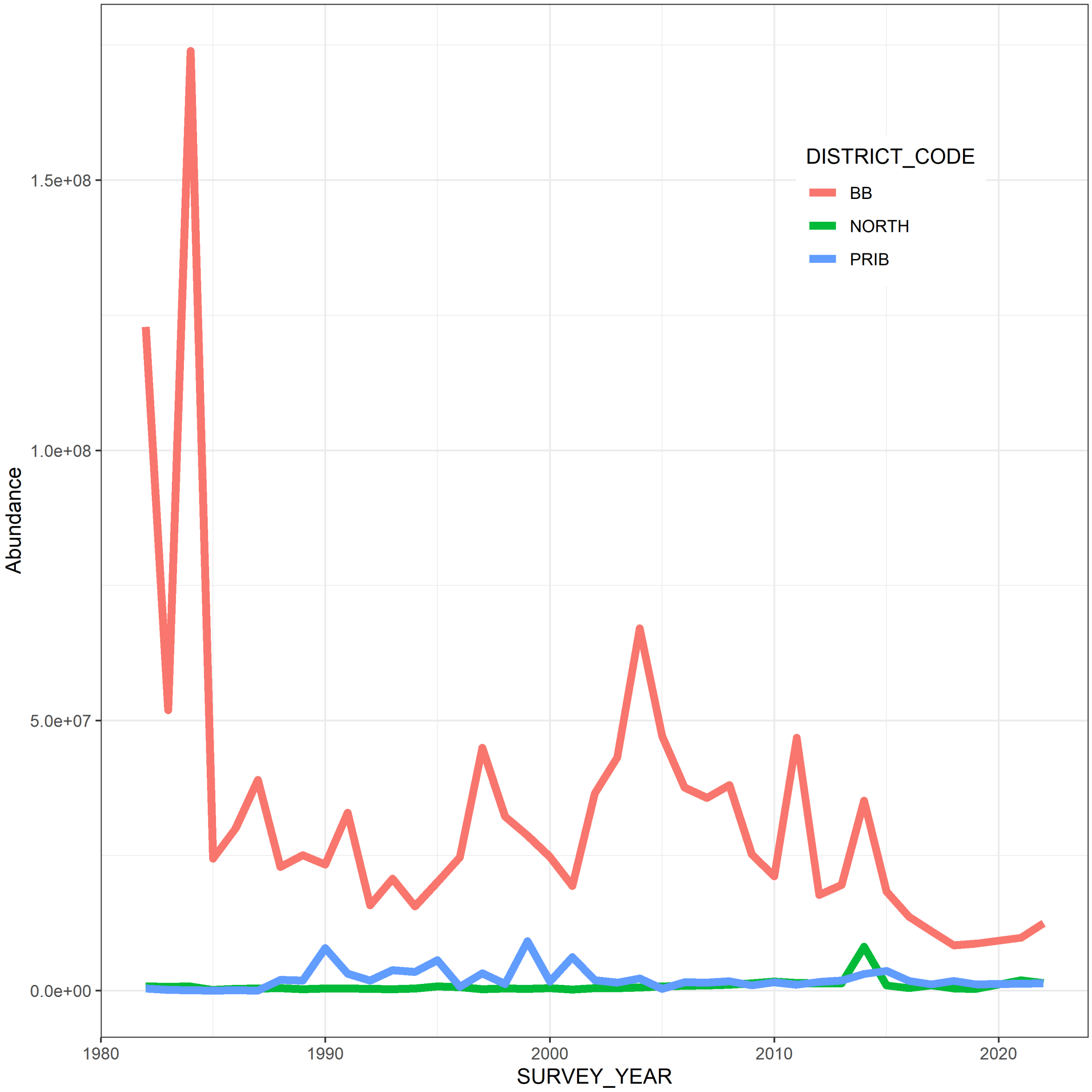

Figure 6: The survey estimated abundance of red king crab by district.

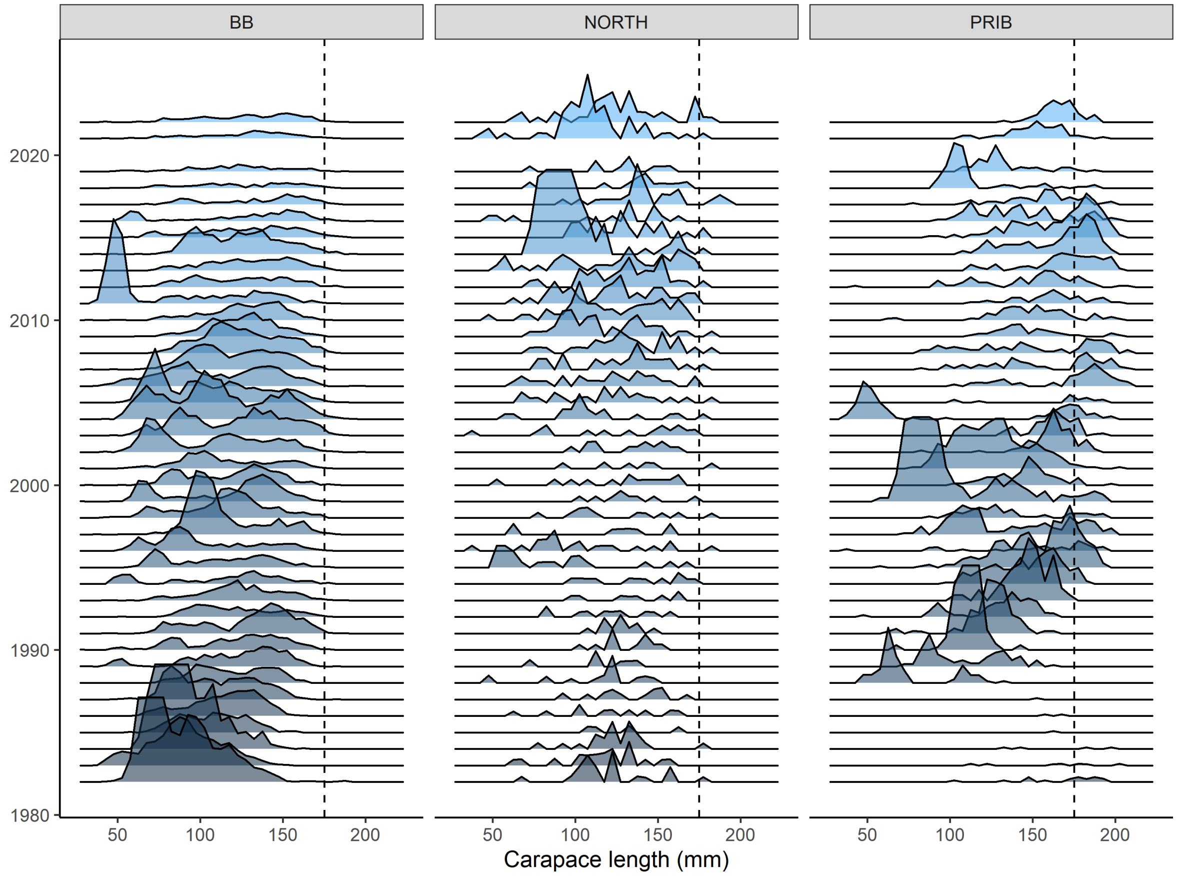

Figure 7: The number by size of male red king crab at carapace length by district. Each district is scaled to the maximum observed in a district, refer to above figure for relative differences. Data were capped in some years and size classes to allow for better resolution of cohorts (e.g. 60-70 mm carapace length in 1982 for Bristol Bay.

