2025 assessment for Pribilof Islands red king crab

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Executive summary

Stock: Pribilof islands red king crab (PIRKC), *Paralithodes camtschaticus*.

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).

Stock biomass: In recent years, observed mature male biomass (>120mm carapace length) peaked in 2015, as a cohort established in the early 2000s moved into the largest size classes. A new cohort was observed in the survey in 2018 and is currently occupying the largest size classes. 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).

Recruitment: Recruitment appears to be episodic, with three large cohorts having passed through the population since the late 1980s. Recruiment has been very low since 2018.

Recent management statistics: PIRKC is on a triennial assessment cycle and was last assessed in 2022. GMACS was adopted as the assessment model platform in 2019.

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
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	3.84	864	648
2020/21	866	6431	0	0	5.09	864	648
2021/22	854	3879	0	0	1.47	864	648
2022/23	641.7	4060.6	0	0	3.92	685	514
2023/24	641.7	3584.5	0	0	3.92	685	514
2024/25	641.7	3146.0	0	0	0.87	685	514
2025/26		2773.8				489.9	367.4

Table 2: Historical status and catch specifications for Pribilof Islands crab (millions of lbs).

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
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	0.01	1.9	1.43
2021/22	1.88	8.55	0	0	0	1.9	1.43
2022/23	1.41	8.95	0	0	0.01	1.51	1.13
2023/24	1.41	7.9	0	0	0.01	1.51	1.13
2024/25	1.41	6.94	0	0	0	1.51	1.13
2025/26		6.12				1.08	0.81

6. *Basis for the OFL*

Table 3: Metrics used in designation of status and OFL (1,000 t). Status represents the status of the population after the completed fishing year and is used for overfished declarations. 'Years' indicates the year range used in the calculation of the proxy for BMSY. 'M' is the natural mortality for mature male crab. MMB here refers to biomass >120mm carapace width. (continued below)

Year	Tier	BMSY	MMB	Status	Proj_MMB	Proj_Status	FOFL
2025/26	4	1283	2774	2.16	2586	1.63	0.21

Years	M
2000-2024	0.21

7. *Basis for the ABC*

ABCs are calculated using a 25% buffer as recommended by the CPT and SSC in 2022.

A. Summary of major changes:

1. *Management*: No major changes.
2. *Input data*: Survey and bycatch data were updated with the most recent data in this draft.
3. *Assessment methodology*: ADFG pot survey data are included in this assessment.
4. *Assessment results*: Overfishing did not occur from 2022-2025 and the stock was not overfished as of the summer of 2025.

B. CPT and SSC comments/requests from June 2025:

The SSC request the author bring forward additional detail on the transition to the new GMACS version and diagnostics in the fall.

Given the large number of changes to GMACS over three years and the difficulty comparing across versions, little progress was made on this request.

The SSC recommends the CPT discuss and bring forward recommendation for revised time interval to align with PIBKC.

To be discussed at CPT.

The SSC recommends this assessment remain in the GMACS framework.

To be discussed at CPT.

C. Assessment scenarios

Models

Three assessment scenarios were considered this year:

- 22.1: accepted model from 2022
- 25.1: Same model configuration as 22.1, but updated GMACS model and survey/catch data
- 25.2: 25.1 + ADFG pot survey

A number of structural and formatting changes occurred in the GMACS code since 2022. For example, functionality was extended to include allowing indices for immature crab, the .CTL file and variable naming schemes were rewritten, implementation of priors was standardized across parameters, and jitter protocols were revised. For an exhaustive list of changes and bug fixes, see the very end of the .TPL file for the most recent GMACS version on the github repo. All of these appear to be improvements, but they resulted in some changes to the model fits and derived management advice.

A pot survey around the Pribilof Islands was performed during 4 years from 2003-2011 (2003, 2005, 2008, 2011). Given the finer spatial resolution compared to the NMFS bottom trawl survey, it is possible that the inclusion of the pot survey in the assessment could provide more clarity on population trends during the 2000s. The number of survey stations and pots dropped varied across years with the most occurring in 2008 (220 stations and 1021 pots) and the fewest in 2011 (161 stations and 644 pots; Figure 1). The number of crab captured each year ranged from 98 to 6507 (2011 and 2008, respectively; Figure 2). The largest number of crab pot hours occurred in 2008 (Figure 3). The number of crab per 1,000,000 hours of soak time were used as an index of abundance from the pot survey. The unit 'crab per 1,000,000 hours' was used in order to put the index on a similar scale as the NMFS bottom trawl survey and avoid convergence issues around estimating very small catchability coefficients that occur because of the parameter space in which catchability is estimated.

Key assumptions of presented models include:

- only males are modeled, with size composition data representing all males observed and the index of abundance representing crab >120 mm carapace length (i.e. 'mature'),
- the probability of molting is a declining logistic function of size that is specified based on the BBRKC assessment,
- a single survey selectivity is estimated as a logistic function, but catchability is specified based on values estimated in the BBRKC assessment,
- growth increment is estimated with a prior based on BBRKC tagging data and is constant across size,
- natural mortality is specified as 0.21 based on an assumed longevity of ~25 years and Hamel's (2015) study relating longevity to natural mortality,
- total and retained fishery selectivity are logistic curves fixed at values estimated in the BBRKC assessment,
- all non-directed bycatch is lumped into a single 'fishery' for which a logistic selectivity is estimated,
- recruitment is estimated yearly and is allocated to the first 7 size bins

D. Introduction

Distribution and stock structure

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 4). 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 (see tech memo; Zacher et al., 2025). 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 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 5). The distribution of red king crab within the Pribilof District is concentrated around the islands (see tech memo; Zacher et al., 2025). The number of stations at which red king crab were observed around the Pribilof Islands was at an all time high in the early 2020s, but has since dropped to some of the lowest levels seen since the 1980s (Figure 6).

The connection between red king crab in the three different 'districts' in the Bering Sea (Bristol Bay, Pribilof Islands, and Northern) is an open question (Figure 5). Much higher abundances of male crab occur in Bristol Bay, 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 (Figure 7). Although there appear to be three to four cohorts in the Pribilof District, five or more can be seen Bristol Bay (Figure 8). The larval crab that developed into the first cohort around the Pribilofs in the late 1980s likely did not originate there given the low numbers of spawners, 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 maximum size of observed crab in Bristol Bay is smaller than that of the crab around the Pribilof Islands, which is unsurprising given there is a size-selective commercial fishery in Bristol Bay and not around the Pribilof Islands. 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.

Populations of red king crab in the Alaska 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 biomass. 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, 0.21, 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. 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 5) 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.

E. Data

The following sources and years of data are available: NMFS trawl survey (1976-2019, 2021-present), retained catch (1993-present), and non-directed bycatch (1991-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 are available during that time period, but no retained catch has been allowed since 1999.

Bycatch and discards

Non-retained (directed and non-directed) pot fishery catches are available 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: α=0.000361, β=3.16; females: α=0.022863, β=2.23382) and 2010 to 2013 (males: α=0.000403, β=3.141; ovigerous females: α=0.003593, β=2.666; non-ovigerous females: α=0.000408, β=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.

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

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

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 presented here as a single fishery with selectivity estimated based on the accompanying size composition data (Figure 10 & 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 and are used in the assessment to estimate bycatch selectivity (Figure 11). 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 NMFS bottom trawl survey results are included in this SAFE report (1976-2019, 2021-2025; 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 6). 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 6). Cohorts can be discerned in the length composition data, with 3 to 4 larger cohorts apparent (Figure 8).

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. Mature male biomass (>120 mm) at the time of the survey has declined in recent years to a low in 2018. A pseudocohort was observed in the 2018 survey data and appears to have persisted through the size classes to 2025, but observed MMB is now near the low seen in 2018 (Figure 8).

F. 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 years 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. GMACS version 2.20.22 was used for the updated models in this document. 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 BBRKC assessment. In the updated assessment, 136 parameters were estimated (Table 6) and 7 parameters were fixed (Table 5). A bin size of 5 mm was selected to model numbers at length in the integrated assessment based on Szuwalski (2015).

Results

Model convergence and comparison

No models displayed signs of non-convergence based on the production of a Hessian and gradients near zero. Total likelihoods are not comparable across all models given the addition of an additional survey (Table 10).

Model fits

There was considerable variability in model fits to mature male biomass, particularly during the 1990s (Figure 12). Broader agreement among models existed from the mid-2000s to present. The fits to the ADFG pot survey missed one of the CIs, and little of the (uncertain) variability in the pot survey CPUE was captured by the model (Figure 13). Estimates of mean growth increment varied somewhat among models in spite of a fairly strong prior (Figure 14). Sensitivities to the value of the variability around the estimated growth increment suggest the currently used variability is close to the variability observed in the tagging data (see June 2025 document). Fits to the available catch data were all satisfactory (Figure 15).

Size composition data are relatively sparse for many years in both the survey and observer data, particularly in early years of the assessment when red king crab were not as abundant around the Pribilof Islands (Figure 6). Consequently, the fits among models to these early data are somewhat noisier than in later years (Figure 16). The models fit the data from the early 2000s until recently more similarly. This pattern of poorer fits in early years is also apparent in the non-directed bycatch size composition data (Figure 17). The ADFG pot survey size composition data were best fit in 2003 and 2011 (Figure 18).

Estimated population processes

Much of the differences in fits to the survey data are related to the interplay of the differences in estimated recruitment, growth, and survey selectivity among models (Figure 20 & Figure 19). Selectivity for the ADFG pot survey was essentially knife-edge with a size at selection of ~88 mm carapace length (Figure 21). Changes in estimated selectivity for non-directed fishery inversely mirrored the changes in survey selectivity (Figure 22). Estimated full-selected fishing mortality increased with the addition of the ADFG pot survey (Figure 23). The probability of molting is specified in all models based on estimates from the BBRKC assessment (Figure 24).

The incorporation of the ADFG pot survey data did not appreciably change the qualitative trajectory of the stock and subsequent management advice. In spite of this, the rationale for keeping this stock in an integrated model has been that the NMFS survey biomass data are noisy enough that any additional data sources are useful. The historical reasoning for moving this assessment into an integrated framework was to incorporate the size composition data to inform biomass trajectories because there was a clear signal in those data. If the intention is to keep PIRKC in GMACS, including the pot survey data extends the spirit of moving to an integrated model.

G. Calculation of reference points

Tier 4 OFL, B_{MSY}, and ABC

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. The stock has been unfished since the 2000 season, so setting the BMSY proxy as 35% of the mean of that unfished period seems like a reasonable definition in the spirit of our HCRs. 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.

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

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, λ is a constant that can be modified by the council to adjust the fraction of M applied (currently set to 1), and α determines the slope of the descending limb of the HCR (here set to 0.1). The acceptable biological catch (ABC) is determined by multiplying the calculated OFL by a buffer meant to account for scientific uncertainty. A buffer of 25% has been used for PIRKC historically.

Variables related to scientific uncertainty in the OFL

Uncertainty in the time series of survey estimated of biomass for Pribilof Islands red king crab is relatively high due to small sample sizes. The CVs had been declining recently as crab were found at more stations, but this trend is beginning to reverse as a result of losing the corner stations (Figure 6). Recruitment, growth, and survey selectivity were estimated within the integrated assessment, but maturity, survey catchability, fishery selectivity, and natural mortality were fixed. Fitting to data to inform these processes might improve both the accuracy of and uncertainty in estimates of management quantities. F_{MSY} was assumed to be equal to natural mortality, which is poorly known.

H. Author Recommendation

The author recommended OFL for PIRKC for the 2025 cycle is 489.9 tonnes based on the application of a Tier 4 HCR to the output of model 25.2, which includes the ADFG pot survey data. The stock is declining without any recruitment back-fill and current model estimates of MMB are substantially higher than the observations. The higher estimates of MMB are likely related to a relatively low, time-invariant M and more informative data from 2021-2023 when the corner stations were still being towed. The CVs of the survey MMB shift from ~0.3 to 0.445 from 2021-23 to 2024-25 as a result of dropping the corner stations. The estimates of MMB from 2024-2025 are derived from far fewer crab than in previous years (~10 to an average of closer to 75, Figure 6). Given that recruitment entering the model does not grow to MMB for at least 5 years, this may foreshadow interaction with management thresholds in the next assessment cycle for this stock. Projections under no fishing and fishing at the OFL signal a continued decline of the stock until at least 2030, and what happens after then depends strongly on whatever recruitment occurs after 2025 (Figure 26).

I. Data gaps and research priorities

The largest data gap for PIRKC is the number of observations from which the population size and biomass is calculated and this will not likely change for the better in the future. The small sample sizes (and decreases in sample size) support the use of as much of the available data as possible in assessment efforts. Research on biological processes specific to the Pribilof Islands might be useful given reliance on data from the 1960s from other populations of red king crab. 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. A better accounting of the bycatch in other crab fisheries may also be useful. Reconstructing the non-directed fishery bycatch before 1991 might also be useful, but unlikely to significantly impact assessment results given the timing of the increase of the population size in the early 1990s. However, if there will continue to be no fishery for this stock, the utility of expending any effort beyond assessments based on survey indices is questionable.

J. 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 (both via recruitment and mortality) 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; Szuwalski et al., 2020). Ocean acidification also appears to have a detrimental effect on red king crab (Long et al., 2013; Litzow et al., 2023), 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 under a changing climate.

A risk table for PIRKC can be seen in appendix A.

K. References

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

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Table 5: Parameters fixed in the assessment. SD is the standard deviation.

Fixed.parameter	Value
Survey catchability	0.925
Size at 50% capture in fishery	138.000
SD of above	0.100
Size at 50% molting probability	139.770
SD of above	0.093
Natural mortality	0.210

Table 6: Parameters estimated in the assessment. NaNs appear when a parameter is not estimated in an assessment (here related primarily to the inclusion of ADFG pot survey data). 'Theta' parameters are primarily the values for initial numbers at size. See control file for more in depth descriptions.

param	25.1 update	25.2 update + ADFG
G__pars__est[1]	16.96	18.47
G__pars__est[2]	0.00	0.00
G__pars__est[3]	0.25	0.25
G__pars__est[4]	139.77	139.77
G__pars__est[5]	0.09	0.09
log__add__cv[1]	-9.21	-9.21
log__add__cv[2]	NaN	-9.21
log__fbar[1]	-2.11	-1.75
log__fbar[2]	-6.72	-6.78
log__fbar[3]	-4.00	-4.00
log__fbar[4]	NaN	-4.00
log__fdev[1]	0.00	0.00
log__fdev[2]	0.00	0.00
log__fdev[3]	0.00	0.00
log__fdev[4]	NaN	0.00
log__fdov[1]	0.00	0.00
log__fdov[2]	0.00	0.00
log__fdov[3]	0.00	0.00
log__fdov[4]	NaN	0.00
log__foff[1]	-4.31	-6.55
log__foff[2]	0.00	0.00
log__foff[3]	0.00	0.00
log__foff[4]	NaN	0.00
log__vn[1]	0.00	0.00
log__vn[2]	0.00	0.00
log__vn[3]	NaN	0.00
logit__rec__prop__est:	0.00	0.00
M__pars__est[1]	0.21	0.21
max gradient	0.00	0.00
number of parameters	133.00	136.00
objective function	-8061.21	-8541.43
par__devs[1]	0.00	0.00
rec__dev__est:	-0.03	-0.03
S__pars__est[1]	4.93	4.93
S__pars__est[10]	NaN	-2.30
S__pars__est[2]	-2.30	-2.30
S__pars__est[3]	5.02	4.98
S__pars__est[4]	2.41	1.97
S__pars__est[5]	4.83	4.77
S__pars__est[6]	2.01	1.75
S__pars__est[7]	4.93	4.48
S__pars__est[8]	-2.30	-4.15
S__pars__est[9]	NaN	4.93
survey__q[1]	0.92	0.92
survey__q[2]	NaN	0.67
theta[1]	16.50	16.50

param	25.1 update	25.2 update + ADFG
theta[10]	-7.09	-6.98
theta[11]	-7.07	-6.96
theta[12]	-7.05	-6.94
theta[13]	-7.03	-6.91
theta[14]	-7.00	-6.87
theta[15]	-6.96	-6.83
theta[16]	-6.92	-6.78
theta[17]	-6.87	-6.73
theta[18]	-6.82	-6.67
theta[19]	-6.76	-6.61
theta[2]	15.00	15.00
theta[20]	-6.71	-6.55
theta[21]	-6.65	-6.49
theta[22]	-6.58	-6.42
theta[23]	-6.52	-6.36
theta[24]	-6.45	-6.29
theta[25]	-6.39	-6.23
theta[26]	-6.32	-6.16
theta[27]	-6.25	-6.09
theta[28]	-6.17	-6.02
theta[29]	-6.10	-5.95
theta[3]	-1.06	-1.31
theta[30]	-6.02	-5.88
theta[31]	-5.93	-5.80
theta[32]	-5.84	-5.72
theta[33]	-5.75	-5.64
theta[34]	-5.65	-5.55
theta[35]	-5.53	-5.45
theta[36]	-5.40	-5.33
theta[37]	-5.27	-5.23
theta[38]	-5.13	-5.13
theta[39]	-4.91	-4.99
theta[4]	32.50	32.50
theta[40]	-4.59	-4.75
theta[41]	-4.30	-4.50
theta[42]	-4.06	-4.27
theta[43]	-3.93	-4.13
theta[5]	1.00	1.00
theta[6]	-0.90	-0.90
theta[7]	0.75	0.75
theta[8]	0.01	0.01
theta[9]	-7.09	-6.99

Table 7: Observed CPUE in crab per million pot hours fished in the ADFG pot survey with associated CVs and observed male biomass >120 mm carapace length in the NMFS summer trawl survey in tonnes with associated CVs.

Survey year	ADFG pot	ADFG CV	NMFS trawl	NMFS CV
1976			165.1	1
1977			118.6	1
1978			1250	0.83
1979			555.8	0.52
1980			1269	0.38
1981			312.3	0.58
1982			1464	0.7
1983			526.7	0.53
1984			317.2	0.55
1985			61.48	1
1986			137.6	0.7
1987			53.58	1
1988			106.7	1
1989			1529	0.91
1990			1141	0.93
1991			4430	0.8
1992			3305	0.6
1993			9873	0.92
1994			9139	0.77
1995			18056	0.6
1996			2362	0.37
1997			6159	0.62
1998			2324	0.36
1999			5523	0.67
2000			4320	0.37
2001			8603	0.79
2002			7037	0.69
2003	7854.87	0.6	5373	0.66
2004			3622	0.59
2005	2224.92	0.27	1238	0.59
2006			7003	0.38
2007			5224	0.49
2008	6069.37	0.54	5462	0.51
2009			2500	0.64
2010			4405	0.44
2011	1760.24	0.24	3834	0.65
2012			4477	0.57
2013			7749	0.62
2014			12047	0.78
2015			15173	0.74
2016			4190	0.7
2017			3689	0.65
2018			937.3	0.43
2019			2105	0.34
2021			3782	0.3
2022			5143	0.3
2023			2761	0.31

Survey year	ADFG pot	ADFG CV	NMFS trawl	NMFS CV
2024			1194	0.46
2025			1247	0.43

Table 8: Observed catches in the directed and non-directed fisheries in tonnes. All years before 1991 are assumed to be zero in the model.

Year	Nondirected_bycatch	Pot_fishery
1991	1.71	0
1992	45.61	0
1993	39.22	1183
1994	5.34	607.3
1995	0.39	407.3
1996	0.83	90.87
1997	0.43	343.3
1998	2.14	246.9
1999	5.38	0
2000	1.67	0
2001	0.39	0
2002	0.31	0
2003	1.79	0
2004	4.23	0
2005	6.44	0
2006	16.31	0
2007	1.82	0
2008	8.26	0
2009	1.37	0
2010	8.21	0
2011	5.87	0
2012	15.71	0
2013	2.68	0
2014	1.18	0
2015	3.35	0
2016	1.01	0
2017	0.65	0
2018	6.55	0
2019	4.49	0
2020	6.54	0
2021	1.67	0
2022	3.92	0
2023	3.92	0
2024	0.87	0

Table 9: Management quantities derived from maximum likelihood estimates using Tier 4 reference points delineated by model. Status and MMB are estimates for February 15 of the completed crab year.

	MMB	BMSY	Status	OFL	FMSY
22.1 Status quo	3616.74	1708.83	2.27	685.07	0.21
25.1 update	2657.91	1297.50	2.20	503.45	0.21
25.2 update + ADFG	2586.24	1283.44	2.16	489.87	0.21

Table 10: Likelihood components by category and model. SRR means 'stock recruit relationship'.

	22.1 Status quo	25.1 update	25.2 update + ADFG
Catch	-76.85	-83.07	-83.07
Index	31.42	38.11	43.10
Size	-8269.17	-8540.45	-9052.89
SRR	0.00	135.38	155.55
Tag	85.49	0.00	0.00
Penalties:	239.20	231.77	230.10
Priors:	104.58	157.05	165.78
Total:	-7885.33	-8061.21	-8541.43

Figure 1: Locations of stations of ADFG pot surveys around the Pribilof Islands by year.

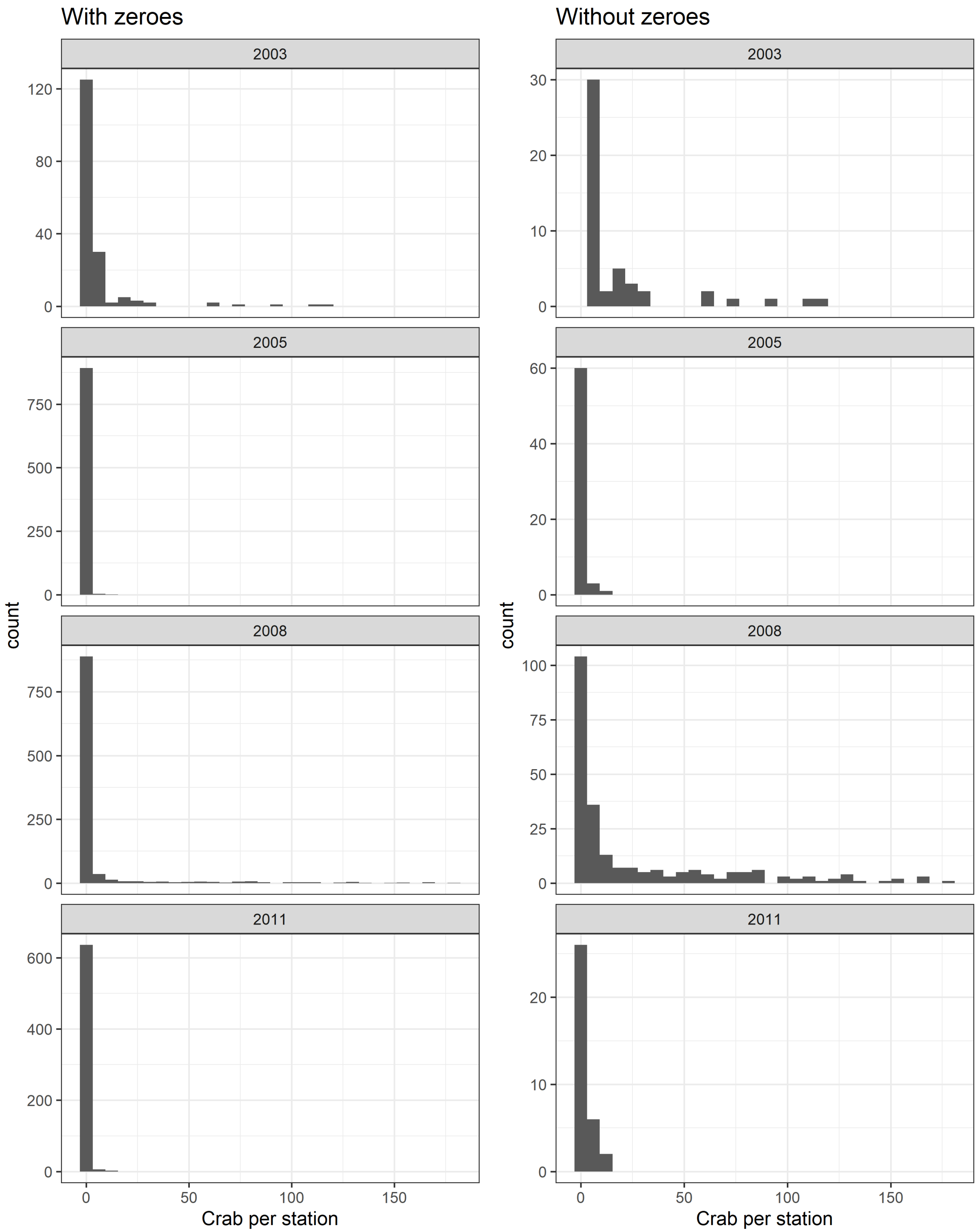

Figure 2: Histograms of the number of crab caught per station by year in ADFG pot survey.

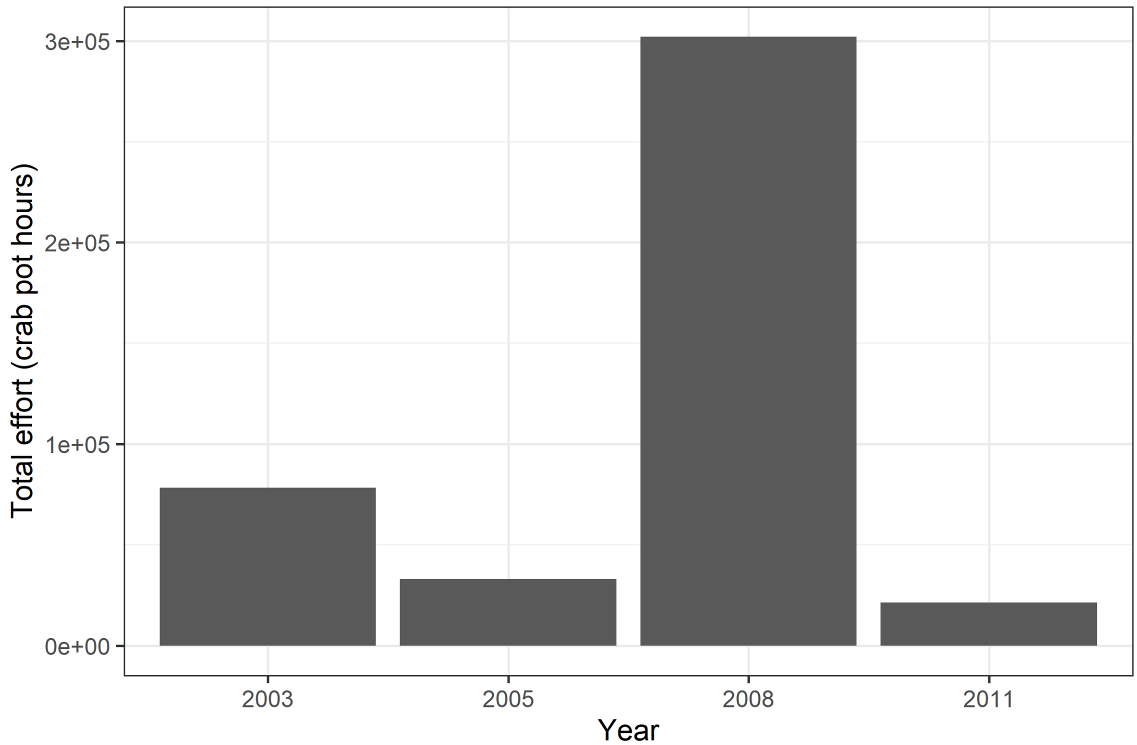

Figure 3: Total hours of sampling effort by year in ADFG pot survey.