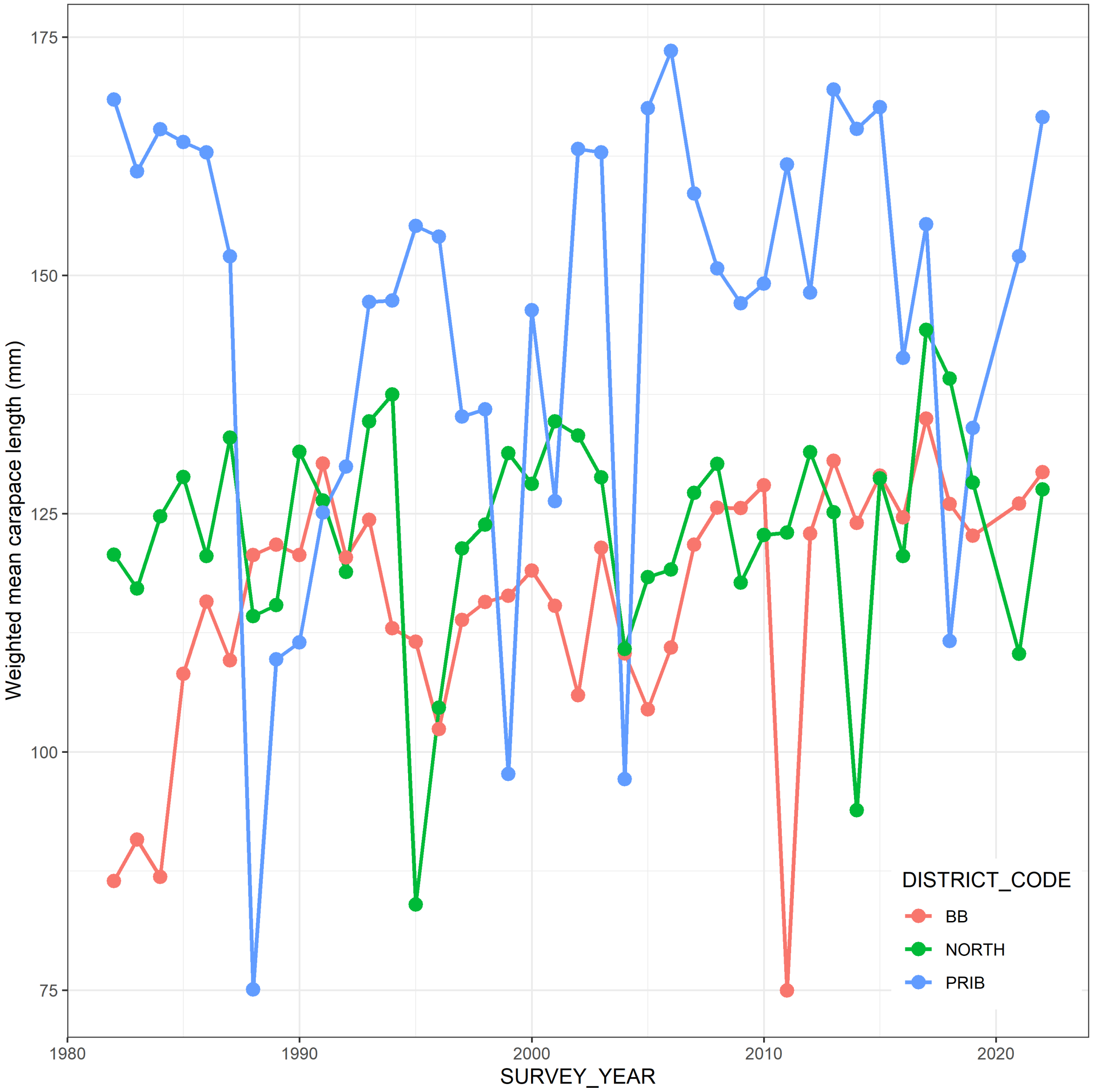

Figure 8: The mean size over time by district for red king crab in the Bering Sea.

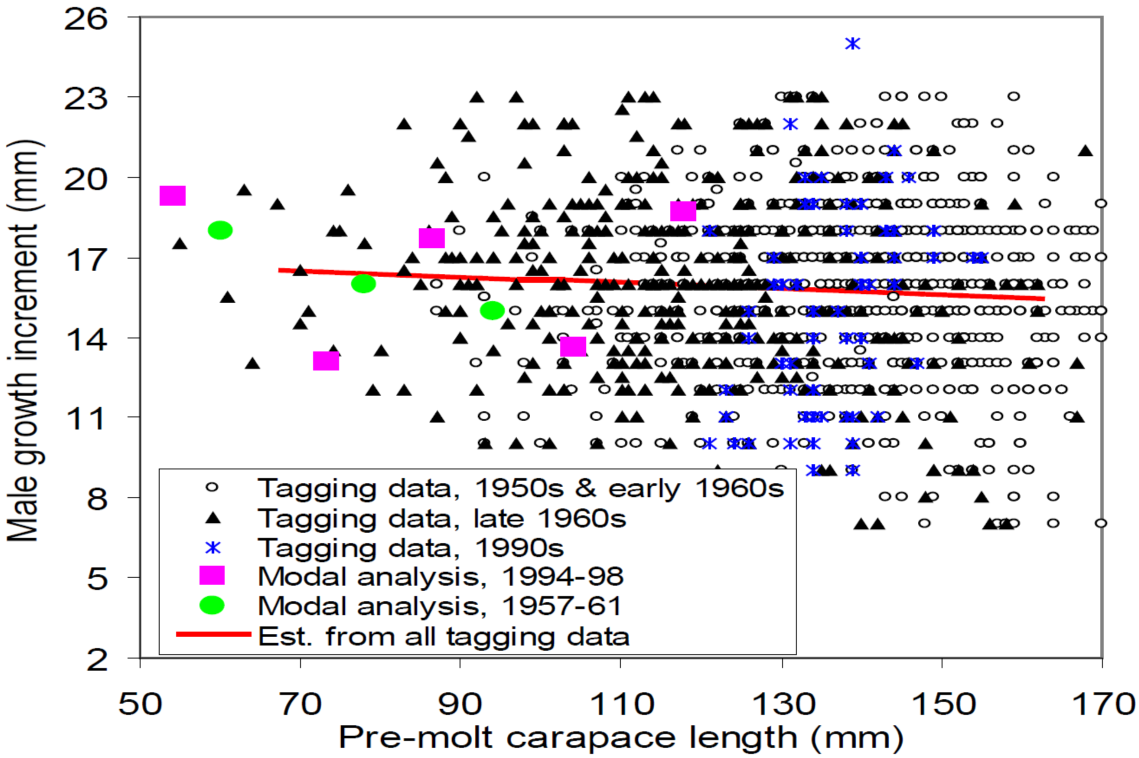

Figure 9: Tagging data used to inform molt increment for Bristol Bay red king crab. Reproduced figure A2 from 2021 BBRKC assessment.

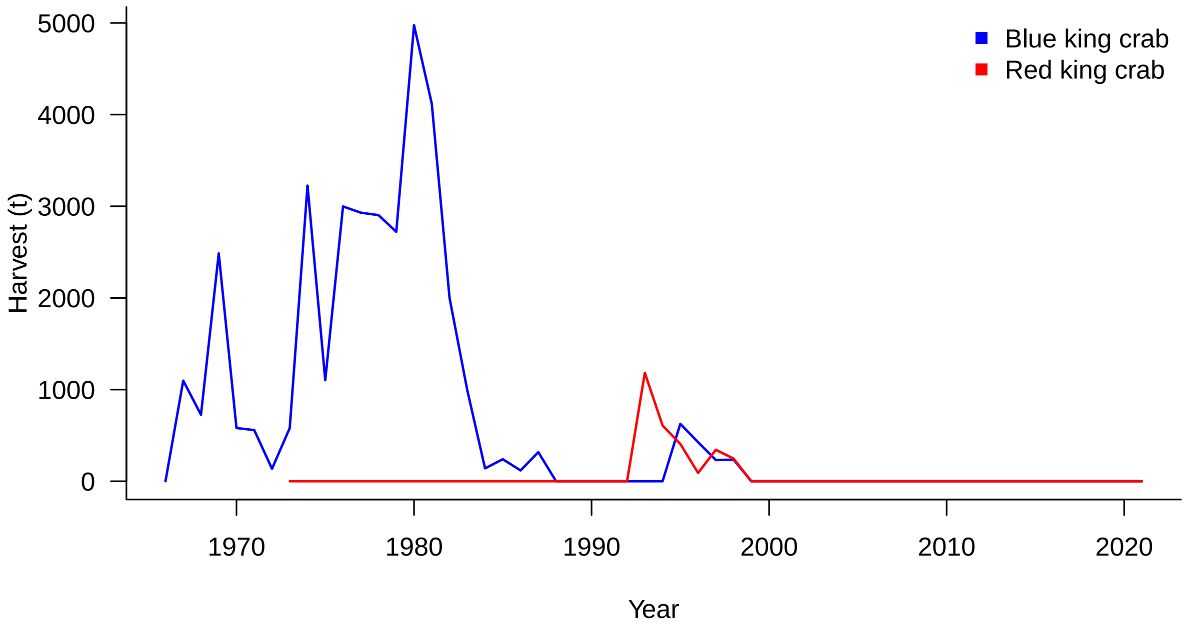

Figure 10: Historical directed harvests of blue king crab and red king crab around the Pribilof Islands.