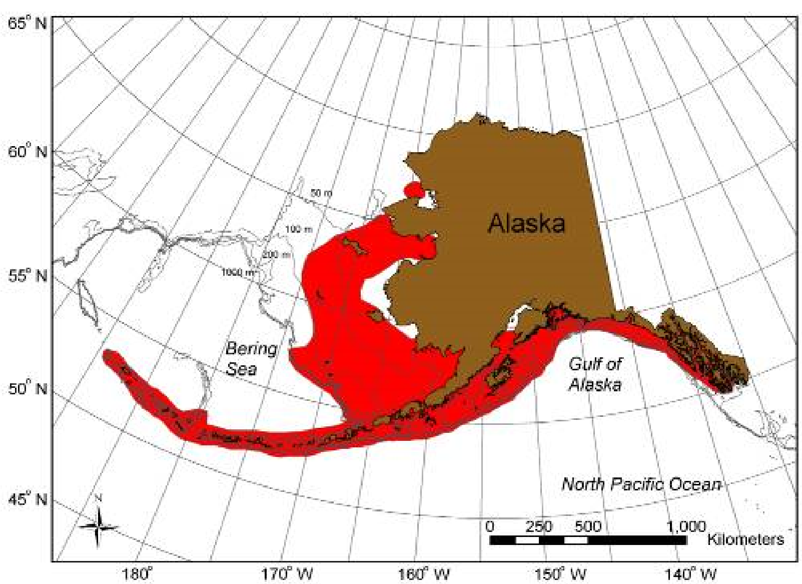

Figure 4: Red king crab distribution in the North Pacific

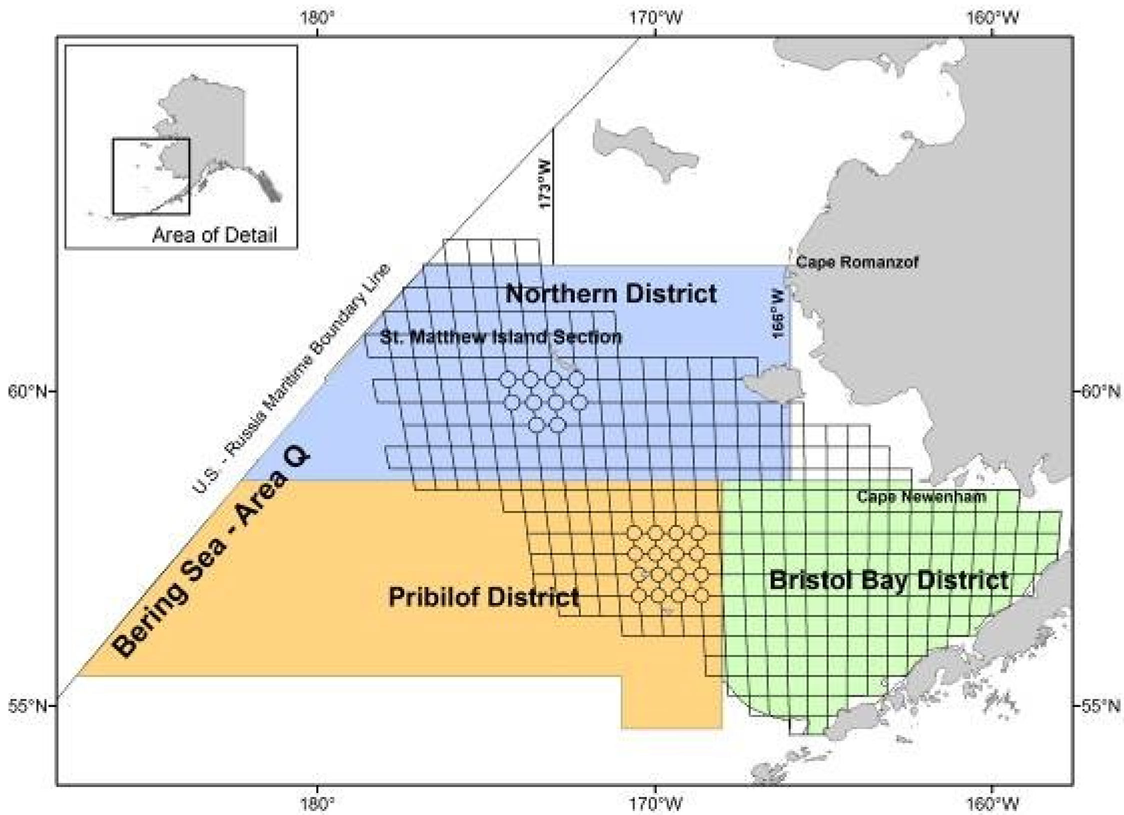

Figure 5: Management areas in the Bering Sea.

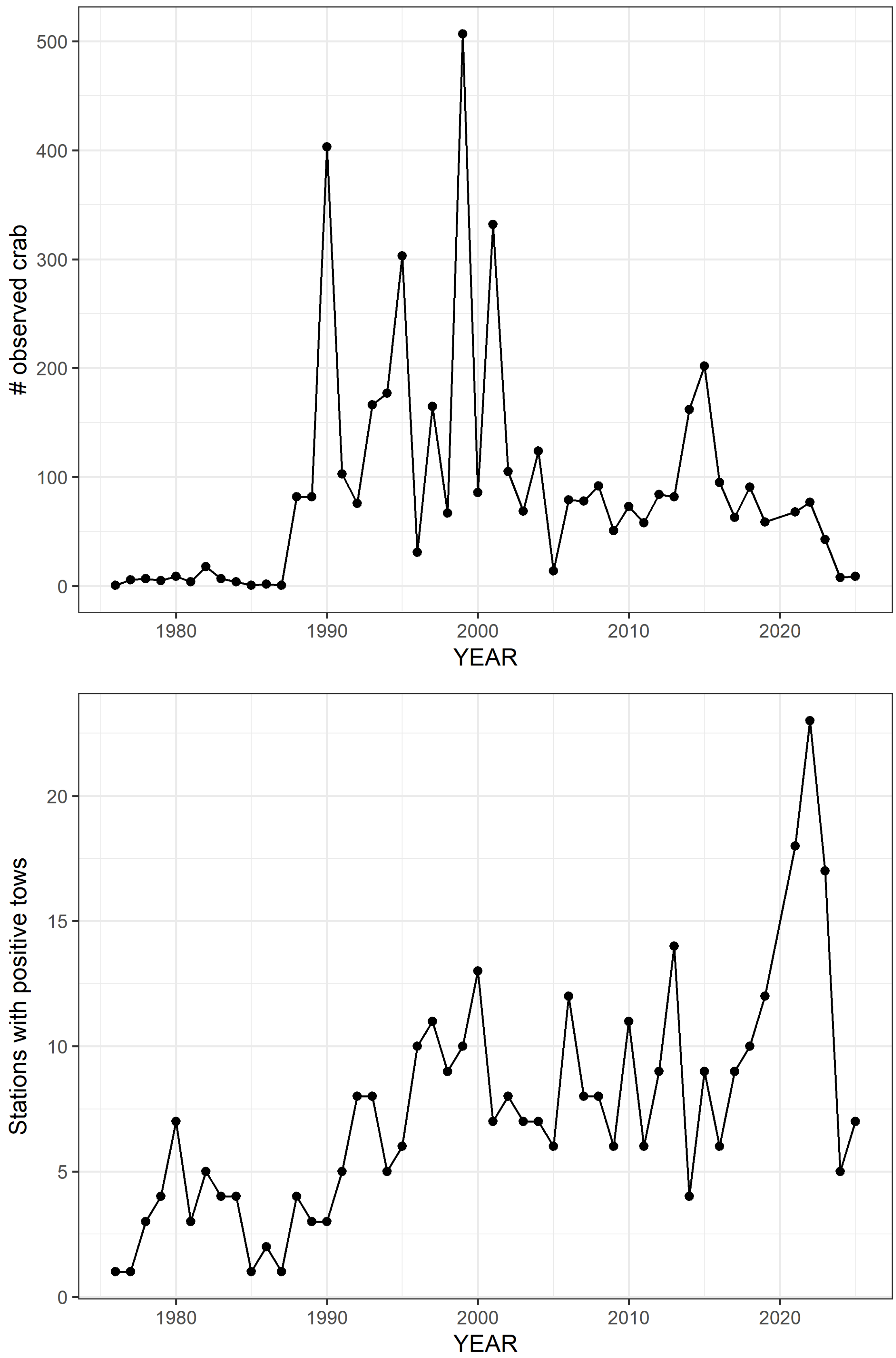

Figure 6: Number of male crab observed around the Pribilof Islands in the NMFS bottom trawl survey (top) and the number of stations with positive catches of male red king crab (bottom).

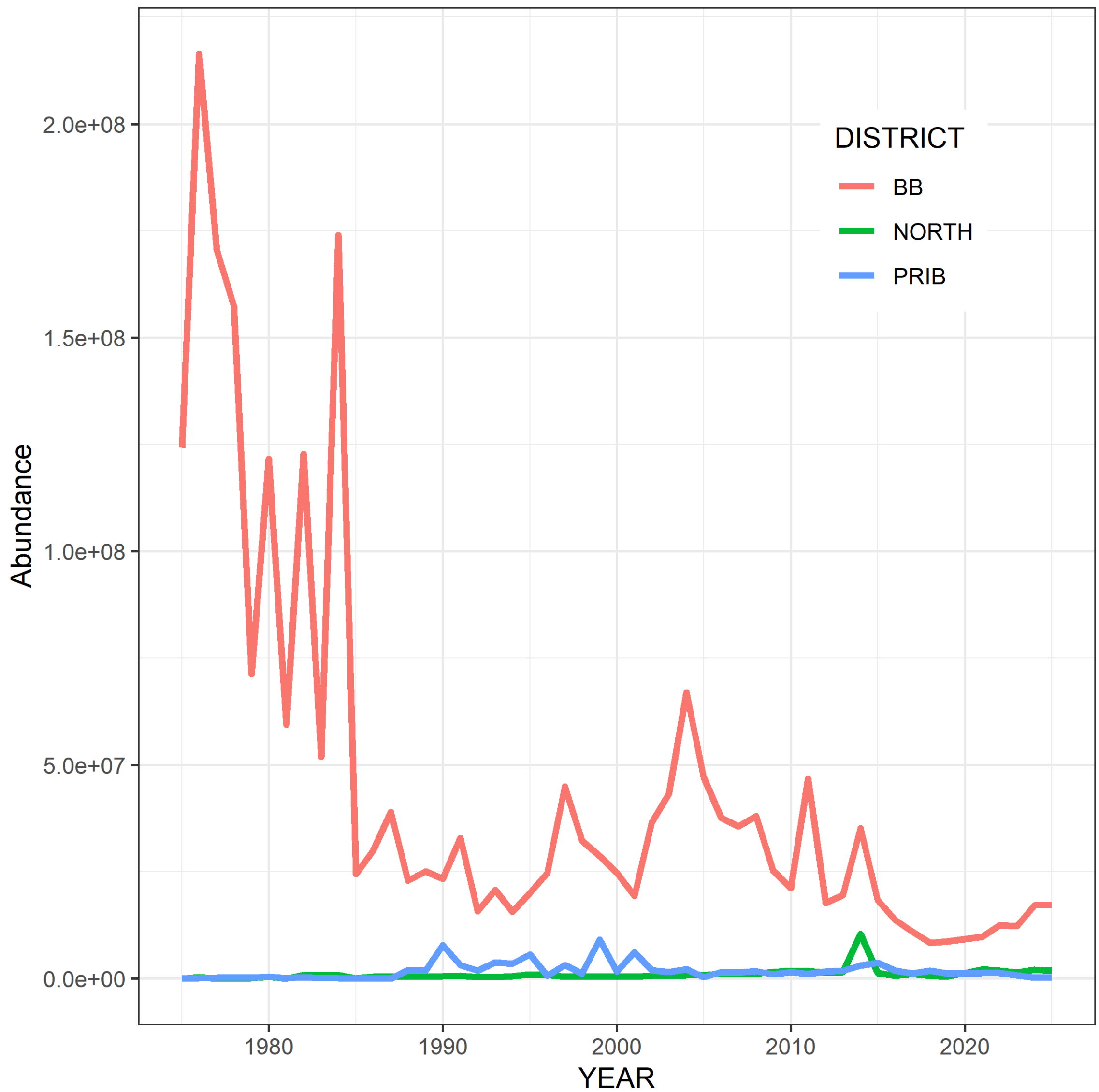

Figure 7: Survey estimates of red king crab abundance by district.

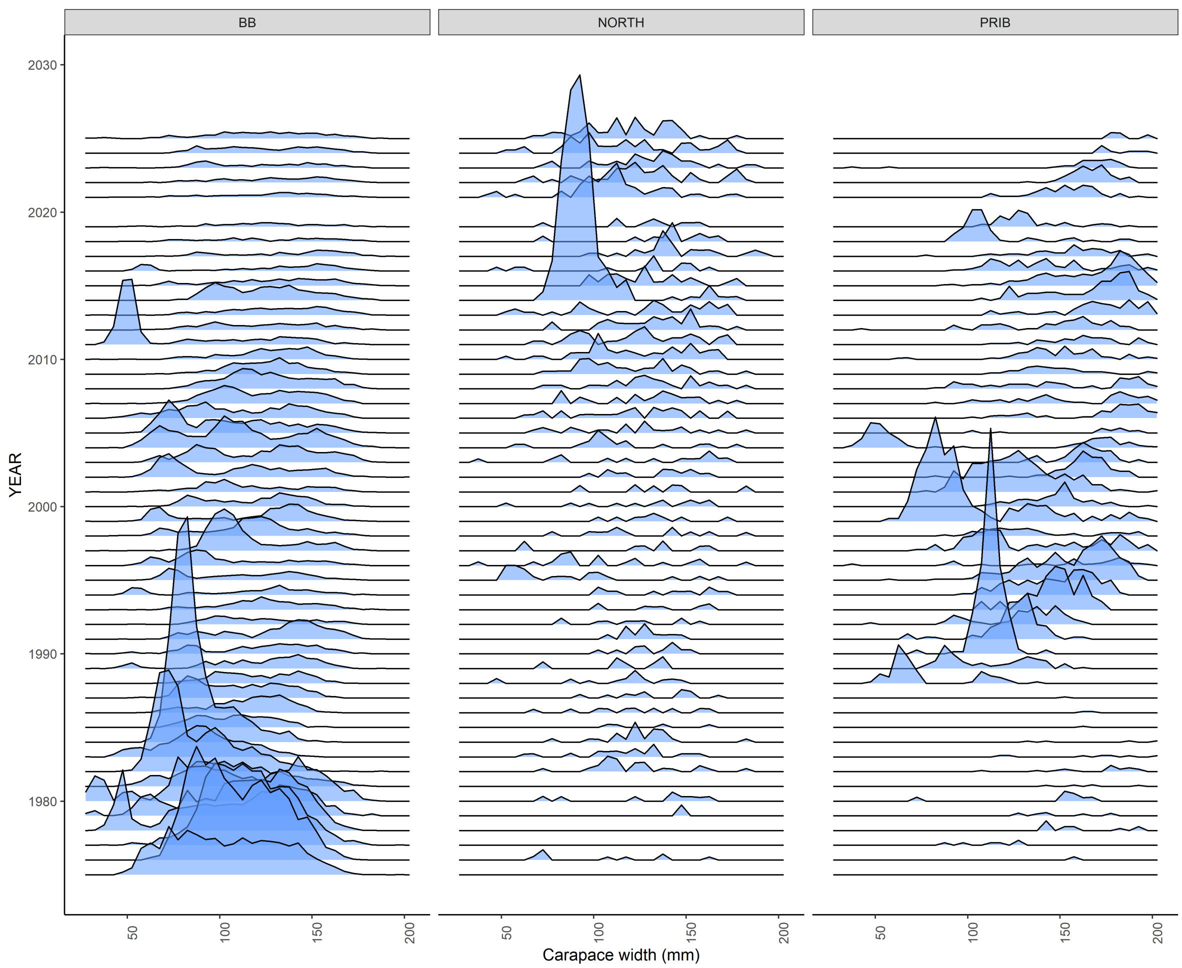

Figure 8: The number of male red king crab at carapace length by district. Each district is scaled to the maximum observed in a district, refer to above figure for relative differences.