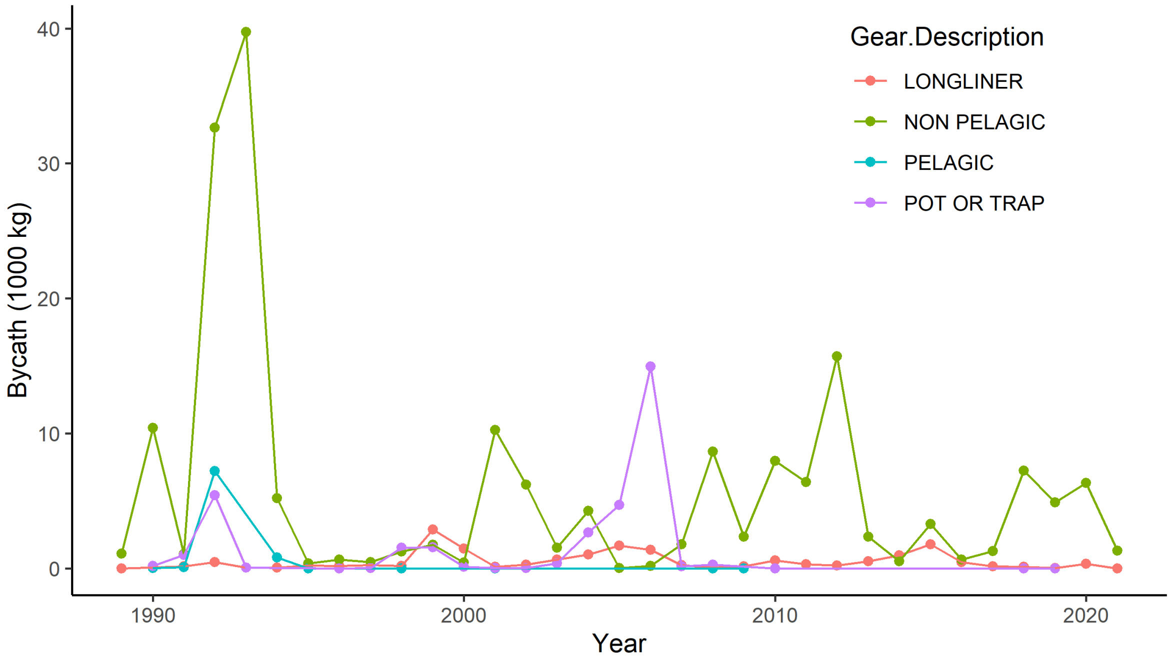

Figure 11: Bycatch by fleet by year in metric tonnes of PIRKC.

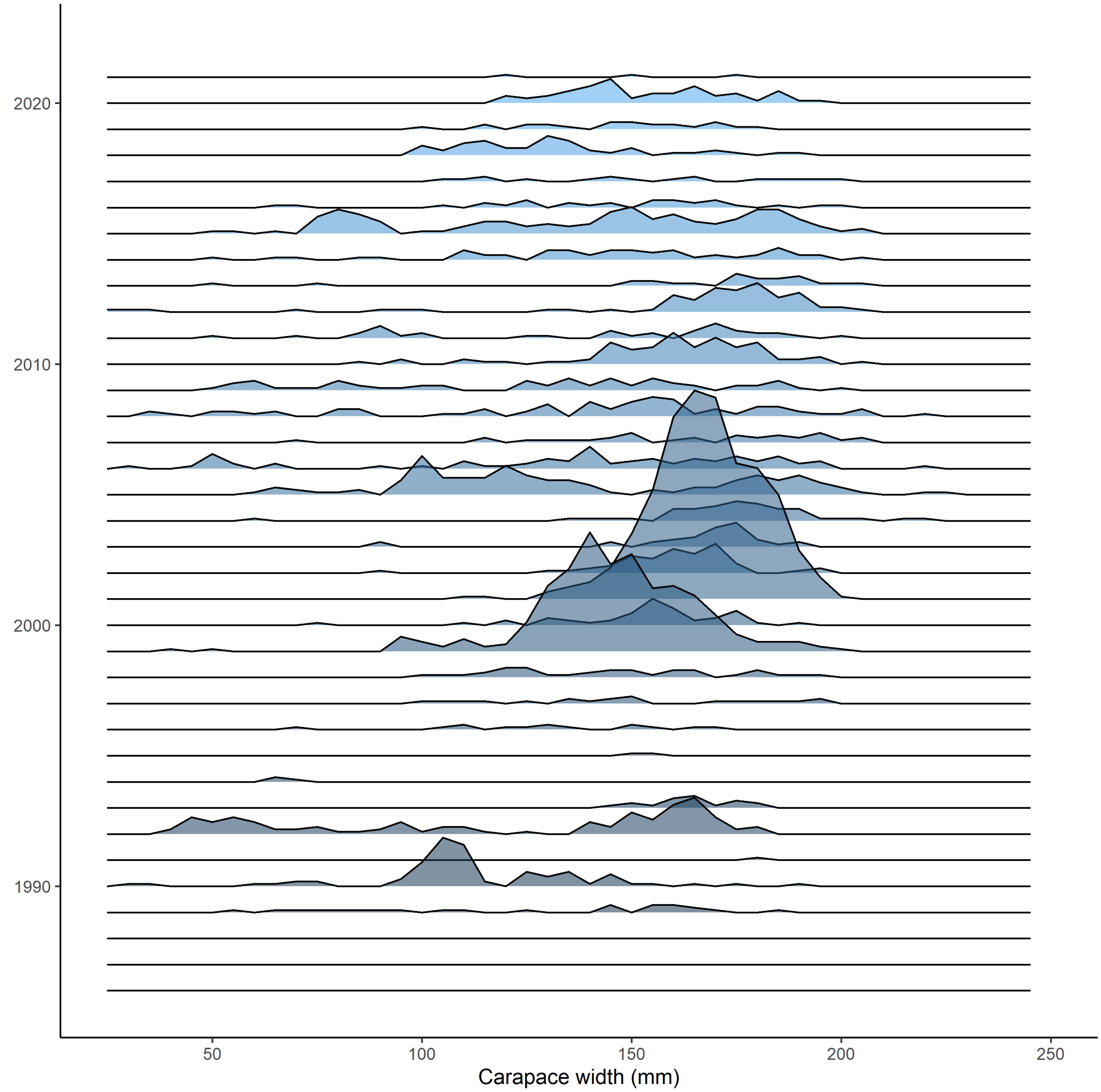

Figure 12: Size composition of the aggregate bycatch by year for red king crab in the Pribilof District.