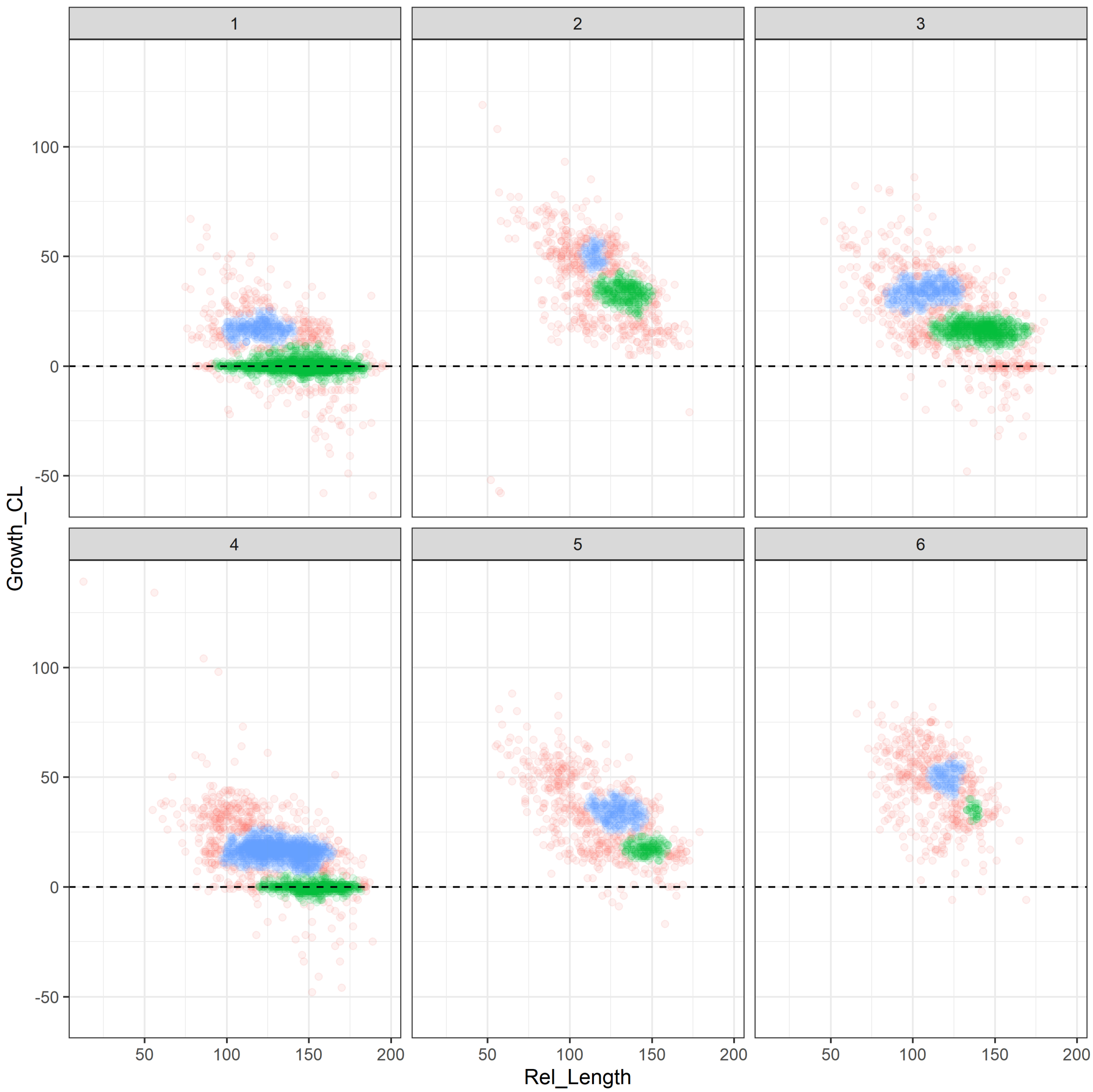

Figure 9: Tagging data for red king crab in the Bering Sea. Each dot represent a released and recaptured crab. Clusters (identified by red and green colors) were identified with DBSCAN and represent different numbers of molts between release and recapture (red points were classified to an 'other' cluster). The title of each panel represents the number of years elapsed since recovery of a tag. Y-axis is the growth from release to recapture; x-axis is the carapace length at release.

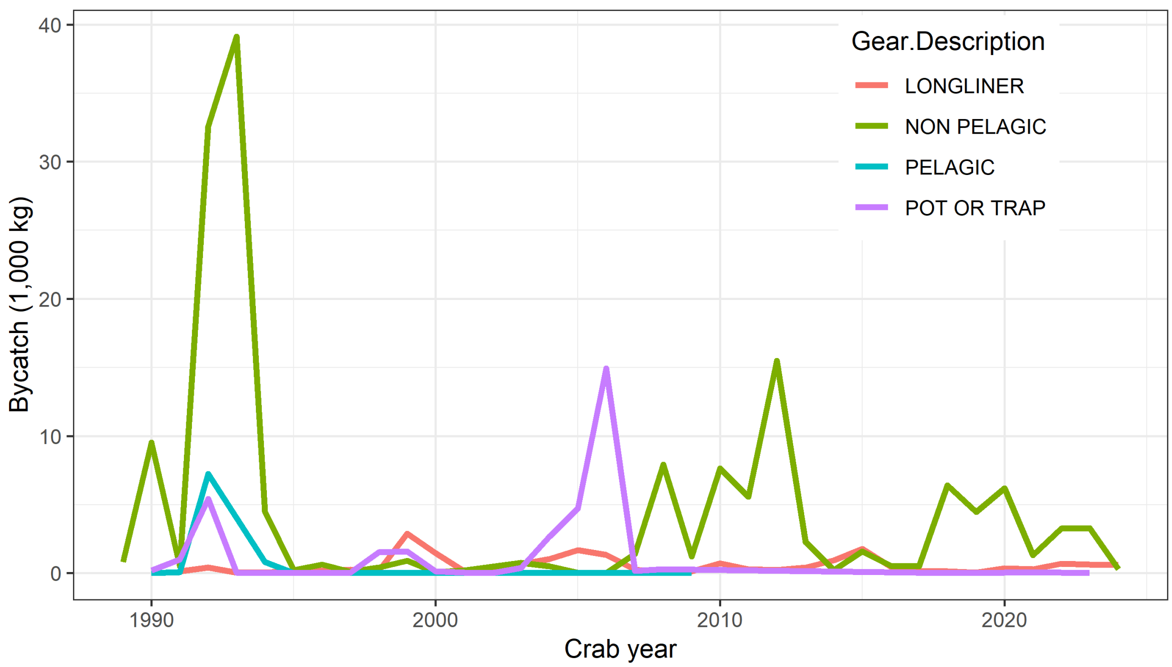

Figure 10: Groundfish fisheries bycatch by gear type.

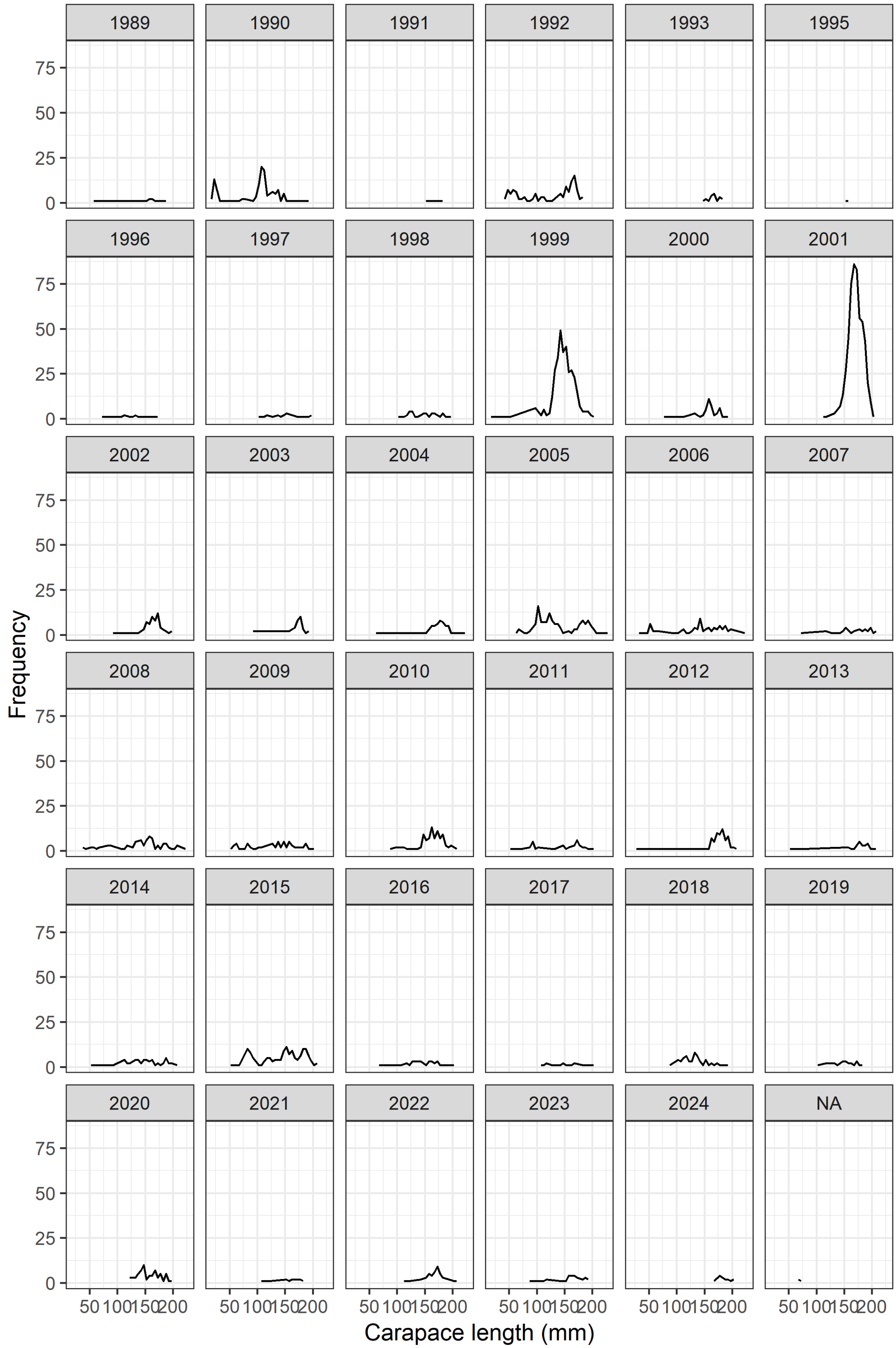

Figure 11: Total groundfish fisheries bycatch numbers at size of PI red king crab.

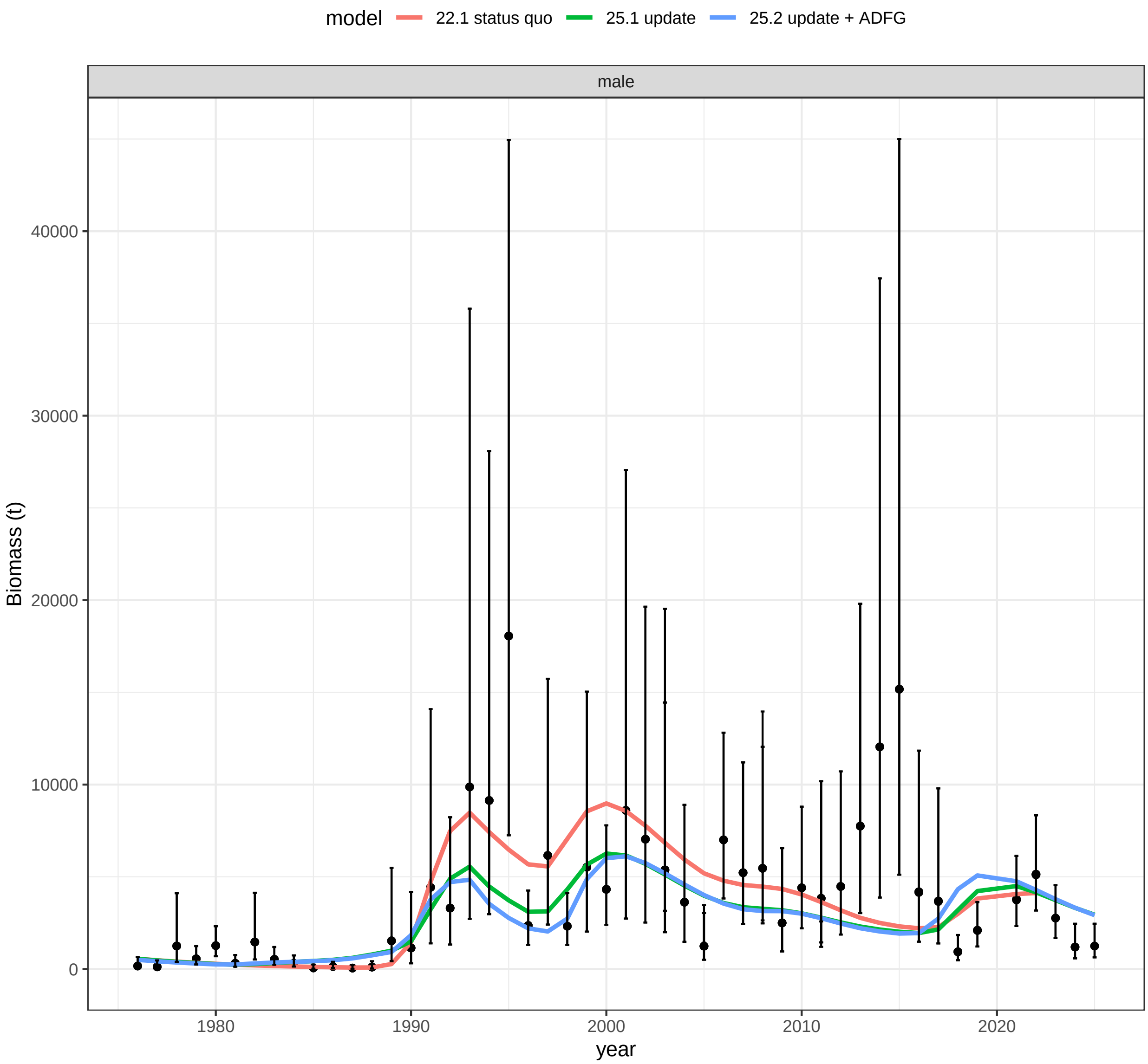

Figure 12: Model fits to the observed mature male biomass at survey.

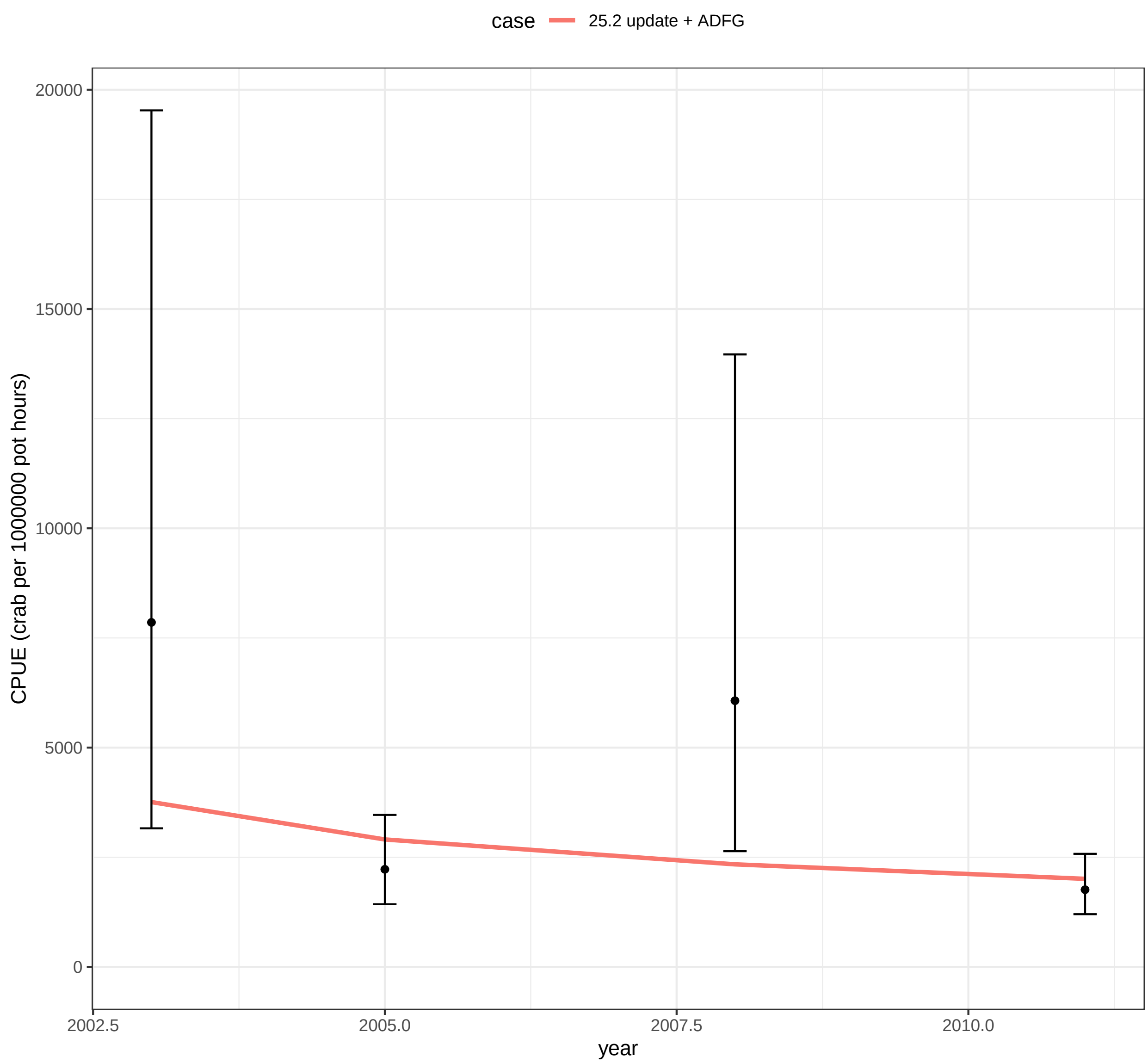

Figure 13: Model fits to the ADFG pot survey data.

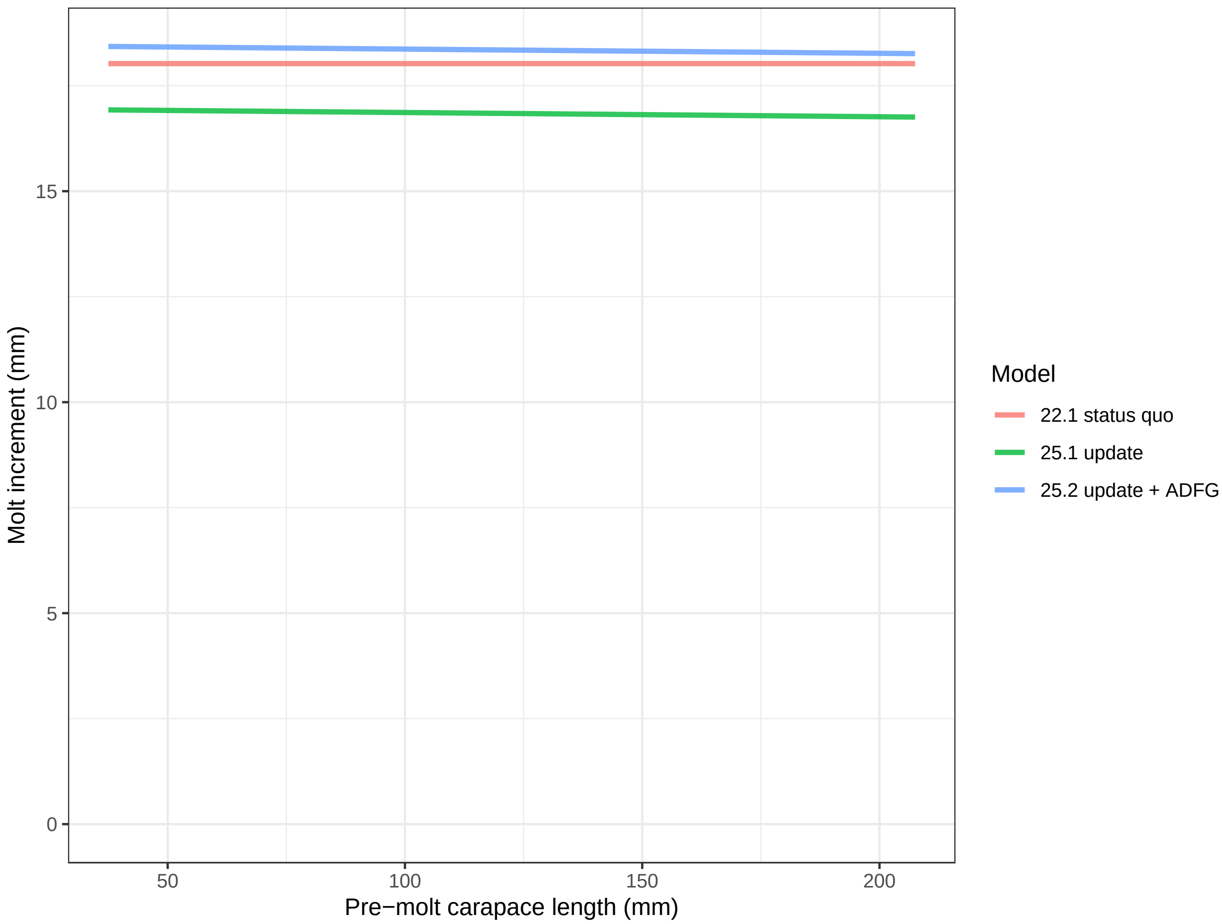

Figure 14: Model estimates of molt increment at size.

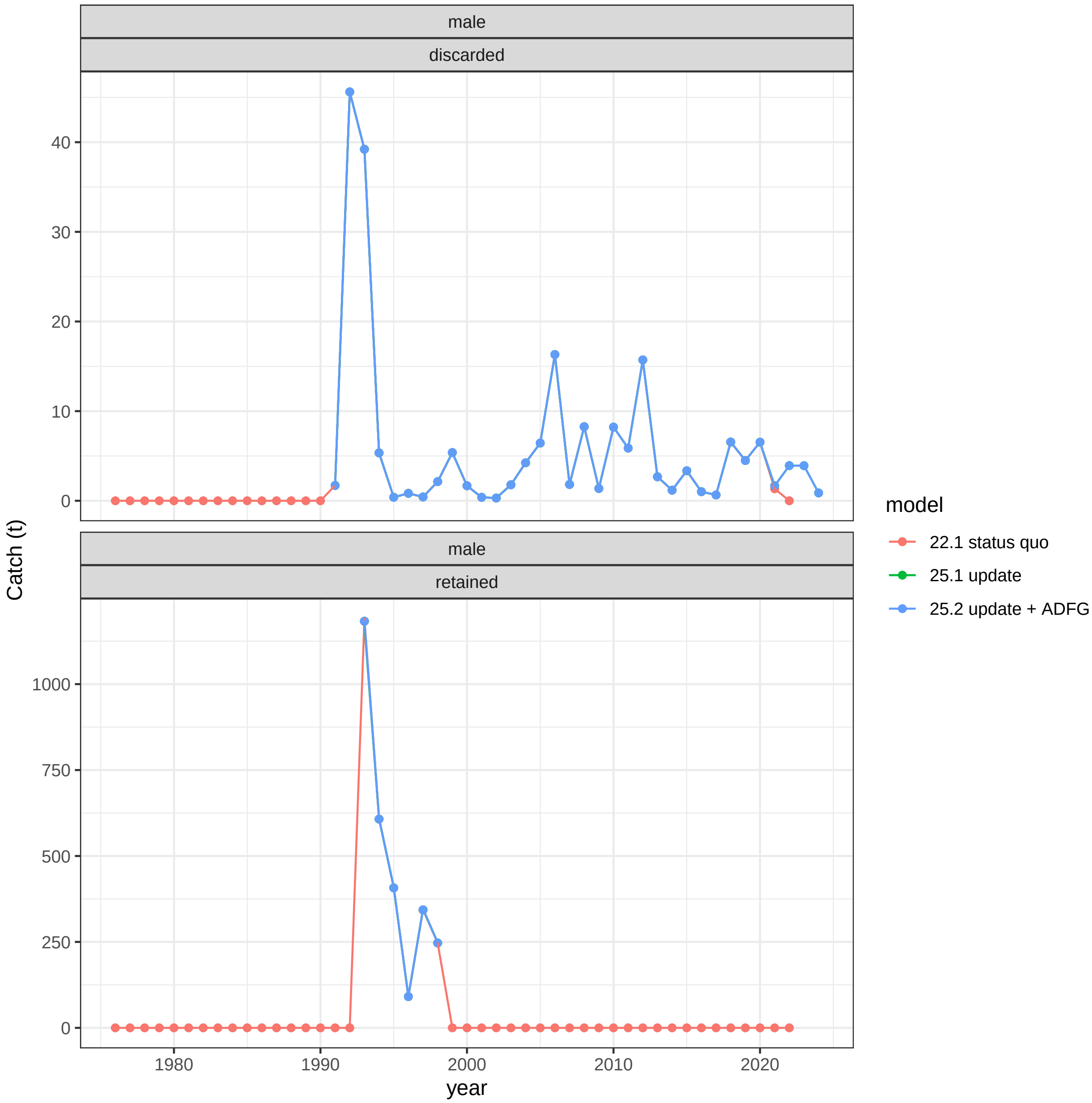

Figure 15: Model fits to non-directed bycatch data (top) and retained catch data (bottom).

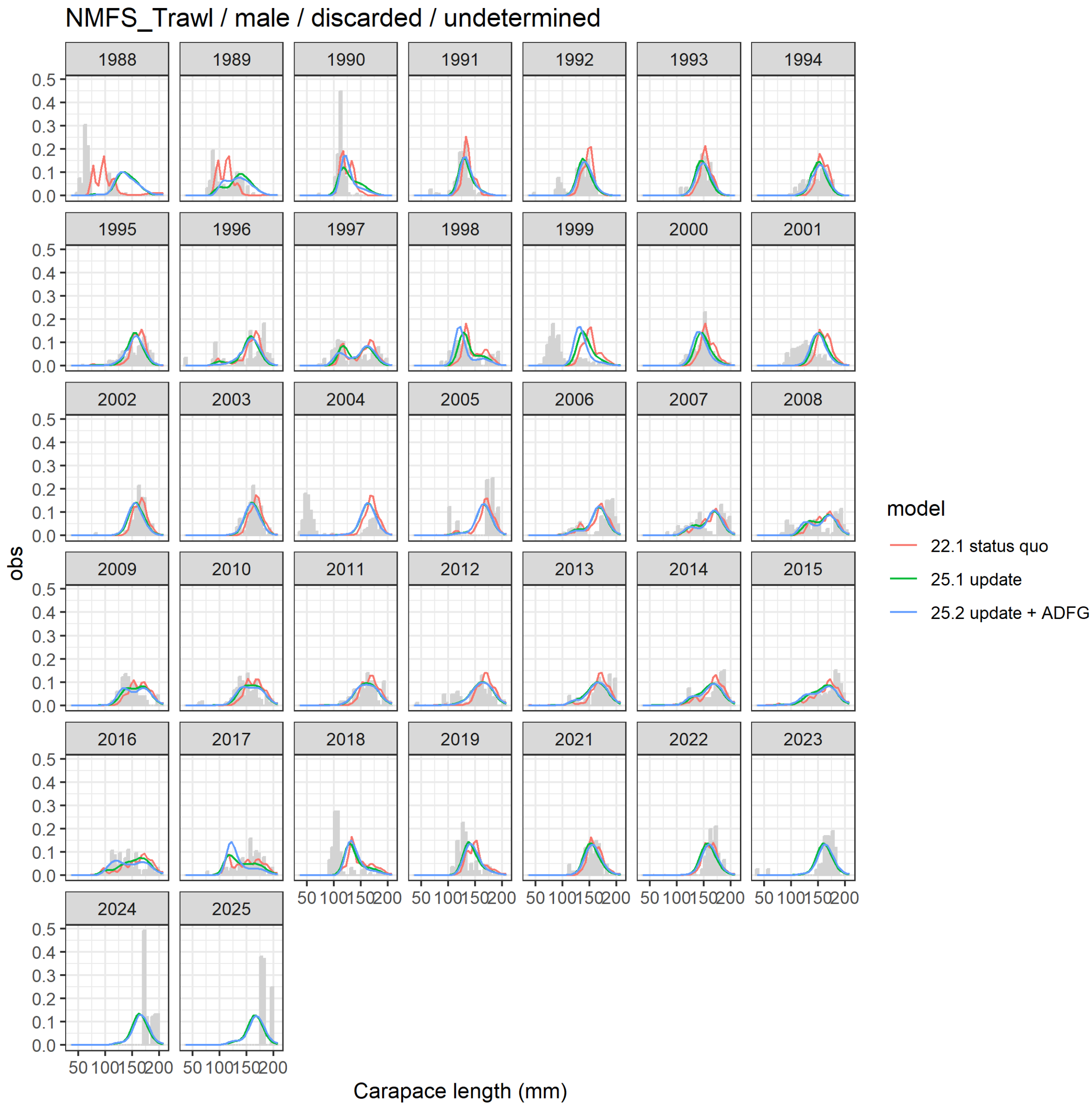

Figure 16: Model fits (lines) to the NMFS bottom trawl survey size composition data (grey bars).