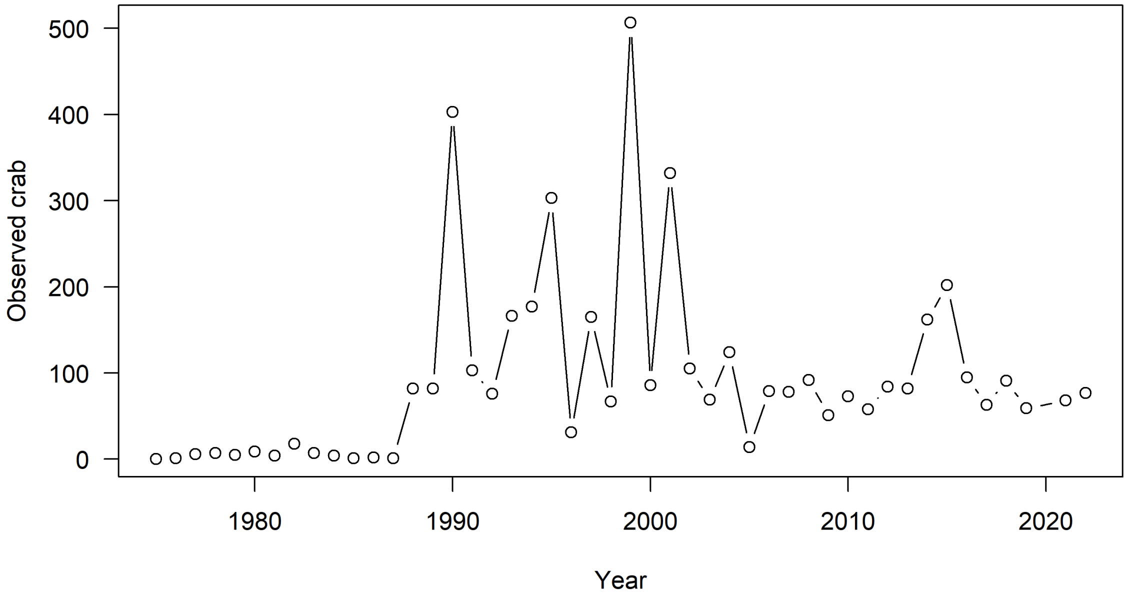

Figure 13: Total number of observed crab by year in the NMFS summer survey.

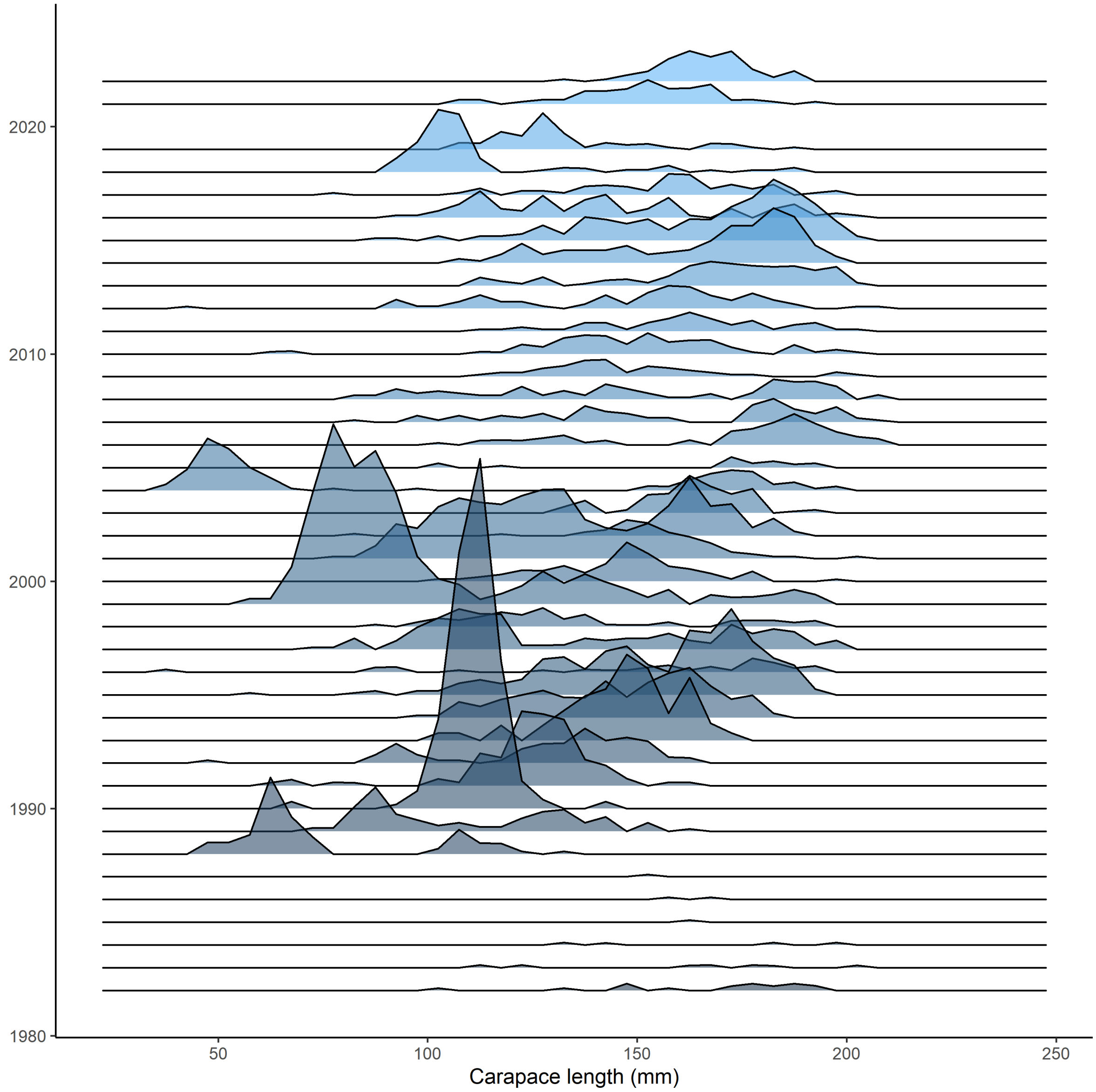

Figure 14: Observed numbers at length by year of male PIRKC.