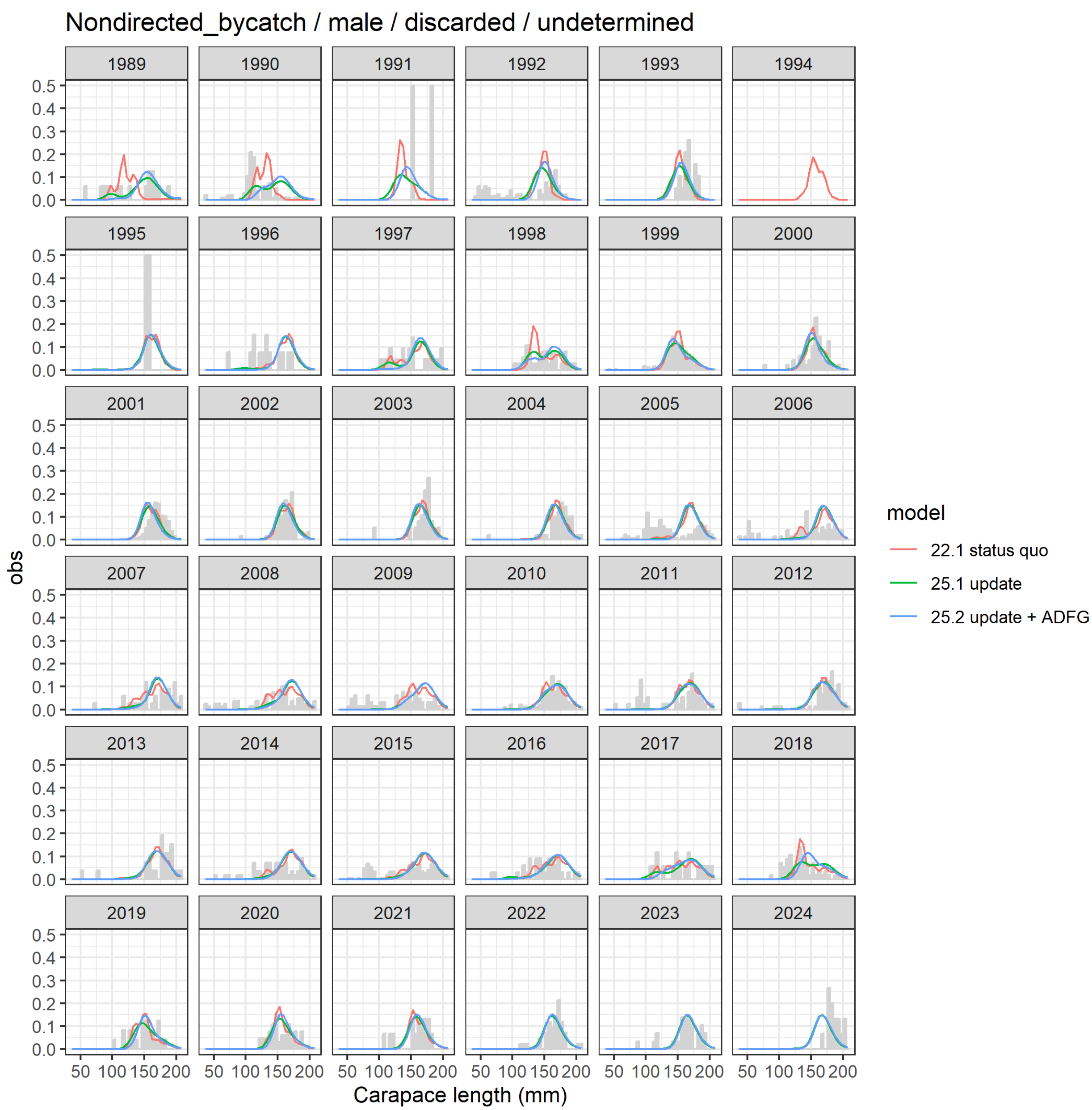

Figure 17: Model fits (lines) to the nondirected bycatch size composition data (grey bars).

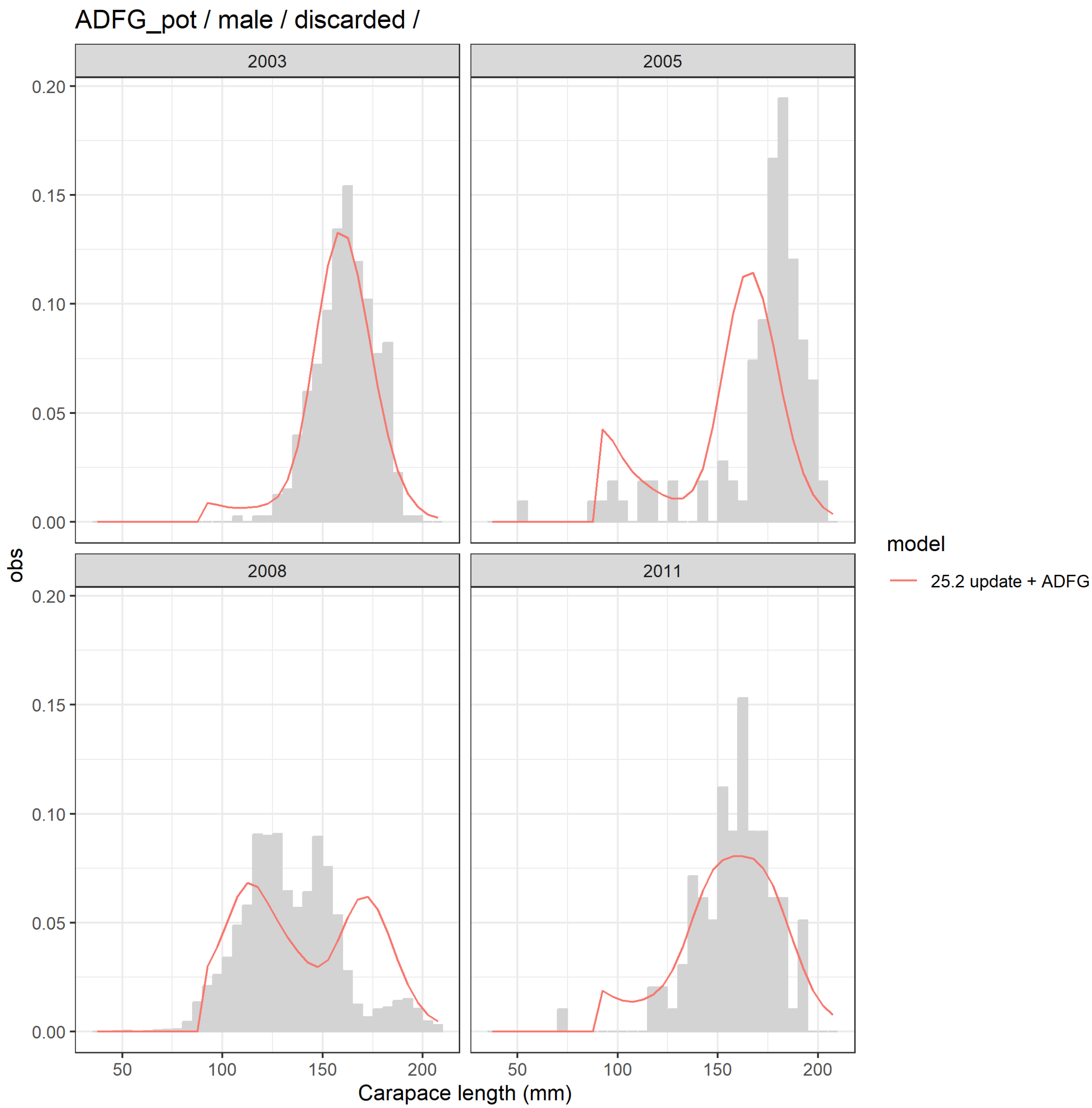

Figure 18: Model fits (lines) to the ADFG pot survey size composition data (grey bars).

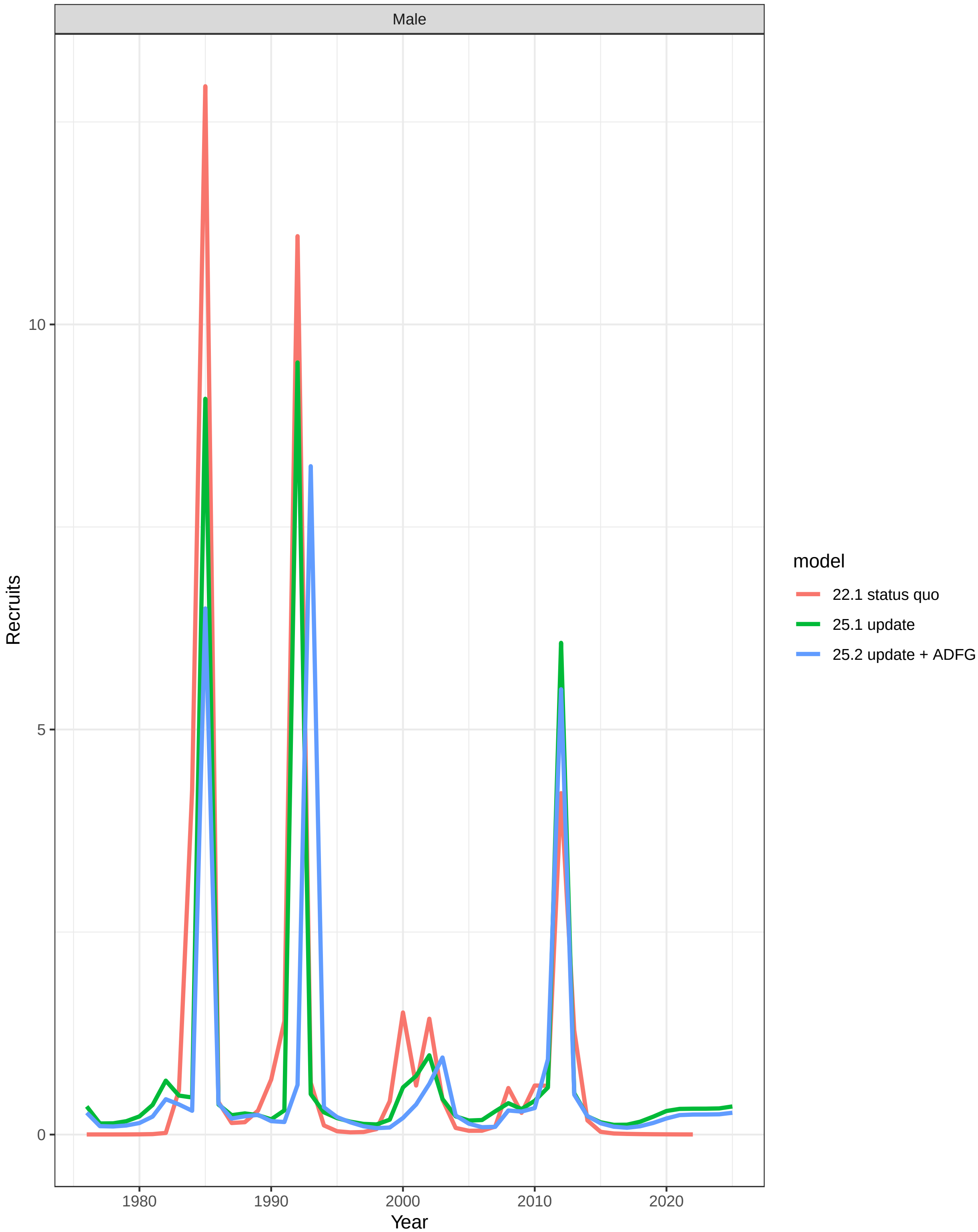

Figure 19: Estimated recruitment by model.

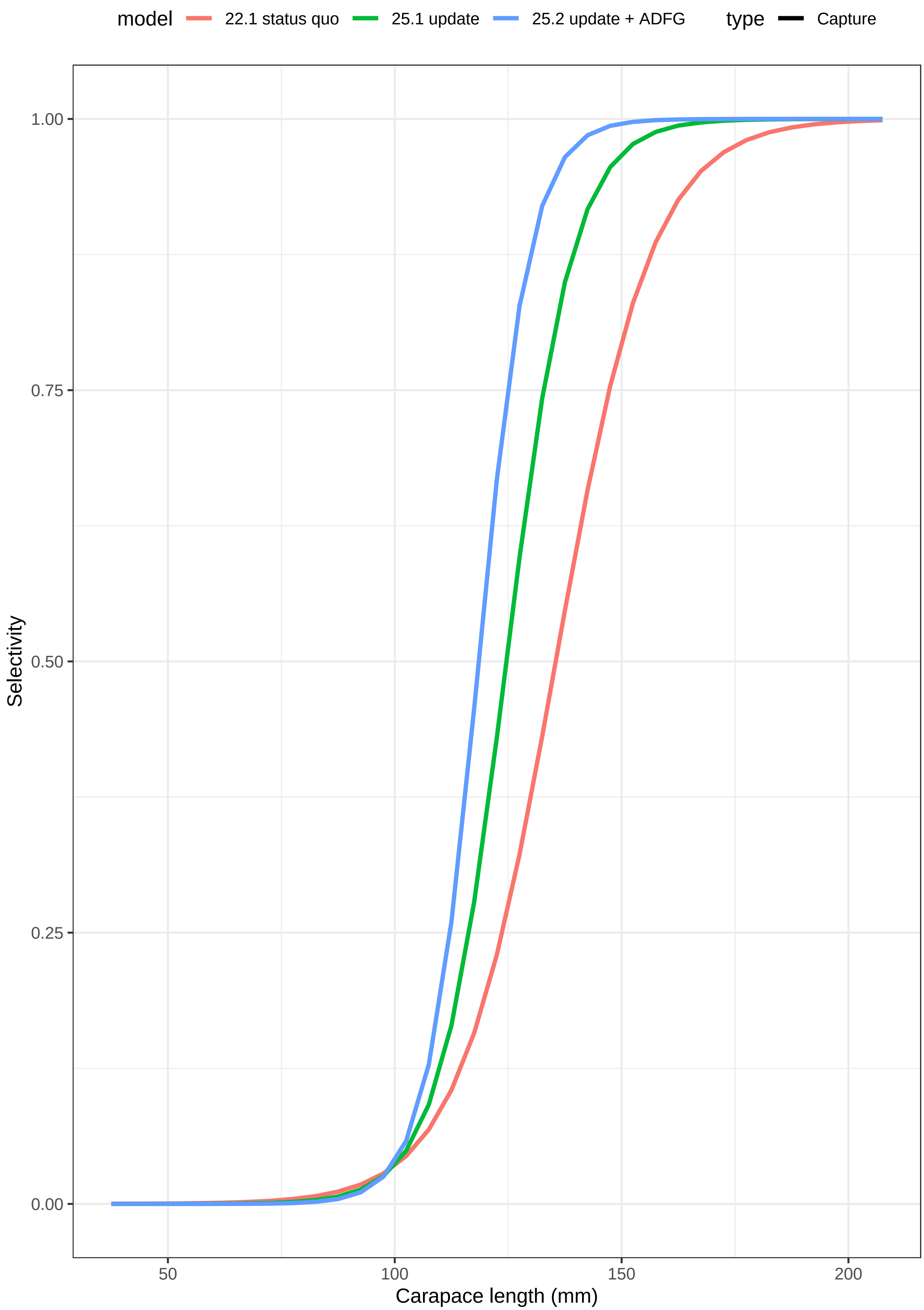

Figure 20: Estimated NMFS bottom trawl survey selectivity at size (x-axis)

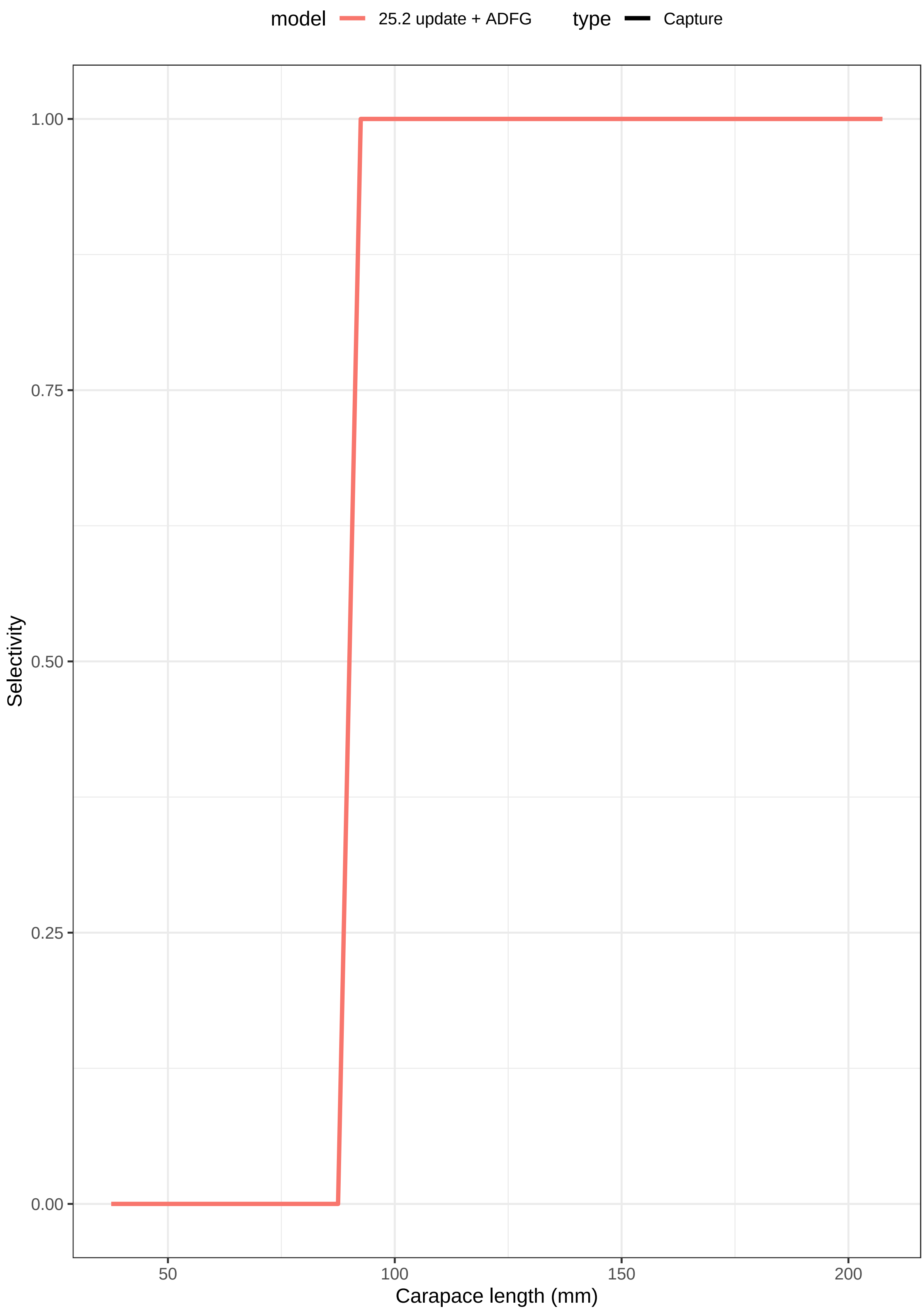

Figure 21: Estimated ADFG pot survey selectivity

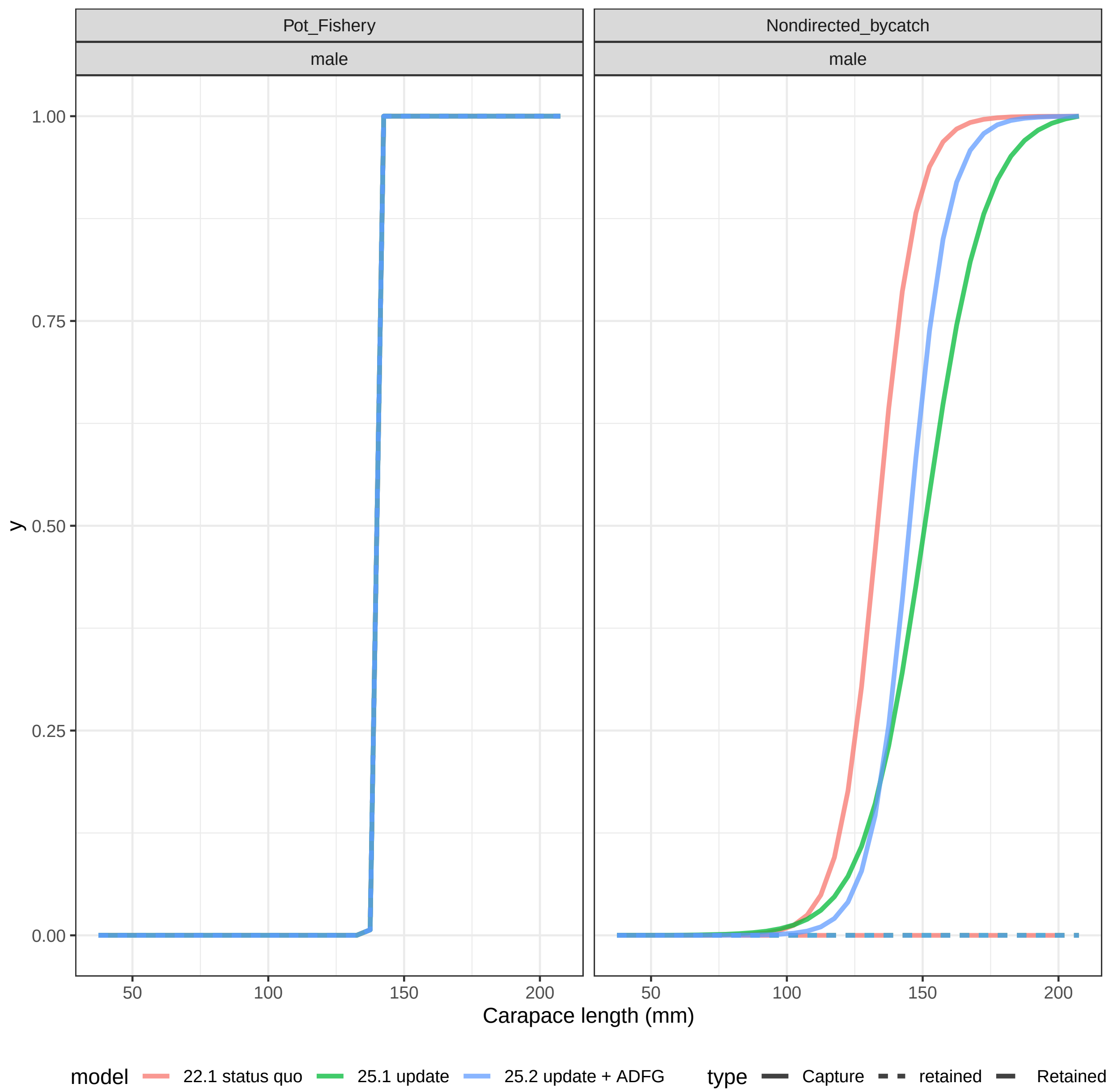

Figure 22: Estimated selectivities by fishing fleet for capture and retained catches.

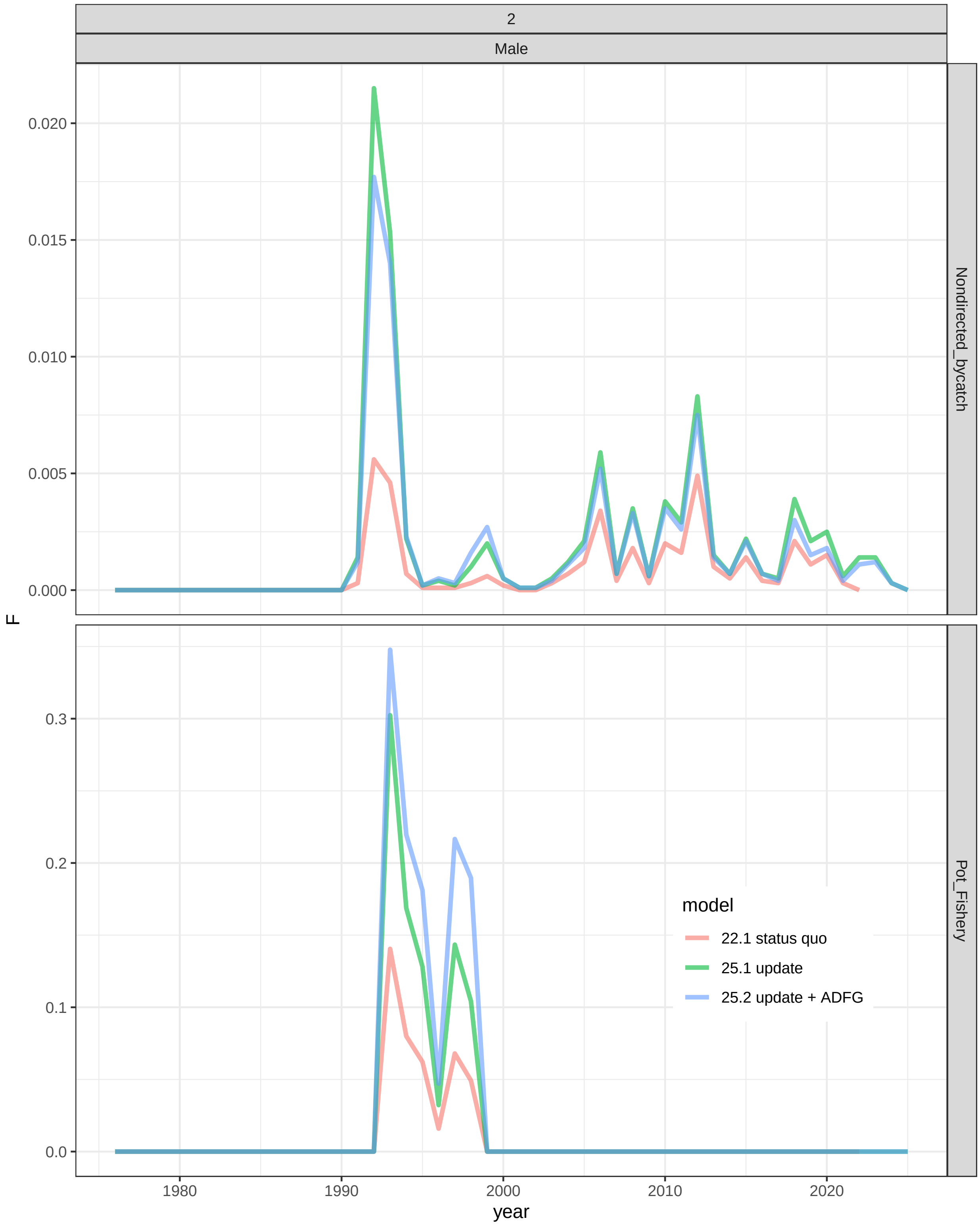

Figure 23: Estimated fishing mortalities for male crab in the directed and non-directed fisheries.