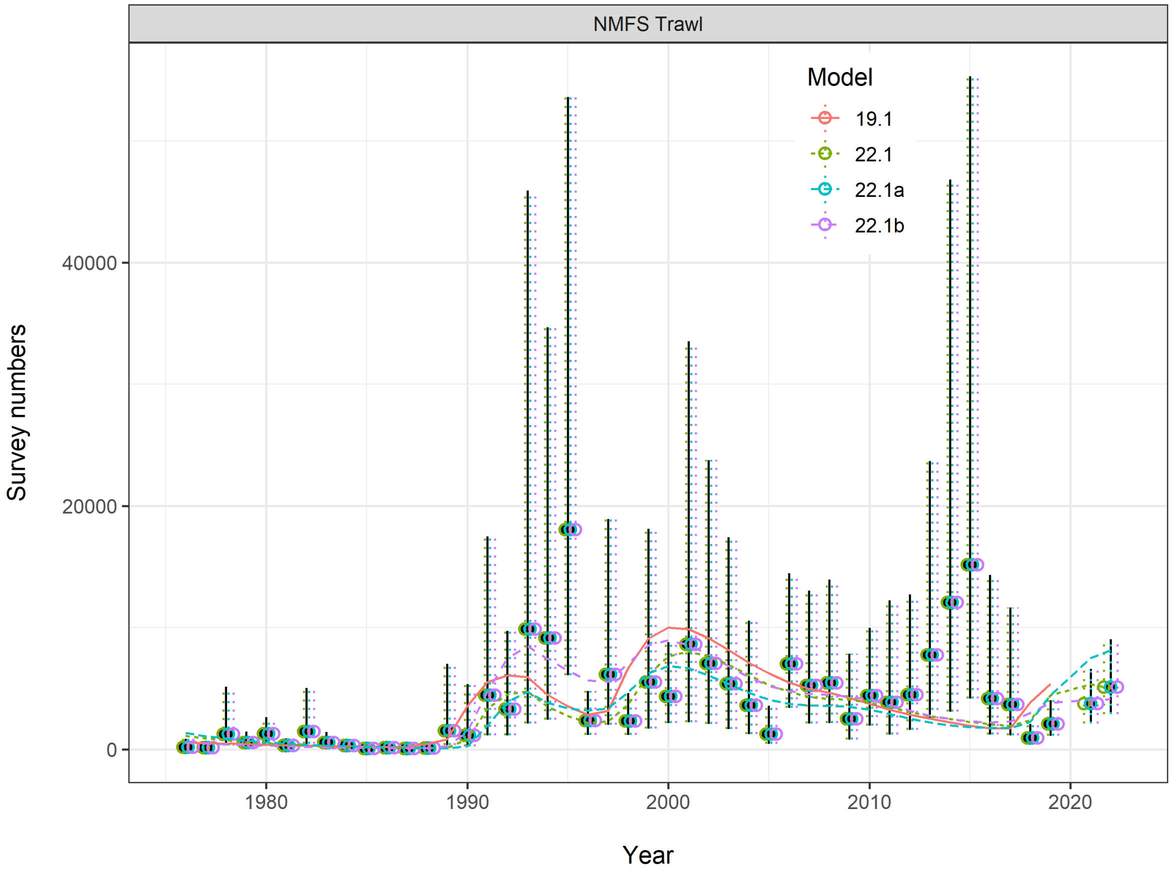

Figure 15: Model fits to mature male biomass from the NMFS summer trawl survey.

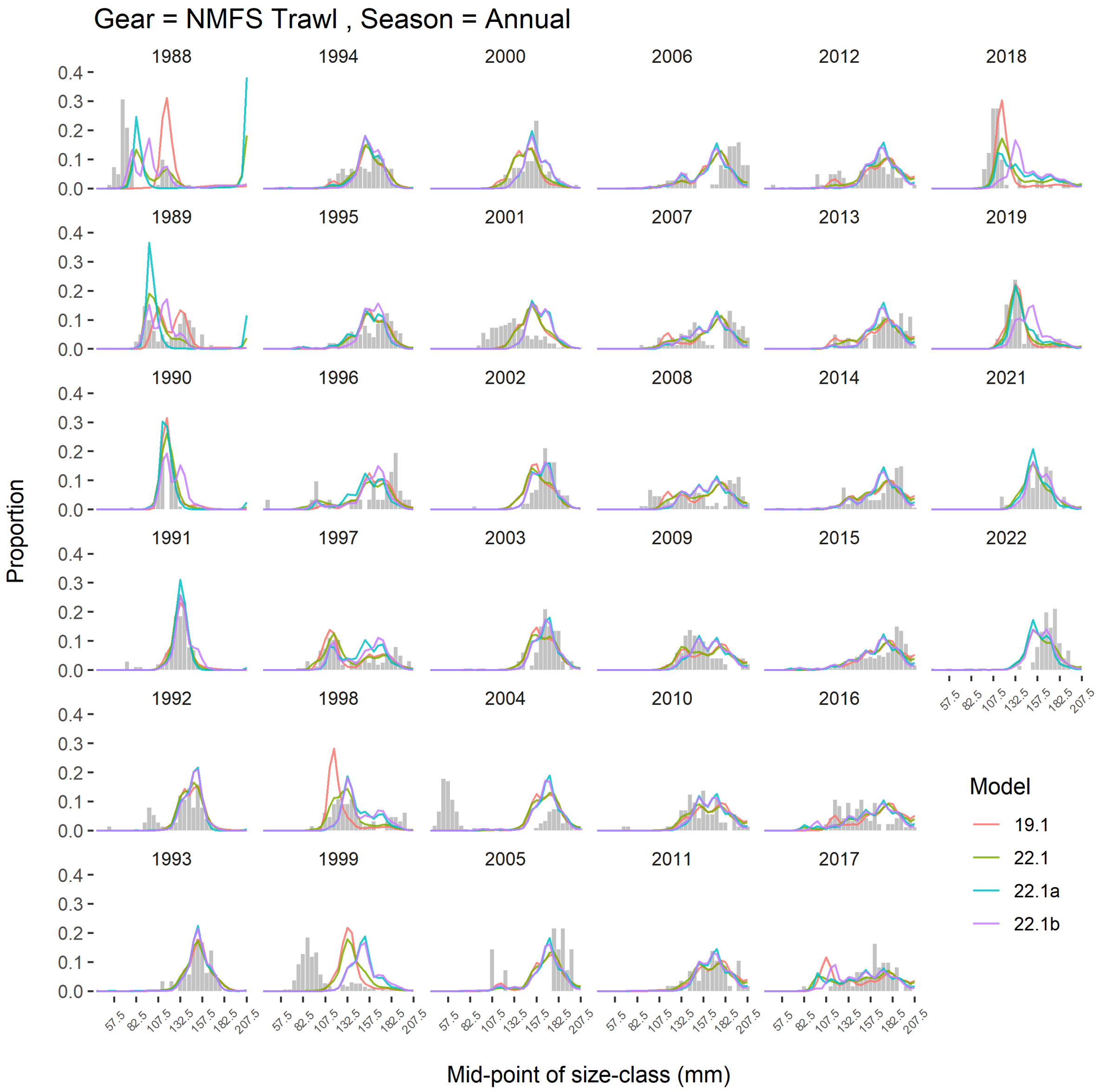

Figure 16: Model fits to survey size composition data.

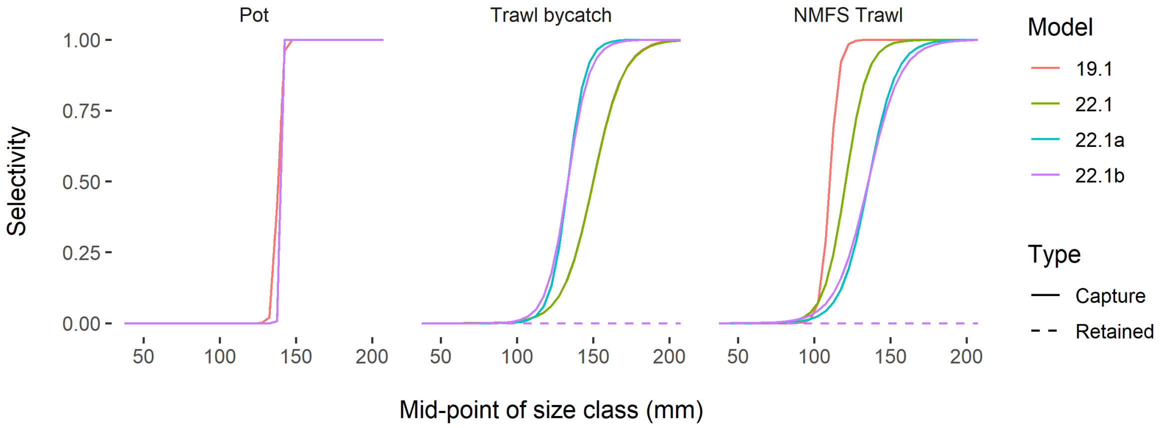

Figure 17: Estimated survey selectivity, assumed directed pot fishery selectivity, assumed and estimated bycatch selectivity.

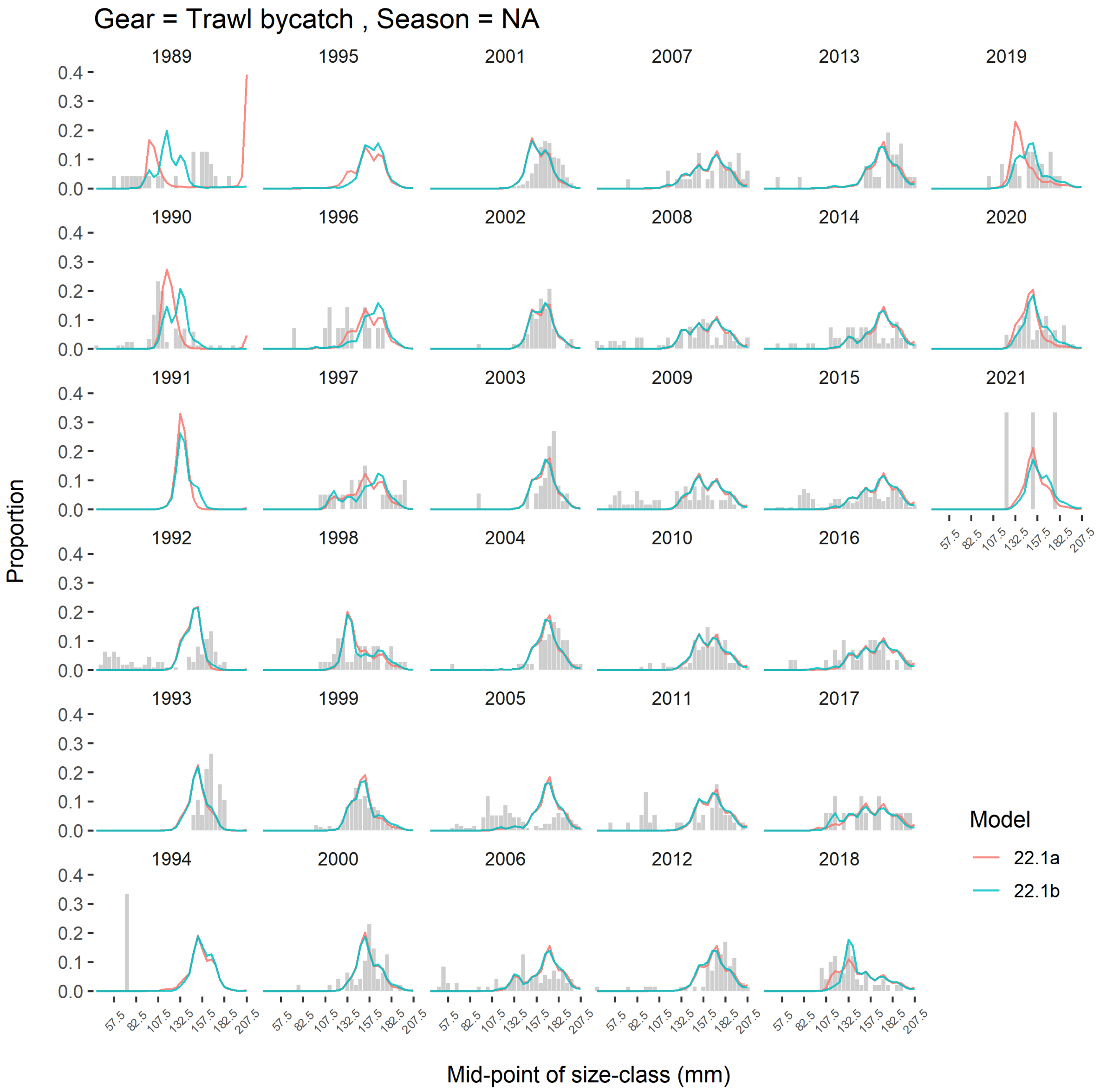

Figure 18: Model fits to bycatch composition data.