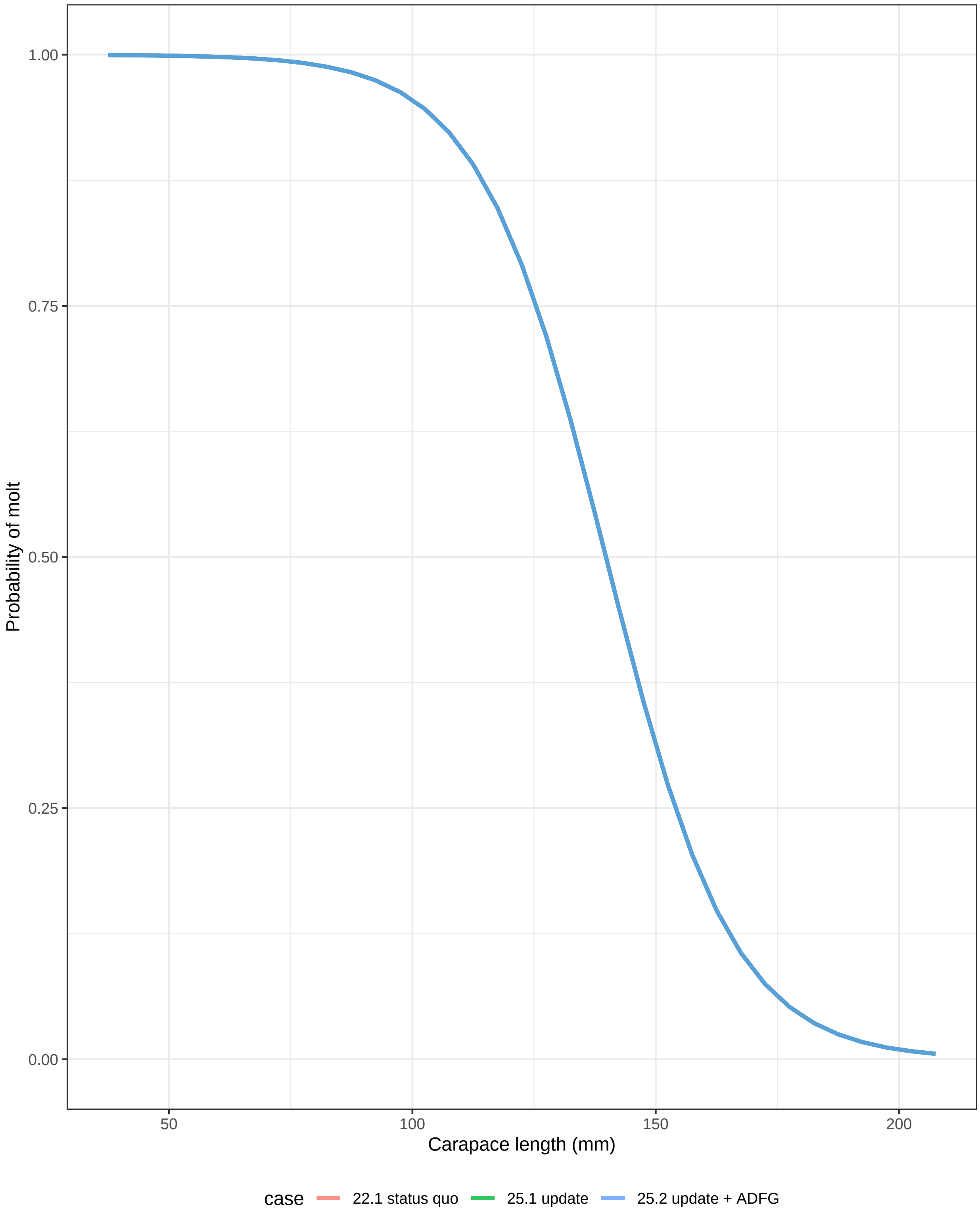

Figure 24: Probability of molting. Probability of molting at size was specified based on BBRKC for all models, so only one line appears.

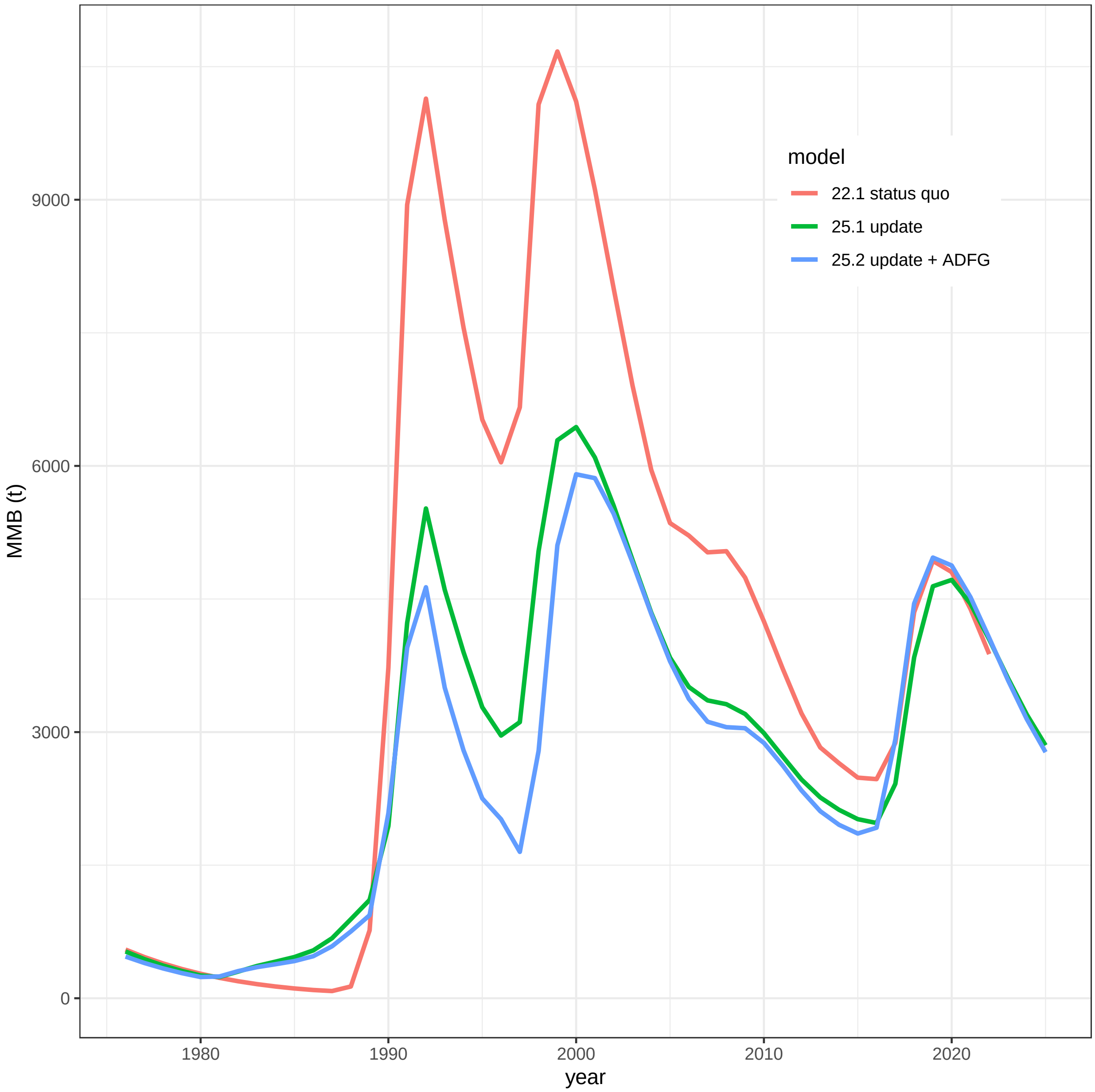

Figure 25: Estimated mature male biomass at mating time in tonnes.

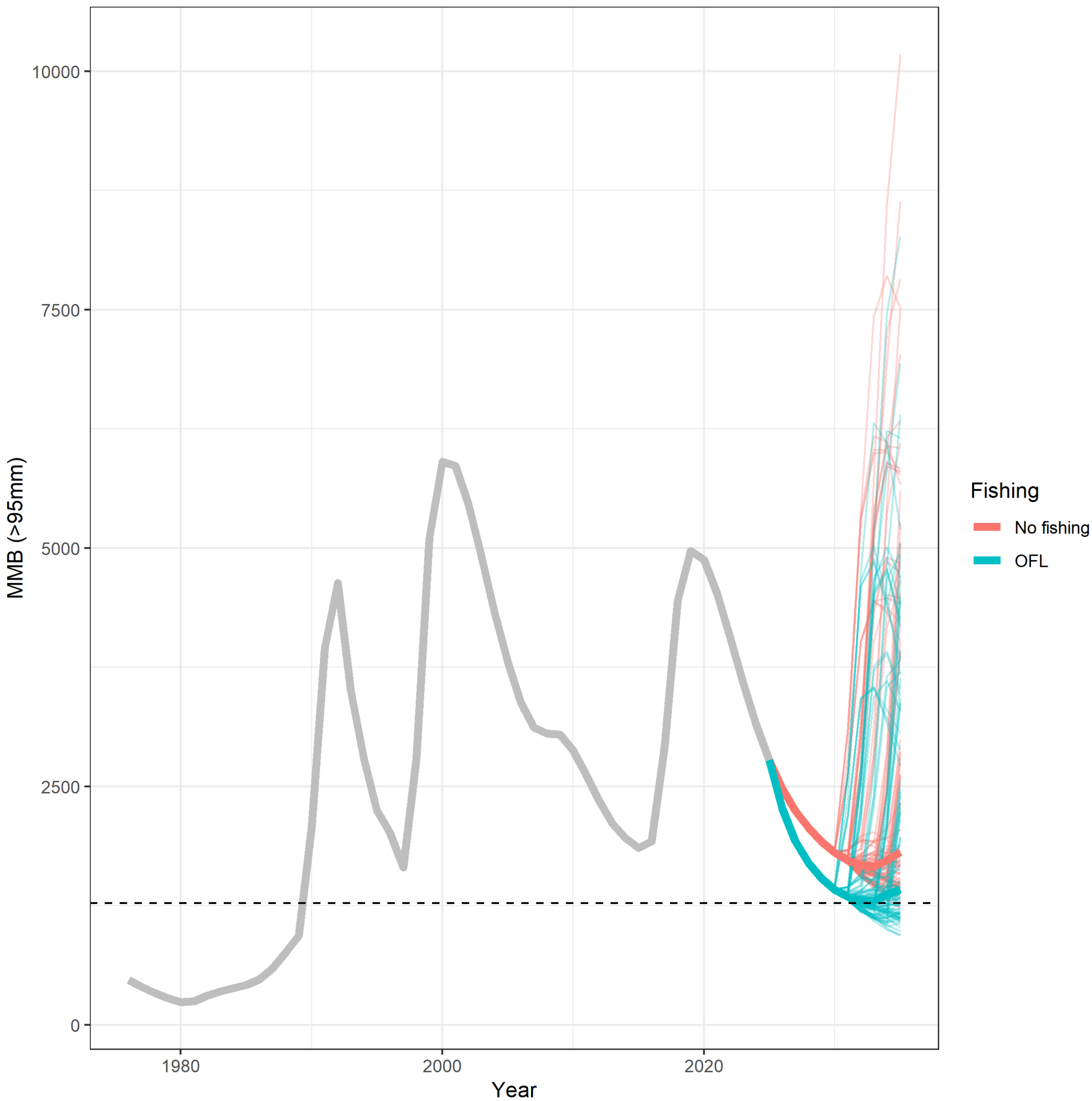

Figure 26: Projected biomass under no fishing and fishing at the OFL. Historcial estimates of MMB are in grey. Dashed horizontal line in the BMSY proxy.

Appendix A: Risk table for Pribilof Islands Red King Crab

Ebett Siddon, Cody Szuwalski

The following is a synthesis and interpretation of the most recent ecosystem information available for Pribilof Islands Red King Crab from the Eastern Bering Sea Ecosystem Status Reports (ESR, Siddon, 2024; Siddon, 2025, in press). This information may be helpful for evaluating risk table score levels and is organized below by the proposed risk table categories.

Category Summary:

Assessment-related Considerations	Population Dynamics Considerations	Ecosystem Considerations	Fishery-informed Stock Considerations
Level 2: Increased concern	**Level 2**: Increased concern	**Level 1:** Normal	**Level 1**: Normal
Removal of the corner stations contributed to the decrease in the number of observed crab from 77 in 2022 to 9 in 2025 and resulted in increased CVs.	No recruitment has been observed since 2018; only very large crab were observed in the 2025 survey	Warm conditions with a reduced cold pool extent in 2024; forecast to be warm with delayed sea ice arrival in 2025. Corrosive bottom waters remain a concern for growth and survival. Overall, ecosystem concerns are minor with uncertain impacts on the stock.	No fishery occurs for PIRKC.

Assessment-related considerations:

- A decrease in the sampling intensity around the Pribilof Islands contributed to increases in CVs for the input data of the assessment. Declining abundances also contributed to the increase in CVs.

Population dynamics considerations:

- Essentially no recruitment has been observed since 2018.
- Only very large crab were observed in the 2025 survey.

Ecosystem Considerations:

Ecosystem indicators are organized into several categories to capture the scope of considerations available in the ESR reports:

- Distribution: December 2023 had significant along-shelf winds that could have driven offshore Ekman transport. March to May 2024 had weaker, but more sustained winds that also favored offshore transport (ESR: Hennon, 2024). Strong summer winds in 2024 resulted in a deep mixed layer (ESR: Hennon, 2024).

- <u>Environmental Processes</u>: During winter 2024-2025, the NPI was negative (ESR: Siddon, 2025) for the first time in 9 years, an indication of a stronger Aleutian Low Pressure System (ESR: Siddon, 2025). This means the Bering Sea was warm, stormy, and had less sea ice.
- Summer bottom trawl SSTs in the EBS were slightly cool, while mean bottom water temperature increased by 0.5°C from 2024 to 2025. The extent of the cold pool was below average and a 29% decrease from 2024 (ESR: Siddon, 2025).
- Sea ice is expected to arrive in the northern Bering Sea later in winter 2025/2026 than 2024/2025 due to comparatively low sea ice extent currently in the Chukchi Sea (ESR: Siddon, 2025 *forecast will be updated for final ESR*).
- The NMME ensemble forecasts as of today show moderate warm SST anomalies over much of the SEBS (<0.5°C) into fall 2025, except Bristol Bay shows anomalies up to +2 °C. The NBS is projected to have SSTs close to the historical mean (ESR: Siddon, 2025 *forecast will be updated for final ESR*).
- Bottom waters remained near threshold levels in 2024 that could negatively impact growth and survival, with the most corrosive bottom waters found in slope waters and over the northwest shelf (ESR: Pilcher, 2024).
- <u>Prey</u>: Diatom abundance anomalies, based on the Continuous Plankton Recorder, remained positive from 2023 to 2024 (ESR: Siddon, 2025), indicating above-average feeding conditions for pelagic crab stages in 2023 and 2024.
- <u>Competitors</u>:Over the southern shelf, motile epifauna (e.g., sea stars, brittle stars) biomass increased from 2023 to 2024 and remains above the long term mean (ESR: Siddon, 2024). Benthic forager (i.e., small-mouthed flatfish) biomass increased from 2023 to 2024, but remains below the time series mean, suggesting competition for prey resources remains low in 2024 (ESR: Siddon, 2024).
- <u>Predators</u>: Bristol Bay sockeye salmon run sizes were closer to the long-term average in 2023-2024 (ESR: Siddon, 2024), after multiple years of large run sizes, indicating a decline in predation pressure.

References

Hennon, T. 2024. Winds at the Shelf Break. In: Physical Environment Synthesis. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Pilcher, D., J. Cross, N. Monacci, E. Kennedy, E. Siddon, and W.C. Long. 2024. Ocean Acidification. In: Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Siddon, E. 2024. Ecosystem Status Report 2024: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.

Siddon, E. 2025 (in press). Ecosystem Status Report 2025: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West 3rd Ave., Suite 400, Anchorage, Alaska 99501.