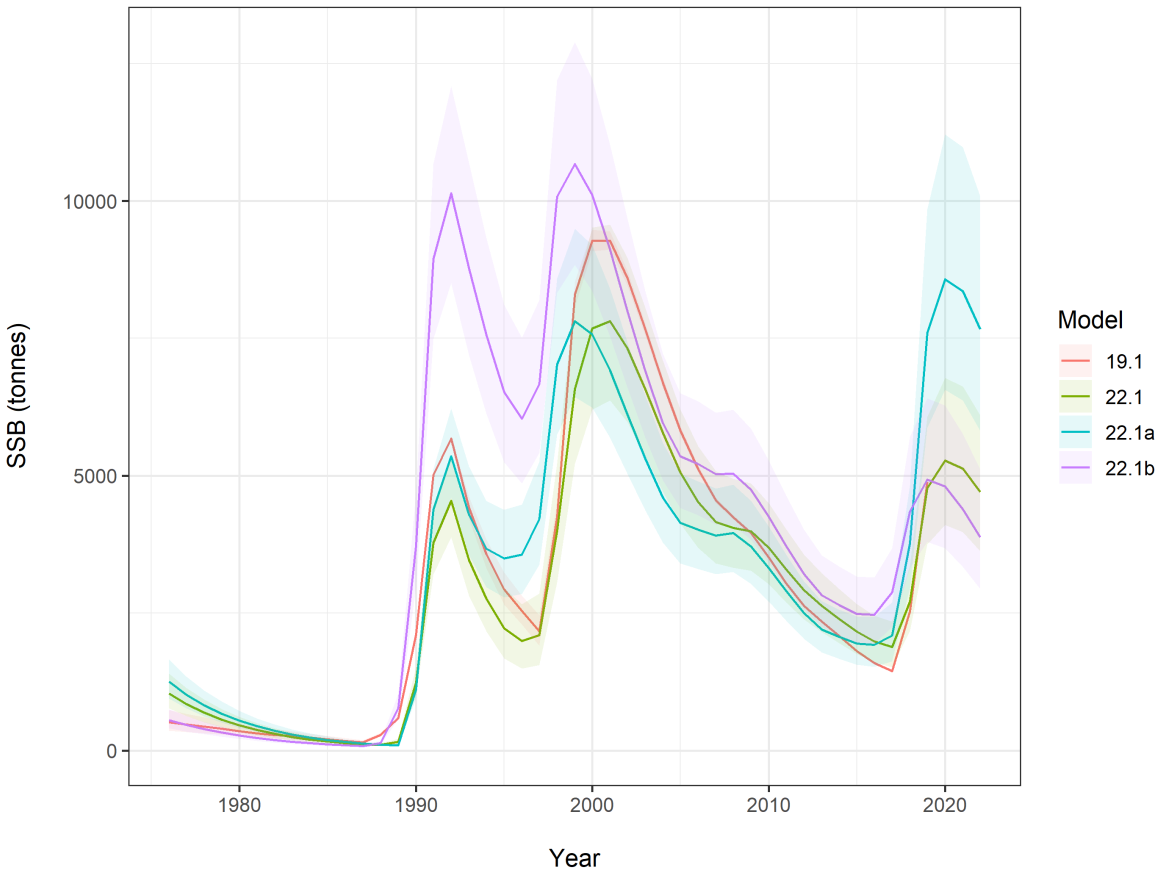

Figure 19: Model predicted mature male biomass at mating time

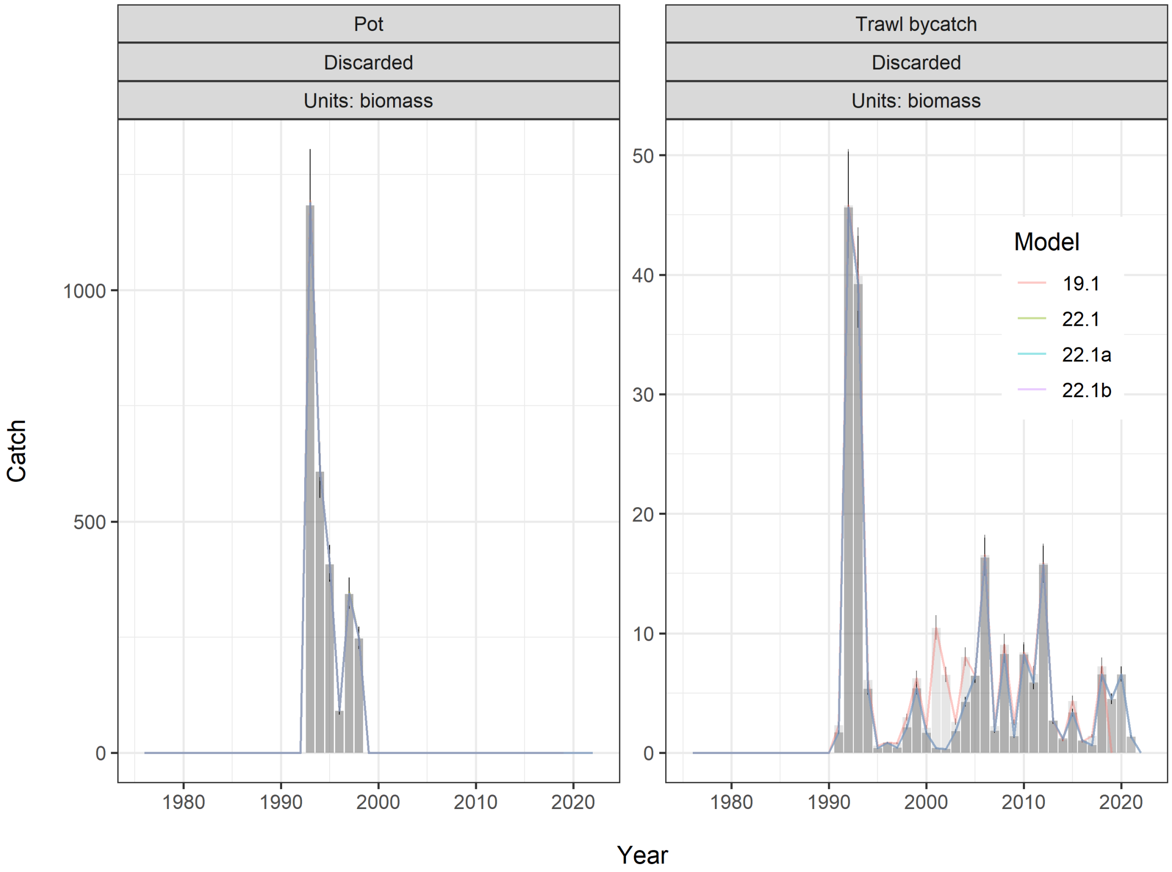

Figure 20: Model fits to catch data. note a difference in scales between figures

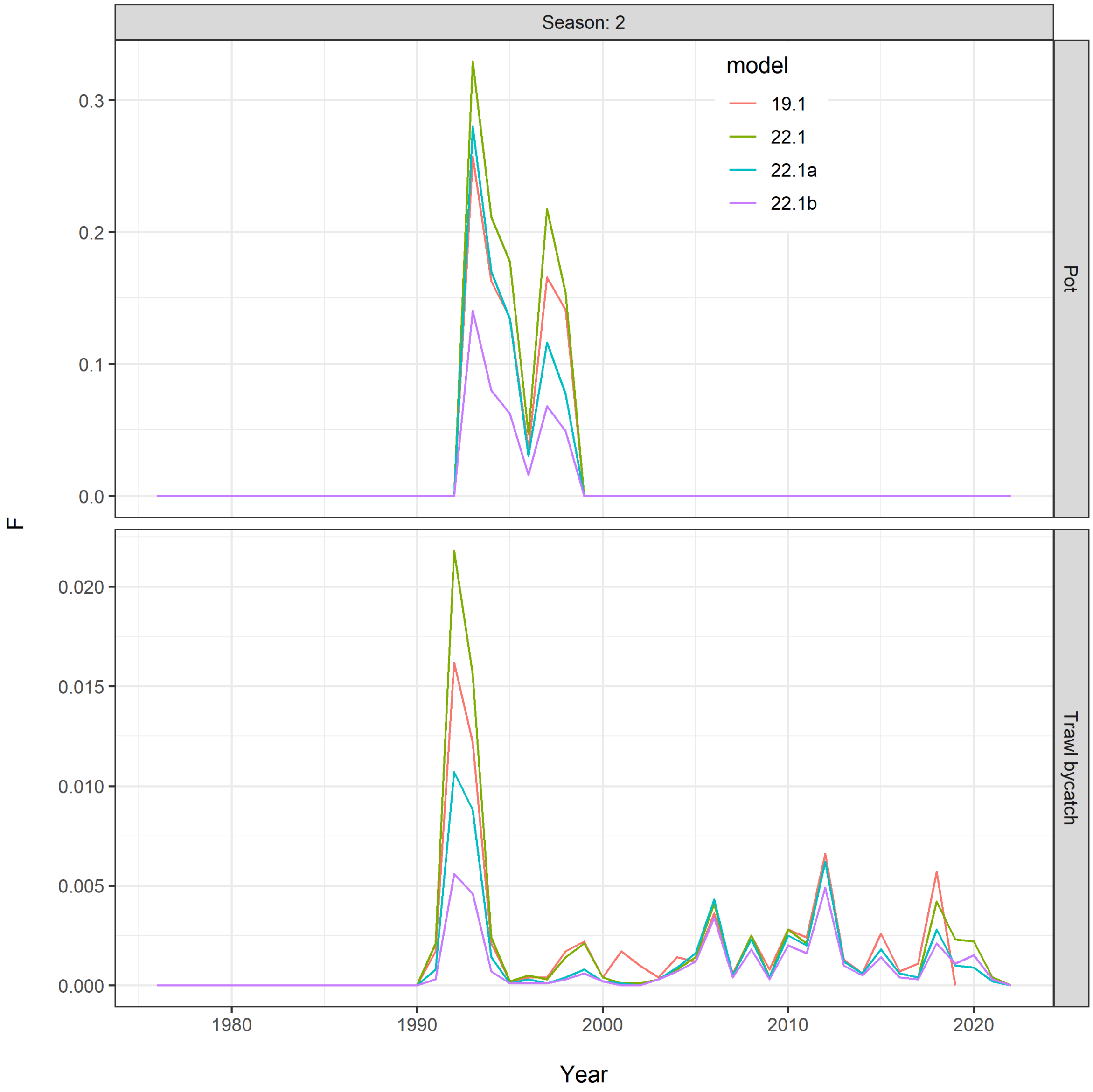

Figure 21: Model predicted fishing mortalities

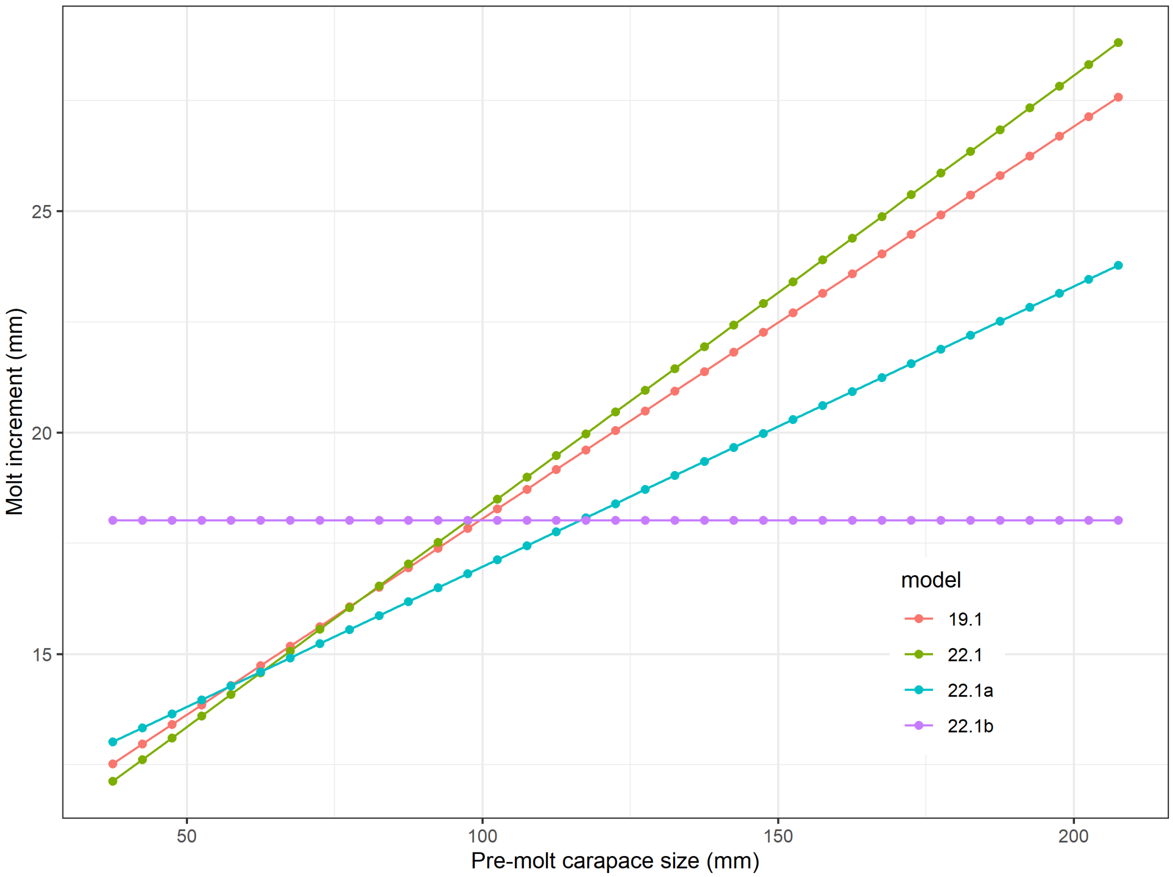

Figure 22: Predicted molt increments

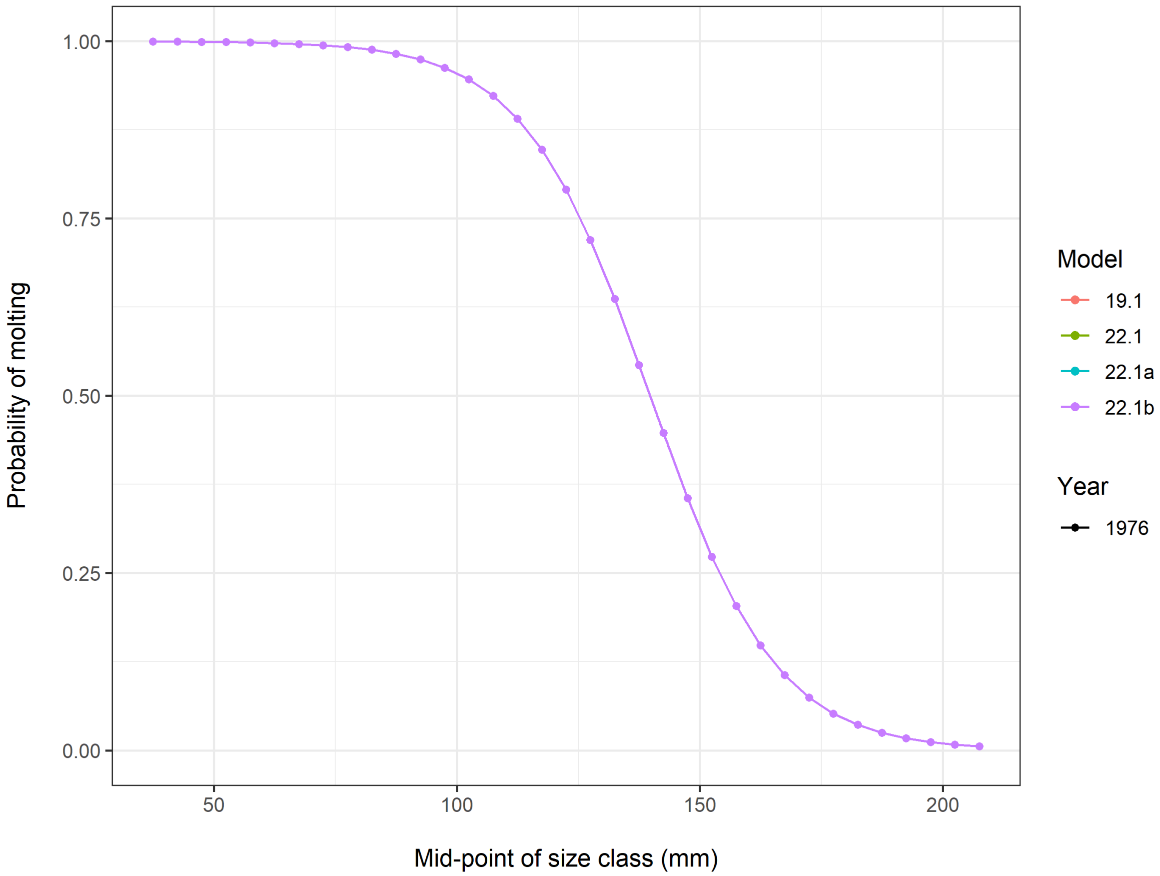

Figure 23: Specified probability of molting by size (mm)

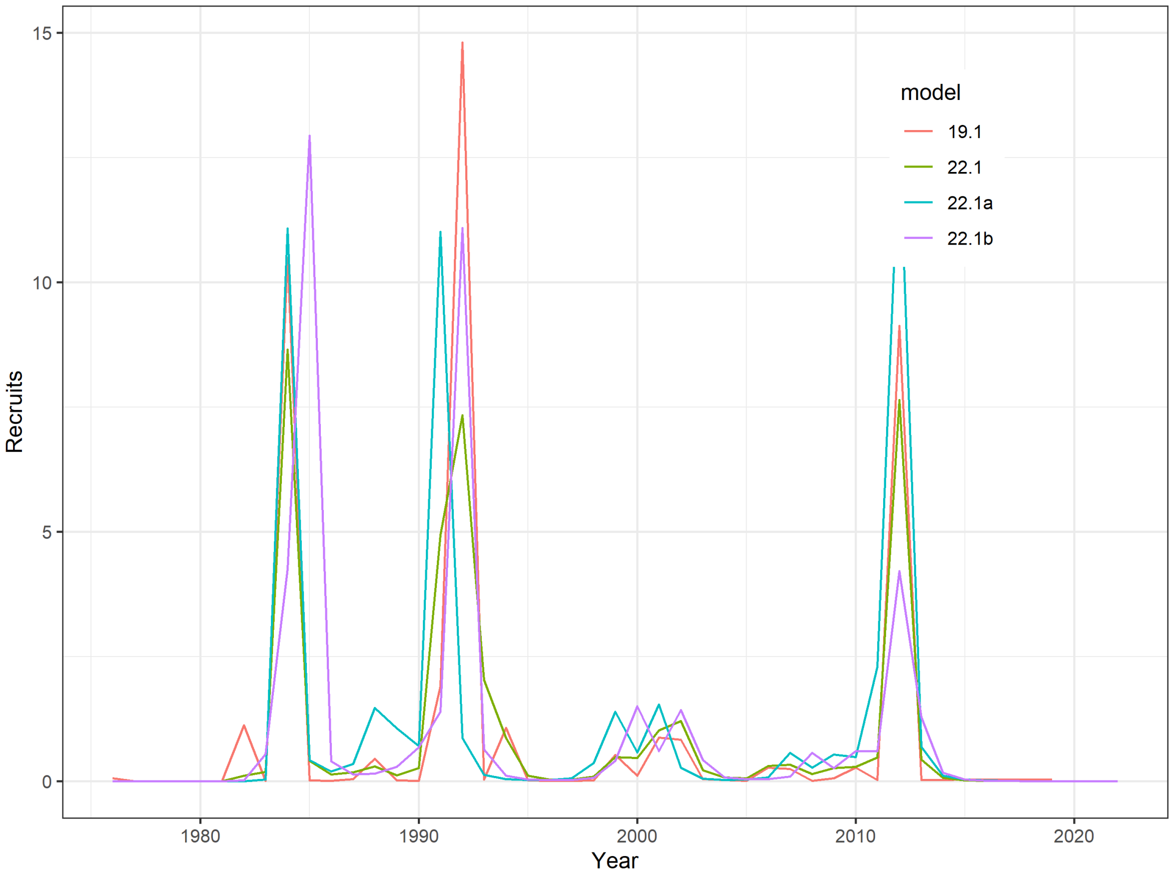

Figure 24: Estimated recruitment.